



Digi XBee3[®] Zigbee[®]

RF Module

User Guide

Revision history—90001539

Revision	Date	Description
A	October 2017	Initial release.
B	January 2018	Added the XBee3 through-hole form factor information.
C	March 2018	Added the Get started with MicroPython section.
D	November 2018	Added Bluetooth (BLE) support, SPI support, and Custom Default AT commands.

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- Trace (if possible)
- Description of issue
- Steps to reproduce

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Digi XBee3[®] Zigbee[®] RF Module User Guide

This manual describes the operation of the XBee3 Zigbee RF Module, which consists of Zigbee firmware loaded onto XBee3 hardware.

The XBee3 Zigbee RF Modules provide wireless connectivity to end-point devices in Zigbee mesh networks. Using the Zigbee 3.0 feature set, these devices are inter-operable with other Zigbee devices, including devices from other vendors. With the XBee3 Zigbee RF Module, users can have their Zigbee network up-and-running in a matter of minutes without configuration or additional development.

For information about XBee3 hardware, see the [XBee3 RF Module Hardware Reference Manual](#).

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Applicable firmware and hardware

This manual supports the following firmware:

- 3002
- v.10xx Zigbee

It supports the following hardware:

- XBee3

Change the firmware protocol

You can switch the firmware loaded onto the XBee3 hardware to run any of the following protocols:

- Zigbee
- 802.15.4
- DigiMesh

To change protocols, use the **Update firmware** feature in XCTU and select the firmware. See the [XCTU User Guide](#).

Regulatory information

See the [Regulatory information](#) section of the [XBee3 RF Module Hardware Reference Manual](#) for the XBee3 hardware's regulatory and certification information.

Get started

Refer to the [XBee Zigbee Mesh Kit User Guide](#) for comprehensive instructions and examples on how to get started with the XBee3 Zigbee RF Module.

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Configure the device using XCTU

XBee Configuration and Test Utility (XCTU) is a multi-platform program that enables users to interact with Digi radio frequency (RF) devices through a graphical interface. The application includes built-in tools that make it easy to set up, configure, and test Digi RF devices.

For instructions on downloading and using XCTU, see the [XCTU User Guide](#).

Customize XBee Zigbee firmware

Once device parameters are tested in an application and finalized, Digi can manufacture devices with specific, customer-defined configurations. These custom configurations can lock in a firmware version or set command values when the devices are manufactured, eliminating the need for customers to adjust device parameters on arrival.

Custom defaults

Custom defaults allow you to preserve a subset of the device configuration parameters even after returning to default settings using [RE \(Restore Defaults\)](#). This can be useful for settings that identify the device—such as [NI \(Node Identifier\)](#)—or settings that could make remotely recovering the device difficult if they were reset—such as [ID \(Extended PAN ID\)](#).

Note You must send these commands as local AT commands, they cannot be set using [Remote AT Command Request frame - 0x17](#).

Set custom defaults

Use [%F \(Set Custom Default\)](#) to set custom defaults. When the XBee3 Zigbee RF Module receives [%F](#) it takes the next command it receives and applies it to both the current configuration and the custom defaults.

To set custom defaults for multiple commands, send a [%F](#) before each command.

Restore factory defaults

[!C \(Clear Custom Defaults\)](#) clears all custom defaults, so that [RE \(Restore Defaults\)](#) will restore the device to factory defaults. Alternatively, [R1 \(Restore Factory Defaults\)](#) restores all parameters to factory defaults without erasing their custom default values.

Limitations

There is a limitation on the number of custom defaults that can be set on a device. The number of defaults that can be set depends on the size of the saved parameters and the devices' firmware version. When there is no more room for custom defaults to be saved, any command sent immediately after a [%F](#) returns an error.

Setting a custom default that has already been set or setting a custom default to the factory default value will not reclaim the space used by the previous value. The new value takes effect but the old value still occupies space in memory, reducing the number of custom defaults that can be set. This can be remedied by using [!C \(Clear Custom Defaults\)](#) to clear all custom defaults when changing custom default values, and by only setting custom defaults that differ from the factory defaults.

Custom configuration: Create a new factory default

You can create a custom configuration that is used as a new factory default. This feature is useful if, for example, you need to maintain certain settings for manufacturing or want to ensure a feature is always enabled. When you use [RE \(Restore Defaults\)](#) to perform a factory reset on the device, the custom configuration is set on the device after applying the original factory default settings.

For example, by default Bluetooth is disabled on devices. You can create a custom configuration in which Bluetooth is enabled by default. When you use **RE** to reset the device to the factory defaults, the Bluetooth configuration set to the custom configuration (enabled) rather than the original factory default (disabled).

The custom configuration is stored in non-volatile memory. You can continue to create and save custom configurations until the XBee3 Zigbee RF Module's memory runs out of space. If there is no space left to save a configuration, the device returns an error.

You can use [!C \(Clear Custom Defaults\)](#) to clear or overwrite a custom configuration at any time.

Set a custom configuration

1. Open XCTU and load your device.
2. [Enter Command mode](#).
3. Perform the following process for each configuration that you want to set as a factory default.
 - a. Send the [Set Custom Default](#) command, **AT%F**. This command enables you to enter a custom configuration.
 - b. Send the custom configuration command. For example: **ATBT 1**. This command sets the default for Bluetooth to enabled.

Clear all custom configuration on a device

After you have set configurations using [%F \(Set Custom Default\)](#), you can return all configurations to the original factory defaults.

1. Open XCTU and load the device.
2. [Enter Command mode](#).
3. Send **AT!C**.

XBee bootloader

You can update firmware on the XBee3 Zigbee RF Module serially. This is done by invoking the XBee3 bootloader and transferring the firmware image using XMODEM.

This process is also used for updating a local device's firmware using XCTU.

XBee devices use a modified version of Silicon Labs' Gecko bootloader. This bootloader version supports a custom entry mechanism that uses module pins DIN, DTR / SLEEP_RQ, and RTS.

To invoke the bootloader, do the following:

1. Set DTR/SLEEP_RQ low (CMOS0V) and RTS high.
2. Send a serial break to the DIN pin and power cycle or reset the module.
3. When the device powers up, set DTR/SLEEP_RQ and DIN to low (CMOS0V) and RTS should be high.
4. Terminate the serial break and send a carriage return at 115200 baud to the device.

5. If successful, the device sends the Silicon Labs' Gecko bootloader menu out the DOUT pin at 115200 baud.
6. You can send commands can be sent to the bootloader at 115200 baud.

Note Disable hardware flow control when entering and communicating with the bootloader.

All serial communications with the module use 8 data bits, no parity bit, and 1 stop bit.

You can update firmware on the XBee3 Zigbee RF Module serially. This is done by invoking the XBee3 bootloader and transferring the firmware image using XMODEM.

This process is also used for updating a local device's firmware using XCTU.

Send a firmware image

After invoking the bootloader, a menu is sent out the UART at 115200 baud. To upload a firmware image through the UART interface:

1. Look for the bootloader prompt **BL >** to ensure the bootloader is active.
2. Send an ASCII **1** character to initiate a firmware update.
3. After sending a **1**, the device waits for an XModem CRC upload of a .gbl image over the serial line at 115200 baud. Send the .gbl file to the device using standard XMODEM-CRC.

If the firmware image is successfully loaded, the bootloader outputs a "complete" string. Invoke the newly loaded firmware by sending a **2** to the device.

If the firmware image is not successfully loaded, the bootloader outputs an "aborted string". It return to the main bootloader menu. Some causes for failure are:

- Over 1 minute passes after the command to send the firmware image and the first block of the image has not yet been sent.
- A power cycle or reset event occurs during the firmware load.
- A file error or a flash error occurs during the firmware load.

Software libraries

One way to communicate with the XBee3 Zigbee RF Module is by using a software library. The libraries available for use with the XBee3 Zigbee RF Module include:

- [XBee Java library](#)
- [XBee Python library](#)

The XBee Java Library is a Java API. The package includes the XBee library, its source code and a collection of samples that help you develop Java applications to communicate with your XBee devices.

The XBee Python Library is a Python API that dramatically reduces the time to market of XBee projects developed in Python and facilitates the development of these types of applications, making it an easy process.

XBee Network Assistant

The XBee Network Assistant is an application designed to inspect and manage RF networks created by Digi XBee devices. Features include:

- Join and inspect any nearby XBee network to get detailed information about all the nodes it contains.
- Update the configuration of all the nodes of the network, specific groups, or single devices based on configuration profiles.
- Geo-locate your network devices or place them in custom maps and get information about the connections between them.
- Export the network you are inspecting and import it later to continue working or work offline.
- Use automatic application updates to keep you up to date with the latest version of the tool.

See the [XBee Network Assistant User Guide](#) for more information.

To install the XBee Network Assistant:

1. Navigate to digi.com/xbeetworkassistant.
2. Click **General Diagnostics, Utilities and MIBs**.
3. Click the **XBee Network Assistant - Windows x86** link.
4. When the file finishes downloading, run the executable file and follow the steps in the XBee Network Assistant Setup Wizard.

Update the firmware over-the-air

The XBee3 Zigbee RF Module supports over-the-air (OTA) firmware updates. To perform an OTA update, the device to be updated must be associated and communicable with a Zigbee network. In this section, the node performing the update is considered the server and the node being updated is the client.

Use XCTU to perform the OTA firmware update using the following process:

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Add the device to XCTU

You must have a local device connected to your computer in order to perform firmware updates, either to update local firmware through the serial connection or to use the local device to remotely upgrade another device in the same network. With a local device properly attached to your computer, follow these steps:

1. Add the local device attached to your computer to XCTU so it displays in the radio modules list.
2. Add the remote module in the network to XCTU:
 - a. Configure the local module you added to work in API mode.
 - b. Click **Discover radio nodes in the same network** to start a search for the remote device.
 - c. When a remote device is found, it is listed in the **Discovering remote devices** dialog.
 - d. Select the device and click **Add selected devices**. The remote device is added to the radio modules list as a subordinate to the local device.

Update to the latest firmware

Firmware is the program code stored in the device's persistent memory that provides the control program for the device. Use XCTU to update the firmware.

1. Click the **Configuration working modes** button .
2. Select a local XBee module from the **Radio Modules** list.
3. Click the **Update firmware** button .

The **Update firmware** dialog displays the available and compatible firmware for the selected XBee module.
4. Select the product family of the XBee module, the function set, and the latest firmware version.

Note XBee3 Zigbee 3.0 does not support forced upgrades to the same version of the firmware.

5. Click **Update**. A dialog displays update progress. Click **Show details** for details of the firmware update process.

Note Once you add your device to the radio modules list in XCTU, the update process is exactly the same whether it is a local or remote device.

Note If there are instances where the upgrade fails with a transmission/waiting for image block request error, retry the update process.

See [How to update the firmware of your modules](#) in the XCTU User Guide for more information.

For information about performing an over-the-air (OTA) firmware update outside of XCTU, see [In-depth OTA firmware upgrade process for Zigbee 3.0](#).

Custom defaults

Custom defaults allow you to preserve a subset of the device configuration parameters even after returning to default settings using [RE \(Restore Defaults\)](#). This can be useful for settings that identify

the device—such as [NI \(Node Identifier\)](#)—or settings that could make remotely recovering the device difficult if they were reset—such as [ID \(Extended PAN ID\)](#).

Note You must send these commands as local AT commands, they cannot be set using [Remote AT Command Request frame - 0x17](#).

Set custom defaults

Use [%F \(Set Custom Default\)](#) to set custom defaults. When the XBee3 Zigbee RF Module receives [%F](#) it takes the next command it receives and applies it to both the current configuration and the custom defaults.

To set custom defaults for multiple commands, send a [%F](#) before each command.

Restore factory defaults

[!C \(Clear Custom Defaults\)](#) clears all custom defaults, so that [RE \(Restore Defaults\)](#) will restore the device to factory defaults. Alternatively, [R1 \(Restore Factory Defaults\)](#) restores all parameters to factory defaults without erasing their custom default values.

Limitations

There is a limitation on the number of custom defaults that can be set on a device. The number of defaults that can be set depends on the size of the saved parameters and the devices' firmware version. When there is no more room for custom defaults to be saved, any command sent immediately after a [%F](#) returns an error.

Setting a custom default that has already been set or setting a custom default to the factory default value will not reclaim the space used by the previous value. The new value takes effect but the old value still occupies space in memory, reducing the number of custom defaults that can be set. This can be remedied by using [!C \(Clear Custom Defaults\)](#) to clear all custom defaults when changing custom default values, and by only setting custom defaults that differ from the factory defaults.

Get started with MicroPython

This user guide provides an overview of how to use MicroPython with the XBee3 Zigbee RF Module. For in-depth information and more complex code examples, refer to the [Digi MicroPython Programming Guide](#). Continue with this user guide for simple examples to get started using MicroPython on the XBee3 Zigbee RF Module.

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About MicroPython

MicroPython is an open-source programming language based on Python 3.0, with much of the same syntax and functionality, but modified to fit on small devices with limited hardware resources, such as an XBee3 Zigbee RF Module.

For more information about MicroPython, see www.micropython.org.

For more information about Python, see www.python.org.

MicroPython on the XBee3 Zigbee RF Module

The XBee3 Zigbee RF Module has MicroPython running on the device itself. You can access a MicroPython prompt from the XBee3 Zigbee RF Module when you install it in an appropriate development board (XBDB or XBIB), and connect it to a computer via a USB cable.

Note MicroPython is only available through the UART interface and does not work with SPI.

Note MicroPython programming on the device requires firmware version 1003 or newer .

The examples in this user guide assume:


- You have [XCTU](#) on your computer. See [Configure the device using XCTU](#).
- You have a serial terminal program installed on your computer. For more information, see [Use the MicroPython Terminal in XCTU](#). This requires XCTU 6.3.10 or higher.
- You have an XBee3 Zigbee RF Module installed on an appropriate development board such as an XBIB-U-DEV or an XBDB-U-ZB.
- The XBee3 Zigbee RF Module is connected to the computer via a USB cable and XCTU recognizes it.

Use XCTU to enter the MicroPython environment

To use the XBee3 Zigbee RF Module in the MicroPython environment:



1. Use XCTU to add the device(s); see [Configure the device using XCTU](#) and [Add devices to XCTU](#).
2. The XBee3 Zigbee RF Module appears as a box in the **Radio Modules** information panel. Each module displays identifying information about itself.
3. Click this box to select the device and load its current settings.

Note To ensure that MicroPython is responsive to input, Digi recommends setting the XBee UART baud rate to 115200 baud. To set the UART baud rate, select **115200 [7]** in the **BD** field and click the **Write** button. We strongly recommend using hardware flow control to avoid data loss, especially when pasting large amounts of code or text. For more information, see [UART flow control](#).

4. To put the XBee3 Zigbee RF Module into MicroPython mode, in the **AP** field select **MicroPython REPL [4]** and click the **Write** button .
5. Note which COM port the XBee3 Zigbee RF Module is using, because you will need this information when you use the MicroPython terminal.

Use the MicroPython Terminal in XCTU

You can use the MicroPython Terminal to communicate with the XBee3 Zigbee RF Module when it is in MicroPython mode.¹ This requires XCTU 6.3.10 or higher. To enter MicroPython mode, follow the steps in [Use XCTU to enter the MicroPython environment](#). To use the MicroPython Terminal:

1. Click the **Tools** drop-down menu  and select **MicroPython Terminal**. The terminal window opens.
2. Click **Open** to open the Serial Port Configuration window.
3. In the **Select the Serial/USB port** area, click the COM port that the device uses.
4. Verify that the baud rate and other settings are correct.
5. Click **OK**. The **Open** icon changes to **Close** , indicating that the device is properly connected.

If the `>>>` prompt appears, you are connected properly. You can now type or paste MicroPython code in the terminal.

MicroPython examples

This section provides examples of how to use some of the basic functionality of MicroPython with the XBee3 Zigbee RF Module.

Example: hello world

1. At the MicroPython `>>>` prompt, type the Python command: `print("Hello, World!")`
2. Press **Enter** to execute the command. The terminal echos back **Hello, World!**

Example: enter MicroPython paste mode

In the following examples it is helpful to know that MicroPython supports [paste mode](#), where you can copy a large block of code from this user guide and paste it instead of typing it character by character. To use paste mode:

1. Copy the code you want to run. For example, copy the following code that is the code from the "Hello world" example:

```
print("Hello World")
```

Note You can easily copy and paste code from the [online version of this guide](#). Use caution with the PDF version, as it may not maintain essential indentations.

2. In the terminal, at the MicroPython `>>>` prompt type **Ctrl-+E** to enter paste mode. The terminal displays **paste mode; Ctrl-C to cancel, Ctrl-D to finish**.
3. Right-click in the MicroPython terminal window and click **Paste** or press **Ctrl+Shift+V** to paste.
4. The code appears in the terminal occupying one line. Each line starts with its line number and three "=" symbols. For example, line 1 starts with **1===**.

¹See [Other terminal programs](#) if you do not use the MicroPython Terminal in XCTU.

5. If the code is correct, press **Ctrl+D** to run the code; “Hello World” should print.

Note If you want to exit paste mode without running the code, or if the code did not copy correctly, press **Ctrl+C** to cancel and return to the normal MicroPython `>>>` prompt).

Example: using the time module

The time module is used for time-sensitive operations such as introducing a delay in your routine or a timer.

The following time functions are supported by the XBee3 Zigbee RF Module:

- **ticks_ms()** returns the current millisecond counter value. This counter rolls over at 0x40000000.
- **ticks_diff()** compares the difference between two timestamps in milliseconds.
- **sleep()** delays operation for a set number of seconds.
- **sleep_ms()** delays operation for a set number of milliseconds.
- **sleep_us()** delays operation for a set number of microseconds.

Note The standard **time.time()** function cannot be used, because this function produces the number of seconds since the epoch. The XBee3 module lacks a realtime clock and cannot provide any date or time data.

The following example exercises the various sleep functions and uses **ticks_diff()** to measure duration:

```
import time

start = time.ticks_ms() # Get the value from the millisecond counter

time.sleep(1)           # sleep for 1 second
time.sleep_ms(500)     # sleep for 500 milliseconds
time.sleep_us(1000)    # sleep for 1000 microseconds

delta = time.ticks_diff(time.ticks_ms(), start)

print("Operation took {} ms to execute".format(delta))
```

Example: AT commands using MicroPython

AT commands control the XBee3 Zigbee RF Module. The "AT" is an abbreviation for "attention", and the prefix "AT" notifies the module about the start of a command line. For a list of AT commands that can be used on the XBee3 Zigbee RF Module, see [AT commands](#).

MicroPython provides an **atcmd()** method to process AT commands, similar to how you can use [Command mode](#) or API frames.

The **atcmd()** method accepts two parameters:

1. The two character AT command, entered as a string.
2. An optional second parameter used to set the AT command value. If this parameter is not provided, the AT command is queried instead of being set. This value is an integer, bytes object, or string, depending on the AT command.

Note The `xbee.atcmd()` method does not support the following AT commands: **IS**, **AS**, **ED**, **ND**, or **DN**.

The following is example code that queries and sets a variety of AT commands using `xbee.atcmd()`:

```
import xbee

# Set the NI string of the radio
xbee.atcmd("NI", "XBee3 module")

# Configure a destination address using two different data types
xbee.atcmd("DH", 0x0013A200)          # Hex
xbee.atcmd("DL", b'\x12\x25\x89\xf5') # Bytes

# Read some AT commands and display the value and data type:
print("\nAT command parameter values:")
commands = ["DH", "DL", "NI", "OI"]
for cmd in commands:
    val = xbee.atcmd(cmd)
    print("{}: {:20} of type {}".format(cmd, repr(val), type(val)))
```

This example code outputs the following:

```
AT command parameter values:
DH: b'\x00\x13\xa2\x00' of type <class 'bytes'>
DL: b'\x12%\x89\xf5'   of type <class 'bytes'>
NI: 'XBee3 module'    of type <class 'str'>
OI: 65535              of type <class 'int'>
```

Note Parameters that store values larger than 16-bits in length are represented as bytes. Python attempts to print out ASCII characters whenever possible, which can result in some unexpected output (such as the "%" in the above output). If you want the output from MicroPython to match XCTU, you can use the following example to convert bytes to hex:

```
dl_value = xbee.atcmd("DL")
hex_dl_value = hex(int.from_bytes(dl_value, 'big'))
```

MicroPython networking and communication examples

This section provides networking and communication examples for using MicroPython with the XBee3 Zigbee RF Module.

Zigbee networks with MicroPython

For small networks, it is suitable to use MicroPython on every node. However, there are some inherent limitations that may prevent you from using MicroPython on some heavily trafficked nodes:

- When running MicroPython, any received messages will be stored in a small receive queue. This queue only has room for 4 packets and must be regularly read to prevent data loss. For networks that will be generating a lot of traffic, the data aggregator may need to operate in API mode in order to capture all incoming data.
- MicroPython does not have support for all of the XBee API frame types, particularly for source routing. If you are planning to operate with a network of more than 40 nodes, Digi highly recommends that you operate with the aggregator in API mode and implement source routing.

For the examples in this section, we use MicroPython to manage a Zigbee network and send and receive data between modules. To follow the upcoming examples, we need to configure a second XBee3 Zigbee RF Module to use MicroPython.

XCTU only allows a single MicroPython terminal. We will be running example code on both modules, which requires a second terminal window.

Open a second instance of XCTU, and configure a different XBee3 module for MicroPython following the steps in [Use XCTU to enter the MicroPython environment](#).



WARNING! The upcoming examples form and join an unencrypted Zigbee network. If the modules were previously associated with a network, they will be disassociated.

Example: forming and joining a Zigbee network using MicroPython

This example forms a two-node Zigbee network using MicroPython. This is a pre-requisite for subsequent networking examples.

This example assumes that you have two XBee3 Zigbee RF Modules configured for MicroPython and two terminals open, one for each radio.

Execute the following code on the first radio; it will be our network coordinator:

```
import xbee, time
# Set the identifying string of the radio
xbec.atcmd("NI", "Coordinator")

# Configure some basic network settings
network_settings = {"CE": 1, "ID": 0xABCD, "EE": 0, "NJ": 0xFF}

for command, value in network_settings.items():
    xbee.atcmd(command, value)
xbec.atcmd("AC") # Apply changes
time.sleep(1)

while xbee.atcmd("AI") != 0:
    time.sleep(0.1)
print("Network Established")

operating_network = ["OI", "OP", "CH"]
print("Operating network parameters:")
for cmd in operating_network:
    print("{}: {}".format(cmd, xbee.atcmd(cmd)))
```

Run the following code on the second radio, it will be a router that will join the established network:

```
import xbee, time

# Set the identifying string of the radio
xbec.atcmd("NI", "Router")

# Configure some basic network settings
network_settings = {"CE": 0, "ID": 0xABCD, "EE": 0}

for command, value in network_settings.items():
    xbee.atcmd(command, value)
xbec.atcmd("AC") # Apply changes
time.sleep(1)
```

```
# Query AI until it reports success

print("Connecting to network, please wait...")
while return xbee.atcmd("AI") != 0:
    time.sleep(0.1)
print("Connected to Network")

operating_network = ["OI", "OP", "CH"]
print("Operating network parameters:")
for cmd in operating_network:
    print("{}: {}".format(cmd, xbee.atcmd(cmd)))
```

After the code has been executed on both radios, the radio reports the operating network parameters. Make sure both radios report the same values to ensure they are on the same network.

Example: network Discovery using MicroPython

The `xbee.discover()` method returns an iterator that blocks while waiting for results, similar to executing an **ND** request. For more information, see [ND \(Network Discovery\)](#).

Each result is a dictionary with fields based on an **ND** response:

- **sender_nwk**: 16-bit network address.
- **sender_eui64**: 8-byte bytes object with EUI-64 address.
- **parent_nwk**: Set to 0xFFFE on the coordinator and routers; otherwise, this is set to the network address of the end device's parent.
- **node_id**: The device's **NI** value (a string of up to 20 characters, also referred to as Node Identification).
- **node_type**: Value of 0, 1 or 2 for coordinator, router, or end device.
- **device_type**: The device's 32-bit **DD** value, also referred to as Digi Device Type; this is used to identify different types of devices or hardware.
- **rsi**: Relative signal strength indicator (in dBm) of the node discovery request packet received by the sending node.

Note When printing the dictionary, fields for **device_type**, **sender_nwk** and **parent_nwk** appear in decimal form. You can use the MicroPython `hex()` method to print an integer in hexadecimal. Check the function code for `format_eui64` from the [Example: communication between two XBee3 Zigbee modules](#) topic for code to convert the **sender_eui64** field into a hexadecimal string with a colon between each byte value.

Use the following example code to perform a network discovery:

```
import xbee, time

# Set the network discovery options to include self
xbee.atcmd("NO", 2)
xbee.atcmd("AC")
time.sleep(.5)

# Perform Network Discovery and print out the results
print ("Network Discovery in process...")
nodes = list(xbee.discover())
if nodes:
```

```

    for node in nodes:
        print("\nRadio discovered:")
        for key, value in node.items():
            print("\t{:<12} : {}".format(key, value))

# Set NO back to the default value
xbee.atcmd("NO", 0)
xbee.atcmd("AC")

```

This produces the following output from two discovered nodes:

```

Radio discovered:
  rssi           : -63
  node_id        : Coordinator
  device_type     : 1179648
  parent_nwk     : 65534
  sender_nwk     : 0
  sender_eui64   : b'\x00\x13\xa2\xff h\x98T'
  node_type      : 0

Radio discovered:
  rssi           : -75
  node_id        : Router
  device_type     : 1179648
  parent_nwk     : 65534
  sender_nwk     : 23125
  sender_eui64   : b'\x00\x13\xa2\xffh\x98c&'
  node_type      : 1

```

Examples: transmitting data

This section provides examples for transmitting data using MicroPython. These examples assume you have followed the above examples and the two radios are on the same network.

Example: transmit message

Use the **xbee** module to transmit a message from the XBee3 Zigbee device. The **transmit()** function call consists of the following parameters:

1. The Destination Address, which can be any of the following:
 - Integer for 16-bit addressing
 - 8-byte bytes object for 64-bit addressing
 - Constant **xbee.ADDR_BROADCAST** to indicate a broadcast destination
 - Constant **xbee.ADDR_COORDINATOR** to indicate the coordinator
2. The Message as a character string.

If the message is sent successfully, **transmit()** returns **None**. If the transmission fails due to an ACK failure or lack of free buffer space on the receiver, the sent packet will be silently discarded.

Example: transmit a message to the network coordinator

1. From the router, access the MicroPython environment.
2. At the MicroPython >>> prompt, type **import xbee** and press **Enter**.

3. At the MicroPython >>> prompt, type `xbee.transmit(xbee.ADDR_COORDINATOR, "Hello World!")` and press **Enter**.
4. On the coordinator, you can issue an `xbee.receive()` call to output the received packet.

Example: transmit custom messages to all nodes in a network

This program performs a network discovery and sends the message **'Hello <Destination Node Identifier>'** to individual nodes in the network. For more information, see [Example: network Discovery using MicroPython](#).

```
import xbee

# Perform a network discovery to gather destination address:
print("Discovering remote nodes, please wait...")
node_list = list(xbee.discover())
if not node_list:
    raise Exception("Network discovery did not find any remote devices")

for node in node_list:
    dest_addr = node['sender_nwk'] # 'sender_eui64' can also be used
    dest_node_id = node['node_id']
    payload_data = "Hello, " + dest_node_id + "!"

    try:
        print("Sending \"{}\" to {}".format(payload_data, hex(dest_addr)))
        xbee.transmit(dest_addr, payload_data)
    except Exception as err:
        print(err)

print("complete")
```

Receiving data

Use the `receive()` function from the `xbee` module to receive messages. When MicroPython is active on a device (**AP** is set to 4), all incoming messages are saved to a receive queue within MicroPython. This receive queue is limited in size and only has room for 4 messages. To ensure that data is not lost, it is important to continuously iterate through the receive queue and process any of the packets within.

If the receive queue is full and another message is sent to the device, it will not acknowledge the packet and the sender generates a failure status of 0x24 (Address not found).

The `receive()` function returns one of the following:

- None: No message (the receive queue is empty).
- Message dictionary consisting of:
 - **sender_nwk**: 16-bit network address of the sending node.
 - **sender_eui64**: 64-bit address (as a "bytes object") of the sending node.
 - **source_ep**: source endpoint as an integer.
 - **dest_ep**: destination endpoint as an integer.
 - **cluster**: cluster id as an integer.
 - **profile**: profile id as an integer.
 - **broadcast**: True or False depending on whether the frame was broadcast or unicast.
 - **payload**: "Bytes object" of the payload. This is a bytes object instead of a string, because the payload can contain binary data.

Example: continuously receive data

In this example, the `format_packet()` helper formats the contents of the dictionary and `format_eui64()` formats the bytes object holding the EUI-64. The `while` loop shows how to poll for packets continually to ensure that the receive buffer does not become full.

```
def format_eui64(addr):
    return ':'.join('%02x' % b for b in addr)

def format_packet(p):
    type = 'Broadcast' if p['broadcast'] else 'Unicast'
    print("%s message from EUI-64 %s (network 0x%04X)" % (type,
        format_eui64(p['sender_eui64']), p['sender_nwk']))
    print("    from ep 0x%02X to ep 0x%02X, cluster 0x%04X, profile 0x%04X:" %
        (p['source_ep'], p['dest_ep'], p['cluster'], p['profile']))
    print(p['payload'])

import xbee, time
while True:
    print("Receiving data...")
    print("Press CTRL+C to cancel.")
    p = xbee.receive()
    if p:
        format_packet(p)
    else:
        time.sleep(0.25)    # wait 0.25 seconds before checking again
```

If this node had previously received a packet, it outputs as follows:

```
Unicast message from EUI-64 00:13:a2:00:41:74:ca:70 (network 0x6D81)
    from ep 0xE8 to ep 0xE8, cluster 0x0011, profile 0xC105:
b'Hello World!'
```

Note Digi recommends calling the `receive()` function in a loop so no data is lost. On modules where there is a high volume of network traffic, there could be data lost if the messages are not pulled from the queue fast enough.

Example: communication between two XBee3 Zigbee modules

This example combines all of the previous examples and represents a full application that configures a network, discovers remote nodes, and sends and receives messages.

First, we will upload some utility functions into the flash space of MicroPython so that the following examples will be easier to read.

Complete the following steps to compile and execute utility functions using flash mode on both devices:

1. Access the MicroPython environment.
2. Press **Ctrl + F**.
3. Copy the following code:

```
import xbee, time
# Utility functions to perform XBee3 Zigbee operations
def format_eui64(addr):
    return ':'.join('%02x' % b for b in addr)
```

```

def format_packet(p):
    type = 'Broadcast' if p['broadcast'] else 'Unicast'
    print("%s message from EUI-64 %s (network 0x%04X)" %
          (type, format_eui64(p['sender_eui64']), p['sender_nwk']))
    print("from ep 0x%02X to ep 0x%02X, cluster 0x%04X, profile 0x%04X:" %
          (p['source_ep'], p['dest_ep'], p['cluster'], p['profile']))
    print(p['payload'], "\n")

def network_status():
    # If the value of AI is non zero, the module is not connected to a network
    return xbee.atcmd("AI")

```

4. At the MicroPython 1^^^ prompt, right-click and select the **Paste** option.
5. Press **Ctrl+D** to finish. The code is uploaded to the flash memory and then compiled. At the "Automatically run this code at startup" [Y/N]?" prompt, select **Y**.
6. Press **Ctrl+R** to run the compiled code; this provides access to these utility functions for the next examples.

Example code on the coordinator module

The following example code forms a Zigbee network as a coordinator, performs a network discovery to find the remote node, and continuously prints out any incoming data.

1. Access the MicroPython environment.
2. Copy the following sample code:

```

print("Forming a new network as a coordinator...")
xbee.atcmd("NI", "Coordinator")
network_settings = {"CE": 1, "ID": 0x3332, "EE": 0, "NJ": 0xFF}
for command, value in network_settings.items():
    xbee.atcmd(command, value)
xbee.atcmd("AC") # Apply changes
time.sleep(1)

while network_status() != 0:
    time.sleep(0.1)
print("Network Established\n")

print("Waiting for a remote node to join...")
node_list = []
while len(node_list) == 0:
    # Perform a network discovery until the router joins
    node_list = list(xbee.discover())
print("Remote node found, transmitting data")

for node in node_list:
    dest_addr = node['sender_nwk'] # using 16 bit addressing
    dest_node_id = node['node_id']
    payload_data = "Hello, " + dest_node_id + "!"

    print("Sending \"{}\" to {}".format(payload_data, hex(dest_addr)))
    xbee.transmit(dest_addr, payload_data)

# Start the receive loop
print("Receiving data...")
print("Hit CTRL+C to cancel")
while True:

```

```

p = xbee.receive()
if p:
    format_packet(p)
else:
    time.sleep(0.25)

```

3. Press **Ctrl+E** to enter paste mode.
4. At the **MicroPython >>>** prompt, right-click and select the **Paste** option. Once you paste the code, it executes immediately.

Example code on the router module

The following example code joins the Zigbee network from the previous example, and continuously prints out any incoming data. This device also sends its temperature data every 5 seconds to the coordinator address.

1. Access the MicroPython environment.
2. Copy the following sample code:

```

print("Joining network as a router...")
xbee.atcmd("NI", "Router")
network_settings = {"CE": 0, "ID": 0x3332, "EE": 0}
for command, value in network_settings.items():
    xbee.atcmd(command, value)
xbee.atcmd("AC") # Apply changes
time.sleep(1)

while network_status() != 0:
    time.sleep(0.1)
print("Connected to Network\n")

last_sent = time.ticks_ms()
interval = 5000 # How often to send a message




# Start the transmit/receive loop
print("Sending temp data every {} seconds".format(interval/1000))
while True:
    p = xbee.receive()
    if p:
        format_packet(p)
    else:
        # Transmit temperature if ready
        if time.ticks_diff(time.ticks_ms(), last_sent) > interval:
            temp = "Temperature: {}".format(xbee.atcmd("TP"))
            print("\tsending " + temp)
            try:
                xbee.transmit(xbee.ADDR_COORDINATOR, temp)
            except Exception as err:
                print(err)
            last_sent = time.ticks_ms()
        time.sleep(0.25)

```

3. Press **Ctrl+E** to enter paste mode.
4. At the **MicroPython >>>** prompt, right-click and select the **Paste** option. Once you paste the code, it executes immediately.

Exit MicroPython mode

To exit MicroPython mode:

1. In the XCTU MicroPython terminal, click the green **Close** button .
2. Click **Close** at the bottom of the terminal to exit the terminal.
3. In XCTU's Configuration working mode , change **AP API Enable** to another mode and click the **Write** button . We recommend changing to Transparent mode **[0]**, as most of the examples use this mode.

Other terminal programs

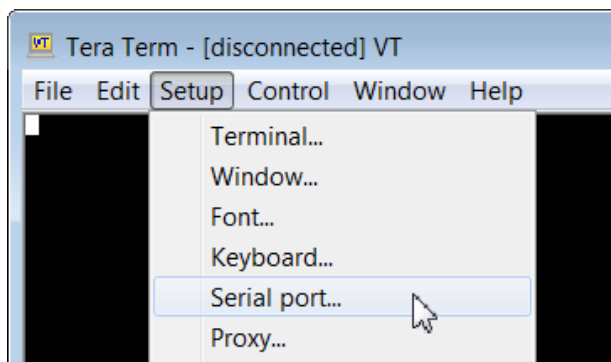
If you do not use the MicroPython terminal in XCTU, you can use other terminal programs to communicate with the XBee3 Zigbee RF Module. If you use Microsoft Windows, follow the instructions for Tera Term; if you use Linux, follow the instructions for picocom. To download these programs:

- Tera Term for Windows, see ttssh2.osdn.jp/index.html.en.
- Picocom for Linux, see developer.ridgerun.com/wiki/index.php/Setting_up_Picocom_-_Ubuntu
- Source code and in-depth information, see github.com/npat-efault/picocom.

Tera Term for Windows

With the XBee3 Zigbee RF Module in MicroPython mode (**AP = 4**), you can access the MicroPython prompt using a terminal.

1. Open Tera Term. The **Tera Term: New connection** window appears.
2. Click the **Serial** radio button to select a serial connection.
3. From the **Port:** drop-down menu, select the COM port that the XBee3 Zigbee RF Module is connected to.
4. Click **OK**. The **COMxx - Tera Term VT** terminal window appears and Tera Term attempts to connect to the device at a baud rate of 9600 bps. The terminal will not allow communication with the device since the baud rate setting is incorrect. You must change this rate as it was previously set to 115200 bps.
5. Click **Setup** and **Serial Port**. The **Tera Term: Serial port setup** window appears.



6. In the **Tera Term: Serial port setup** window, set the parameters to the following values:
 - **Port:** Shows the port that the XBee3 Zigbee RF Module is connected on.
 - **Baud rate:** 115200
 - **Data:** 8 bit
 - **Parity:** none
 - **Stop:** 1 bit
 - **Flow control:** hardware
 - **Transmit delay:** N/A
7. Click **OK** to apply the changes to the serial port settings. The settings should go into effect right away.
8. To verify that local echo is not enabled and that extra line-feeds are not enabled:
 - a. In Tera Term, click **Setup** and select **Terminal**.
 - b. In the **New-line** area of the **Tera Term: Serial port setup** window, click the **Receive** drop-down menu and select **AUTO** if it does not already show that value.
 - c. Make sure the **Local echo** box is not checked.
9. Click **OK**.
10. Press **Ctrl+B** to get the MicroPython version banner and prompt.

```
MicroPython v1.9.3-716-g507d0512 on 2018-02-20; XBee3 Zigbee with EFR32MG
Type "help()" for more information.
>>>
```

Now you can type MicroPython commands at the **>>>** prompt.

Use picocom in Linux

With the XBee3 Zigbee RF Module in MicroPython mode (**AP = 4**), you can access the MicroPython prompt using a terminal.

Note The user must have read and write permission for the serial port the XBee3 Zigbee RF Module is connected to in order to communicate with the device.

1. Open a terminal in Linux and type **picocom -b 115200 /dev/ttyUSB0**. This assumes you have no other USB-to-serial devices attached to the system.
2. Press **Ctrl+B** to get the MicroPython version banner and prompt. You can also press **Enter** to bring up the prompt.

If you do have other USB-to-serial devices attached:

1. Before attaching the XBee3 Zigbee RF Module, check the directory **/dev/** for any devices named **ttyUSBx**, where **x** is a number. An easy way to list these is to type: **ls /dev/ttyUSB***. This produces a list of any device with a name that starts with **ttyUSB**.
2. Take note of the devices present with that name, and then connect the XBee3 Zigbee RF Module.
3. Check the directory again and you should see one additional device, which is the XBee3 Zigbee RF Module.

4. In this case, replace `/dev/ttyUSB0` at the top with `/dev/ttyUSB<number>`, where `<number>` is the new number that appeared.

It connects and shows "Terminal ready".

```

@ -VirtualBox: ~
File Edit View Search Terminal Help
@ -VirtualBox:~$ sudo picocom -b 115200 /dev/ttyUSB0
[sudo] password for :
picocom v1.7

port is      : /dev/ttyUSB0
flowcontrol  : none
baudrate is  : 115200
parity is    : none
databits are : 8
escape is    : C-a
local echo is : no
noinit is   : no
noreset is   : no
nolock is    : no
send_cmd is  : SZ -vv
receive_cmd is : rz -vv
imap is      :
omap is      :
emap is      : crclrf,delbs,

Terminal ready

>>> █

```

You can now type MicroPython commands at the `>>>` prompt.

Micropython help ()

When you type the `help()` command at the prompt, it provides a link to online help, control commands and also usage examples.

```

>>> help()
Welcome to MicroPython!
For online docs please visit http://docs.micropython.org/.
Control commands:
CTRL-A      -- on a blank line, enter raw REPL mode
CTRL-B      -- on a blank line, enter normal REPL mode
CTRL-C      -- interrupt a running program
CTRL-D      -- on a blank line, reset the REPL
CTRL-E      -- on a blank line, enter paste mode
CTRL-F      -- on a blank line, enter flash upload mode
For further help on a specific object, type help(obj)
For a list of available modules, type help('modules')
-----
-----

```

When you type `help('modules')` at the prompt, it displays all available MicroPython modules.

```

>>> help('modules')
-----
__main__      hashlib      sys          umachine
array         io           time         uos
binascii     machine     ubinascii   ustruct
builtins     micropython uerrno      utime
errno        os          uhashlib    xbee
gc           struct      uio
-----

```

When you import a module and type **help()** with the module as the object, you can query all the functions that the object supports.

```

>>> import sys
>>> help(sys)
object <module 'sys'> is of type module
__name__ -- sys
path -- []
argv -- []
version -- 3.4.0
version_info -- (3, 4, 0)
implementation -- ('micropython', (1, 9, 4))
platform -- xbee3-zigbee
byteorder -- little
maxsize -- 2147483647
exit -- <function>
stdin -- <io.FileIO 0>
stdout -- <io.FileIO 1>
stderr -- <io.FileIO 2>
print_exception -- <function>
-----

```

Get started with BLE

Bluetooth® Low Energy (BLE) is a RF protocol that enables you to connect your XBee device to another device. Both devices must have BLE enabled.

For example, you can use your cellphone to connect to your XBee device, and then from your phone, configure and program the device.

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Enable BLE on the XBee3 Zigbee RF Module

To enable BLE on a XBee3 Zigbee RF Module and verify the connection:

1. Set up the XBee3 Zigbee RF Module and make sure to connect the antenna to the device.
2. [Enable BLE and configure the BLE password.](#)
3. [Get the Digi XBee Mobile phone application.](#)
4. [Connect with BLE and configure your XBee3 device.](#)

Note The BLE protocol is disabled on the XBee3 Zigbee RF Module by default. You can create a custom factory default configuration that ensures BLE is always enabled. See [Custom configuration: Create a new factory default.](#)


Enable BLE and configure the BLE password

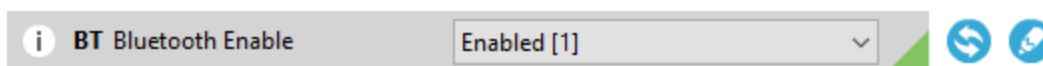
Some of the latest XBee3 devices support Bluetooth Low Energy (BLE) as an extra interface for configuration. If you want to use this feature, you have to enable BLE. You must also enable security by setting a password on the XBee3 Zigbee RF Module in order to connect, configure, or send data over BLE.

Use XCTU to configure the BLE password. Make sure you have installed or updated XCTU to version 6.4.2 or newer. Earlier versions of XCTU do not include the BLE configuration features. See [Download and install XCTU](#) for installation instructions.

Before you begin, you should determine the password you want to use for BLE on the XBee3 Zigbee RF Module and store it in a secure place. We recommend a secure password of at least eight characters and a random combination of letters, numbers, and special characters. We recommend using a security management tool such as LastPass or KeePass for generating and storing passwords for many devices.

Note When you enter the BLE password in XCTU, the salt and verifier values are calculated as you set your password. For more information on how these values are used in the authentication process, see [BLE Unlock API frame - 0x2C.](#)

1. Launch XCTU.
2. Switch to Configuration working mode .
3. Select a BLE compatible radio module from the device list.
4. Select **Enabled[1]** from the **BT Bluetooth Enable** command drop-down.



5. Click the **Write setting** button . The **Bluetooth authentication not set** dialog appears.

Note If BLE has been previously configured, the **Bluetooth authentication not set** dialog does not appear. If this happens, click **Configure** in the Bluetooth Options section to display the **Configure Bluetooth Authentication** dialog.

6. Click **Configure** in the dialog. The **Configure Bluetooth Authentication** dialog appears.
7. In the **Password** field, type the password for the device. As you type, the **Salt** and **Verifier** fields are automatically calculated and populated in the dialog as shown above. This password is used when you connect to this XBee device via BLE using the [Digi XBee Mobile app](#).

Basic configuration

i Password:

Advanced configuration

i Salt:

i Verifier:

Note that you must know the password which originated this verifier. Connecting to the XBee via BLE requires the known password.

8. Click **OK** to save the configuration.

Get the Digi XBee Mobile phone application

To see the nearby devices that have BLE enabled, you must get the free Digi XBee Mobile application from the iOS App Store or Google Play and downloaded to your phone.

1. On your phone, go to the App store.
2. Search for: **Digi XBee Mobile**.
3. Download and install the app.

The Digi is compatible with the following operating systems and versions:

- Android 5.0 or higher
- iOS 11 or higher

Connect with BLE and configure your XBee3 device

You can use the Digi XBee Mobile application to verify that BLE is enabled on your XBee device.

1. [Get the Digi XBee Mobile phone application.](#)
2. Open the Digi XBee Mobile application. The **Find XBee devices** screen appears and the app automatically begins scanning for devices. All nearby devices with BLE enabled are displayed in a list.
3. Scroll through the list to find your XBee device.
The first time you open the app on a phone and scan for devices, the device list contains only the name of the device and the BLE signal strength. No identifying information for the device displays. After you have authenticated the device, the device information is cached on the phone. The next time the app on this phone connects to the XBee device, the IMEI for the device displays in the app device list.

Note The IMEI is derived from the **SH** and **SL** values.

4. Tap the XBee device name in the list. A password dialog appears.
5. Enter the [password](#) you previously configured for the device in XCTU.
6. Tap **OK**. The **Device Information** screen displays. You can now scroll through the settings for the device and change the device's configuration as needed.

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BLE advertising behavior and services

When the Bluetooth radio is enabled, periodic BLE advertisements are transmitted. The advertisement data includes the product name in the Complete Local Name field. When an XBee device connects to the Bluetooth radio, the BLE services are listed:

- [Device Information Service](#)
- [XBee API BLE Service](#)

Device Information Service

The standard Device Information Service is used. The Manufacturer, Model, and Firmware Revision characters are provided inside the service.

XBee API BLE Service

You can configure the XBee3 Zigbee RF Module through the BLE interface using API frame requests and responses. The API frame format through Bluetooth is equivalent to setting **AP = 1** and transmitting the frames over the UART or SPI interface. API frames can be executed over Bluetooth regardless of the AP setting.

The BLE interface allows these frames:

- [BLE Unlock API frame - 0x2C](#)
- [BLE Unlock Response frame - 0xAC](#)
- [AT Command Frame - 0x08](#)
- [AT Command - Queue Parameter Value frame - 0x09](#)

This API reference assumes that you are familiar with Bluetooth and GATT services. The specifications for Bluetooth are an open standard and can be found at the following links:

- Bluetooth Core Specifications: [bluetooth.com/specifications/bluetooth-core-specification](https://www.bluetooth.com/specifications/bluetooth-core-specification)
- Bluetooth GATT: [bluetooth.com/specifications/gatt/generic-attributes-overview](https://www.bluetooth.com/specifications/gatt/generic-attributes-overview)

The XBee API BLE Service contains two characteristics: the API Request characteristic and the API Response characteristic. The UUIDs for the service and its characteristics are listed in the table below.

Characteristic	UUID
API Service UUID	53da53b9-0447-425a-b9ea-9837505eb59a
API Request Characteristic UUID	7dddca00-3e05-4651-9254-44074792c590
API Response Characteristic UUID	f9279ee9-2cd0-410c-81cc-adf11e4e5aea

API Request characteristic

UUID: 7dddca00-3e05-4651-9254-44074792c590

Permissions: Writeable

XBee API frames are broken into chunks and transmitted sequentially to the request characteristic using write operations. Valid frames are then processed and the result is returned through indications on the response characteristic.

API frames do not need to be written completely in a single write operation to the request characteristic. In fact, Bluetooth limits the size of a written value to 3 bytes smaller than the configured Maximum Transmission Unit (MTU), which defaults to 23, meaning that by default, you can only write 20 bytes at a time.

After connecting you must send a valid [Bluetooth Unlock API Frame](#) in order to authenticate the connection. If the BLE Unlock API - 0x2C frame has not been executed, all other API frames are silently ignored and are not processed.

API Response characteristic

UUID: f9279ee9-2cd0-410c-81cc-adf11e4e5aea

Permissions: Readable, Indicate

Responses to API requests made to the request characteristic are returned through the response characteristics. This characteristic cannot be read directly.

Response data is presented through indications on this characteristic. Indications are acknowledged and re-transmitted at the BLE link layer and application layer and provide a robust transport for this data.

Serial communication

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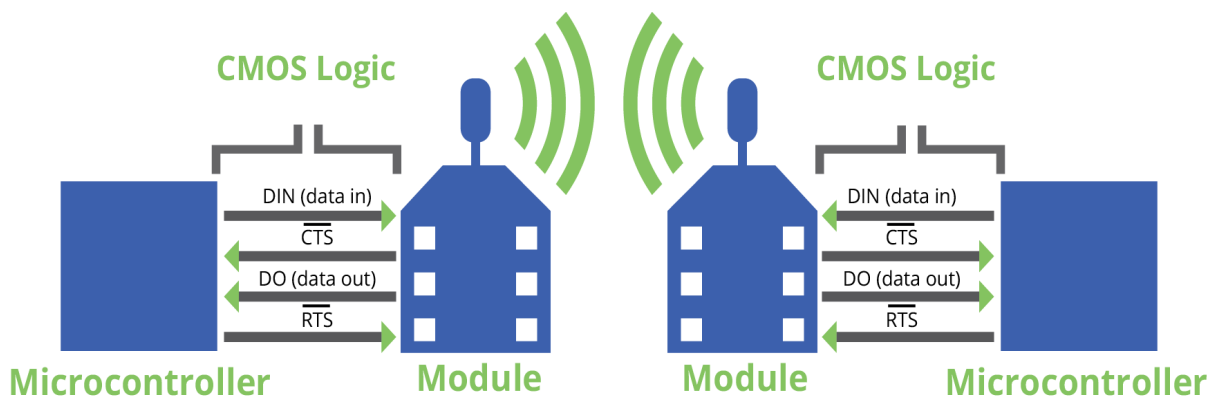
Serial interface

The XBee3 Zigbee RF Module interfaces to a host device through a serial port. The device can communicate through its serial port:

- Through logic and voltage compatible universal asynchronous receiver/transmitter (UART).
- Through a level translator to any serial device, for example through an RS-232 or USB interface board.
- Through SPI, as described in [SPI communications](#).

UART data flow

Devices that have a UART interface connect directly to the pins of the XBee3 Zigbee RF Module as shown in the following figure. The figure shows system data flow in a UART-interfaced environment. Low-asserted signals have a horizontal line over the signal name.



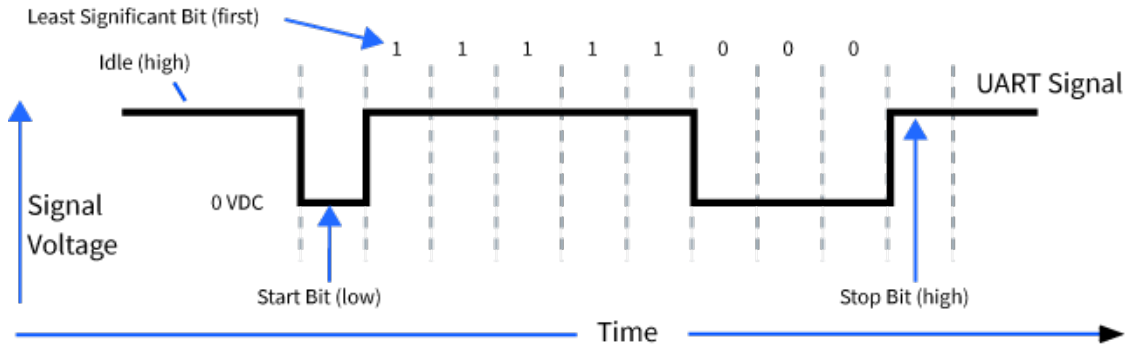
For more information about hardware specifications for the UART, see the [XBee3 Hardware Reference Manual](#).

Serial data

A device sends data to the XBee3 Zigbee RF Module's UART as an asynchronous serial signal. When the device is not transmitting data, the signals should idle high.

For serial communication to occur, you must configure the UART of both devices (the microcontroller and the XBee3 Zigbee RF Module) with compatible settings for the baud rate, parity, start bits, stop bits, and data bits.

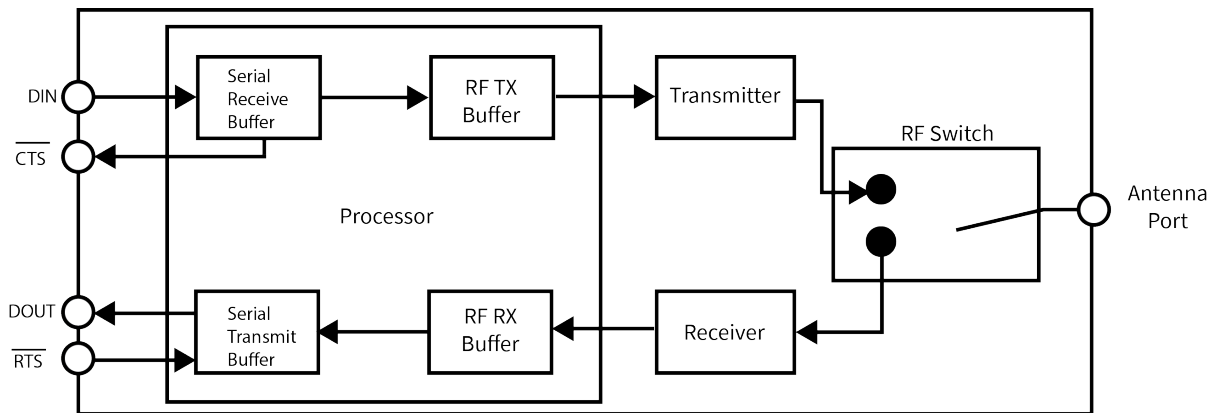
Each data byte consists of a start bit (low), 8 data bits (least significant bit first) and a stop bit (high). The following diagram illustrates the serial bit pattern of data passing through the device. The diagram shows UART data packet 0x1F (decimal number 31) as transmitted through the device.



You can configure the UART baud rate, parity, and stop bits settings on the device with the **BD**, **NB**, and **SB** commands respectively. For more information, see [Serial interfacing commands](#).

Serial buffers

The XBee3 Zigbee RF Module maintains internal buffers to collect serial and RF data that it receives. The serial receive buffer collects incoming serial characters and holds them until the device can process them. The serial transmit buffer collects the data it receives via the RF link until it transmits that data out the serial port. The following figure shows the process of device buffers collecting received serial data.



Serial receive buffer

When serial data enters the XBee3 Zigbee RF Module through the serial port, the device stores the data in the serial receive buffer until it can be processed. Under certain conditions, the device may receive data when the serial receive buffer is already full. In that case, the device discards the data.

The serial receive buffer becomes full when data is streaming into the serial port faster than it can be processed and sent over the air (OTA). While the speed of receiving the data on the serial port can be much faster than the speed of transmitting data for a short period, sustained operation in that mode causes the device to drop data due to running out of places to put the data. Some things that may delay over the air transmissions are address discovery, route discovery, and retransmissions. Processing received RF data can also take away time and resources for processing incoming serial data.

If the UART is the serial port and you enable the CTS flow control, the device alerts the external data source when the receive buffer is almost full. The host delays sending data to the device until the module asserts CTS again, allowing more data to come in.

Serial transmit buffer

When the device receives RF data, it moves the data into the serial transmit buffer and sends it out the UART. If the serial transmit buffer becomes full and the system buffers are also full, then it drops the entire RF data packet. Whenever the device receives data faster than it can process and transmit the data out the serial port, there is a potential of dropping data.

In situations where the serial transmit buffer may become full, resulting in dropped RF packets:

1. If the RF data rate is set higher than the interface data rate of the device, the device may receive data faster than it can send the data to the host. Even occasional transmissions from a large number of devices can quickly accumulate and overflow the transmit buffer.
2. If the host does not allow the device to transmit data out from the serial transmit buffer due to being held off by hardware flow control.

UART flow control

You can use the $\overline{\text{RTS}}$ and $\overline{\text{CTS}}$ pins to provide $\overline{\text{RTS}}$ and/or $\overline{\text{CTS}}$ flow control. $\overline{\text{CTS}}$ flow control provides an indication to the host to stop sending serial data to the device. $\overline{\text{RTS}}$ flow control allows the host to signal the device to not send data in the serial transmit buffer out the UART. To enable $\overline{\text{RTS/CTS}}$ flow control, use the **D6** and **D7** commands.

$\overline{\text{CTS}}$ flow control

If you enable CTS flow control (**D7** command), when the serial receive buffer is 17 bytes away from being full, the device de-asserts $\overline{\text{CTS}}$ (sets it high) to signal to the host device to stop sending serial data.

$\overline{\text{RTS}}$ flow control

If you set **D6 (DIO6/RTS)** to enable $\overline{\text{RTS}}$ flow control, the device does not send data in the serial transmit buffer out the DOUT pin as long as $\overline{\text{RTS}}$ is de-asserted (set high). Do not de-assert $\overline{\text{RTS}}$ for long periods of time or the serial transmit buffer will fill. If the device receives an RF data packet and the serial transmit buffer does not have enough space for all of the data bytes, it discards the entire RF data packet.

If the device sends data out the UART when $\overline{\text{RTS}}$ is de-asserted (set high) the device could send up to five characters out the UART port after $\overline{\text{RTS}}$ is de-asserted.

Break control

If a serial break (DIN held low) signal is sent for over five seconds, the device resets, and it boots into Command mode with default baud settings (9600 baud). If either **P3** or **P4** are not enabled, this break function is disabled.

SPI operation

This section specifies how SPI is implemented on the device, what the SPI signals are, and how full duplex operations work.

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SPI communications

The XBee3 Zigbee RF Module supports SPI communications in slave mode. Slave mode receives the clock signal and data from the master and returns data to the master. The following table shows the signals that the SPI port uses on the device.

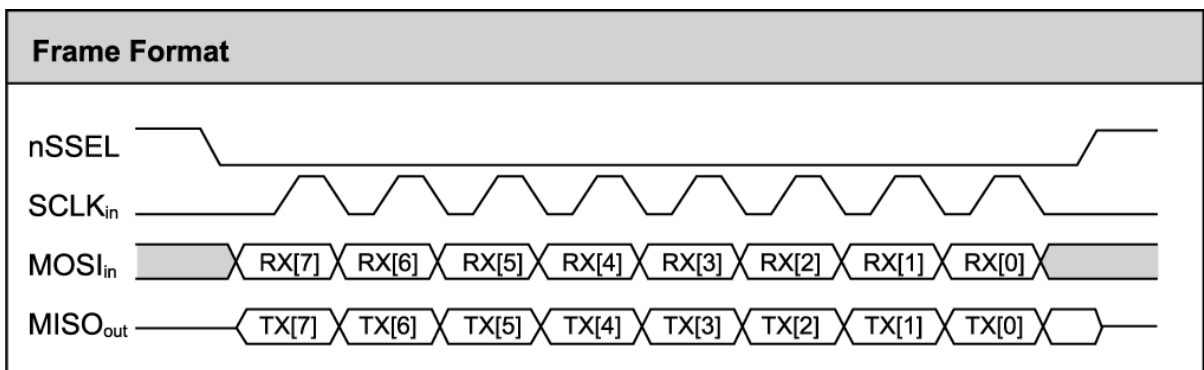
Refer to the [XBee3 Hardware Reference Guide](#) for the pinout of your device.

Signal	Direction	Function
SPI_MOSI (Master Out, Slave In)	Input	Inputs serial data from the master
SPI_MISO (Master In, Slave Out)	Output	Outputs serial data to the master
SPI_SCLK (Serial Clock)	Input	Clocks data transfers on MOSI and MISO
SPI_SSEL (Slave Select)	Input	Enables serial communication with the slave
SPI_ATT \bar{N} (Attention)	Output	Alerts the master that slave has data queued to send. The XBee3 Zigbee RF Module asserts this pin as soon as data is available to send to the SPI master and it remains asserted until the SPI master has clocked out all available data.

In this mode:

- SPI clock rates up to 5 MHz (burst) are possible.
- Data is most significant bit (MSB) first; bit 7 is the first bit of a byte sent over the interface.
- Frame Format mode 0 is used. This means CPOL= 0 (idle clock is low) and CPHA = 0 (data is sampled on the clock's leading edge).
- The SPI port only supports API Mode (**AP = 1**).

The following diagram shows the frame format mode 0 for SPI communications.



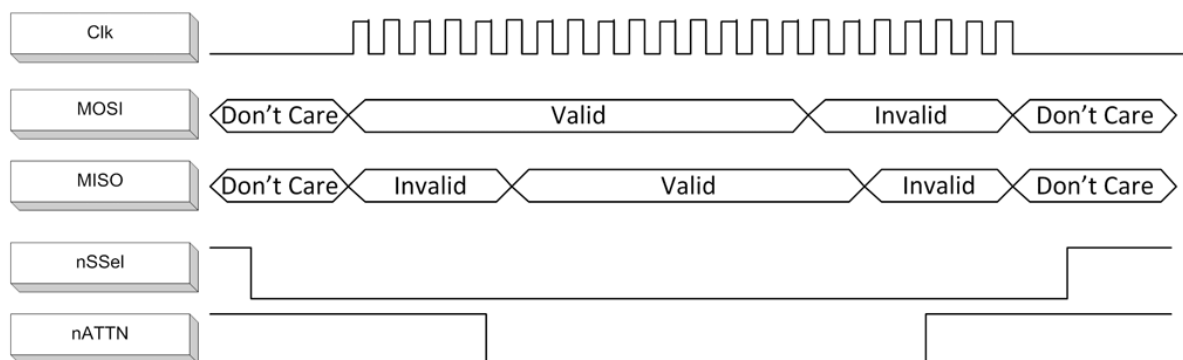
SPI mode is chip to chip communication. We do not supply a SPI communication interface on the XBee development evaluation boards included in the development kit.

Full duplex operation

When using SPI on the XBee3 Zigbee RF Module the device uses API operation without escaped characters to packetize data. The device ignores the configuration of **AP** because SPI does not operate in any other mode. SPI is a full duplex protocol, even when data is only available in one direction. This means that whenever a device receives data, it also transmits, and that data is normally invalid. Likewise, whenever a device transmits data, invalid data is probably received. To determine whether or not received data is invalid, the firmware places the data in API packets.

SPI allows for valid data from the slave to begin before, at the same time, or after valid data begins from the master. When the master sends data to the slave and the slave has valid data to send in the middle of receiving data from the master, a full duplex operation occurs, where data is valid in both directions for a period of time. Not only must the master and the slave both be able to keep up with the full duplex operation, but both sides must honor the protocol.

The following figure illustrates the SPI interface while valid data is being sent in both directions.



Low power operation

Sleep modes generally work the same on SPI as they do on UART. However, due to the addition of SPI mode, there is an option of another sleep pin, as described below.

By default, Digi configures DIO8 (SLEEP_REQUEST) as a peripheral and during pin sleep it wakes the device and puts it to sleep. This applies to both the UART and SPI serial interfaces.

If SLEEP_REQUEST is not configured as a peripheral and SPI_SSEL is configured as a peripheral, then pin sleep is controlled by SPI_SSEL rather than by SLEEP_REQUEST. Asserting SPI_SSEL by driving it low either wakes the device or keeps it awake. Negating SPI_SSEL by driving it high puts the device to sleep.

Using SPI_SSEL to control sleep and to indicate that the SPI master has selected a particular slave device has the advantage of requiring one less physical pin connection to implement pin sleep on SPI. It has the disadvantage of putting the device to sleep whenever the SPI master negates SPI_SSEL (meaning time is lost waiting for the device to wake), even if that was not the intent.

If the user has full control of SPI_SSEL so that it can control pin sleep, whether or not data needs to be transmitted, then sharing the pin may be a good option in order to make the SLEEP_REQUEST pin available for another purpose.

If the device is one of multiple slaves on the SPI, then the device sleeps while the SPI master talks to the other slave, but this is acceptable in most cases.

If you do not configure either pin as a peripheral, then the device stays awake, being unable to sleep in **SM1** mode.

Select the SPI port

To force SPI mode on through-hole devices, hold DOUT/DIO13 low while resetting the device until SPI_ATT \bar{N} asserts. This causes the device to disable the UART and go straight into SPI communication mode. Once configuration is complete, the device queues a modem status frame to the SPI port, which causes the SPI_ATT \bar{N} line to assert. The host can use this to determine that the SPI port is configured properly.

On surface-mount devices, forcing DOUT low at the time of reset has no effect. To use SPI mode on the SMT modules, assert the SPI_SSEL low after reset and before any UART data is input.

Forcing DOUT low on TH devices forces the device to enable SPI support by setting the following configuration values:

Through-hole	Micro and Surface-mount	SPI signal
D1 (AD1/DIO1/TH_SPI_ATT \bar{N} Configuration)	P9 (DIO19/SPI_ATT \bar{N} Configuration)	ATT \bar{N}
D2 (DIO2/AD2/TH_SPI_CLK Configuration)	P8 (DIO18/SPI_CLK Configuration)	SCLK
D3 (DIO3/AD3/TH_SPI_SSEL Configuration)	P7 (DIO17/SPI_SSEL Configuration)	SSEL $\bar{}$
D4 (DIO4/TH_SPI_MOSI Configuration)	P6 (DIO16/SPI_MOSI Configuration)	MOSI
P2 (DIO12/TH_SPI_MISO Configuration)	P5 (DIO15/SPI_MISO Configuration)	MISO

Note The ATT \bar{N} signal is optional—you can still use SPI mode if you disable the SPI_ATT \bar{N} pin (D1 on through-hole or P9 on surface-mount devices).

As long as the host does not issue a **WR** command, these configuration values revert to previous values after a power-on reset. If the host issues a **WR** command while in SPI mode, these same parameters are written to flash, and after a reset the device continues to operate in SPI mode.

If the UART is disabled and the SPI is enabled in the written configuration, then the device comes up in SPI mode without forcing it by holding DOUT low. If both the UART and the SPI are configured (P3 (DIO13/DOUT Configuration) through P9 (DIO19/SPI_ATT \bar{N} Configuration) are set to 1) at the time of reset, then output goes to the UART until the host sends the first input to the SPI interface. As soon as the first input comes on the SPI port, then all subsequent output goes to the SPI port and the UART is disabled.

Once you select a serial port (UART or SPI), all subsequent output goes to that port, even if you apply a new configuration. Once the SPI interface is made active, the only way to switch the selected serial port back to UART is to reset the device.

When the master asserts the slave select (SPI_SSEL $\bar{}$) signal, SPI transmit data is driven to the output pin SPI_MISO, and SPI data is received from the input pin SPI_MOSI. The SPI_SSEL pin has to be asserted to enable the transmit serializer to drive data to the output signal SPI_MISO. A rising edge on SPI_SSEL causes the SPI_MISO line to be tri-stated such that another slave device can drive it, if so desired.

If the output buffer is empty, the SPI serializer transmits the last valid bit repeatedly, which may be either high or low. Otherwise, the device formats all output in API mode 1 format, as described in [Operate in API mode](#). The attached host is expected to ignore all data that is not part of a formatted API frame.

Force UART operation

If you configure a device with only the SPI enabled and no SPI master is available to access the SPI slave port, you can recover the device to UART operation by holding DIN / CONFIG low at reset time. DIN/CONFIG forces a default configuration on the UART at 9600 baud and brings up the device in Command mode on the UART port. You can then send the appropriate commands to the device to configure it for UART operation. If you write those parameters, the device comes up with the UART enabled on the next reset.

Modes

The XBee3 Zigbee RF Module is in Receive Mode when it is not transmitting data. It shifts into the other modes of operation under the following conditions:

- Transmit mode (Serial data in the serial receive buffer is ready to be packetized)
- Command mode (Command mode sequence is issued)
- Sleep mode

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Transparent operating mode

When operating in Transparent mode, the devices act as a serial line replacement. The device queues up all UART data received through the DIN pin for RF transmission. When RF data is received, the device sends the data out through the serial port. Use the Command mode interface to configure the device configuration parameters.

Serial-to-RF packetization

The device buffers data in the serial receive buffer and packetizes and transmits the data when it receives the following:

- No serial characters for the amount of time determined by the **RO** (Packetization Timeout) parameter. If **RO** = 0, packetization begins when the device received a character.
- Command mode Sequence (**GT** + **CC** + **GT**). Any character buffered in the serial receive buffer before the device transmits the sequence.
- Maximum number of characters that fit in an RF packet.

API operating mode

API operating mode is an alternative to Transparent operating mode. The frame-based API extends the level to which a host application can interact with the networking capabilities of the device. When in API mode, the device contains all data entering and leaving in frames that define operations or events within the device.

The API provides alternative means of configuring devices and routing data at the host application layer. A host application can send data frames to the device that contain address and payload information instead of using Command mode to modify addresses. The device sends data frames to the application containing status packets, as well as source and payload information from received data packets.

The API operation option facilitates many operations such as:

- Transmitting data to multiple destinations without entering Command mode
- Receive success/failure status of each transmitted RF packet
- Identify the source address of each received packet

Command mode

Command mode is a state in which the firmware interprets incoming characters as commands. It allows you to modify the device's configuration using parameters you can set using AT commands. When you want to read or set any parameter of the XBee3 Zigbee RF Module using this mode, you have to send an AT command. Every AT command starts with the letters **AT** followed by the two characters that identify the command and then by some optional configuration values.

The operating modes of the XBee3 Zigbee RF Module are controlled by the [AP \(API Enable\)](#) setting, but Command mode is always available as a mode the device can enter while configured for any of the operating modes.

Command mode is available on the UART interface for all operating modes. You cannot use the SPI interface to enter Command mode.

Enter Command mode

To get a device to switch into Command mode, you must issue the following sequence: **+++** within one second. There must be at least one second preceding and following the **+++** sequence. Both the command character (**CC**) and the silence before and after the sequence (**GT**) are configurable. When the entrance criteria are met the device responds with **OK\r** on UART signifying that it has entered Command mode successfully and is ready to start processing AT commands.

If configured to operate in [Transparent operating mode](#), when entering Command mode the XBee3 Zigbee RF Module knows to stop sending data and start accepting commands locally.

Note Do not press **Return** or **Enter** after typing **+++** because it interrupts the guard time silence and prevents you from entering Command mode.

When the device is in Command mode, it listens for user input and is able to receive AT commands on the UART. If **CT** time (default is 10 seconds) passes without any user input, the device drops out of Command mode and returns to the previous operating mode. You can force the device to leave Command mode by sending **CN** ([Exit Command mode](#)).

You can customize the command character, the guard times and the timeout in the device’s configuration settings. For more information, see [CC \(Command Character\)](#), [CT \(Command Mode Timeout\)](#) and [GT \(Guard Times\)](#).

Troubleshooting

Failure to enter Command mode is often due to baud rate mismatch. Ensure that the baud rate of the connection matches the baud rate of the device. By default, **BD (UART Baud Rate)** = **3** (9600 b/s).

There are two alternative ways to enter Command mode:

- A serial break for six seconds enters Command mode. You can issue the "break" command from a serial console, it is often a button or menu item.
- Asserting DIN (serial break) upon power up or reset enters Command mode. XCTU guides you through a reset and automatically issues the break when needed.

Note You must assert RTS for both of these methods, otherwise the device enters the bootloader.

Both of these methods temporarily set the device's baud rate to 9600 and return an **OK** on the UART to indicate that Command mode is active. When Command mode exits, the device returns to normal operation at the baud rate that **BD** is set to.

Send AT commands

Once the device enters Command mode, use the syntax in the following figure to send AT commands. Every AT command starts with the letters **AT**, which stands for "attention." The AT is followed by two characters that indicate which command is being issued, then by some optional configuration values.

To read a parameter value stored in the device’s register, omit the parameter field.

“AT” prefix + ASCII command + Space (optional) + Parameter (optional, HEX) + Carriage return



Example: AT NI 2 <CR>

The preceding example changes [NI \(Node Identifier\)](#) to **My XBee**.

Multiple AT commands

You can send multiple AT commands at a time when they are separated by a comma in Command mode; for example, **ATNIMy XBee,AC<cr>**.

The preceding example changes the **NI (Node Identifier)** to **My XBee** and makes the setting active through [AC \(Apply Changes\)](#).

Parameter format

Refer to the list of [AT commands](#) for the format of individual AT command parameters. Valid formats for hexadecimal values include with or without a leading **0x** for example **FFFF** or **0xFFFF**.

Response to AT commands

When using AT commands to set parameters the XBee3 Zigbee RF Module responds with **OK<cr>** if successful and **ERROR<cr>** if not.

Apply command changes

Any changes you make to the configuration command registers using AT commands do not take effect until you apply the changes. For example, if you send the **BD** command to change the baud rate, the actual baud rate does not change until you apply the changes. To apply changes:

1. Send [AC \(Apply Changes\)](#).
2. Send [WR \(Write\)](#).
or:
3. [Exit Command mode](#).

Make command changes permanent

Send a [WR \(Write\)](#) command to save the changes. **WR** writes parameter values to non-volatile memory so that parameter modifications persist through subsequent resets.

Send as [RE \(Restore Defaults\)](#) to wipe settings saved using **WR** back to their factory defaults, or custom defaults if you have set any.

Note You still have to use **WR** to save the changes enacted with **RE**.

Exit Command mode

1. Send [CN \(Exit Command mode\)](#) followed by a carriage return.
or:
2. If the device does not receive any valid AT commands within the time specified by [CT \(Command Mode Timeout\)](#), it returns to Transparent or API mode. The default Command mode timeout is 10 seconds.

For an example of programming the device using AT Commands and descriptions of each configurable parameter, see [AT commands](#).

Idle mode

When not receiving or transmitting data, the device is in Idle mode. During Idle mode, the device listens for valid data on both the RF and serial ports.

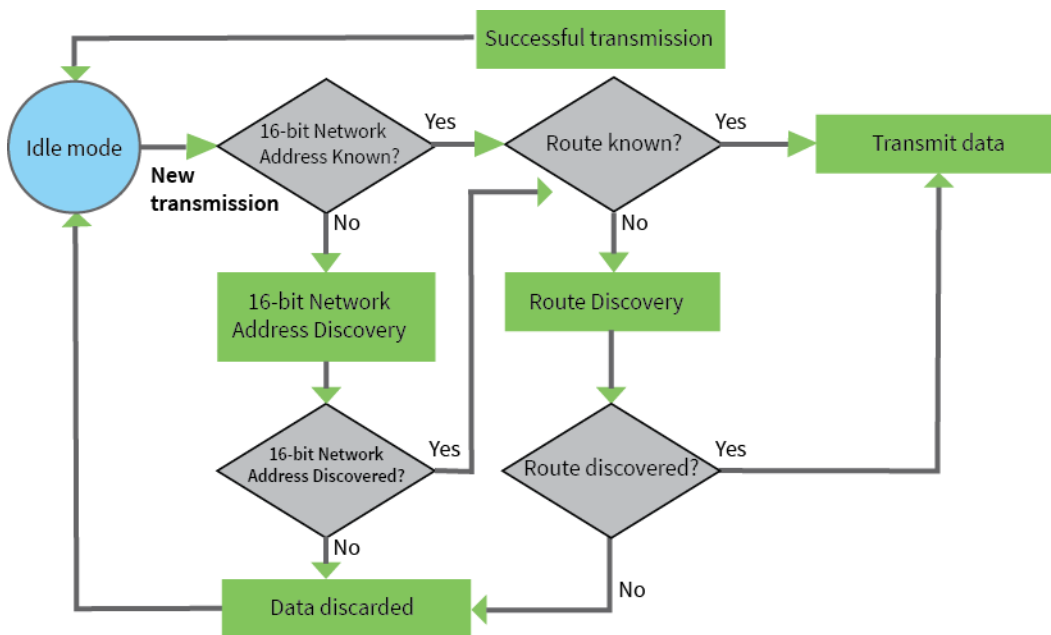
The device shifts into the other modes of operation under the following conditions:

- Transmit mode (serial data in the serial receive buffer is ready to be packetized).
- Receive mode (valid RF data received through the antenna).
- Command mode (Command mode sequence issued).

Transmit mode

Prior to transmitting data, the module ensures that a 16-bit network address and route to the destination node have been established.

If a 16-bit network address is not provided, a Network Address Discovery takes place. In order for data to be sent, a route discovery takes place for the purpose of establishing a route to the destination node. If a device with a matching network address is not discovered, it discards the packet. The device transmits the data once a route is established. If route discovery fails to establish a route, the device discards the packet. The following diagram shows the Transmit Mode sequence.



When Zigbee data is transmitted from one node to another, the destination node transmits a network-level acknowledgment back across the established route to the source node. This acknowledgment packet indicates to the source node that the destination node received the data packet. If the source node does not receive a network acknowledgment, it retransmits the data.

It is possible in rare circumstances for the destination to receive a data packet, but for the source to not receive the network acknowledgment. In this case, the source retransmits the data, which can cause the destination to receive the same data packet multiple times. The XBee modules do not filter out duplicate packets. We recommend that the application includes provisions to address this issue.

For more information, see [Transmission, addressing, and routing](#).

Receive mode

When data is received over the air, the module sends the data out the serial port.

The **AP** and **AO** parameters can be used to adjust the types of messages are filtered out by the XBee3. By default, the module operates in transparent mode where the the device will only output the payload of received packets. In API modes, the entire packet is emitted, and **AO** adjusts whether raw ZDO messages should be emitted.

Sleep mode

Sleep modes allow the device to enter states of low power consumption when not in use. The XBee3 Zigbee RF Module supports both pin sleep (Sleep mode entered on pin transition) and cyclic sleep (device sleeps for a fixed time).

Sleep modes allow the device to enter states of low power consumption when not in use. The device is almost completely off during sleep, and is incapable of sending or receiving data until it wakes up. XBee devices support pin sleep, where the device enters sleep mode upon pin transition, and cyclic sleep, where the device sleeps for a fixed time.

For more information, see [Manage End Devices](#).

Zigbee networks

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The Zigbee specification

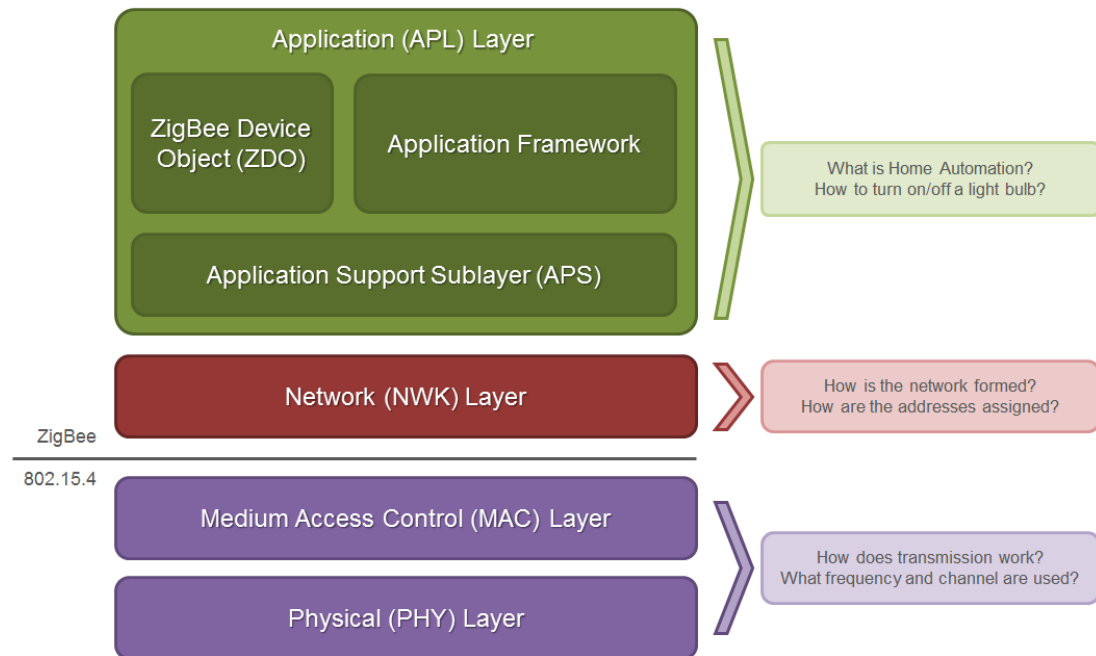
Zigbee is an open global standard for low-power, low-cost, low-data-rate, wireless mesh networking based on the IEEE 802.15.4 standard. It represents a network layer above the 802.15.4 layers to support advanced mesh routing capabilities. The Zigbee specification is developed by a consortium of companies that make up the Zigbee Alliance. For more information, see zigbee.org.

Zigbee stack layers

Most network protocols use the concept of layers to separate different components and functions into independent modules that can be assembled in different ways.

Zigbee is built on the Physical (PHY) layer and Medium Access Control (MAC) sub-layer defined in the IEEE 802.15.4 standard. These layers handle low-level network operations such as addressing and message transmission/reception.

The Zigbee specification defines the Network (NWK) layer and the framework for the application (APL) layer. The Network layer takes care of the network structure, routing, and security. The application layer framework consists of the Application Support sub-layer (APS), the Zigbee device objects (ZDO) and user-defined applications that give the device its specific functionality.



This table describes the Zigbee layers.

Zigbee layer	Descriptions
PHY	Defines the physical operation of the Zigbee device including receive sensitivity, channel rejection, output power, number of channels, chip modulation, and transmission rate specifications. Most Zigbee applications operate on the 2.4 GHz ISM band at a 250 kb/s data rate. See the IEEE 802.15.4 specification for details.

Zigbee layer	Descriptions
MAC	Manages RF data transactions between neighboring devices (point to point). The MAC includes services such as transmission retry and acknowledgment management, and collision avoidance techniques (CSMA-CA).
Network	Adds routing capabilities that allows RF data packets to traverse multiple devices (multiple hops) to route data from source to destination (peer to peer).
APS (AF)	Application layer that defines various addressing objects including profiles, clusters, and endpoints.
ZDO	Application layer that provides device and service discovery features and advanced network management capabilities.

Zigbee networking concepts

Device types

Zigbee defines three different device types: coordinator, router, and end device.

Coordinator

Zigbee networks may only have a single coordinator device. This device:

- Starts the network, selecting the channel and PAN ID (both 64-bit and 16-bit).
- Distributes 16-bit network addresses, allowing routers and end devices to join the network. Assists in routing data.
- Buffers wireless data packets for sleeping end device children.
- Manages the other functions that define the network, secure it, and keep it healthy.
- Cannot sleep; the coordinator must be powered on all the time.

Router

A router is a full-featured Zigbee node. This device:

- Can join existing networks and send, receive, and route information. Routing involves acting as a messenger for communications between other devices that are too far apart to convey information on their own.
- Can buffer wireless data packets for sleeping end device children. Can allow other routers and end devices to join the network.
- Cannot sleep; router(s) must be powered on all the time.
- May have multiple router devices in a network.

End device

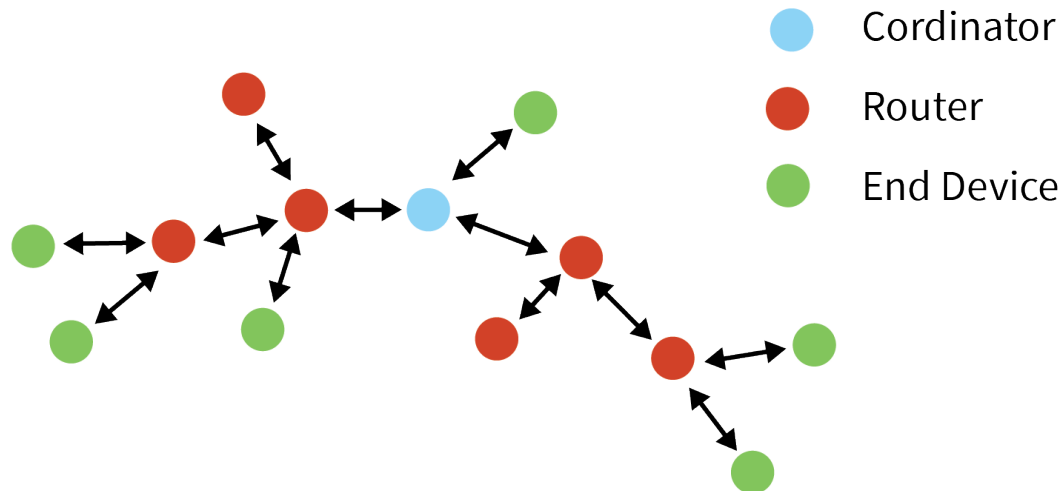
An end device is essentially a reduced version of a router. This device:

- Can join existing networks and send and receive information, but cannot act as messenger between any other devices.
- Cannot allow other devices to join the network.

- Uses less expensive hardware and can power itself down intermittently, saving energy by temporarily entering a non responsive sleep mode.
- Always needs a router or the coordinator to be its parent device. The parent helps end devices join the network, and stores messages for them when they are asleep.

Zigbee networks may have any number of end devices. In fact, a network can be composed of one coordinator, multiple end devices, and zero routers.

The following diagram shows a generic Zigbee network.



Note Each Zigbee network must be formed by one, and only one, coordinator and at least one other device (router or end device).

In Zigbee networks, the coordinator must select a PAN ID (64-bit and 16-bit) and channel to start a network. After that, it behaves essentially like a router. The coordinator and routers can allow other devices to join the network and can route data.

After an end device joins a router or coordinator, it must be able to transmit or receive RF data through that router or coordinator. The router or coordinator that allowed an end device to join becomes the “parent” of the end device. Since the end device can sleep, the parent must be able to buffer or retain incoming data packets destined for the end device until the end device is able to wake and receive the data.

A device can only operate as one of the three device types. The device type is selected by configuration rather than by firmware image as was the case on earlier hardware platforms.

By default, the device operates as a router. To select coordinator operation, set **CE** to 1. To select end device operation, set **SM** to a non-zero value. To select router operation, both **CE** and **SM** must be 0.

If a device is a coordinator and it needs to be changed into an end device, you must set **CE** to 0 first. If not, the **SM** configuration will conflict with the **CE** configuration. Likewise, to change an end device into a coordinator, you must change it into a router first.

Another complication is that default parameters do not always work well for a coordinator.

For example:

- **DH/DL** is 0 by default, which allows routers and end devices to send transparent data to the coordinator when they first come up. If **DH/DL** is not changed from the default value when the device is changed to a coordinator, then the device sends data to itself, causing characters to be echoed back to the screen as they are typed. Since this is probably not the desired

operation, set **DH/DL** to the broadcast address or some specific unicast address when the device is changed to a coordinator.

In general, it is your responsibility to ensure that parameters are set to be compatible with the new device type when changing device types.

PAN ID

Zigbee networks are called personal area networks (PANs). Each network is defined with a unique PAN identifier (PAN ID), which is common among all devices of the same network. Zigbee devices are either preconfigured with a PAN ID to join, or they can discover nearby networks and select a PAN ID to join.

Zigbee supports both a 64-bit and a 16-bit PAN ID. Both PAN IDs are used to uniquely identify a network. Devices on the same Zigbee network must share the same 64-bit and 16-bit PAN IDs. If multiple Zigbee networks are operating within range of each other, each should have unique PAN IDs.

16-bit PAN ID

The 16-bit PAN ID is used as a MAC layer addressing field in all RF data transmissions between devices in a network. However, due to the limited addressing space of the 16-bit PAN ID (65,535 possibilities), there is a possibility that multiple Zigbee networks (within range of each other) could use the same 16-bit PAN ID. To resolve potential 16-bit PAN ID conflicts, the Zigbee Alliance created a 64-bit PAN ID.

64-bit PAN ID

The 64-bit PAN ID (also called the extended PAN ID), is intended to be a unique, non-duplicated value. When a coordinator starts a network, it can either start a network on a preconfigured 64-bit PAN ID, or it can select a random 64-bit PAN ID. Devices use a 64-bit PAN ID during joining; if a device has a preconfigured 64-bit PAN ID, it will only join a network with the same 64-bit PAN ID. Otherwise, a device could join any detected PAN and inherit the PAN ID from the network when it joins. All Zigbee beacons include the 64-bit PAN ID and is used in 16-bit PAN ID conflict resolution.

Routers and end devices

Routers and end devices are typically configured to join a network with any 16-bit PAN ID as long as the 64-bit PAN ID is valid. Coordinators typically select a random 16-bit PAN ID for their network.

Since the 16-bit PAN ID only allows up to 65,535 unique values, and the device randomly selects the 16-bit PAN ID, provisions exist in Zigbee to detect if two networks (with different 64-bit PAN IDs) are operating on the same 16-bit PAN ID. If the device detects a conflict, the Zigbee stack can perform PAN ID conflict resolution to change the 16-bit PAN ID of the network in order to resolve the conflict. See the Zigbee specification for details.

Zigbee routers and end devices should be configured with the 64-bit PAN ID of the network they want to join, and they typically acquire the 16-bit PAN ID when they join a network.

Only enable **CE** on one device to avoid PAN ID conflicts and network problems.

Operating channels

Zigbee uses direct-sequence spread spectrum modulation and operates on a fixed channel. The 802.15.4 PHY defines 16 operating channels (channels 11 to 26) in the 2.4 GHz frequency band. XBee modules support all 16 channels.

FCC regulations mandate lower power levels on channel 26, so if you fix your network to channel 26, you will experience significantly less range on the devices.

Zigbee application layers: in depth

The following topics provide a more in-depth look at the Zigbee application stack layers (APS, ZDO) including a discussion on Zigbee endpoints, clusters, and profiles. Much of the material in these topics discuss details of the Zigbee stack that are not required in many cases.

Read these topics if:

- The XBee3 Zigbee RF Module may talk to non-Digi Zigbee devices.
- The XBee3 Zigbee RF Module requires network management and discovery capabilities of the ZDO layer.
- The XBee3 Zigbee RF Module needs to operate in a public application profile (for example, smart energy, home automation, and so on).

Skip these topics if:

- The XBee3 Zigbee RF Module does not need to interoperate or talk to non-Digi Zigbee devices.
- The XBee3 Zigbee RF Module simply needs to send data between devices.

Application Support Sublayer (APS)

The APS layer in Zigbee adds support for application profiles, cluster IDs, and endpoints.

Application profiles

Application profiles specify various device descriptions including required functionality for various devices. The collection of device descriptions forms an application profile. Application profiles are defined as Public or Private profiles. Private profiles are defined by a manufacturer whereas public profiles are defined, developed, and maintained by the Zigbee Alliance. Each application profile has a unique profile identifier assigned by the Zigbee Alliance.

Examples of public profiles include:

- Home automation
- Smart Energy
- Commercial building automation

For example, the Smart Energy profile defines various device types including an energy service portal, load controller, thermostat, in-home display, and so on. The Smart Energy profile defines required functionality for each device type. For example, a load controller must respond to a defined command to turn a load on or off. By defining standard communication protocols and device functionality, public profiles allow interoperable Zigbee solutions to be developed by independent manufacturers.

Digi XBee Zigbee firmware operates on a private profile called the Digi Drop-In Networking profile. However, in many cases the XBee3 Zigbee RF Module can use API mode to talk to devices in public profiles or non-Digi private profiles. For more information, see [API Operation](#).

Clusters

A cluster is an application message type defined within a profile. You can use clusters to specify a unique function, service, or action. The following examples are some clusters defined in the home automation profile:

- On/Off - Used to switch devices on or off (lights, thermostats, and so forth)
- Level Control - Used to control devices that can be set to a level between on and off
- Color Control - Controls the color of color capable devices

Each cluster has an associated 2-byte cluster identifier (cluster ID). All application transmissions include the cluster ID. Clusters often have associated request and response messages. For example, a smart energy gateway (service portal) might send a load control event to a load controller in order to schedule turning on or off an appliance. Upon executing the event, the load controller sends a load control report message back to the gateway.

Devices that operate in an application profile (private or public) must respond correctly to all required clusters. For example, a light switch that operates in the home automation public profile must correctly implement the On/Off and other required clusters in order to interoperate with other home automation devices. The Zigbee Alliance has defined a Zigbee cluster library (ZCL) that contains definitions or various general use clusters that could be implemented in any profile.

XBee modules implement various clusters in the Digi private profile. You can also use the API to send or receive messages on any cluster ID (and profile ID or endpoint). For more information, see [Explicit Rx Indicator frame - 0x91](#).

Endpoints

The APS layer includes supports for endpoints. An endpoint can be thought of as a running application, similar to a TCP/IP port. A single device can support one or more endpoints. A 1-byte value identifies each application endpoint, ranging from 1 to 240. Each defined endpoint on a device is tied to an application profile. A device could, for example, implement one endpoint that supports a Smart Energy load controller, and another endpoint that supports other functionality on a private profile.

No TX Status frame is generated for API frames that have both **0xE6** as the destination endpoint and **0xC105** as the Profile ID as this combination is reserved for internal XBee3 Zigbee RF Module operations.

Zigbee device profile

Profile ID 0x0000 is reserved for the Zigbee device profile. This profile is implemented on all Zigbee devices. Device Profile defines many device and service discovery features and network management capabilities. Endpoint 0 is a reserved endpoint that supports the Zigbee device profile. This endpoint is called the Zigbee device objects (ZDO) endpoint.

Zigbee device objects

The ZDO (endpoint 0) supports the discovery and management capabilities of the Zigbee device profile. See the Zigbee specification for a complete listing of all ZDP services. Each service has an associated cluster ID.

The XBee Zigbee firmware allows applications to easily send ZDO messages to devices in the network using the API. For more information, see [ZDO transmissions](#).

Zigbee coordinator operation

Form a network

The coordinator is responsible for selecting the channel, PAN ID, security policy, and stack profile for a network. Since a coordinator is the only device type that can start a network, each Zigbee network must have one coordinator. After the coordinator has started a network, it can allow new devices to join the network. It can also route data packets and communicate with other devices on the network.

To ensure the coordinator starts on a good channel and unused PAN ID, the coordinator performs a series of scans to discover any RF activity on different channels (energy scan) and to discover any nearby operating PANs (PAN scan). The process for selecting the channel and PAN ID are described in the following topics.

Security policy

The security policy determines which devices are allowed to join the network, and which device(s) can authenticate joining devices. See [Zigbee security](#) for a detailed discussion of various security policies.

Channel selection

When starting a network, the coordinator must select a “good” channel for the network to operate on. To do this, it performs an energy scan on multiple channels (that is, frequencies) to detect energy levels on each channel. The coordinator removes channels with excessive energy levels from its list of potential channels to start on.

PAN ID selection

After completing the energy scan, the coordinator scans its list of potential channels (remaining channels after the energy scan) to obtain a list of neighboring PANs. To do this, the coordinator sends a beacon request (broadcast) transmission on each potential channel. All nearby coordinators and routers that have already joined a Zigbee network respond to the beacon request by sending a beacon back to the coordinator. The beacon contains information about which PAN the device is on, including the PAN identifiers (16-bit and 64-bit). This scan (collecting beacons on the potential channels) is typically called an active scan or PAN scan.

After the coordinator completes the channel and PAN scan, it selects a random channel and unused 16-bit PAN ID to start on.

Persistent data

Once a coordinator starts a network, it retains the following information through power cycle or reset events:

- PAN ID
- Operating channel
- Security policy and frame counter value
- Child table (end device children that are joined to the coordinator)
- Binding table
- Group table

The coordinator retains this information indefinitely until it leaves the network. When the coordinator leaves a network and starts a new network, the previous PAN ID, operating channel, link key table, and child table data are lost.

Coordinator startup

The following table provides the network formation commands that the coordinator uses to form a network.

Command	Description
CE	Must be set to 1 to specify that the device will act as a coordinator and form a network.
ID	Used to determine the 64-bit PAN ID. If set to 0 (default), a random 64-bit PAN ID will be selected.
SC	Determines the scan channels bitmask used by the coordinator when forming a network. The coordinator will perform an energy scan on all enabled SC channels. It will then perform a PAN ID scan.
SD	Set the scan duration, or time that the router will listen for beacons on each channel.
ZS	Set the Zigbee stack profile for the network.
EE	Enable or disable security in the network.
KY	If encryption is enabled, a preconfigured link key can be set. Any device with a matching link key will be allowed to join when the join window is open. If KY is set to 0, a random link key will be assigned, and devices will have to be registered to join or allowed to insecurely join using a default link key.
NK	Set a preconfigured network key for secured networks. NK is only applicable to the device with CE = 1 and defines the initial network key. In most situations you should leave this value at 0.
EO	Set the security policy for the network if encryption is enabled. EO defines whether the coordinator should act as a centralized trust center or form the network as a router in a distributed trust center network. You can also optionally allow insecure devices to join using a well-known link key.

Configuration changes delay the start of network formation for five seconds after the last change.

Once the coordinator starts a network, the network configuration settings and child table data persist through power cycles as mentioned in [Persistent data](#).

When the coordinator has successfully started a network, it:

- Allows other devices to join the network for a time; see [NJ \(Node Join Time\)](#)
- Sets **AI** = 0
- Starts blinking the Associate LED
- Sends an API modem status frame (“coordinator started”) out the serial port when using API mode

These behaviors are configurable using the following commands:

Command	Description
NJ	Sets the permit-join time on the coordinator, measured in seconds.
D5	Enables the Associate LED functionality.
LT	Sets the Associate LED blink time when joined. If LT = 0, the default is 1 blink per 500 ms (coordinator) 250 ms (router/end device).

If any of the command values in the network formation commands table changes, the coordinator leaves its current network and starts a new network, possibly on a different channel.

Note Command changes must be applied (**AC** or **CN** command) before taking effect.

Permit joining

You can use **NJ (Node Join Time)** to configure the permit joining attribute on the coordinator. By default, the join window opens for 254 seconds, after which joining will not be allowed until the join window opens again.

Joining temporarily enabled

Set **NJ** < **0xFF**, to enable joining for only a number of seconds, based on the **NJ** parameter. Once the XBee3 Zigbee RF Module joins a network, the timer starts. The coordinator does not re-enable joining if the device is power cycled or reset. The following actions restart the permit-joining timer:

- Changing **NJ** to a different value (and applying changes with the **AC** or **CN** commands).
- Pressing the Commissioning button twice.
- Issuing the **CB** command with a parameter of **2**.

The last two actions enable joining for one minute if **NJ** is **0x0**. Otherwise, the Commissioning button and the **CB2** command enable joining for **NJ** seconds.

Joining always enabled

If **NJ** = **0xFF**, joining is permanently enabled.



Use this mode carefully. Once a network has been deployed, we strongly recommend that the application consider disabling joining to prevent unwanted joins from occurring. An always-open network operates outside of the Zigbee 3.0 specifications.

Reset the coordinator

When you reset or power cycle the coordinator, it checks its PAN ID, operating channel and stack profile against the network configuration settings (**ID**, **CH**, **ZS**). It also verifies the saved security policy against the security configuration settings (**EE**, **NK**, **KY**). If the coordinator's PAN ID, operating channel, stack profile, or security policy is not valid based on its network and security configuration settings, the coordinator leaves the network and attempts to form a new network based on its network formation command values.

To prevent the coordinator from leaving an existing network, issue the **WR** command after all network formation commands have been configured in order to retain these settings through power cycle or reset events.

Leave a network

The following mechanisms cause the coordinator to leave its current PAN and start a new network based on its network formation parameter values.

- Change the **ID** command such that the current 64-bit PAN ID is invalid.
- Change the **SC** command such that the current channel (**CH**) is not included in the channel mask.
- Change the **ZS** or any of the security command values.

- Issue the **NR0** command to cause the coordinator to leave.
- Issue the **NR1** command to send a broadcast transmission, causing all devices in the network to leave and migrate to a different channel.
- Press the commissioning button four times or issue the **CB** command with a parameter of **4**. This restores the device to a default configuration state.
- Issue a network ZDO leave command.

Note Changes to **ID**, **SC**, **ZS**, and security command values only take effect when changes are applied (**AC** or **CN** commands).

Replace a coordinator (security disabled only)

On rare occasions, it may become necessary to replace an existing coordinator in a network with a new physical device. If security is not enabled in the network, you can configure a replacement XBee coordinator with the PAN ID (16-bit and 64-bit), channel, and stack profile settings of a running network in order to replace an existing coordinator.

Note Avoid having two coordinators on the same channel, stack profile, and PAN ID (16-bit and 64-bit) as it can cause problems in the network. When replacing a coordinator, turn off the old coordinator before starting the new coordinator.

To replace a coordinator, read the following commands from a device on the network:

Command	Description
OP	Read the operating 64-bit PAN ID.
OI	Read the operating 16-bit PAN ID.
CH	Read the operating channel.
ZS	Read the stack profile.

Each of the commands listed above can be read from any device on the network. These parameters will be the same on all devices in the network. After reading the commands from a device on the network, program the parameter values into the new coordinator using the following commands.

Command	Description
ID	Set the 64-bit PAN ID to match the read OP value.
II	Set the initial 16-bit PAN ID to match the read OI value.
SC	Set the scan channels bitmask to enable the read operating channel (CH command). For example, if the operating channel is 0x0B, set SC to 0x0001. If the operating channel is 0x17, set SC to 0x1000.
ZS	Set the stack profile to match the read ZS value.

II is the initial 16-bit PAN ID. Under certain conditions, the Zigbee stack can change the 16-bit PAN ID of the network. For this reason, you cannot save the **II** command using the **WR** command. Once **II** is set, the coordinator leaves the network and starts on the 16-bit PAN ID specified by **II**.

Example: start a coordinator

1. Set **CE (Device Role)** to **1** to indicate to the local device that it should form a network. Use **WR (Write)** to save the changes.
2. Set **SC** and **ID** to the desired scan channels and PAN ID values. The defaults are usually sufficient.
3. If you change **SC** or **ID** from the default, issue the **WR** command to save the changes.
4. If you change **SC** or **ID** from the default, apply changes (make **SC** and **ID** changes take effect) either by sending the **AC** command or by exiting **AT** Command mode.
5. If an Associate LED has been connected, it starts blinking once the coordinator has selected a channel and PAN ID and the network has started.
6. The API Modem Status frame (Coordinator Started) is sent out the serial port when using API mode.
7. Reading the **AI** command (association status) returns a value of 0, indicating a successful startup.
8. Reading the **MY** command (16-bit address) returns a value of 0, the Zigbee-defined 16-bit address of the coordinator.

After startup, the coordinator allows joining based on its **NJ** value. We highly recommend that you issue a **WR** command to write all applied settings to flash.

Example: replace a coordinator (security disabled)

1. Read the **OP**, **OI**, **CH**, and **ZS** commands on the running coordinator.
2. Set the **CE**, **ID**, **SC**, and **ZS** parameters on the new coordinator to match the existing coordinator, followed by **WR** command to save these parameter values.
3. Turn off the running coordinator.
4. Set the **II (Initial 16-bit PAN ID)** parameter on the new coordinator to match the read **OI** value on the old coordinator.
5. Wait for the new coordinator to start (**AI = 0**).

Router operation

Routers must discover and join a valid Zigbee network before they can participate in a Zigbee network. After a router has joined a network, it can allow new devices to join the network. It can also route data packets and communicate with other devices on the network.

Discover Zigbee networks

To discover nearby Zigbee networks, the router performs a PAN (or active) scan, just like the coordinator does when it starts a network. During the PAN scan, the router sends a beacon request (broadcast) transmission on the first channel in its scan channels list. All nearby coordinators and routers operating on that channel that are already part of a Zigbee network respond to the beacon request by sending a beacon back to the router.

The beacon contains information about the PAN the nearby device is on, including the PAN identifier (PAN ID), and whether or not joining is allowed. The router evaluates each beacon received on the channel to determine if it finds a valid PAN. A PAN is valid if any of the following exist:

- Has a valid 64-bit PAN ID (PAN ID matches **ID** if **ID** > 0)
- Has the correct stack profile (**ZS** command)
- Allows joining the network

If the router does not find a valid PAN, it performs the PAN scan on the next channel in its scan channels list and continues scanning until it finds a valid network, or until all channels have been scanned. If the router scans all channels and does not discover a valid PAN, it scans all channels again.

The Zigbee Alliance requires that certified solutions not send beacon request messages too frequently. To meet certification requirements, the XBee firmware attempts nine scans per minute for the first five minutes, and three scans per minute thereafter. If a valid PAN is within range of a joining router, it typically discovers the PAN within a few seconds.

Join a network

Once the router discovers a valid network, it sends an association request to the device that sent a valid beacon requesting a join on the Zigbee network. The device allowing the join then sends an association response frame that either allows or denies the join.

When a router joins a network, it receives a 16-bit address from the device that allowed the join. The device that allowed the join randomly selects the 16-bit address.

Authentication

In a network where security is enabled, the router must follow an authentication process. See [Zigbee security](#) for a discussion on security and authentication.

After the router is joined (and authenticated, in a secure network), it can allow new devices to join the network.

Persistent data

Once a router joins a network, it retains the following information through power cycle or reset events:

- PAN ID
- Operating channel
- Security policy and frame counter values
- Child table (end device children that are joined to the coordinator)
- Binding table
- Group table

The router retains this information indefinitely until it leaves the network. When the router leaves a network, it loses the previous PAN ID, operating channel, and child table data.

Router joining

When the router powers on, if it is not already joined to a valid Zigbee network, it immediately attempts to find and join a valid Zigbee network.

Set [DJ \(Disable Joining\)](#) to **1** to disable joining. You cannot write the **DJ** parameter with the **WR** command, so a power cycle always clears the **DJ** setting.

The following commands control the router joining process.

Command	Description
ID	Sets the 64-bit PAN ID to join. Setting ID = 0 allows the router to join any 64-bit PAN ID.
SC	Set the scan channels bitmask that determines which channels a router scans to find a valid network. Set SC on the router to match SC on the coordinator. For example, setting SC to 0x281 enables scanning on channels 11, 18 and 20, in that order.
SD	Set the scan duration, or time that the router listens for beacons on each channel.
ZS	Set the stack profile on the device.
EE	Enable or disable security in the network. This must be set to match the EE value (security policy) of the coordinator.
KY	Set the trust center link key. If set to 0 (default), the link key is expected to be obtained (unencrypted) during joining.
EO	If encryption is enabled (EE = 1), set the joining device's Encryption Options to match the Encryption Options of the network.

Configuration changes delay the start of joining for five seconds after the last change.

Once the router joins a network, the network configuration settings and child table data persist through power cycles as mentioned in [Persistent data](#). If joining fails, read the status of the last join attempt in the **AI** command register.

If any of the above command values change, when command register changes are applied (**AC** or **CN** commands), the router leaves its current network and attempts to discover and join a new valid network. When a Zigbee router has successfully joined a network, it:

- Allows other devices to join the network for a time
- Sets **AI = 0**
- Starts blinking the Associate LED
- Sends an API modem status frame (associated) out the serial port when using API mode

You can configure these behaviors using the following commands:

Command	Description
NJ	Sets the permit-join time on the router, or the time that it allows new devices to join the network, measured in seconds. Set NJ = 0xFF to always enable permit joining.
D5	Enables the Associate LED functionality.
LT	Sets the Associate LED blink time when joined. The default is 2 blinks per second (router).

Router network connectivity

Once a router joins a Zigbee network, it remains connected to the network on the same channel and PAN ID unless it is forced to leave (see [Leave a network](#)). If the scan channels (**SC**), PAN ID (**ID**) and security settings (**EE**, **KY**) do not change after a power cycle, the router remains connected to the network after a power cycle.

If a router is physically moved out of range of the network it initially joined, make sure the application includes provisions to detect if the router can still communicate with the original network. If

communication with the original network is lost, the application may choose to force the router to leave the network. The XBee firmware includes two provisions to automatically detect the presence of a network and leave if the check fails.

Power-On join verification

JV (Coordinator Join Verification) enables the power-on join verification check. If enabled, the XBee3 Zigbee RF Module attempts to discover the 64-bit address of the coordinator when it first joins a network. Once it has joined, it also attempts to discover the 64-bit address of the coordinator after a power cycle event. If 3 discovery attempts fail, the router leaves the network and try to join a new network. The default setting for Power-on join verification is disabled (**JV** defaults to **0**).

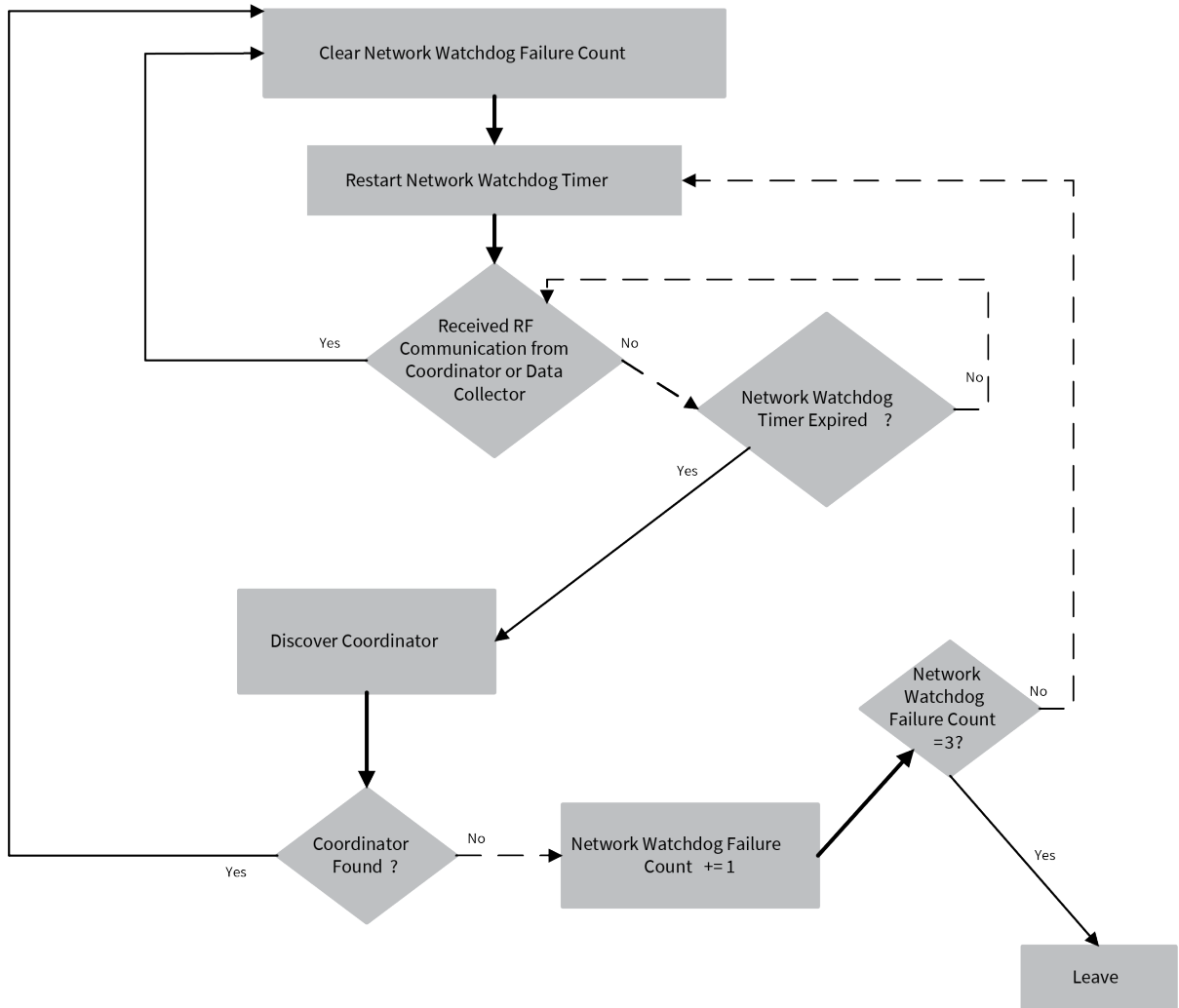
Network watchdog

Use **NW (Network Watchdog Timeout)** for a powered router to periodically check for the presence of a coordinator to verify network connectivity. The **NW** command specifies a timeout in minutes where the router must receive communication from the coordinator or data collector. The following events restart the network watchdog timer:

- RF data received from the coordinator
- RF data sent to the coordinator and an acknowledgment was received
- Many-to-one route request was received (from any device)
- Change the value of **NW**

If the watchdog timer expires (no valid data received for **NW** time), the router attempts to discover the 64-bit address of the coordinator. If the router cannot discover the address, it records one watchdog timeout. After three consecutive network watchdog timeouts expire ($3 * \mathbf{NW}$) and the coordinator has not responded to the address discovery attempts, the router leaves the network and attempts to join a new network.

Anytime a router receives valid data from the coordinator or data collector, it clears the watchdog timeouts counter and restarts the watchdog timer. You can set the network watchdog timer (**NW** command) to several days. The default setting for the network watchdog feature is disabled (**NW** defaults to 0). The following flowchart illustrates network watchdog behavior:



Network Locator option

The Device Options Network Locator option supports swapping or replacing a Coordinator in a running network. The Network Locator option, if enabled (**DO= 80**), modifies the behavior of the **JV** and **NW** options. If there is no communication with the Coordinator, the radio starts a search for the network across the channels of the Search Channel mask (**SC**) rather than leaving the network.

If the device finds a network on the old channel with the same **OI** (operating **ID**), the search mode ends and reschedules **NW** if enabled. If the device finds a network with a new **OI** but satisfies the radio's search for a matching **ID** and **ZS**, the device leaves the old network and joins the new network with the new **OI**.

Reset the router

When you reset or power cycle the router, it checks its PAN ID, operating channel and stack profile against the network configuration settings (**ID, SC, ZS**). It also verifies the saved security policy is valid based on the security configuration commands (**EE, KY**). If the router's PAN ID, operating channel, stack profile, or security policy is invalid, the router leaves the network and attempts to join a new network based on its network joining command values.

To prevent the router from leaving an existing network, issue the **WR** command after all network joining commands have been configured; this retains the settings through power cycle or reset events.

Example: join a network

After starting a coordinator that is allowing joins, the following steps cause a router to join the network:

1. Set **ID** to the desired 64-bit PAN ID, or to 0 to join any PAN.
2. Set **SC** to the list of channels to scan to find a valid network.
3. Set the security settings to match the coordinator.
4. If you **SC** or **ID** from the default, apply changes (that is, make **SC** and **ID** changes take effect) by issuing the **AC** or **CN** command.
5. The Associate LED starts blinking once the router has joined a PAN.
6. If the Associate LED is not blinking, read the **AI** command to determine the cause of join failure.
7. Once the router joins, the **OP** and **CH** commands indicate the operating 64-bit PAN ID and channel the router joined.
8. The **MY** command reflects the 16-bit address the router received when it joined.
9. The API Modem Status frame (“Associated”) is sent out the serial port when using API mode.
10. The joined router allows other devices to join for a time based on its **NJ** setting.

End device operation

Similar to routers, end devices must discover and join a valid Zigbee network before they can participate in the network. After an end device joins a network, it can communicate with other devices on the network. Because end devices are battery powered and support low power (sleep) modes, they cannot allow other devices to join or route data packets.

Discover Zigbee networks

End devices go through the same process as routers to discover networks by issuing a PAN scan. After sending the broadcast beacon request transmission, the end device listens for a short time in order to receive beacons sent by nearby routers and coordinators on the same channel. The end device evaluates each beacon received on the channel to determine if it finds a valid PAN. A PAN is valid if any of the following exist:

- Has a valid 64-bit PAN ID (PAN ID matches ID if **ID > 0**)
- Has the correct stack profile (**ZS** command)
- Allows joining the network
- Has capacity for additional end devices

If the end device does not find a valid PAN, it performs the PAN scan on the next channel in its scan channels list and continues this process until it finds a valid network, or until all channels have been scanned. If the end device scan all channels and does not discover a valid PAN, it may enter a low power sleep state and scan again later.

If scanning all **SC** channels fails to discover a valid PAN, XBee Zigbee devices attempt to enter a low power state and retries scanning all **SC** channels after the device wakes from sleeping. If the device cannot enter a low power state, it retries scanning all channels, similar to the router. To meet Zigbee

Alliance requirements, the end device attempts up to nine scans per minute for the first five minutes, and three scans per minute thereafter.

Note The XBee Zigbee end device will not enter sleep until it has completed scanning all **SC** channels for a valid network.

Join a network

Once the end device discovers a valid network, it joins the network, similar to a router, by sending an association request (to the device that sent a valid beacon) to request a join on the Zigbee network. The device allowing the join then sends an association response frame that either allows or denies the join.

When an end device joins a network, it receives a 16-bit address from the device that allowed the join. The device that allowed the join randomly selects the 16-bit address.

Parent child relationship

Since an end device may enter low power sleep modes and not be immediately responsive, the end device relies on the device that allowed the join to receive and buffer incoming messages on its behalf until it is able to wake and receive those messages. The device that allowed an end device to join becomes the parent of the end device, and the end device becomes a child of the device that allowed the join.

End device capacity

Routers and coordinators maintain a table of all child devices that have joined called the child table. This table is a finite size and determines how many end devices can join. If a router or coordinator has at least one unused entry in its child table, the device has end device capacity. In other words, it can allow one or more additional end devices to join. Zigbee networks have sufficient routers to ensure adequate end device capacity.

The initial release of software on this platform supports up to 20 end devices when configured as a coordinator or a router.

In Zigbee firmware, use the **NC** command (number of remaining end device children) to determine how many additional end devices can join a router or coordinator. If **NC** returns 0, then the router or coordinator device has no more end device capacity.

Note Because routers cannot sleep, there is no equivalent need for routers or coordinators to track joined routers. There is no limit to the number of routers that can join a given router or coordinator device and no “router capacity” metric.

Authentication

In a network where security is enabled, the end device must then go through an authentication process. For more information, see [Zigbee security](#).

Persistent data

The end device can retain its PAN ID, operating channel, and security policy information through a power cycle. However, since end devices rely heavily on a parent, the end device does an orphan scan to try and contact its parent. If the end device does not receive an orphan scan response (coordinator

realignment command), it leaves the network and tries to discover and join a new network. When the end device leaves a network, it loses the previous PAN ID and operating channel settings.

Orphan scans

When an end device comes up from a power cycle, it performs an orphan scan to verify it still has a valid parent. The device sends the orphan scan as a broadcast transmission and contains the 64-bit address of the end device. Nearby routers and coordinator devices that receive the broadcast check their child tables for an entry that contains the end device's 64-bit address. If the devices find an entry with a matching 64-bit address, they send a coordinator realignment command to the end device that includes the 16-bit address of the end device, 16-bit PAN ID, operating channel, and the parent's 64-bit and 16-bit addresses.

If the orphaned end device receives a coordinator realignment command, it joins the network. Otherwise, it attempts to discover and join a valid network.

End device joining

When you power on an end device, if it is not joined to a valid Zigbee network, or if the orphan scan fails to find a parent, the device attempts to find and join a valid Zigbee network.

Note Set the **DJ** command to 1 to disable joining. You cannot write the **DJ** parameter with **WR**, so a power cycle always clears the **DJ** setting.

The following commands control the end device joining process.

Command	Description
ID	Sets the 64-bit PAN ID to join. Setting ID = 0 allows the router to join any 64-bit PAN ID.
SC	Set the scan channels bitmask that determines which channels an end device will scan to find a valid network. SC on the end device should be set to match SC on the coordinator and routers in the desired network. For example, setting SC to 0x281 enables scanning on channels 0x0B, 0x12, and 0x14, in that order.
SD	Set the scan duration, or time that the end device will listen for beacons on each channel.
ZS	Set the stack profile on the device.
EE	Enable or disable security in the network. This must be set to match the EE value (security policy) of the coordinator.
KY	Set the trust center link key. If set to 0 (default), the link key is expected to be obtained (unencrypted) during joining.
EO	If encryption is enabled (EE = 1), set the joining device's Encryption Options to match the Encryption Options of the network.

Once the end device joins a network, the network configuration settings persist through power cycles as mentioned in [Persistent data](#). If joining fails, read the status of the last join attempt in the **AI** command register.

If any of these command values change when command register changes are applied, the end device leaves its current network and attempts to discover and join a new valid network.

When a Zigbee end device has successfully started a network, it:

- Sets **AI** equal to **0**
- Starts blinking the Associate LED if one has been connected to the device's ASSC pin (Micro pin 26/SMT pin 28/TH pin 15)
- Sends an API modem status frame (“associated”) out the serial port when using API mode
- Attempts to enter the sleep mode defined by the **SM** parameter

You can use the following commands to configure these behaviors:

Command	Description
D5	Enables the Associate LED functionality.
LT	Sets the Associate LED blink time when joined. Default is 2 blinks per second (end devices).
SM, SP, ST, SN, SO	Parameters that configure the sleep mode characteristics. See End Device configuration .

Parent connectivity

The XBee3 Zigbee RF Module end device sends regular poll transmissions to its parent when it is awake. These poll transmissions query the parent for any new received data packets. The parent always sends a MAC layer acknowledgment back to the end device. The acknowledgment indicates whether the parent has data for the end device.

If the end device does not receive an acknowledgment for three consecutive poll requests, it considers itself disconnected from its parent and attempts to discover and join a valid Zigbee network. For more information, see [Manage End Devices](#).

Reset the end device

When the end device is reset or power cycled, if the orphan scan successfully locates a parent, the end device then checks its PAN ID, operating channel and stack profile against the network configuration settings (**ID, SC, ZS**). It also verifies the saved security policy is valid based on the security configuration commands (**EE, EO, KY**). If the end device's PAN ID, operating channel, stack profile, or security policy is invalid, the end device will leave the network and attempt to join a new network based on its network joining command values.

To prevent the end device from leaving an existing network, the **WR** command should be issued after all network joining commands have been configured in order to retain these settings through power cycle or reset events.

Channel scanning

Routers and end devices must scan one or more channels to discover a valid network to join. When a join attempt begins, the device sends a beacon request transmission on the lowest channel specified in the **SC** ([Scan Channels](#)) bitmask. If the device finds a valid PAN on the channel, it attempts to join the PAN on that channel. Otherwise, if the device does not find a valid PAN on the channel, it attempts scanning on the next higher channel in the **SC** bitmask.

The device continues to scan each channel (from lowest to highest) in the **SC** bitmask until it finds a valid PAN or all channels have been scanned. Once the device scans all channels, the next join attempt starts scanning on the lowest channel specified in the **SC** bitmask.

For example, if the **SC** command is set to **0x400F**, the device starts scanning on channel 11 (**0x0B**) and scans until it finds a valid beacon, or until it scans channels 11, 12, 13, 14, and 25 have been scanned (in that order).

Once an XBee router or end device joins a network on a given channel, if the XBee device receives a network leave command (see [Leave a network](#)), it leaves the channel it joined on and continues scanning on the next higher channel in the **SC** bitmask.

For example, if the **SC** command is set to **0x400F** and the device joins a PAN on channel 12 (**0x0C**), if the XBee3 Zigbee RF Module leaves the channel, it starts scanning on channel 13, followed by channels 14 and 25 if it does not find a valid network. Once all channels have been scanned, the next join attempt starts scanning on the lowest channel specified in the **SC** bitmask.

Manage multiple Zigbee networks

In some applications, multiple Zigbee networks may exist in proximity of each other. The application may need provisions to ensure the device joins the desired network. There are a number of features in Zigbee to manage joining among multiple networks. These include the following:

- PAN ID filtering
- Preconfigured security keys
- Permit joining
- Application messaging

Filter PAN ID

Set **ID (Extended PAN ID)** to a non-zero value to configure the XBee3 Zigbee RF Module with a fixed PAN ID.

If you set the PAN ID to a non-zero value, the device will only join a network with the same PAN ID.

Configure security keys

Similar to PAN ID filtering, this method requires that you install a known security key on a router to ensure it joins a Zigbee network with the same security key.

1. Use **EE (Encryption Enable)** to enable security.
2. Use **KY (AES Encryption Key)** to set the preconfigured link key to a non-zero value.

Now the XBee router or end device will only join a network with the same security key.

Prevent unwanted devices from joining

You can disable the permit-joining parameter in a network to prevent unwanted devices from joining. When you need to add a new device to a network, enable permit-joining for a short time on the desired network.

In the XBee firmware:

1. Set **NJ (Node Join Time)** to a value less than **0xFF** on all routers and coordinator devices to restrict joining (recommended).
2. Use the Commissioning pushbutton or **CB (Commissioning Pushbutton)** to allow joining for a short time; for more information, see [Network commissioning and diagnostics](#).

Application messaging framework

If none of the previous mechanisms are feasible, you can build a messaging framework between the coordinator and devices that join its network into the application. For example, the application code in joining devices could send a transmission to the coordinator after joining a network, and wait to receive a defined reply message. If the application does not receive the expected response message after joining, it could force the device to leave and continue scanning; see [NR \(Network Reset\)](#).

Transmission, addressing, and routing

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Addressing

All Zigbee devices have two different addresses, a 64-bit and a 16-bit address. This section describes the characteristics of each.

64-bit device addresses

The 64-bit address is a device address which is unique to each physical device. It is sometimes also called the MAC address or extended address and is assigned during the manufacturing process. The first three bytes of the 64-bit address is a Organizationally Unique Identifier (OUI) assigned to the manufacturer by the IEEE. The OUI of XBee devices is 0x0013A2.

16-bit device addresses

A device receives a 16-bit address when it joins a Zigbee network. For this reason, the 16-bit address is also called the network address. The 16-bit address of 0x0000 is reserved for the coordinator. All other devices receive a randomly generated address from the router or coordinator device that allows the join. The 16-bit address can change under certain conditions:

- An address conflict is detected where two devices are found to have the same 16-bit address
- A device leaves the network and later joins (it can receive a different address)

All Zigbee transmissions are sent using the source and destination 16-bit addresses. The routing tables on Zigbee devices also use 16-bit addresses to determine how to route data packets through the network. However, since the 16-bit address is not static, it is not a reliable way to identify a device.

To solve this problem, the 64-bit destination address is often included in data transmissions to guarantee data is delivered to the correct destination. The Zigbee stack can discover the 16-bit address, if unknown, before transmitting data to a remote.

Application layer addressing

Zigbee devices support multiple application profiles, cluster IDs, and endpoints (for more information, see [Zigbee application layers: in depth](#)). Application layer addressing allows data transmissions to be addressed to specific profile IDs, cluster IDs, and endpoints. Application layer addressing is useful if an application must do any of the following:

- Interoperate with other Zigbee devices outside of the Digi application profile.
- Use service and network management capabilities of the ZDO.
- Operate on a public application profile such as Home Automation or Smart Energy.

API mode provides a simple yet powerful interface that easily sends data to any profile ID, endpoint, and cluster ID combination on any device in a Zigbee network.

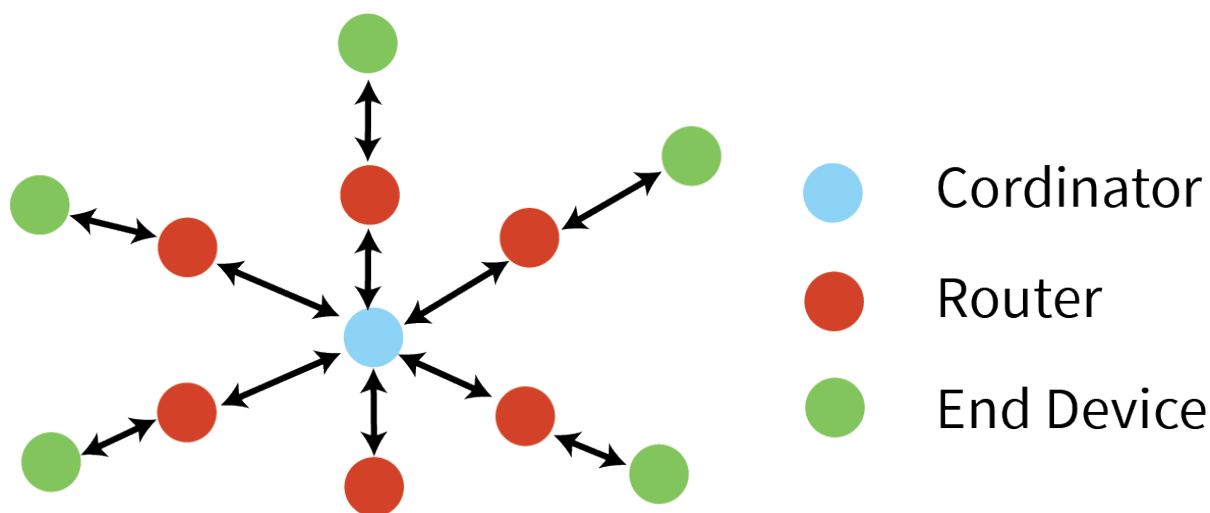
Data transmission

You can send Zigbee data packets as either unicast or broadcast transmissions. Unicast transmissions route data from one source device to one destination device, whereas broadcast transmissions are sent to many or all devices in the network.

Broadcast transmissions

Broadcast transmissions within the Zigbee protocol are intended to be propagated throughout the entire network such that all nodes receive the transmission. To accomplish this, the coordinator and all routers that receive a broadcast transmission retransmits the packet three times.

Note When a router or coordinator delivers a broadcast transmission to an end device child, the transmission is only sent once (immediately after the end device wakes and polls the parent for any new data). For more information, see [Parent operation](#).



Each node that transmits the broadcast also creates an entry in a local broadcast transmission table. This entry keeps track of each received broadcast packet to ensure the packets are not transmitted endlessly. Each entry persists for 8 seconds, and the broadcast transmission table holds 8 entries, effectively limiting network broadcast transmissions to once per second.

For each broadcast transmission, the Zigbee stack reserves buffer space for a copy of the data packet that retransmits the packet as needed. Large broadcast packets require more buffer space. Users cannot change any buffer spacing; information on buffer space is for general knowledge only. The XBee3 Zigbee RF Module handles buffer spacing automatically.

Since each device in the network retransmits broadcast transmissions, use broadcast messages sparingly to avoid network congestion.

Unicast transmissions

Unicast transmissions are sent from one source device to another destination device. The destination device could be an immediate neighbor of the source, or it could be several hops away. Unicast transmissions sent along a multiple hop path require some means of establishing a route to the destination device. For more information, see [RF packet routing](#).

Address resolution

Each device in a Zigbee network has both a 16-bit (network) address and a 64-bit (extended) address. The 64-bit address is unique and assigned to the device during manufacturing, and the 16-bit address is obtained after joining a network. The 16-bit address can also change under certain conditions.

When sending a unicast transmission, the Zigbee network layer uses the 16-bit address of the destination and each hop to route the data packet. If you do not know the 16-bit address of the

destination, the Zigbee stack includes a discovery provision to automatically discover the destination 16-bit address of the device before routing the data.

To discover a 16-bit address of a remote, the device initiating the discovery sends a broadcast address discovery transmission. The address discovery broadcast includes the 64-bit address of the remote device with the 16-bit address being requested. All nodes that receive this transmission check the 64-bit address in the payload and compare it to their own 64-bit address. If the addresses match, the device sends a response packet back to the initiator. This response includes the remote's 16-bit address. When the device receives the discovery response, the initiator transmits the data.

You can address frames using either the extended or the network address. If you use the extended address form, set the 16-bit network address field to 0xFFFE (unknown). If you use the 16-bit network address form, set the 64-bit extended address field to 0xFFFFFFFFFFFFFFFF (unknown).

If you use an invalid 16-bit address as a destination address, and the 64-bit address is unknown (0xFFFFFFFFFFFFFFFF), the modem status message shows a delivery status code of 0x21 (network ack failure) and a discovery status of 0x00 (no discovery overhead). If you use a non-existent 64-bit address as a destination address, and the 16-bit address is unknown (0xFFFE), the device attempts address discovery and the modem status message shows a delivery status code of 0x24 (address not found) and a discovery status code of 0x01 (address discovery was attempted).

Address table

Each Zigbee device maintains an address table that maps a 64-bit address to a 16-bit address. When a transmission is addressed to a 64-bit address, the Zigbee stack searches the address table for an entry with a matching 64-bit address to determine the destination's 16-bit address. If the Zigbee stack does not find a known 16-bit address, it performs address discovery to discover the device's current 16-bit address.

64-bit address	16-bit address
0013 A200 4000 0001	0x4414
0013 A200 400A 3568	0x1234
0013 A200 4004 1122	0xC200
0013 A200 4002 1123	0xFFFE (unknown)

The XBee3 Zigbee RF Module supports up to 20 address table entries. For applications where a single device (for example, coordinator) sends unicast transmissions to more than 10 devices, the application implements an address table to store the 16-bit and 64-bit addresses for each remote device. Use API mode for any XBee device that sends data to more than 10 remotes. The application can then send both the 16-bit and 64-bit addresses to the XBee device in the API transmit frames which significantly reduces the number of 16-bit address discoveries and greatly improves data throughput.

If an application supports an address table, the size should be larger than the maximum number of destination addresses the device communicates with. Each entry in the address table should contain a 64-bit destination address and its last known 16-bit address.

When sending a transmission to a destination 64-bit address, the application searches the address table for a matching 64-bit address. If it finds a match, the application populates the 16-bit address into the 16-bit address field of the API frame. If it does not find a match, set the 16-bit address to 0xFFFE (unknown) in the API transmit frame. The API provides indication of a remote device's 16-bit address in the following frames:

- All receive data frames
- Rx Data (0x90)
- Rx Explicit Data (0x91)
- I/O Sample Data (0x92)
- Node Identification Indicator (0x95)
- Route Record Indicator (0xA1) and so forth
- Transmit status frame (0x8B)

Group table

Each router and the coordinator maintain a persistent group table. Each entry contains the following:

- Endpoint value
- Two byte group ID
- Optional name string of zero to 16 ASCII characters
- Index into the binding table

More than one endpoint may be associated with a group ID, and more than one group ID may be associated with a given endpoint. The capacity of the group table is 16 entries.

The application always updates the 16-bit address in the address table when it receives one of the frames to ensure the table has the most recently known 16-bit address. If a transmission failure occurs, the application sets the 16-bit address in the table to 0xFFFFE (unknown).

Binding transmissions

Binding transmissions use indirect addressing to send one or more messages to other destination devices. The device handles an [Explicit Addressing Command frame - 0x11](#) using the Indirect Tx Option (0x04) as a binding transmission request.

Multicast transmissions

XBee modules use multicast transmissions to broadcast a message to destination devices that have active endpoints associated with a common group ID. The device handles an [Explicit Addressing Command frame - 0x11](#) using the Multicast Tx Option (0x08) as a multicast transmission request.

Address resolution

The 64 bit destination address value does not matter and we recommend that it be set to 0xFFFFFFFFFFFFFFFF. Set the 16 bit destination address value to the destination groupID.

Address resolution

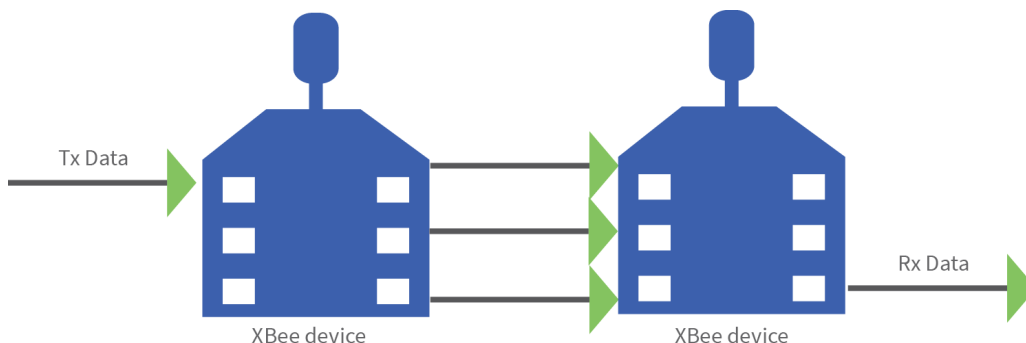
The XBee3 Zigbee RF Module use the source endpoint and cluster ID values of a binding transmission as keys to lookup matching binding table entries. For each matching binding table entry, the type field of the entry indicates whether to send a unicast or a multicast message. In the case of a unicast entry, the transmission request is updated with the Destination Endpoint and MAC Address, and unicast to its destination. In the case of a multicast entry, the device updates the message using the two least significant bytes of the Destination MAC Address as the groupID, and multicast to its destinations.

Binding table

Each router and coordinator maintain a persistent binding table to map source endpoint and cluster ID values into 64 bit destination address and endpoint values. The capacity of the binding table is 16 entries.

Fragmentation

Each unicast transmission may support up to 84 bytes of RF payload, although enabling security or using source routing can reduce this number. For more information, see [NP \(Maximum Packet Payload Bytes\)](#). However, the XBee Zigbee firmware supports a Zigbee feature called fragmentation that allows a single large data packet to be broken up into multiple RF transmissions and reassembled by the receiver before sending data out its serial port.



The transmit frame can include up to 255 bytes of data broken up into multiple transmissions and reassembled on the receiving side. If one or more of the fragmented messages are not received by the receiving device, it drops the entire message, and the sender indicates a transmission failure in [Transmit Status frame - 0x8B](#).

Applications that do not wish to use fragmentation should avoid sending more than the maximum number of bytes in a single RF transmission (see [Maximum RF payload size](#)).

If you enable `RTS` flow control on the receiving device (using the `D6` command) it receives a fragmented message, it ignores `RTS` flow control.

Note Broadcast transmissions do not support fragmentation. Maximum payload size = up to 84 bytes.

Data transmission examples

This section provides examples for data transmission.

Send a packet in Transparent mode

To send a data packet in Transparent mode (`AP = 0`), set the `DH` and `DL` commands to match the 64-bit address of the destination device. `DH` must match the upper 4-bytes, and `DL` must match the lower 4 bytes. Since the coordinator always receives a 16-bit address of 0x0000, a 64-bit address of 0x0000000000000000 is the coordinator's address (in Zigbee firmware). The default values of `DH` and `DL` are 0x00, which sends data to the coordinator.

Example: Send a transmission to the coordinator.

In this example, a `\r` refers to a carriage return character.

A router or end device can send data in two ways. First, set the destination address (**DH** and **DL** commands) to 0x00.

1. Enter Command mode (+++).
2. After receiving an **OK\r**, issue the following commands:
 - **ATDH0\r**
 - **ATDLO\r**
 - **ATCN\r**
3. Verify that each of the three commands returned an **OK\r** response.
4. After setting these command values, all serial characters received on the UART are sent as a unicast transmission to the coordinator.

Alternatively, if the coordinator's 64-bit address is known, you can set **DH** and **DL** to the coordinator's 64-bit address. Suppose the coordinator's address is 0x0013A200404A2244.

1. Enter Command mode (+++).
2. After receiving an **OK\r**, issue the following commands:
 - a. **ATDH13A200\r**
 - b. **ATDL404A2244\r**
 - c. **ATCN\r**
3. Verify that each of the three commands returned an **OK\r** response.
4. After setting these command values, all serial characters received on the UART are sent as a unicast transmission to the coordinator.

Send data in API mode

API mode is used exclusively for outgoing and incoming messages when the **AP** parameter is non-zero. Use the transmit request, or explicit transmit request frame (0x10 and 0x11 respectively) to send data to the coordinator. The 64-bit address can either be set to 0x0000000000000000, or to the 64-bit address of the coordinator. The 16-bit address should be set to 0xFFFE when using the 64-bit address of all 0x00s.

To send an ASCII **1** to the coordinator's 0x00 address, use the following API frame:

7E 00 0F 10 01 0000 0000 0000 0000 FFFE 00 00 31 C0

If you use the explicit transmit frame, set the the cluster ID to 0x0011, the profile ID to 0xC105, and the source and destination endpoints to 0xE8. These are the recommended defaults for data transmissions in the Digi profile.

You can send the same transmission using the following explicit transmit frame:

7E 00 15 11 01 0000 0000 0000 0000 FFFE E8 E8 0011 C105 00 00 31 18

The 16-bit address is set to 0xFFFE. This is required when sending to a 64-bit address of 0x00s.

Suppose the coordinator's 64-bit address is 0x0013A200404A2244. The following transmit request API frame (0x10) sends an ASCII **1** to the coordinator:

7E 00 0F 10 01 0013 A200 404A 2244 0000 0000 31 18

Example: Send a broadcast transmission

In this example, a '\r' refers to a carriage return character.

Perform the following steps to configure a broadcast transmission:

1. Enter Command mode (+++)
2. After receiving an **OK\r**, issue the following commands:
 - **ATDH0\r**
 - **ATDLffff\r**
 - **ATCN\r**
3. Verify that each of the three commands returned an **OK\r** response.
4. After setting these command values, all serial characters are sent as a broadcast transmission.

API frame examples

A transmit request API frame (0x10) can send an ASCII **1** in a broadcast transmission using the following API frame:

```
7E 00 0F 10 01 0000 0000 0000 FFFF FFFE 00 00 31 C2
```

The destination 16-bit address is set to 0xFFFFE for broadcast transmissions.

Example: Send an indirect (binding) transmission.

This example uses the explicit transmit request frame (0x11) to send a transmission using indirect addressing through the binding table. It assumes the binding table has already been set up to map a source endpoint of 0xE7 and cluster ID of 0x0011 to a destination endpoint and 64 bit destination address. The message data is a manufacturing specific profile message using profile ID 0xC105, command ID 0x00, a ZCL Header of 151E10, transaction number EE, and a ZCL payload of 000102030405:

```
7E 001E 11 e4 FFFFFFFFFFFFFFFF FFFE E7 FF 0011 C105 00 04 151E10EE000102030405 14
```

Note The 64 bit destination address has been set to all 0xFF values, and the destination endpoint set to 0xFF. The Tx Option 0x04 indicates indirect addressing. The 64 bit destination address and destination endpoint are completed by looking up data associated with binding table entries. This matches the following example.

Example: Send a multicast (group ID) broadcast.

This example uses the explicit transmit request frame (0x11) to send a transmission using multicasting. It assumes the destination devices already have their group tables set up to associate an active endpoint with the group ID (0x1234) of the multicast transmission. The message data is a manufacturing specific profile message using profile ID 0xC105 command ID 0x00, a ZCL Header of 151E10, transaction number EE, and a ZCL payload of 000102030405:

```
7E 001E 11 01 FFFFFFFFFFFFFFFF 1234 E6 FE 0001 C105 00 08 151E10EE000102030405 BC
```

Note The 64 bit destination address has been set to all 0xFF values, and the destination endpoint set to 0xFE. The Tx Option 0x08 indicates use of multicast (group) addressing.

RF packet routing

Unicast transmissions may require some type of routing. Zigbee includes several different methods to route data, each with its own advantages and disadvantages as summarized in the following table.

Routing approach	Description	When to use
Ad hoc On-demand Distance Vector (AODV) Mesh Routing	Routing paths are created between source and destination, possibly traversing multiple nodes (“hops”). Each device knows where to send data next to eventually reach the destination.	Use in networks that will not scale beyond about 40 destination devices.
Many-to-One Routing	A single broadcast transmission configures reverse routes on all devices into the device that sends the broadcast.	Useful when many remote devices must send data to a single gateway or collector device.
Source Routing	Data packets include the entire route the packet should traverse to get from source to destination.	Improves routing efficiency in large networks (over 40 remote devices).

Note End devices do not make use of these routing protocols. Rather, an end device sends a unicast transmission to its parent and allows the parent to route the data packet in its behalf.

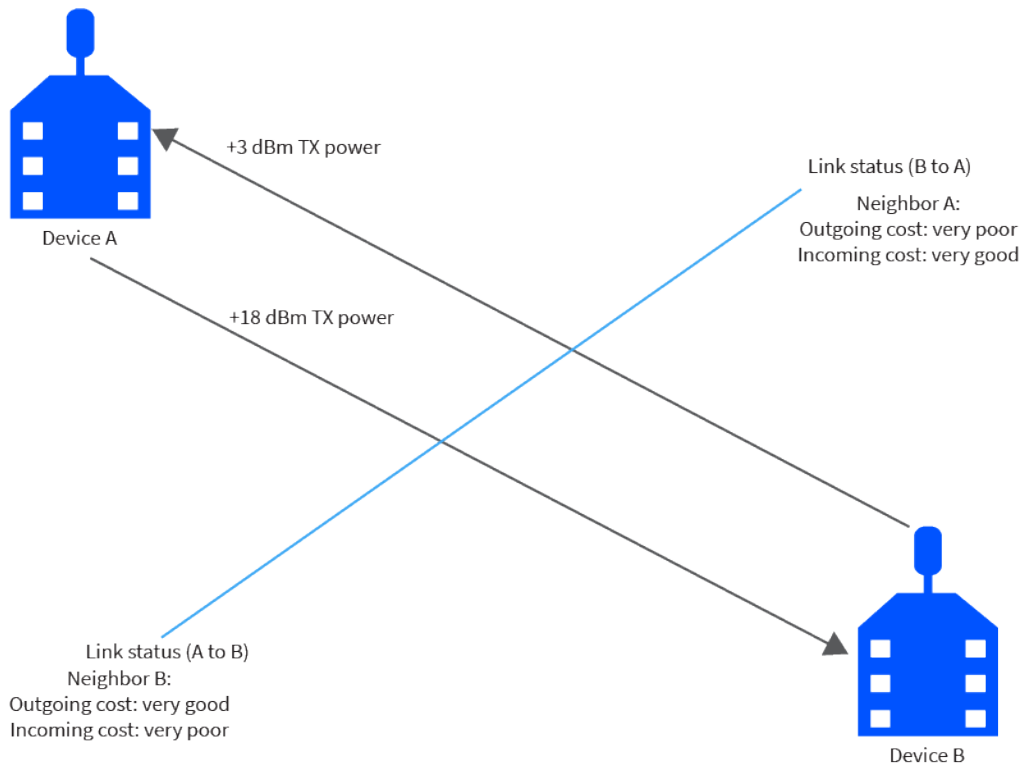
Note To revert from Many-to-One routing to AODV routing, a network must first do a network reset (NR).

Link status transmission

Before discussing the various routing protocols, it is worth understanding the primary mechanism in Zigbee for establishing reliable bi-directional links. This mechanism is especially useful in networks that may have a mixture of devices with varying output power and/or receiver sensitivity levels.

Each coordinator or router device periodically sends a link status message as a 1-hop broadcast transmission, received only by one-hop neighbors. The link status message contains a list of neighboring devices and incoming and outgoing link qualities for each neighbor. Using these messages, neighboring devices determines the quality of a bi-directional link with each neighbor and uses that information to select a route that works well in both directions.

For example, consider a network of two neighboring devices that send periodic link status messages. Suppose that the output power of device A is +18 dBm, and the output power of device B is +3 dBm (considerably less than the output power of device A). The link status messages might indicate the following:



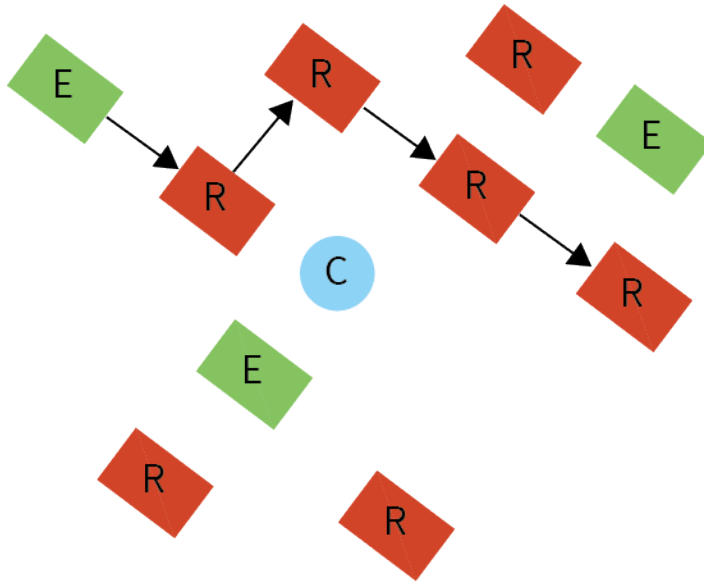
This mechanism enables devices A and B to recognize that the link is not reliable in both directions and select a different neighbor when establishing routes. Such links are called asymmetric links, meaning the link quality is not similar in both directions.

When a router or coordinator device powers on, it sends link status messages every couple seconds to attempt to discover link qualities with its neighbors quickly. After being powered on for some time, the link status messages are sent at a much slower rate, about every 3-4 times per minute.

AODV mesh routing

Zigbee employs mesh routing to establish a route between the source device and the destination. Mesh routing allows data packets to traverse multiple nodes (hops) in a network to route data from a source to a destination. Routers and coordinators can participate in establishing routes between source and destination devices using a process called route discovery. The Route discovery process is based on the Ad-hoc On-demand Distance Vector routing (AODV) protocol.

Sample transmission through a mesh network:



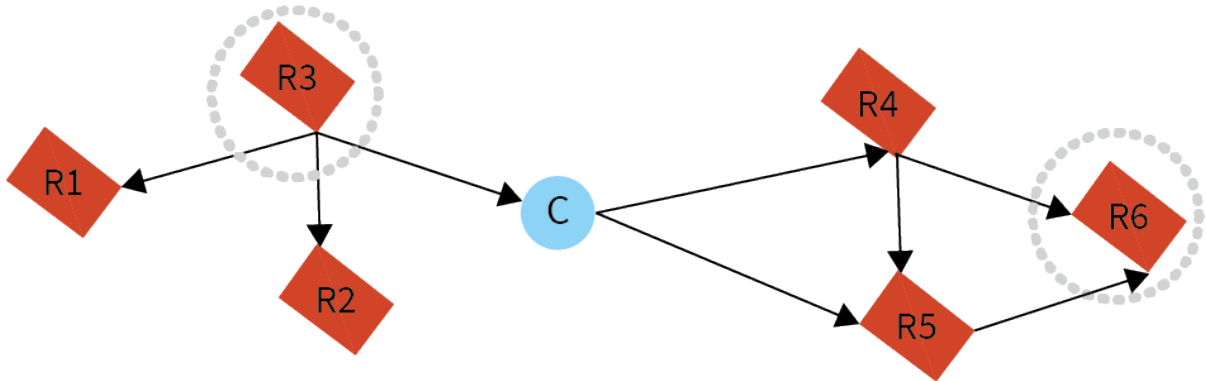
AODV routing algorithm

Routing under the AODV protocol uses tables in each node that store the next hop (intermediary node between source and destination nodes) for a destination node. If a next hop is unknown, route discovery takes place to find a path. Since only a limited number of routes can be stored on a router, route discovery takes place more often on a large network with communication between many different nodes.

Node	Destination address	Next hop address
R3	Router 6	Coordinator
C	Router 6	Router 5
R5	Router 6	Router 6

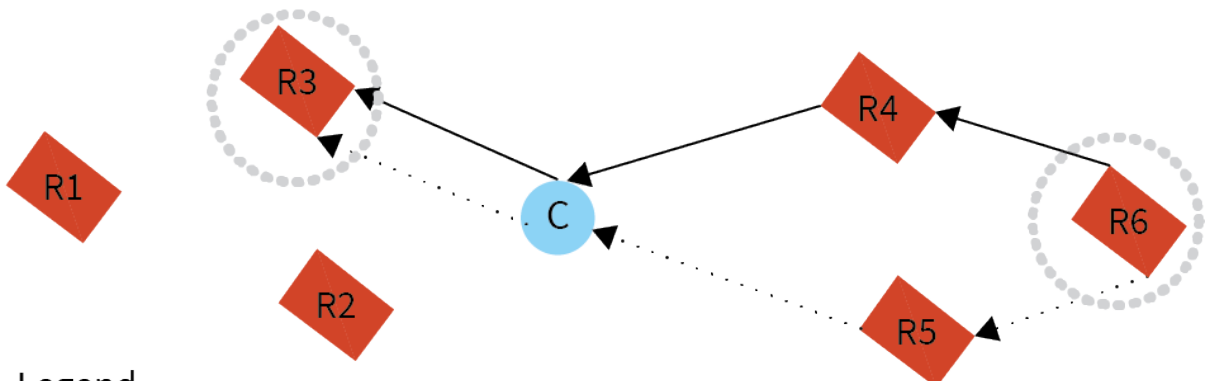
When a source node discovers a route to a destination node, it sends a broadcast route request command. The route request command contains the source network address, the destination network address and a path cost field (a metric for measuring route quality). As the route request command propagates through the network (see [Broadcast transmissions](#)), each node that re-broadcasts the message updates the path cost field and creates a temporary entry in its route discovery table.

The following graphic is a sample route request (broadcast) transmission where R3 is trying to discover a route to R6:



When the destination node receives a route request, it compares the 'path cost' field against previously received route request commands. If the path cost stored in the route request is better than any previously received, the destination node transmits a route reply packet to the node that originated the route request. Intermediate nodes receive and forward the route reply packet to the source node (the node that originated route request).

The following graphic is a sample route reply (unicast) where R6 sends a route reply to R3:



Legend

- ▶ First route reply
-▶ Second route reply

Note R6 could send multiple replies if it identifies a better route.

Retries and acknowledgments

Zigbee includes acknowledgment packets at both the Mac and Application Support (APS) layers. When data is transmitted to a remote device, it may traverse multiple hops to reach the destination. As the device transmits data from one node to its neighbor, it transmits an acknowledgment packet (Ack) in the opposite direction to indicate that the transmission was successfully received. If the Ack is not received, the transmitting device retransmits the data, up to four times.

This Ack is called the Mac layer acknowledgment. In addition, the device that originated the transmission expects to receive an acknowledgment packet (Ack) from the destination device. This Ack traverses the same path the data traversed, but in the opposite direction. If the originator fails to receive this Ack, it retransmits the data, up to two times until it receives an Ack. This Ack is called the Zigbee APS layer acknowledgment.

Note Refer to the Zigbee specification for more details.

Many-to-One routing

In networks where many devices must send data to a central collector or gateway device, AODV mesh routing requires significant overhead. If every device in the network had to discover a route before it could send data to the data collector, the network could easily become inundated with broadcast route discovery messages.

Many-to-one routing is an optimization for these kinds of networks. Rather than require each device to do its own route discovery, the device sends a single many-to-one broadcast transmission from the data collector to establish reverse routes on all devices.

The many-to-one broadcast is a route request message with the target discovery address set to the address of the data collector. Devices that receive this route request create a reverse many-to-one routing table entry to create a path back to the data collector. The Zigbee stack on a device uses historical link quality information about each neighbor to select a reliable neighbor for the reverse route.

When a device sends data to a data collector, and it finds a many-to-one route in its routing table, it transmits the data without performing a route discovery. Send the many-to-one route request periodically to update and refresh the reverse routes in the network.

Applications that require multiple data collectors can also use many-to-one routing. If more than one data collector device sends a many-to-one broadcast, devices create one reverse routing table entry for each collector.

The Zigbee firmware uses [AR \(Aggregate Routing Notification\)](#) to enable many-to-one broadcasting on a device. **AR** sets a time interval (measured in 10 second units) for sending the many to one broadcast transmission.

High/Low RAM Concentrator mode

When Many to One (MTO) requests are broadcast, **DO** = 40 (bit 6) determines if the concentrator is operating in high or low RAM mode. High RAM mode indicates the concentrator has enough memory to store source routes for the whole network, and remote nodes may stop sending route records after the concentrator has successfully received one. Low RAM mode indicates the concentrator lacks RAM to store route records, and that route records be sent to the concentrator to precede every inbound APS unicast message. By default the device uses high RAM mode. If you have a network with more than 40 devices or will be using a Digi gateway, we recommend operating in low RAM concentrator mode and externally manage source routing.

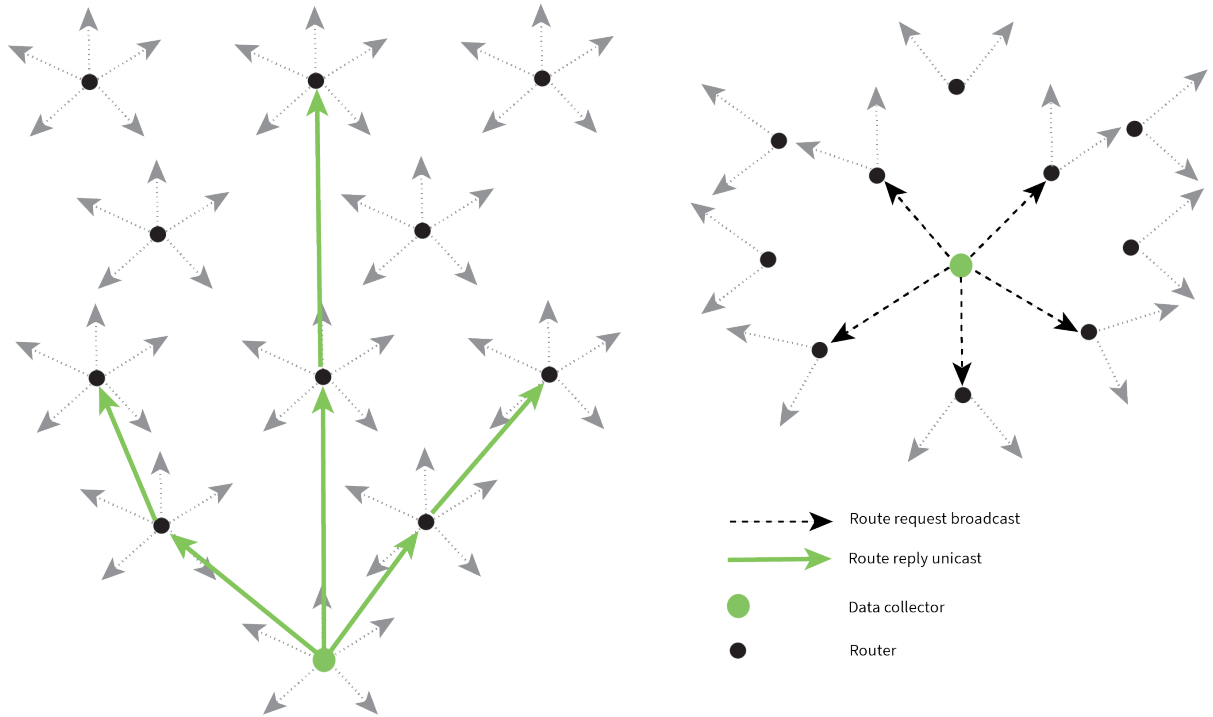
Source routing

In applications where a device must transmit data to many remotes, AODV routing requires performing one route discovery for each destination device to establish a route. If there are more destination devices than there are routing table entries, new routes overwrite established AODV routes, causing route discoveries to occur more regularly. This can result in larger packet delays and poor network performance.

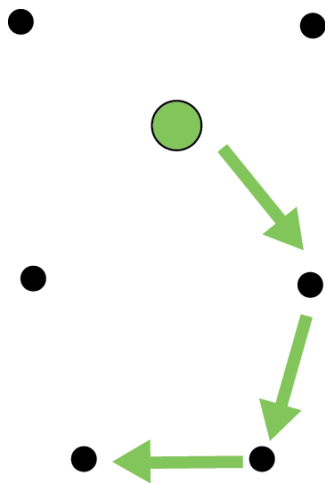
Zigbee source routing helps solve these problems. In contrast to many-to-one routing that establishes routing paths from many devices to one data collector, source routing allows the collector to store and specify routes for many remotes.

To use source routing, a device must use the API mode, and it must send periodic many-to-one route request broadcasts (AR command) to create a many-to-one route to it on all devices. When remote devices send RF data using a many-to-one route, they first send a route record transmission. The route record transmission is unicast along the many-to-one route until it reaches the data collector. As the route record traverses the many-to-one route, it appends the 16-bit address of each device in the route into the RF payload. When the route record reaches the data collector, it contains the

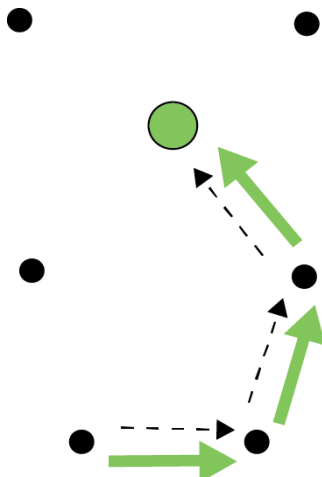
address of the sender, and the 16-bit address of each hop in the route. The data collector can store the routing information and retrieve it later to send a source routed packet to the remote as shown in the following images.



The data collector sends a many-to-one route request broadcast to create reverse routes on all devices.



A remote device sends an RF data packet to the data collector. This is prefaced by a route record transmission to the data collector.



After obtaining a source route, the data collector sends a source routed transmission to the remote device.

Acquire source routes

Acquiring source routes requires the remote devices to send a unicast to a data collector (device that sends many-to-one route request broadcasts). There are several ways to force remotes to send route record transmissions.

1. If the application on remote devices periodically sends data to the data collector, each transmission forces a route record to occur.
2. The data collector can issue a network discovery command (**ND** command) to force all XBee devices to send a network discovery response. A route record prefaces each network discovery response.
3. You can enable periodic I/O sampling on remotes to force them to send data at a regular rate. A route record prefaces each I/O sample. For more information, see [Analog and digital I/O lines](#).
4. If the **NI** string of the remote device is known, the **DN** command can be issued with the **NI** string of the remote in the payload. The remote device with a matching **NI** string would send a route record and a DN response.

Store source routes

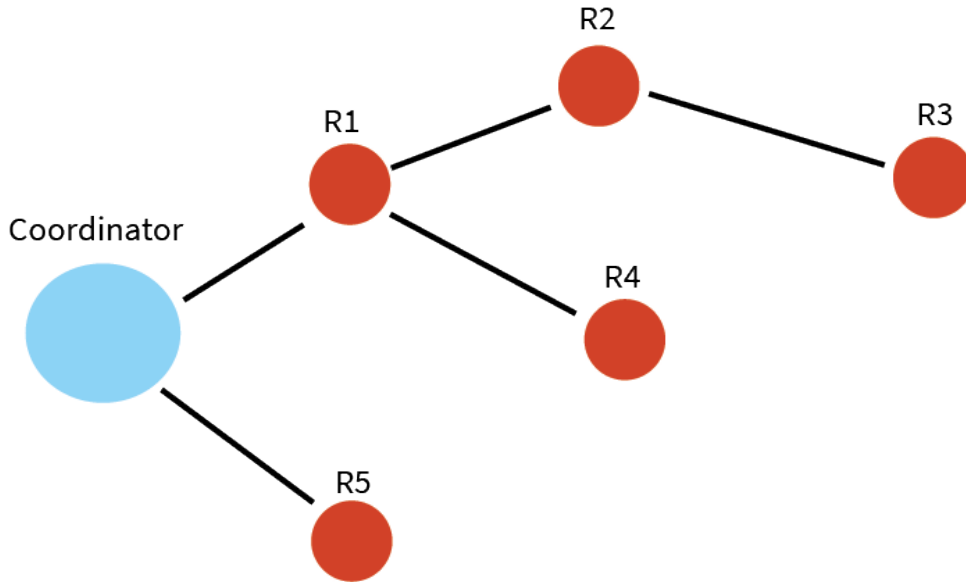
When a data collector receives a route record, it sends it out the serial port as a [Route Record Indicator - 0xA1](#). To use source routing, the application receives these frames and stores the source route information.

Send a source routed transmission

To send a source routed transmission, the application must send a [Create Source Route - 0x21](#) to the XBee3 Zigbee RF Module to create a source route in its internal source route table. After sending the Create Source Route frame, the application can send data transmission or remote command request frames as needed to the same destination, or any destination in the source route. Once data must be sent to a new destination (a destination not included in the last source route), the application must first send a new [Create Source Route - 0x21](#).

Note If a Create Source Route API frame does not precede the data frames, you may encounter data loss.

The XBee3 Zigbee RF Module can buffer one source route that includes up to 11 hops (excluding source and destination). For example, suppose a network exists with a coordinator and 5 routers (R1, R2, R3, R4, R5) with known source routes as shown in the following image.



To send a source-routed packet to R3, the application sends a Create Source Route API frame (0x21) to the XBee, with a destination of R3, and 2 hops (R1 and R2). If the 64-bit address of R3 is 0x0013A200 404a1234 and the 16-bit addresses of R1, R2, and R3 are:

Device	16-bit address
R1	0xAABB
R2	0xCCDD
R3	0xEEFF

The Create Source Route API frame would be:
 7E 0012 21 00 0013A200 404A1234 EEFF 00 02 CCDD AABB 5C

Field composition

0x0012	length
0x21	API ID (create source route)
0x00	frame ID (set to 0 always)
0x0013A200 404A1234	64-bit address of R3 (destination)

0xEEFF	16-bit address of R3 (destination)
0x00	Route options (set to 0)
0x02	Number of intermediate devices in the source route
0xCCDD	Address of furthest device (1-hop from target)
0xAABB	Address of next-closer device
0x5C	Checksum (0xFF - SUM (all bytes after length))

Repair source routes

It is possible for a network to have an existing source route fail (for example, a device in the route moves or goes down). If a device goes down in a source routed network, all routes that used the device will be broken.

As mentioned previously, source routing must be used with many-to-one routing. A device that uses source routing must also send a periodic many-to-one broadcast in order to keep routes fresh. If a source route breaks, remote devices send in new route record transmissions to the data collector to provide it with a new source route. This requires that remote devices periodically send data transmissions into the data collector. For more information, see [Acquire source routes](#).

Retries and acknowledgments

Zigbee includes acknowledgment packets at both the Mac and Application Support (APS) layers. When data transmits to a remote device, it may traverse multiple hops to reach the destination. As data transmits from one node to its neighbor, an acknowledgment packet (Ack) transmits in the opposite direction to indicate that the transmission was successfully received. If the transmitting device does not receive the Ack, it retransmits the data up to four times. This Ack is called the Mac layer acknowledgment.

In addition, the device that originated the transmission expects to receive an acknowledgment packet (Ack) from the destination device. This Ack traverses the same path that the data traversed, but in the opposite direction. If the originator fails to receive this Ack, it retransmits the data, up to two times until an Ack is received. This Ack is called the Zigbee APS layer acknowledgment.

Note Refer to the Zigbee specification for more details.

Disable MTO routing

To disable MTO (many-to-one) routing in a network, first reconfigure the **AR** setting on the aggregator and then broadcast a network wide power reset to rebuild the routing tables.

1. Set **AR** on the aggregator to **0xFF**.
2. Complete an **AC** command to enact the change.
3. Complete a **WR** command if the saved configuration setting value for **AR** is not 0xFF.

This ends the periodic broadcast of aggregator messages if the previous setting was 0x01 - 0xFE, and prevents a single broadcast after a power reset if the previous setting was 0x00. Broadcast a **FR** remote command to the network and wait for the network to reform. This removes the aggregator's status as an aggregator from the network's routing tables so that no more route records will be sent to the aggregator.

Disable route records

If an aggregator collects route records from the nodes of the network and no longer needs route records sent (which consume network throughput) :

1. Set Bit 6 of **DO** to Enable High RAM Concentrator mode. High RAM mode means the aggregator has sufficient memory to hold route records for its potential destinations.
2. Set **AR** to 0x00 for a one-time broadcast (which some nodes might miss), or a value in the range of 0x01 to 0xFE (in units of 10 seconds) to periodically send a broadcast to inform the network that the aggregator is operating in High RAM Concentrator mode and no longer needs to receive route records.
3. Use [Create Source Route - 0x21](#) to load the route record for a destination into the local device's source route table.
4. Send a unicast to the destination. The route record embeds in the payload and determines the sequence of routers to use in transmitting the unicast to the destination. After receiving the unicast, the destination no longer sends route records to the aggregator, now that it has confirmed the High RAM Concentrator aggregator 'knows' its route record.

Clear the source route table

To clear the source route table, change the **AR** setting from a non-0xFF setting to 0xFF and complete an **AC** command. To re-establish periodic aggregator broadcasts, change the **AR** setting to a non-0xFF setting and complete an **AC** command.

Encrypted transmissions

Encrypted transmissions are routed similar to non-encrypted transmissions with one exception. As an encrypted packet propagates from one device to another, each device decrypts the packet using the network key and authenticates the packet by verifying packet integrity. It then re-encrypts the packet with its own source address and frame counter values and sends the message to the next hop. This process adds some overhead latency to unicast transmissions, but it helps prevent replay attacks. For more information see [Zigbee security](#).

Maximum RF payload size

The **NP** command returns the maximum payload size in bytes. The actual maximum payload is a function of the following:

- message type (broadcast or unicast)
- AP setting
- APS encryption option
- Source-routing

Broadcasts, which cannot be encrypted with APS or fragmented have a maximum payload of 0x54 bytes (84 bytes).

For broadcast messages and unicast messages when **AP**=0, the maximum payload is 0x54 bytes.

For unicast messages, the maximum payload is 0xFF (255 bytes) bytes. If the combination of payload and optional APS encryption overhead (EE1, TxOption 0x20) is too high, the message fragments into a maximum of five fragments. The firmware encrypts and transmits each fragment separately. The destination radio reassembles the fragments into a full message.

The maximum payload is calculated to estimate for aggregator source-routing. To reduce the maximum payload, when an aggregator sends a source-routed message it embeds the route into the message as overhead, or into each fragment of the message, if fragmentation is necessary. If you use APS encryption (EE1, Tx Option 0x20), it reduces the number further.

The route overhead is 2 bytes plus 2 bytes per hop. The bytes are:

- One byte is the number of hops
- One byte is an index into the route list that increments in value at each hop
- Other data is a list of the 16-bit network addresses of the routing radios

Aggregator source-routed payload maximums do not apply to messages that are sourced by non-aggregator nodes, which send route records ahead of their messages to aggregators. Aggregators are either Coordinators or Routers which have the following:

- Source routing enabled or
- **AR** setting which is not 0xFF

The following table shows the aggregator source-routed payload maximums as a function of hops and APS encryption:

Hops	Maximum encrypted payload	Maximum unencrypted payload
1	255	255
2	255	255
3	255	255
4	255	255
5	255	255
6	215	255
7	205	250
8	195	240
9	185	230
10	175	220
11	165	210
12	155	200
13	145	190
14	135	180
15	125	170
16	115	160
17	105	150
18	95	140

Hops	Maximum encrypted payload	Maximum unencrypted payload
19	85	130
20	75	120
21	65	110
22	55	100
23	45	90
24	35	80
25	25	70

Throughput

Throughput in a Zigbee network can differ by a number of variables, including:

- Number of hops
- Encryption enabled/disabled
- Sleeping end devices
- Failures/route discoveries

ZDO transmissions

Zigbee defines a Zigbee device objects layer (ZDO) that provides device and service discovery and network management capabilities.

Cluster name	Cluster ID	Description
Network Address Request	0x0000	Request a 16-bit address of the radio with a matching 64-bit address (required parameter).
Active Endpoints Request	0x0005	Request a list of endpoints from a remote device.
LQI Request	0x0031	Request data from a neighbor table of a remote device.
Routing Table Request	0x0032	Request to retrieve routing table entries from a remote device.
Network Address Response	0x8000	Response that includes the 16-bit address of a device.
LQI Response	0x8031	Response that includes neighbor table data from a remote device.
Routing Table Response	0x8032	Response that includes routing table entry data from a remote device.

Refer to the Zigbee specification for a detailed description of all Zigbee device profile services.

Send a ZDO command

You must use an explicit transmit API frame (0x11) to send a ZDO command, and you must format it correctly.

1. Set the source and destination endpoints and profile ID to 0.
2. Set the cluster ID to match the cluster ID of the appropriate service. For example, to send an active endpoints request, set the cluster ID to 0x0005.
3. The first byte of payload in the API frame is an application sequence number (transaction sequence number) that can be set to any single byte value. The first byte of the ZDO response uses this same value.
4. All remaining payload bytes must be set as required by the ZDO. All multi-byte values must be sent in little endian byte order.

Receiving ZDO command and responses

In XBee ZB firmware, you can easily send ZDO commands using the API. To receive incoming ZDO commands, enable receiver application addressing with the **AO** command. See the examples later in this section. Not all incoming ZDO commands are passed up to the application.

When a ZDO message is received on endpoint 0 and profile ID 0, the cluster ID indicates the type of ZDO message received. The first byte of payload is generally a sequence number that corresponds to a sequence number of a request. The remaining bytes are set as defined by the ZDO. Similar to a ZDO request, all multi-byte values in the response are in little endian byte order.

Example 1: Send a ZDO LQI request to read the neighbor table contents of a remote

Looking at the Zigbee specification, the cluster ID for an LQI Request is 0x0031, and the payload only requires a single byte (start index). This example sends an LQI request to a remote device with a 64-bit address of 0x0013A200 40401234. The start index is set to 0, and the transaction sequence number is set to 0x76.

API Frame

```
7E 0016 11 01 0013A200 40401234 FFFE 00 00 0031 0000 00 00 76 00 CE
```

Field composition

0x0016	length
0x11	Explicit transmit request
0x01	Frame ID (set to a non-zero value to enable the transmit status message, or set to 0 to disable)
0x0013A200 40401234	64-bit address of the remote
0xFFFFE	16-bit address of the remote (0xFFFFE = unknown). Optionally, set to the 16-bit address of the destination if known.
0x00	Source endpoint

0x00	Destination endpoint
0x0031	Cluster ID (LQI Request, or Neighbor table request)
0x0000	Profile ID (Zigbee device profile)
0x00	Broadcast radius
0x00	Tx Options
0x76	Transaction sequence number
0x00	Required payload for LQI request command
0xCE	Checksum (0xFF - SUM (all bytes after length))

Description

This API frame sends a ZDO LQI request (neighbor table request) to a remote device to obtain data from its neighbor table. You must set the **AO** command correctly on an API device to enable the explicit API receive frames to receive the ZDO response.

Example 2: Send a ZDO network Address Request to discover the 16-bit address of a remote

Looking at the Zigbee specification, the cluster ID for a network Address Request is 0x0000, and the payload only requires the following:

[64-bit address] + [Request Type] + [Start Index]

This example sends a Network Address Request as a broadcast transmission to discover the 16-bit address of the device with a 64-bit address of 0x0013A200 40401234. The request type and start index are set to 0, and the transaction sequence number is set to 0x44.

API frame

```
7E 001F 11 01 00000000 0000FFFF FFFE 00 00 0000 0000 00 00 44 34124040 00A21300 00 00 33
```

Field composition

0x001F	length
0x11	Explicit transmit request
0x01	Frame ID (set to a non-zero value to enable the transmit status message, or set to 0 to disable)
0x00000000 0000FFFF	64-bit address for a broadcast transmission
0xFFFFE	Set to this value for a broadcast transmission
0x00	Source endpoint
0x00	Destination endpoint
0x0000	Cluster ID (Network Address Request)
0x0000	Profile ID (Zigbee device profile)

0x00	Broadcast radius
0x00	Tx Options
0x44	Transaction sequence number
0x34124040 00A21300 00 00	Required payload for Network Address Request command
0x33	Checksum (0xFF - SUM (all bytes after length))

Description

This API frame sends a broadcast ZDO Network Address Request to obtain the 16-bit address of a device with a 64-bit address of 0x0013A200 40401234. We inserted the bytes for the 64-bit address in little endian byte order. You must insert data for all multi-byte fields in the API payload of a ZDO command in little endian byte order. You must set the **AO** command correctly on an API device to enable the explicit API receive frames to receive the ZDO response.

Transmission timeouts

The Zigbee stack includes two kinds of transmission timeouts, depending on the nature of the destination device. Destination devices such as routers with receivers always on use a unicast timeout. The unicast timeout estimates a timeout based on the number of unicast hops the packet should traverse to get data to the destination device. For transmissions destined for end devices, the Zigbee stack uses an extended timeout that includes the unicast timeout (to route data to the end device's parent), and it includes a timeout for the end device to finish sleeping, wake, and poll the parent for data.

The Zigbee stack includes some provisions for a device to detect if the destination is an end device. The Zigbee stack uses the unicast timeout unless it knows the destination is an end device.

The XBee API includes a transmit options bit that you can set to specify the extended timeout used for a given transmission. If you set this bit, the extended timeout will be used when sending RF data to the specified destination. To improve routing reliability, applications set the extended timeout bit when sending data to end devices if:

- The application sends data to 10 or more remote devices, some of which are end devices.
- The end devices may sleep longer than the unicast timeout.

Equations for these timeouts are computed in the following sections.

Note The timeouts in this section are worst-case timeouts and should be padded by a few hundred milliseconds. These worst-case timeouts apply when an existing route breaks down (for example, intermediate hop or destination device moved).

Unicast timeout

Set the unicast timeout with the **NH** command. The actual unicast timeout is computed as $((50 * NH) + 100)$. The default **NH** value is 30 which equates to a 1.6 second timeout.

The unicast timeout includes 3 transmission attempts (1 attempt and 2 retries).

The maximum total timeout is approximately:

$$3 * ((50 * NH) + 100)$$

For example, if $NH=30$ (0x1E), the unicast timeout is approximately $3 * ((50 * 30) + 100)$ or one of the following:

- $3 * (1500 + 100)$
- $3 * (1600)$
- 4800 ms
- 4.8 seconds

Extended timeout

The worst-case transmission timeout when you are sending data to an end device is a larger issue than when transmitting to a router or coordinator. As described in [Parent operation](#), RF data packets are sent to the parent of the end device, which buffers the packet until the end device wakes to receive it. The parent buffers an RF data packet for up to $(1.2 * SP)$ time.

To ensure the end device has adequate time to wake and receive the data, the extended transmission timeout to an end device is:

$$(50 * NH) + (1.2 * SP)$$

This timeout includes the packet buffering timeout $(1.2 * SP)$ and time to account for routing through the mesh network $(50 * NH)$.

If no acknowledgment is received within this time, the sender resends the transmission up to two more times. With retries included, the longest transmission timeout when sending data to an end device is:

$$3 * ((50 * NH) + (1.2 * SP))$$

The **SP** value in both equations must be entered in millisecond units. The **SP** command setting uses 10 ms units and must be converted to milliseconds to be used in this equation.

For example, suppose a router is configured with $NH=30$ (0x1E) and $SP=0x3E8$ (10,000 ms), and that it is either trying to send data to one of its end device children, or to a remote end device. The total extended timeout to the end device is approximately:

$3 * ((50 * NH) + (1.2 * SP))$ or one of the following:

- $3 * (1500 + 12000)$
- $3 * (13500)$
- 40500 ms
- 40.5 seconds

Transmission examples

Example 1: Send a unicast API data transmission to the coordinator using 64-bit address 0, with payload "TxData".

API frame

```
7E 0014 10 01 00000000 00000000 FFFE 00 00 54 78 44 61 74 61 AB
```

Field composition

0x0014	length
--------	--------

0x10	API ID (TX data)
0x01	Frame ID (set greater than 0 to enable the TX-status response)
0x00000000 00000000	64-bit address of coordinator (ZB definition)
0xFFFFE	Required 16-bit address if sending data to 64-bit address of 0
0x00	Broadcast radius (0 = max hops)
0x00	Tx options
0x54 78 44 61 74 61	ASCII representation of “TxData” string
0xAB	Checksum (0xFF - SUM (all bytes after length))

Description

This transmission sends the string “TxData” to the coordinator, without knowing the 64-bit address of the coordinator device. ZB firmware defines a 64-bit address of 0 as the coordinator. If the coordinator's 64-bit address was known, the 64-bit address of 0 could be replaced with the coordinator's 64-bit address, and the 16-bit address could be set to 0.

Example 2: Send a broadcast API data transmission that all devices can receive (including sleeping end devices), with payload “TxData”.

API frame

```
7E 0014 10 01 00000000 0000FFFF FFFE 00 00 54 78 44 61 74 61 AD
```

Field composition

0x0014	length
0x10	API ID (TX data)
0x01	Frame ID (set to a non-zero value to enable the TX-status response)
0x00000000 0000FFFF	Broadcast definition (including sleeping end devices)
0xFFFFE	Required 16-bit address to send broadcast transmission
0x00	Broadcast radius (0 = max hops)
0x00	Tx options
0x54 78 44 61 74 61	ASCII representation of “TxData” string
0xAD	Checksum (0xFF - SUM (all bytes after length))

Description

This transmission sends the string “TxData” as a broadcast transmission. Since the destination address is set to 0xFFFF, all devices, including sleeping end devices can receive this broadcast.

If receiver application addressing is enabled, the XBee3 Zigbee RF Module reports all received data frames in the explicit format (0x91) to indicate the source and destination endpoints, cluster ID, and

profile ID where each packet was received. Status messages like modem status and route record indicators are not affected.

To enable receiver application addressing, set the **AO** command to 1 using the [AT Command Frame - 0x08](#) as follows:

API frame

7E 0005 08 01 414F 01 65

Field composition

0x0005	length
0x08	API ID (AT command)
0x01	Frame ID (set to a non-zero value to enable AT command response frames)
0x414F	ASCII representation of 'A','O' (the command being issued)
0x01	Parameter value
0x65	Checksum (0xFF - SUM (all bytes after length))

Description

Setting **AO = 1** is required for the XBee3 Zigbee RF Module to use the [Explicit Rx Indicator frame - 0x91](#) when receiving RF data packets. This is required if the application needs indication of source or destination endpoint, cluster ID, or profile ID values used in received Zigbee data packets. ZDO messages can only be received if **AO = 1**.

Zigbee security

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Security overview

Zigbee security protects network traffic using 128-bit AES cryptography techniques. A standard security model is defined for supporting authentication and key management. Security is a very important factor in designing a mesh network. Digi makes it easy to find the right level of security for your specific application, ranging from a completely open and unencrypted network to a high security model with out-of-band device registration.



WARNING! The out-of-the-box default configuration is an unencrypted network with a generous join window. These defaults are meant for ease of development and should not be used on the finished product. Enabling security is highly recommended.

Enabling encryption also enables source routing with the coordinator acting as a high RAM concentrator by default. For smaller networks (less than 40 nodes) and low-throughput applications, this will not have a significant impact to the network, as source routing will automatically be handled by the XBee application. If you are deploying a larger network, you will likely require a full source routing implementation with the coordinator configured as a low RAM concentrator. For more information, see [Source routing](#).

Network key

The network key encrypts and decrypts over the air messages at the network layer. When you enable encryption, each node on the network is required to have the network key to communicate with other nodes. The network key is shared by every device on the network and only needs to be set on the network coordinator. Use the **NK** parameter to set a user-defined network key; this parameter is only applicable to a coordinator (**CE = 1**). In most situations, the network key should be randomly generated (**NK = 0**) and managed by the network.

If you are running a centralized trust center, you can change the **NK** parameter on the trust center which propagates to the rest of the network a few seconds later. This is useful for high-security applications where regular network key rotation may be desired. In a distributed trust center, the key is defined when the network is formed and cannot be changed without reforming the network.

Optionally, network keys can be sent and received in-the-clear by setting the **EO** bit 0 (**EO = 1**) on the forming and joining nodes. Digi strongly discourages this setting, because it could allow unauthorized devices to obtain a copy of the network key.

Link key

Link keys are used at the APS layer to provide an extra level of encryption for end-to-end security. The XBee3 Zigbee application uses global link keys for both joining and APS-encrypted transmissions. When joining a network with encryption enabled, the network key is securely exchanged by encrypting it with the link key.

When using a centralized trust center, the link key that is used to join is exchanged with a more secure key that is randomly generated by the trust center.

This section provides information about the types of link keys.

Preconfigured link key - moderate security

Using a preconfigured global link key provides a very simple way to secure a network, which is accomplished by configuring the same write-only **KY** value on every node on the network. Defining a

link key in this manner provides a moderate level of security while allowing for easy network deployment. The security configuration can be done during manufacturing rather than at deployment. If the joining node has a preconfigured link key that the trust center is not aware of, then it must be registered using an out-of-band method. Issue a 0x24 registration frame on the trust center, which contains the link key and serial number of the joining device.

Well-known default link key - low security

The Zigbee Alliance specifies a well-known default link key. You can use this link key to allow unsecured devices to easily join a secured network. By default, the XBee3 rejects any device that attempts to join using this well-known key. To allow these devices to join, set the **EO** bit 4 (**EO**=0x10) on the centralized trust center.

If a joining device has **KY** = **0** (default), it attempts to use the well-known default link key to join.

Install code derived link key - high security

Every device supporting Zigbee 3.0 is required to have an install code. Read the install code by querying the **I?** command, which consists of a 16-byte install code + 2 byte CRC. The install code must be read from the joining node and entered to the trust center through an out-of-band method. Typically, the user reads an install code from some type of display or application on the joining node. The user then provides the joiner's install code and serial number to the trust center using a locally issued 0x24 registration API frame and setting bit 0 of the options field.

Using install codes for generating link keys is the most secure method, because it allows users to clearly identify the joining node to the trust center, and it guarantees that each joining device has a random link key.

For a joining device to use an install code, **DC** bit 0 (**DC** = **1**) must be set on the joining device. This generates a link key based on the install code and the **KY** parameter will be ignored.

Join window

Zigbee imposes a limited window of time in which a network can permit joining. The maximum joining window time allowed by the Zigbee specifications is 254 seconds (**NJ** = **0xFE**). Whenever the join window opens, the **NJ** value of the device that opens the window is used. This timeout value is not shared by the rest of the network.

The following conditions cause the network join window to open for **NJ** seconds:

- A network is formed.
- A router joins the network. This uses the router's **NJ** value to open the window.
- The commissioning button is enabled (**DO** = **1**) and pressed twice on a router or coordinator on the network.
- A CB2 command is issued to a router or coordinator on the network.
- A device is successfully registered to the trust center via 0x24 API frame.

When the join window opens, the device sends a broadcast to the rest of the network. The joining device does not need to be adjacent to the device that opened the joining window.

If **NJ** is set to **0**, the join window remains closed unless explicitly opened via the commissioning button or **CB** command. In this scenario, the join window opens for a fixed period of 60 seconds when opened. For a highly-secured network, Digi recommends setting **NJ** to **0** on every device so the join window does not open inadvertently.



WARNING! An always-open join window is permitted (**NJ = 0xFF**), but this causes the network to operate outside of the Zigbee specifications. This option is provided for ease of development and should not be used on the finished product.

Key management

Zigbee defines two security models for key management: centralized security model and distributed security model.

Centralized security

A centralized trust center network is defined as a Zigbee network where one node acts as the centralized key authority. This centralized trust center defines the network key and manages its distribution, determines when and if nodes can join the network, and issues application link keys. Upon formation of the network, the network coordinator assumes the role of the trust center. The trust center has a reserved address of 0 on the network, and any traffic sent to this address is routed to the trust center.

When a node attempts to join, it first establishes a MAC association with a router on the network. The router sends a request to the trust center, indicating the node wants to join. The trust center decides if the node can join based on the current join policy (Open join window + **EO** options). If the trust center approves the attempt to join, the network key is encrypted using a trust center link key and sent to the joining node. The joining node must have a copy of the link key in order to decrypt the network key and successfully join the network.

If the joining node does not have a link key that matches the network or has an install code derived link key, then it must be registered to the trust center. Registration is the means by which a link key is given to the trust center using an out-of-band method. Registration requires the trust center operate in API mode (AP=1 or 2) and cannot be performed in Command or Transparent mode.

Distributed security

A distributed trust center does not have a node designated as a coordinator. All routers in the network have a copy of the network key and are able to authorize joining devices, meaning every router on the network is a trust center. The network key is set at the time the network is formed and cannot change. The network forms on the device that has **CE=1**, and there will be no coordinator on the network (the device forms the network as a router.) This means any traffic directed to a 0 address fails.

When a node joins a distributed trust center network, an adjacent router shares a copy of the network key to the joining device. The network key is protected by encrypting the exchange with the joining device with a global link key. The network key can optionally be sent in-the-clear by setting **EO** bit 1 on every device on the network. Digi strongly discourages this setting, because it allows unsecure devices access the network key.

You can perform device registration on a distributed trust center, but the 0x24 registration frame must be issued on a router that is adjacent to the joining device; registration information is not shared with the rest of the network.

Device registration

When a device attempts to joins a secure network, it must obtain a copy of the network key to successfully communicate.

You can send the network key in the clear, but in most situations it will be encrypted with a link key. If the link key is not preconfigured on both devices, the trust center must be told the link key the joining device will be using to join. We call this process "registration" and is the method by which a link key and serial number of the joining device is securely given to the trust center through the physical serial interface. Because the registration information is not provided over-the-air, this is considered out-of-band registration and provides the highest level of security since the credentials cannot be extracted through RF channels.

Registration is performed using a [Register Joining Device - 0x24](#) frame and is issued to the trust center (either centralized or distributed). The registration frame is used to register a link key, register an install code derived link key, or remove a previously registered device.

Centralized trust center

On a centralized trust center (**EO = 2**), registration is transient, meaning that the registered device will only be authorized to join for a fixed period of time. This period is separate from the network join window and is defined by the **KT** parameter on the centralized trust center. By default, a registered device is authorized to join for a period of five minutes. If the device fails to join within this period, it must be re-registered. After joining, it securely rejoins and does not need to be registered again unless the device is explicitly removed from the network using an **NR** command or leave request. The 0x24 registration frame must be issued to the centralized trust center in this scenario, and routers that are adjacent to the joining device route the join request to the trust center. The key table entries on a centralized trust center is stored in RAM and is not preserved across a power cycle.

Distributed trust center

On a distributed trust center (**EO = 0**), registration is persistent, meaning that the registered device will always be authorized to join as long as the join window is open. Registration information is not shared to the rest of the network, so the 0x24 registration frame must be issued to a router that is adjacent to the joining device. Because the link key table has a limited number of entries, you must explicitly remove key table entries by deregistering devices using a 0x24 frame after they successfully join to add subsequent devices. The key table on a distributed trust center is stored in flash and persists across a power cycle.

Once a device joins the network and obtains a copy of the network key, it retains information about the network and performs a secure rejoin, if power cycled. If you change a network parameter on the device, it receives a leave request or a secure rejoin fails after three tries. The device must join the network via association which requires registration.

Example: Forming a secure network

The following example show how to form a secure Zigbee 3.0 network. This is the recommended configuration for most networks, because it allows for ease of deployment while also maintaining a moderate level of security.

Configure an XBee3 device with the following parameters:

- **CE = 1**

This indicates that the device attempts to form a network rather than join an existing one.

- **EE = 1**

This enables encryption for the network.

- **EO = 2**
 - This forms the network as a centralized trust center. If you want a distributed trust center, set this parameter to 0.
 - Any joining device must have the same value set to properly handle any key exchanges that occur.
- **KY = non-zero**
 - This defines a preconfigured link key for the network.
 - This key can be configured on joining devices as a preconfigured global link key.
 - If joining devices do not use the preconfigured link key, they must be registered to the trust center before joining.
- **NK = 0**
 - Using a zero **NK** value is preferred, as the XBee will generate a random network key that cannot be read.
 - If acting as a centralized trust center, this parameter can be changed after network formation to update the network key for all devices on the network.
- **NJ < 0xFF**

This defines the amount of time you want to allow devices to join when the join window opens. You can modify this after the network forms.

If you want to increase the level of security for this network, set **KY = 0** on the forming node. This generates a random link key that cannot be read and requires every joining device to be individually registered. This configuration guarantees that only authorized devices can join the network, because the global link key is unclear and cannot be read.

Example: Join a secure network using a preconfigured link key

The following examples show you how join an existing network that has security enabled and the preconfigured link key configured on the network is known. Using this example, it is easy to deploy a secure network, because each device is preconfigured to join the network. An installer only needs to be concerned with opening the join window for new devices.

Configure a joining XBee3 device with the following parameters:

- **EE = 1**

The joining node must have the same encryption settings as the network it will be joining.
- **EO = 2**
 - If joining a centralized trust center, **EO** bit 1 must be set so the joining device is aware that a link key exchange is needed.
 - If joining a distributed trust center, clear **EO** bit 1.
- **KY = KY from trust center**

Because the **KY** value is known, it should be preconfigured on the joining device. Provided the **KY** values match, it will be able to obtain the network key and join.

- **NJ < 0xFF**

Consider the join time that is configured on joining devices. If the device successfully joins the network as a router (**SM = 0**), it immediately opens the join window for **NJ** seconds, effectively

refreshing the window. If you do not wish to reopen the join window in this manner, set **NJ = 0** on all joining devices.

To join the device to the network, write the previous configuration to flash with a **WR** command, and bring it within RF range of the network.

To open the join window, press the commissioning button twice on a network router or the trust center. If the pushbutton is not available, you can issue a **CB2** command.

Joining devices continuously attempt to join a network (unless explicitly told not to via a **DJ = 0** command). However, if you want to have the module immediately attempt to join, press the commissioning button once, or issue a **CB1** command on the joining node.

Example: Register a joining node without a preconfigured link key

Using the previous example for joining a network, if the joining node is not aware of the link key on the trust center (that is, it is either obscured (**KY = 0**) or otherwise unknown to the joining device) then it must be registered to the trust center.

Configure a joining XBee3 device with the following parameters:

- **EE = 1**

The joining node must have the same encryption settings as the network it will be joining.

- **EO = 2**

- If joining a centralized trust center, **EO** bit 1 must be set so the joining device is aware that a link key exchange is needed.
- If joining a distributed trust center, clear **EO** bit 1.

- **KY = non-zero value**

Configure a known link key value for this particular joining device. This value must be known by the installer, because it must be passed to the trust center out-of-band.

On the trust center, you must register this device using an API frame. Generate a 0x24 frame that contains the following information:

- The link key (**KY**) of the joining device.
- The serial number of the joining device.

Link Key registration example

A device with the serial number **0013A200 12345678** that has a **KY** of **12345** is trying to join a secure network.

The following 0x24 frame is generated and passed into the UART of the trust center:

```
7E 00 10 24 7B 00 13 A2 00 12 34 56 78 FF FE 00 01 23 45 31
```

The trust center will respond with the following 0xA4 registration response frame:

```
7E 00 03 A4 7B 00 E0
```

Note The Frame ID (0x7B) in the response corresponds with the Frame ID of the registration attempt. A 00 result indicates that the key was successfully registered.

When the registration succeeds, the join window automatically opens for **NJ** seconds (or 60 seconds if **NJ = 0**).

If the trust center is centralized, this registered key table entry is transient and expires after **KT** seconds. In a distributed trust center, it persists until it is explicitly cleared.

Example: Register a joining node using an install code

To provide the highest level of security, Digi recommends using install codes to register devices. Install codes are randomly assigned to each Zigbee 3.0 device at the factory for the purpose of securely joining a network. The process to register a device using an install code is similar to registering a link key, but with some additional steps:

Configure a joining XBee3 device with the following parameters:

- **EE = 1**

The joining node must have the same encryption settings as the network it is joining.

- **EO = 2**

- If joining a centralized trust center, **EO** bit 1 must be set so the joining device is aware a link key exchange is needed.
- If joining a distributed trust center, clear **EO** bit 1.

- **DC = 1**

This tells the joining device to generate a link key from the install code of the device. If this bit is enabled, then the device ignores and does not use the **KY** parameter.

On the trust center, you must register this device using an API frame. Generate a 0x24 frame that contains the following information:

- The install code (**I?**) of the joining device.
- The serial number of the joining device.

Link key registration example

A device with the serial number **0013A200 12345678** that has a **I?** value of **F6F1913D834A08D6ADAF1F91BAF4052D7316** is trying to join a secure network.

The following 0x24 frame is generated and passed into the UART of the trust center. Set the options field of the API frame to 01 to indicate that the supplied key is actually an install code:

```
7E 00 1F 24 D5 00 13 A2 00 12 34 56 78 FF FE 01 F6 F1 91 3D 83 4A 08 D6 AD AF 1F 91 BA
F4 05 2D 73 16 6A
```

The trust center will respond with the following 0xA4 registration response frame:

```
7E 00 03 A4 D5 00 86
```

Note The Frame ID (0xD5) in the response corresponds with the Frame ID of the registration attempt. A 00 result indicates that the key was successfully registered.

When the registration succeeds, the join window automatically opens for **NJ** seconds (or 60 seconds if **NJ=0**).

If the trust center is centralized, this registered key table entry is transient and expires after **KT** seconds. In a distributed trust center, it persists until explicitly cleared.

Example: Deregister a previously registered device

This feature is only needed in a distributed trust center, because the key table entries are persistent and stored in flash. In a distributed trust center, there are only a limited number of entries available, proper management of the key table is required if more than 10 devices will be joining using registration.

To deregister a device, issue a 0x24 registration frame on the trust center with the serial number of the registered device and a null (blank) key.

Link key registration example

A device with the serial number **0013A200 12345678** that was previously registered has successfully joined the network, and needs to be deregistered to make room for subsequently joining devices.

The following 0x24 frame is generated and passed into the UART of the trust center. Note, that there is no key field, indicating that the key entry should be removed:

```
7E 00 0D 24 C4 00 13 A2 00 12 34 56 78 FF FE 00 51
```

The trust center will respond with the following 0xA4 registration response frame:

```
7E 00 03 A4 C4 00 86
```

Note The Frame ID (0xC4) in the response corresponds with the Frame ID of the registration attempt. A 00 result indicates that the key was successfully removed from the table.

Registration scenario

It is possible to combine some of the previously mentioned security features to maintain a high level of security with simplified deployment, while also providing a means for authorized devices to securely join via registration.

For example, an established Zigbee network with a centralized trust center is exhibiting some issues that require analysis by a network engineer. Due to the nature of the deployment, the end user does not want to disclose any of the security credentials to the contracted network engineer.

To allow the network engineer onto the network, the end user must be authorized to join via registration. The network administrator sets the **KT** parameter on the centralized trust center to 0x7080, which sets the registration timeout to 8 hours. Because the network engineer is not yet on-site, the **NJ** parameter is set to 0xFF to allow open joining.

A 0x24 frame is issued to the trust center that contains the serial number of the network engineer's device and a one-time-use link key. The network engineer can then use this link key to join the network and perform whatever work is necessary.

After the analysis has been performed and the network engineer has left the site, the network administrator closes the join window by setting **NJ** to **0**. Additionally, the network key (**NK**) on the trust center is updated, which then propagates to the rest of the network, further securing the network. Deregistration is not needed, because this is a centralized trust center. The temporary link key expires after **KT** seconds.

Network commissioning and diagnostics

We call the process of discovering and configuring devices in a network for operation, "network commissioning." Devices include several device discovery and configuration features. In addition to configuring devices, you must develop a strategy to place devices to ensure reliable routes. To accommodate these requirements, modules include features to aid in placing devices, configuring devices, and network diagnostics.

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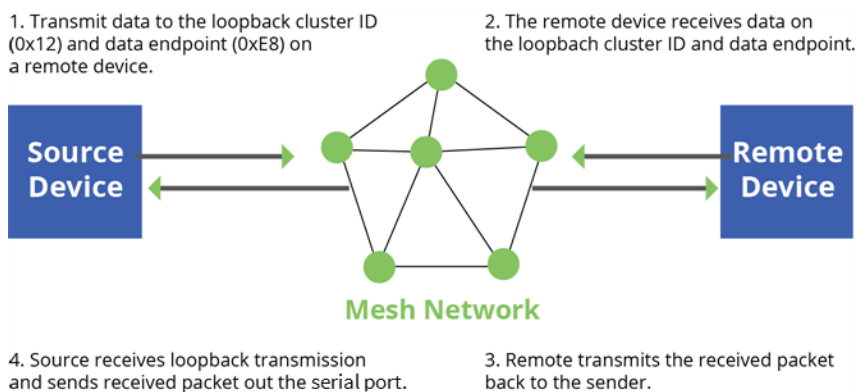
Place devices

For a network installation to be successful, installers must be able to determine where to place individual XBee devices to establish reliable links throughout the network.

Test links in a network - loopback cluster

To measure the performance of a network, you can send unicast data through the network from one device to another to determine the success rate of several transmissions. To simplify link testing, the devices support a Loopback cluster ID (0x12) on the data endpoint (0xE8). The cluster ID on the data endpoint sends any data transmitted to it back to the sender.

The following figure demonstrates how you can use the Loopback cluster ID and data endpoint to measure the link quality in a mesh network.



The configuration steps for sending data to the loopback cluster ID depend on what mode the device is in. For details on setting the mode, see [AP \(API Enable\)](#). The following sections list the steps based on the device's mode.

Transparent operating mode configuration (AP = 0)

To send data to the loopback cluster ID on the data endpoint of a remote device:

1. Set the **CI** command to **0x12**.
2. Set the **SE** and **DE** commands to **0xE8** (default value).
3. Set the **DH** and **DL** commands to the address of the remote (**0** for the coordinator, or the 64-bit address of the remote).

After exiting Command mode, the device transmits any serial characters it received to the remote device, which returns those characters to the sending device.

API operating mode configuration (AP = 1 or AP = 2)

Send an [Explicit Addressing Command frame - 0x11](#) using **0x12** as the cluster ID and **0xE8** as both the source and destination endpoint.

The remote device echoes back the data packets it receives to the sending device.

RSSI indicators

It is possible to measure the received signal strength on a device using the **DB** command. **DB** returns the RSSI value (measured in -dBm) of the last received packet. However, this number can be

misleading in Zigbee networks. The **DB** value only indicates the received signal strength of the last hop. If a transmission spans multiple hops, the **DB** value provides no indication of the overall transmission path, or the quality of the worst link; it only indicates the quality of the last link.

Determine the **DB** value in hardware using the RSSI/PWM device pin (Micro pin 7/SMT pin 7/TH pin 6). If you enable the RSSI PWM functionality (**P0** command), when the device receives data, it sets the RSSI PWM to a value based on the RSSI of the received packet (this value only indicates the quality of the last hop). You could connect this pin to an LED to indicate if the link is stable or not.

Device discovery

Network discovery

Use the network discovery command to discover all devices that have joined a network. Issuing the **ND** command sends a broadcast network discovery command throughout the network. All devices that receive the command send a response that includes:

- Device addressing information
- Node identifier string (see [NI \(Node Identifier\)](#))
- Other relevant information

You can use this command for generating a list of all module addresses in a network.

ZDO discovery

The Zigbee device profile includes provisions to discover devices in a network that are supported on all Zigbee devices (including non-Digi products). These include the LQI Request (cluster ID 0x0031) and the Network Update Request (cluster ID 0x0038). You can use the LQI Request to read the devices in the neighbor table of a remote device, and the Network Update Request for a remote device to complete an active scan to discover all nearby Zigbee devices. You can send both of these ZDO commands using the [Explicit Addressing Command frame - 0x11](#). For more information, see [API Operation](#). Refer to the Zigbee specification for formatting details of these two ZDO frames.

Joining Announce

All Zigbee devices send a ZDO Device Announce broadcast transmission when they join a Zigbee network (ZDO cluster ID 0x0013). These frames are sent out the device's serial port as an [Explicit Rx Indicator frame - 0x91](#) if **AO** is set to **1**. The device announce payload includes the following information:

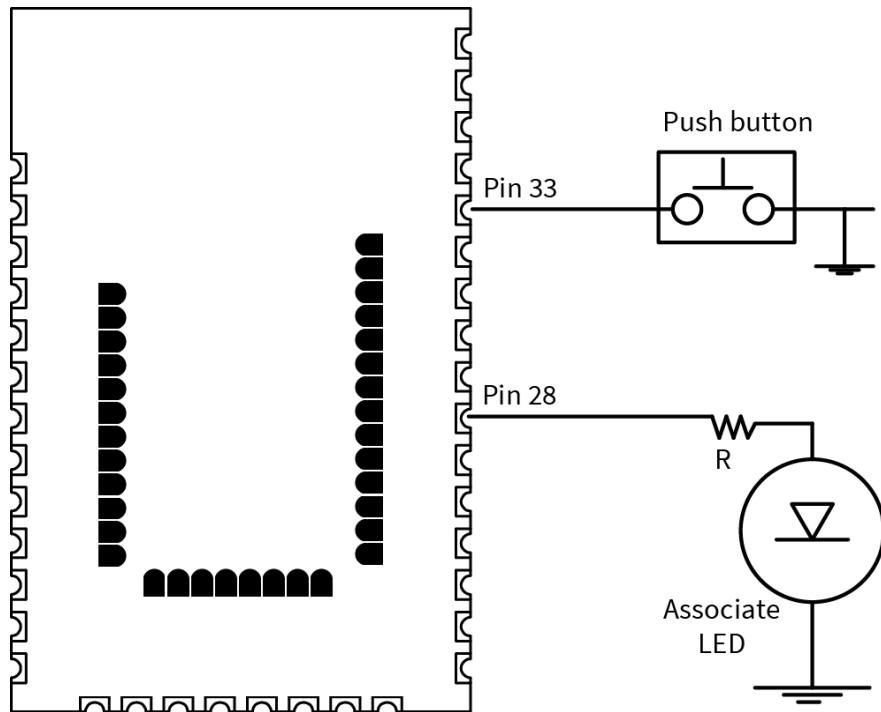
[Sequence Number] + [16-bit address] + [64-bit address] + [Capability]

The 16-bit and 64-bit addresses are received in little-endian byte order (LSB first). See the Zigbee specification for details.

Commissioning pushbutton and associate LED

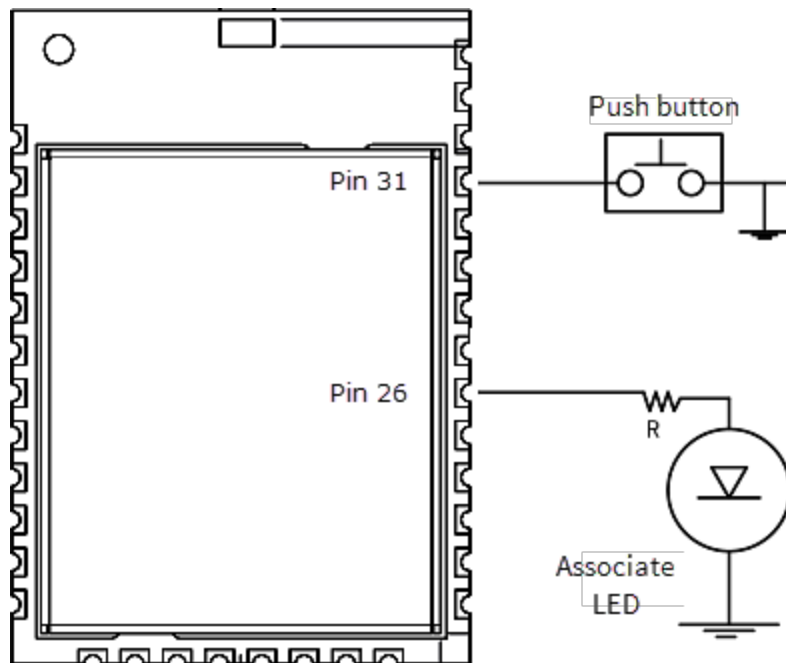
XBee devices support a set of commissioning pushbutton and LED behaviors to aid in device deployment and commissioning. These include the commissioning push button definitions and associate LED behaviors. The following features can be supported in hardware:

XBee3 SMT



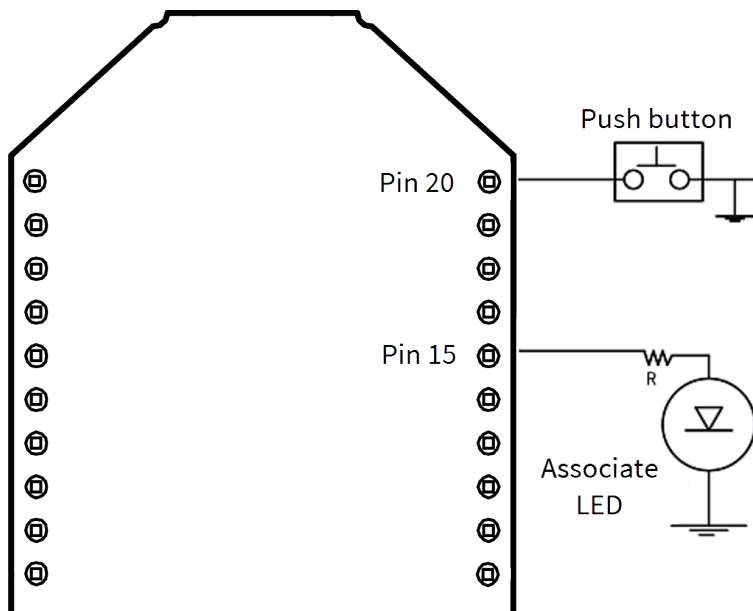
A pushbutton and an LED can be connected to the surface-mount device to support the commissioning pushbutton and associate LED functionalities.

XBee3 Micro



A pushbutton and an LED can be connected to the Micro device to support the commissioning pushbutton and associate LED functionalities.

XBee3 Through-hole



A pushbutton and an LED can be connected to the through-hole-mount device to support the commissioning pushbutton and associate LED functionalities.

Commissioning pushbutton

The commissioning pushbutton definitions provide a variety of simple functions to help with deploying devices in a network. Enable the commissioning button functionality by setting [D0 \(DIO0/AD0/Commissioning Button Configuration\)](#) to **1** (enabled by default).

Button presses	Description
1	Start Joining. Wakes a sleeping end device for 30 seconds, regardless of the ST/SN setting. It also sends node identification broadcast if joined to a network. A Zigbee device blinks a numeric error code on the Associate pin indicating the cause of join failure for (AI - 32) times. A SE router or SE end device which is associated but not authenticated to a network leaves its network; then attempt to join.
2	Enable Joining. Broadcast a Mgmt_Permit_Joining_req (ZDO ClusterID 0x0036) with TC_Significance set to 0x00 . If NJ is 0x00 or 0xFF , PermitDuration is set to one minute, otherwise PermitDuration is set to NJ .
4	Restore configuration to default values and leave the network. Equivalent to issuing NR , RE , and AC commands.

Use **CB** (Commissioning Pushbutton) to simulate button presses in software. Issue a **CB** command with a parameter set to the number of button presses you want executed. For example, sending **CB1** executes the actions associated with a single button press.

The node identification frame is similar to the node discovery response frame; it contains the device's address, node identifier string (**NI** command), and other relevant data. All API devices that receive the node identification frame send it out their serial interface as a **Node Identification Indicator frame - 0x95**.

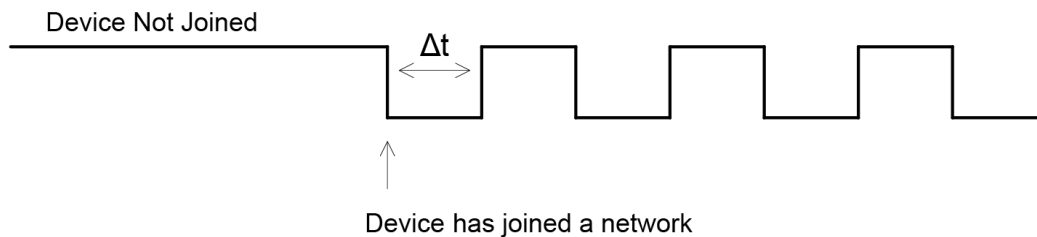
Associate LED

The Associate pin provides an indication of the device's network status and diagnostics information. Connect an LED to the Associate pin as shown in the figure in [Commissioning pushbutton and associate LED](#). Enable the Associate LED functionality the **D5** command to 1 (enabled by default). If the Associate pin is enabled, it configured as an output.

Joined indication

The Associate pin indicates the network status of a device. If the device is not joined to a network, the Associate pin is set high. Once the device successfully joins a network, the Associate pin blinks at a regular time interval. The following figure shows the joined status of a device.

Associate



The associate pin can indicate the joined status of a device. Once the device has joined a network, the associate pin toggles state at a regular interval (Δt). Use the **LT** command to set the time.

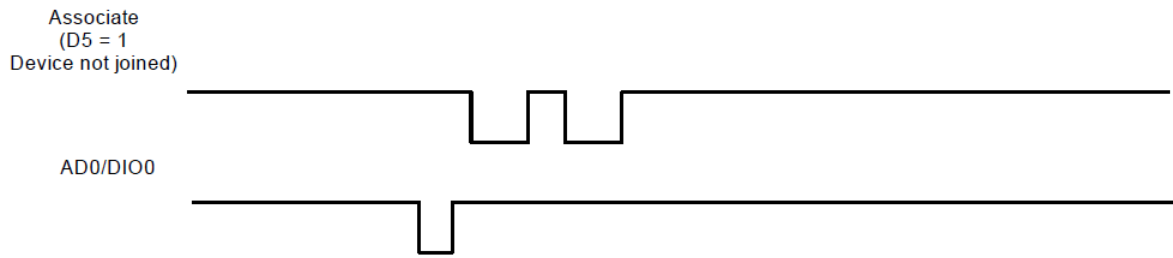
The **LT** command defines the blink time of the Associate pin. If it is set to **0**, the device uses the default blink time (500 ms for coordinator, 250 ms for routers and end devices).

Diagnostics support

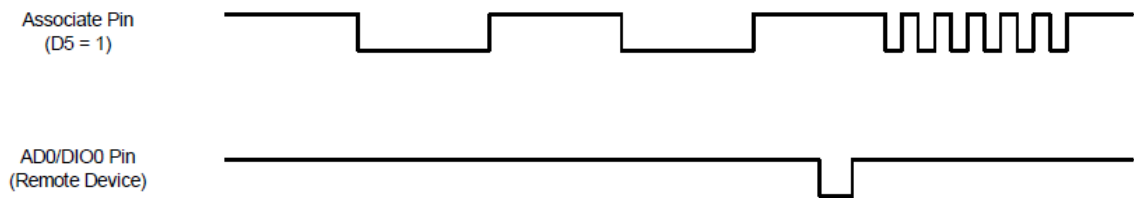
The Associate pin works with the commissioning pushbutton to provide additional diagnostics behaviors to aid in deploying and testing a network. If the commissioning push button is pressed once, and the device has not joined a network, the Associate pin blinks a numeric error code to indicate the cause of join failure. The number of blinks is equal to (**AI** value - 0x20). For example, if **AI** = **0x22**, two blinks occur.

If the commissioning push button is pressed once and the device has joined a network, the device transmits a broadcast node identification packet. If the Associate LED functionality is enabled (**D5** command), a device that receives this transmission will blink its Associate pin rapidly for 1 second.

The following image illustrates the behavior pressing the commissioning button press once when the device has not joined a network, causing the associate pin to blink to indicate the **AI** Code where: **AI** = # blinks + 0x20. In this example, **AI** = **0x22**.



The following image illustrates the behavior pressing the button once on a remote device, causing a broadcast node identification transmission to be sent. All devices that receive this transmission blink their associate pin rapidly for one second if the associate LED functionality is enabled (**D5 = 1**).



Binding

The Digi XBee firmware supports three binding request messages:

- End Device Bind
- Bind
- Unbind

End_Device_Bind_req

The End Device Bind request (ZDO cluster 0x0020) is described in the Zigbee Specification.

During a deployment, an installer may need to bind a switch to a light. After pressing a commissioning button sequence on each device, this causes them to send End_Device_Bind_req messages to the Coordinator within a time window (60 s). The payload of each message is a simple descriptor which lists input and output clusterIDs. The Coordinator matches the requests by pairing complementary clusterIDs. After a match has been made, it sends messages to bind the devices together. When the process is over, both devices will have entries in their binding tables which support indirect addressing of messages between their bound endpoints.

R1->C End_Device_Bind_req

R2->C End_Device_Bind_req

R1, R2 send End_Device_Bind_req within 60 s of each other to C

C matches the requests.

C tests one to see if binding is already in place:

R2<-C Unbind_req

R2->C Unbind-rsp (status code - NO_ENTRY)

C proceeds to create binding table entries on the two devices.

R1<-C Bind_req

R1->C Bind_rsp
 R2-<-C Bind_req
 R2->C Bind_rsp
 C sends responses to the original End_Device_Bind_req messages.
 R1-<-C End_Device_Bind_rsp
 R2-<-C End_Device_Bind_rsp

End Device binding sequence (binding)

This message has a toggle action. If the same two devices were to subsequently send End_Device_Bind_req messages to the Coordinator, the Coordinator would detect they were already bound, and then send Unbind_req messages to remove the binding.

An installer can use this to remove a binding which was made incorrectly, say from a switch to the wrong lamp, by repeating the commissioning button sequence used beforehand.

R1->C End_Device_Bind_req
 R2->C End_Device_Bind_req
 R1, R2 send End_Device_Bind_req within 60 s of each other to C
 C matches the requests.
 C tests one to see if binding is already in place:
 R2-<-C Unbind_req
 R2->C Unbind_rsp (status code - SUCCESS)
 C proceeds to remove binding table entries from the two devices.
 R1-<-C Unbind_req
 R1->C Unbind_rsp
 R2-<-C Unbind_req
 R2->C Unbind_rsp
 C sends responses to the original End_Device_Bind_req messages.
 R1-<-C End_Device_Bind_rsp
 R2-<-C End_Device_Bind_rsp

End Device binding sequence (removal)

This example shows a correctly formatted End_Device_Bind_req (ZDO cluster 0x0020) using a Digi 0x11 Explicit API Frame:

The frame as a bytelist:

7e002811010000000000000000fffe000000200000000001f2995cb5474000a21300e605c101010001020046

Same frame broken into labeled fields.

Note Multibyte fields are represented in big-endian format.

7e	Frame Delimiter
0028	Frame Length

11	API Frame Type (Explicit Frame)
01	Frame Identifier (for response matching)
0000000000000000	Coordinator address
fffe	Code for unknown network address
00	Source Endpoint (need not be 0x00)
00	Destination Endpoint (ZDO endpoint)
0020	Cluster 0x0020 (End_Device_Bind_req)
0000	ProfileID (ZDO)
00	Radius (default, maximum hops)
00	Transmit Options
01f2995cb5474000a21300e605c1010100010200	RFData (ZDO payload)
46	Checksum

Here is the RFData (the ZDO payload) broken into labeled fields. Note the multi-byte fields of a ZDO payload are represented in little-endian format.

01	Transaction Sequence Number
f299	Binding Target (16 bit network address of sending device)
5cb5474000a21300	(64 bit address of sending device)
e6	Source Endpoint on sending device
05c1	ProfileID (0xC105) - used when matching End_Device_Bind_requests
01	Number of input clusters
0100	Input cluster ID list (0x0100)
01	Number of output clusters
0200	Output cluster ID list (0x0200)

Example of a End_Device_Bind_req

Bind_req

The Bind request (ZDO cluster 0x0021) is described in the Zigbee Specification. A binding may be coded for either a unicast or a multicast/groupID message.

Unbind_req

The Unbind request (ZDO cluster 0x0022) is described in the Zigbee Specification.

Group Table API

Unlike the Binding Table that is managed with ZDO commands, a Zigbee group table is managed by the Zigbee cluster library Groups Cluster (0x0006) with ZCL commands.

The Digi Zigbee XBee firmware is intended to work with an external processor where a Public Application Profile with endpoints and clusters is implemented, including a Groups Cluster. Configure the Zigbee XBee firmware to forward all ZCL commands addressed to this Group Cluster out the UART (see ATA03). The XBee Zigbee will not use remote Groups Cluster commands to manage its own Group Table.

But to implement multicast (group) addressing within the XBee, the external processor must keep the XBee device's group table state in sync with its own. For this reason, a Group Table API has been defined where the external processor can manage the state of the XBee3 Zigbee RF Module group table.

The design of the Group Table API of the XBee firmware derives from the ZCL Group Cluster 0x0006. Use the [Explicit Addressing Command frame - 0x11](#) addressed to the Digi Device Object endpoint (0xE6) with the Digi XBee ProfileID (0xC105) to send commands and requests to the local device.

The Zigbee home automation public application profile says groups should only be used for sets of more than five devices. This implies sets of five or fewer devices should be managed with multiple binding table entries.

There are five commands implemented in the API:

- [Add Group command](#)
- [View group](#)
-
- [Remove Group](#)
- [Remove All Groups](#)

There is a sixth command of the Group Cluster described in the ZCL: Add Group If Identifying. This command is not supported in this API, because its implementation requires access to the Identify Cluster, which is not maintained on the XBee. The external processor needs to implement that server command while using the Group Table API to keep the XBee device's group table in sync using the five command primitives.

Add Group command

The purpose of the Add Group command is to add a group table entry to associate an active endpoint with a groupID and optionally a groupName. The groupID is a two byte value. The groupName consists of zero to 16 ASCII characters.

The following example adds a group table entry which associates endpoint E7 with groupID 1234 and groupName "ABCD".

The example packet is given in three parts, the preamble, ZCL Header, and ZCL payload:

Preamble = "11 01 "+LocalDevice64Addr+"FFFE E6 E7 0006 C105 00 00"

The packet is addressed to the local node, using a source endpoint of 0xE6, clusterID of 0x0006, and profileID of 0xC105. The destination endpoint E7 holds the endpoint parameter for the "Add Group" command.

ZCL_header = "01 ee 00"

The first field (byte) is a frame control field which specifies a Cluster Specific command (0x01) using a Client->Server direction(0x00). The second field is a transaction sequence number used to associate the response with the command request. The third field is the command identifier for "Add Group" (0x00).

```
ZCL_payload = "3412 04 41 42 43 44"
```

The first two bytes is the group Id to add in little endian representation. The next byte is the string name length (00 if there is no string). The other bytes are the descriptive ASCII string name ("ABCD") for the group table entry. The string is represented with its length in the first byte, and the other bytes containing the ASCII characters.

The example packet in raw hex byte form:

```
7e001e11010013a2004047b55cffffe6e70006c105000001ee0034120441424344c7
```

The response in raw hex byte form, consisting of two packets:

```
7e0018910013a2004047b55cffffe7e68006c1050009ee0000341238
```

```
7e00078b01fffe00000076
```

The response in decoded form:

```
Zigbee Explicit Rx Indicator
```

```
API 0x91 64DestAddr 0x0013A2004047B55C 16DestAddr 0xFFFFE SrcEP 0xE7 DestEP 0xE6
```

```
ClusterID 0x8006 ProfileID 0xC105 Options 0x00
```

```
RF_Data 0x09EE00003412
```

The response in terms of Preamble, ZCL Header, and ZCL payload:

```
Preamble = "910013a2004047b55cffffe7e68006c10500"
```

The packet has its endpoint values reversed from the request, and the clusterID is 0x8006 indicating a Group cluster response.

```
ZCL_header = "09 ee 00"
```

The first field is a frame control field which specifies a Cluster Specific command (0x01) using a Server->Client direction. The second field is a transaction sequence number used to associate the response with the command request. The third field is the command identifier "Add Group" (0x00).

```
ZCL_payload = "00 3412"
```

The first byte is a status byte (SUCCESS=0x00). The next two bytes hold the group ID (0x1234) in little endian form.

This is the decoded second message, which is a Tx Status for the original command request. If the Frameld value in the original command request had been zero, or if no space was available in the transmit UART buffer, then no Tx Status message occurs.

```
Zigbee Tx Status
```

```
API 0x8B FrameID 0x01 16DestAddr 0xFFFFE
```

```
Transmit Retries 0x00 Delivery Status 0x00 Discovery Status 0x00 Success
```

View group

The purpose of the View Group command is to get the name string which is associated with a particular endpoint and groupID.

The following example gets the name string associated with the endpoint E7 and groupID 1234.

The packet:

```
Preamble = "11 01 "+LocalDevice64Addr+"FFFFE E6 E7 0006 C105 00 00"
```

The packet is addressed to the local node, using a source endpoint of 0xE6, clusterID of 0x0006, and profileID of 0xC105. The destination endpoint E7 is the endpoint parameter for the "View Group" command.

```
ZCL_header = "01 ee 01"
```

The first field is a frame control field which specifies a Cluster Specific command (0x01) using a Client->Server direction(0x00). The second field is a transaction sequence number which is used to associate the response with the command request. The third field is the command identifier “View Group” (0x01) .

```
ZCL_payload = "3412"
```

The two byte value is the groupID in little-endian representation.

The packet in raw hex byte form:

```
7e001911010013a2004047b55cffffee6e70006c105000001ee013412d4
```

The response in raw hex byte form, consisting of two packets:

```
7e001d910013a2004047b55cffffee7e68006c1050009ee01003412044142434424
7e00078b01ffffe00000076
```

The command response in decoded form:

```
Zigbee Explicit Rx Indicator
API 0x91 64DestAddr 0x0013A2004047B55C 16DestAddr 0xFFFE SrcEP 0xE7 DestEP 0xE6
ClusterID 0x8006 ProfileID 0xC105 Options 0x00
RF_Data 0x09EE010034120441424344
```

The response in terms of Preamble, ZCL Header, and ZCL payload:

```
Preamble = "910013a2004047b55cffffee7e68006c10500"
```

The packet has its endpoint values reversed from the request, and the clusterID is 0x8006 indicating a Group cluster response.

```
ZCL_header = "09 ee 01"
```

The first field is a frame control field which specifies a Cluster Specific command (0x01) using a Server->Client direction (0x08). The second field is a transaction sequence number which associates the response with the command request. The third field is the command identifier “View Group” (0x01) .

```
ZCL_payload = "00 3412 0441424344"
```

The first byte is a status byte (SUCCESS=0x00). The next two bytes hold the groupID (0x1234) in little-endian form. The next byte is the name string length (0x04). The remaining bytes are the ASCII name string characters (“ABCD”).

The following is the decoded second message, which is a Tx Status for the original command request. If the Frameld value in the original command request had been zero, or if no space was available in the transmit UART buffer, then no Tx Status message would occur.

```
Zigbee Tx Status
API 0x8B FrameID 0x01 16DestAddr 0xFF
Transmit Retries 0x00 Delivery Status 0x00 Discovery Status 0x00 Success
```

Get Group Membership (1 of 2)

The purpose of this first form of the Get Group Membership command is to get all the groupIDs associated with a particular endpoint.

The intent of the example is to get all the groupIDs associated with endpoint E7.

The example packet is given in three parts, the preamble, ZCL Header, and ZCL payload:

```
Preamble = "11 01 "+LocalDevice64Addr+"FFFE E6 E7 0006 C105 00 00"
```

The packet is addressed to the local node, using a source endpoint of 0xE6, clusterID of 0x0006, and profileID of 0xC105. The destination endpoint E7 holds the endpoint parameter for the "Get Group Membership" command.

```
ZCL_header = "01 ee 02"
```

The first field (byte) is a frame control field which specifies a Cluster Specific command (0x02) using a Client->Server direction(0x00). The second field is a transaction sequence number which is used to associate the response with the command request. The third field is the command identifier for "Get Group Membership" (0x02).

```
ZCL_payload = "00"
```

The first byte is the group count. If it is zero, then all groupIDs with an endpoint value which matches the given endpoint parameter will be returned in the response.

The example packet in raw hex byte form:

```
7e001811010013a2004047b55cffffee6e70006c105000001ee020019
```

The response in raw hex byte form, consisting of two packets:

```
7e0019910013a2004047b55cffffee7e68006c1050009ee02ff01341235
```

```
7e00078b01ffffe00000076
```

The response in decoded form:

```
Zigbee Explicit Rx Indicator
API 0x91 64DestAddr 0x0013A2004047B55C 16DestAddr 0xFFFE SrcEP 0xE7 DestEP 0xE6
ClusterID 0x8006 ProfileID 0xC105 Options 0x00
RF_Data 0x09EE02FF013412
```

The response in terms of Preamble, ZCL Header, and ZCL Payload:

```
Preamble = "910013a2004047b55cffffee7e68006c10500"
```

The packet has the endpoints reversed from the request, and the clusterID is 0x8006 indicating a Group cluster response.

```
ZCL_header = "09 ee 02"
```

The first field is a frame control field which specifies a Cluster Specific command (0x01) using a Server->Client direction (0x08). The second field is a transaction sequence number which is used to associate the response with the command request. The third field is the command identifier "Get Group Membership" (0x02).

```
ZCL_payload = "FF 01 3412"
```

The first byte is the remaining capacity of the group table. 0xFF means unknown. The XBee returns this value because the capacity of the group table is dependent on the remaining capacity of the binding table, thus the capacity of the group table is unknown. The second byte is the group count (0x01). The remaining bytes are the groupIDs in little-endian representation.

The following is the decoded second message, which is a Tx Status for the original command request. If the Frameld value in the original command request had been zero, or if no space was available in the transmit UART buffer, then no Tx Status message would occur.

```
Zigbee Tx Status
API 0x8B FrameID 0x01 16DestAddr 0xFFFE
Transmit Retries 0x00 Delivery Status 0x00 Discovery Status 0x00 Success
```

Get Group Membership (2 of 2)

The purpose of this second form of the Get Group Membership command is to get the set of groupIDs associated with a particular endpoint which are a subset of a list of given groupIDs.

The following example gets the groupIDs associated with endpoint E7 which are a subset of a given list of groupIDs (0x1234, 0x5678).

The example packet is given in three parts, the preamble, ZCL Header, and ZCL payload:

```
Preamble = "11 01 "+LocalDevice64Addr+"FFFE E6 E7 0006 C105 00 00"
```

The packet is addressed to the local node, using a source endpoint of 0xE6, clusterID of 0x0006, and profileID of 0xC105. The destination endpoint E7 is the endpoint parameter for the "Get Group Membership" command.

```
ZCL_header = "01 ee 02"
```

The first field (byte) is a frame control field which specifies a Cluster Specific command (0x02) using a Client->Server direction(0x00). The second field is a transaction sequence number which is used to associate the response with the command request. The third field is the command identifier for "Get Group Membership" (0x02) .

```
ZCL_payload = "02 34127856"
```

The first byte is the group count. The remaining bytes are a groupIDs which use little-endian representation.

The example packet in raw hex byte form:

```
7e001c11010013a2004047b55cfffefee6e70006c105000001ee02023412785603
```

The response in raw hex byte form, consisting of two packets:

```
7e0019910013a2004047b55cfffefee7e68006c1050009ee02ff01341235
7e00078b01ffffe00000076
```

The response in decoded form:

```
Zigbee Explicit Rx Indicator
```

```
API 0x91 64DestAddr 0x0013A2004047B55C 16DestAddr 0xFFFE SrcEP 0xE7 DestEP
0xE6
ClusterID 0x8006 ProfileID 0xC105 Options 0x00
RF_Data 0x09EE02FF013412
```

The response in terms of Preamble, ZCL Header, and ZCL Payload:

```
Preamble = "910013a2004047b55cfffefee7e68006c10500"
```

The packet has the endpoints reversed from the request, the clusterID is 0x8006 indicating a Group cluster response.

```
ZCL_header = "09 ee 02"
```

The first field is a frame control field which specifies a Cluster Specific command (0x01) using a Server->Client direction (0x08). The second field is a transaction sequence number which is used to associate the response with the command request. The third field is the command identifier “Get Group Membership” (0x02) .

```
ZCL_payload = "FF 01 3412"
```

The first byte is the remaining capacity of the group table. 0xFF means unknown. The XBee returns this value because the capacity of the group table is dependent on the remaining capacity of the binding table, thus the capacity of the group table is unknown. The second byte is the group count (0x01). The remaining bytes are the groupIDs in little-endian representation.

The following is the decoded second message, which is a Tx Status for the original command request. If the FrameID value in the original command request had been zero, or if no space was available in the transmit UART buffer, then no Tx Status message occurs.

```
Zigbee Tx Status
API 0x8B      FrameID 0x01    16DestAddr 0xFFFE
Transmit Retries 0x00 Delivery Status 0x00 Discovery Status 0x00 Success
```

Remove Group

The purpose of the Remote Group command is to remove a Group Table entry which associates a given endpoint with a given groupID.

The intent of the example is to remove the association of groupID [TBD] with endpoint E7.

The example packet is given in three parts: the preamble, ZCL Header, and ZCL payload.

```
Preamble = "11 01 "+LocalDevice64Addr+"FFFE E6 E7 0006 C105 00 00"
```

The packet is addressed to the local node, using a source endpoint of 0xE6, clusterID of 0x0006, and profileID of 0xC105. The destination endpoint E7 is the endpoint parameter for the “Remove Group” command.

```
ZCL_header = "01 ee 03"
```

The first field is a frame control field which specifies a Cluster Specific command (0x01) using a Client->Server direction(0x00). The second field is a transaction sequence number which is used to associate the response with the command request. The third field is the command identifier “Remove Group” (0x03) .

```
ZCL_payload = "3412"
```

The two bytes value is the groupID to be removed in little-endian representation.

The packet in raw hex byte form:

```
7e001911010013a2004047b55cffffee6e70006c105000001ee033412d2
```

The response in raw hex byte form, consisting of two packets:

```
7e0018910013a2004047b55cffffee7e68006c1050009ee0300341235
7e00078b01ffffe00000076
```

The command response in decoded form:

```
Zigbee Explicit Rx Indicator
API 0x91 64DestAddr 0x0013A2004047B55C 16DestAddr 0xFFFE      SrcE 0xE DestEP 0xE6
```

```
ClusterID 0x8006 ProfileID 0xC105 Options 0x00
RF_Data 0x09EE03003412
```

The response in terms of Preamble, ZCL Header, and ZCL payload:

```
Preamble = "910013a2004047b55cfffee7e68006c10500"
```

The packet has its endpoint values reversed from the request, and the clusterID is 0x8006 indicating a Group cluster response.

```
ZCL_header = "09 ee 03"
```

The first field is a frame control field which specifies a Cluster Specific command (0x01) using a Server->Client direction (0x08). The second field is a transaction sequence number which is used to associate the response with the command request. The third field is the command identifier "Remove Group" (0x03).

```
ZCL_payload = "00 3412"
```

The first byte is a status byte (SUCCESS=0x00). The next two bytes is the groupID (0x1234) value in little-endian form.

The following is the decoded second message, which is a Tx Status for the original command request. If the FrameID value in the original command request had been zero, or if no space was available in the transmit UART buffer, then no Tx Status message would occur.

```
Zigbee Tx Status
API 0x8B FrameID 0x01 16DestAddr 0xFFFFE
Transmit Retries 0x00 Delivery Status 0x00 Discovery Status 0x00 Success
```

Remove All Groups

The purpose of the Remove All Groups command is to clear all entries from the group table which are associated with a target endpoint.

The following example removes all groups associated with endpoint E7.

The packet:

```
Preamble = "11 01 "+LocalDevice64Addr+"FFFE E6 E7 0006 C105 00 00"
```

The packet is addressed to the local node, using a source endpoint of 0xE6, clusterId of 0x0006, and profileID of 0xC105. The destination endpoint E7 is the endpoint parameter for the "Remove All Groups" command.

```
ZCL_header = "01 ee 04"
```

The first field is a frame control field which specifies a Cluster Specific command (0x01) using a Client->Server direction (0x00). The second field is a transaction sequence number which is used to associate the response with the command request. The third field is the command identifier "Remove All Groups" (0x04).

```
ZCL_payload = ""
```

No payload is needed for this command.

The packet in raw hex byte form:

```
7e001711010013a2004047b55cffffee6e70006c105000001ee0417
```

The response in raw hex byte form, consisting of two packets:

```
7e0016910013a2004047b55cffffee7e68006c1050009ee04007c
7e00078b01ffffe00000076
```

The command response in decoded form:

```
Zigbee Explicit Rx Indicator
API 0x91 64DestAddr 0x0013A2004047B55C 16DestAddr 0xFFFFE SrcEP 0xE7 DestEP
0xE6
ClusterID 0x8006 ProfileID 0xC105 Options 0x00
RF_Data 0x09ee0400
```

The response in terms of Preamble, ZCL Header, and ZCL payload.

```
Preamble = "910013a2004047b55cffffee7e68006c10500"
```

The packet has its endpoints values reversed from the request, and the clusterID is 0x8006 indicating a Group cluster response.

```
ZCL_header = "09 ee 04"
```

The first field is a frame control field which specifies a Cluster Specific command (0x01) using a Server->Client direction (0x08). The second field is a transaction sequence number which is used to associate the response with the command request. The third field is the command identifier "Remove All Groups" (0x04) .

```
ZCL_payload = "00"
```

The first byte is a status byte (SUCCESS=0x00)[4].

And here is the decoded second message, which is a Tx Status for the original command request. If the FrameID value in the original command request had been zero, or if no space was available in the transmit UART buffer, then no Tx Status message would occur.

```
Zigbee Tx Status
API 0x8B FrameID 0x01 16DestAddr 0xFFFFE
Transmit Retries 0x00 Delivery Status 0x00 Discovery Status 0x00 Success
```

Default responses

Many errors are returned as a default response. For example, an RFData payload of a response containing 08010b788b would be decoded as:

```
ZCL_header = "08 01 03" - general command/server-to-client, transseqnum=1,
default_response_command(0x03)
ZCL_payload = "78 8b" - original cmdID, status code (0x8b)
EMBER_ZCL_STATUS_NOT_FOUND
```

Common status codes

This section lists some of the more frequently occurring status codes.

0x00 EMBER_ZCL_STATUS_SUCCESS: Command request was successful
0x01 EMBER_ZCL_STATUS_FAILURE: Command request failed - for example,
a call to remove an entry from the group table returned an error
0x80 EMBER_ZCL_STATUS_MALFORMED_COMMAND: no RFData in the API frame;
ZCL Payload appears truncated from what is expected
0x81 EMBER_ZCL_STATUS_UNSUP_CLUSTER_COMMAND: unexpected direction
in the Frame Control Field of the ZCL Header; unexpected command identifier code
value
in the ZCL header
0x82 EMBER_ZCL_STATUS_UNSUP_GENERAL_COMMAND: unexpected frametype
in the Frame Control Field of the ZCL Header
0x84 EMBER_ZCL_STATUS_UNSUP_MANUF_GENERAL_COMMAND: unexpected
manufacturer specific indication in the Frame Control Field of the ZCL Header
0x8b EMBER_ZCL_STATUS_NOT_FOUND: An attempt at Get Group Membership or
Remove Group could not find a matching entry in the group table

Manage End Devices

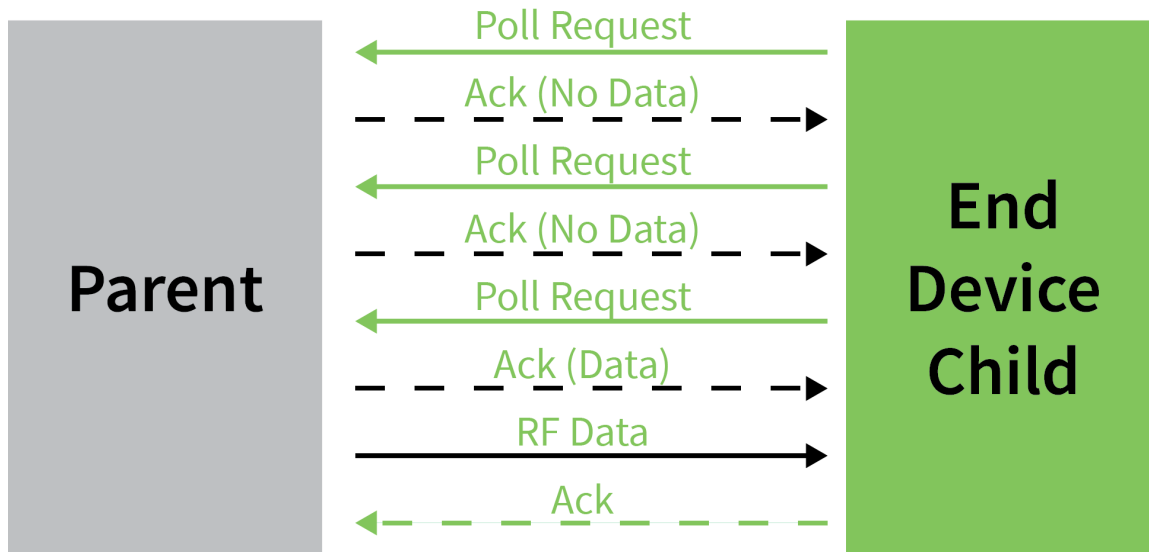
Zigbee end devices are intended to be battery-powered devices capable of sleeping for extended periods of time. Since end devices may not be awake to receive RF data at a given time, routers and coordinators are equipped with additional capabilities (including packet buffering and extended transmission timeouts) to ensure reliable data delivery to end devices.

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End device operation

When an end device joins a Zigbee network, it must find a router or coordinator device that is allowing end devices to join. Once the end device joins a network, it forms a parent-child relationship with the end device and the router or coordinator that allowed it to join. For more information, see [Zigbee networks](#).

When the end device is awake, it sends poll request messages to its parent. When the parent receives a poll request, it checks a packet queue to see if it has any buffered messages for the end device. It then sends a MAC layer acknowledgment back to the end device that indicates if it has data to send to the end device or not.



If the end device receives the acknowledgment and finds that the parent has no data for it, the end device can return to idle mode or sleep. Otherwise, it remains awake to receive the data. This polling mechanism allows the end device to enter idle mode and turn its receiver off when RF data is not expected in order to reduce current consumption and conserve battery life.

The end device can only send data directly to its parent. If an end device must send a broadcast or a unicast transmission to other devices in the network, it sends the message directly to its parent and the parent performs any necessary route or address discoveries to route the packet to the final destination.

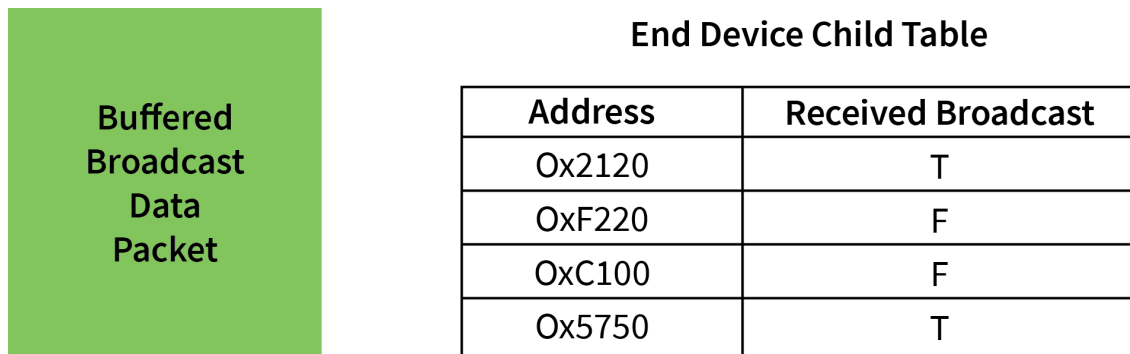
The parent of the receiving device does not send the network ACK back to the originator until the sleeping end device wakes and polls the data or until the timeout occurs.

Parent operation

Each router or coordinator maintains a child table that contains the addresses of its end device children. A router or coordinator that has unused entries in its child table has end device capacity, or the ability to allow new end devices to join. If the child table is completely filled (such that the number of its end device children matches the number of child table entries), the device cannot allow any more end devices to join.

Since the end device children are not guaranteed to be awake at a given time, the parent is responsible for managing incoming data packets of its end device children. If a parent receives an RF data transmission destined for one of its end device children, and if the parent has enough unused buffer space, it buffers the packet. The data packet remains buffered until a timeout expires, or until the end device sends a poll request to retrieve the data.

The parent can buffer one broadcast transmission for all of its end device children. When the parent receives and buffers a broadcast transmission, it sets a flag in its child table when each child polls and retrieves the packet. Once all children have received the broadcast packet, the parent discards the buffered broadcast packet. If all children have not received a buffered broadcast packet and the parent receives a new broadcast, it discards the old broadcast packet, clears the child table flags, and buffers the new broadcast packet for the end device children as shown in the following figure.



When an end device sends data to its parent that is destined for a remote device in the network, the parent buffers the data packet until it can establish a route to the destination. The parent may perform a route or 16-bit address discovery of its end device children. Once a route is established, the parent sends the data transmission to the remote device.

End Device poll timeouts

To better support mobile end devices (end devices that can move within a network), parent router and coordinator devices have a poll timeout for each end device child. If an end device does not send a poll request to its parent within the poll timeout, the parent removes the end device from its child table. This allows the child table on a router or coordinator to better accommodate mobile end devices in the network.

Packet buffer usage

Packet buffer usage on a router or coordinator varies depending on the application. The following activities can require use of packet buffers for up to several seconds:

- Route and address discoveries
- Application broadcast transmissions
- Stack broadcasts (for example ZDO “Device Announce” messages when devices join a network)
- Unicast transmissions buffered until acknowledgment is received from destination or retries exhausted
- Unicast messages waiting for end device to wake

Applications that use regular broadcasting or that require regular address or route discoveries use up a significant number of buffers, reducing the buffer availability for managing packets for end device children. Applications can reduce the number of required application broadcasts, and consider implementing an external address table or many-to-one and source routing if necessary to improve routing efficiency.

Non-Parent device operation

Devices in the Zigbee network treat data transmissions to end devices differently than transmissions to other routers and coordinators. When a device sends a unicast transmission, if it does not receive a network acknowledgment within a timeout, the device resends the transmission. When transmitting data to remote coordinator or router devices, the transmission timeout is relatively short since these devices are powered and responsive.

However, since end devices may sleep for some time, unicast transmissions to end devices use an extended timeout mechanism in order to allow enough time for the end device to wake and receive the data transmission from its parent.

If a non-parent device does not know the destination is an end device, it uses the standard unicast timeout for the transmission. However, provisions exist in the Silicon Labs Zigbee stack for the parent to inform the message sender that the destination is an end device. Once the sender discovers the destination device is an end device, future transmissions will use the extended timeout. For more information see [Router/Coordinator configuration](#).

End Device configuration

XBee end devices support three different sleep modes:

- Pin sleep
- Cyclic sleep
- Cyclic sleep with pin wake-up

Pin sleep allows an external microcontroller to determine when the XBee3 Zigbee RF Module sleeps and when it wakes by controlling the SLEEP_RQ pin. In contrast, cyclic sleep allows the sleep period and wake times to be configured through the use of AT commands. Cyclic sleep with pin wake-up is the same as cyclic sleep except the device can be awakened before the sleep period expires by lowering the SLEEP_RQ line. The **SM** command configures the sleep mode.

In both pin and cyclic sleep modes, XBee end devices poll their parent every 100 ms while they are awake to retrieve buffered data. When the end device sends a poll request, it enables the receiver until it receives an acknowledgment from the parent. It typically takes less than 10 ms between sending the poll request to receiving the acknowledgment. The acknowledgment indicates if the parent has buffered data for the end device child. If the acknowledgment indicates the parent has pending data, the end device leaves the receiver on to receive the data. Otherwise, the end device turns off the receiver and enter idle mode (until it sends the next poll request) to reduce current consumption (and improve battery life).

Once the device enters sleep mode, the On/Sleep pin (Micro pin 25/SMT pin 26) it de-asserts (low) to indicate the device is entering sleep mode. If the device enables CTS hardware flow control (**D7** command), it de-asserts (high) the CTS pin (Micro pin 24/SMT pin 25) when entering sleep to indicate that serial data should not be sent to the device.

If the Associate LED pin is configured (**D5** command), the associate pin is driven low to avoid using power to light the LED. The SLEEP_RQ pin is configured as a pulled-down input so that an external device must drive it low to wake the device. All other pins are left unmodified during sleep so that they can operate as previously configured by the user. The device does not respond to serial or RF data when it is sleeping.

Applications that must communicate serially to sleeping end devices are encouraged to observe CTS flow control.

When the device wakes from sleep, it asserts (high) the On/Sleep pin, and if it enables flow control, it also asserts (low) the CTS pin. The associate LED and all other pins resume their former configured

operation. If the device has not joined a network, it scans all **SC** channels after waking to try and find a valid network to join.

Pin sleep

Pin sleep allows the module to sleep and wake according to the state of the SLEEP_RQ pin (Micro pin 9/SMT pin 10/TH pin 9). Pin sleep mode is enabled by setting the **SM** command to 1.

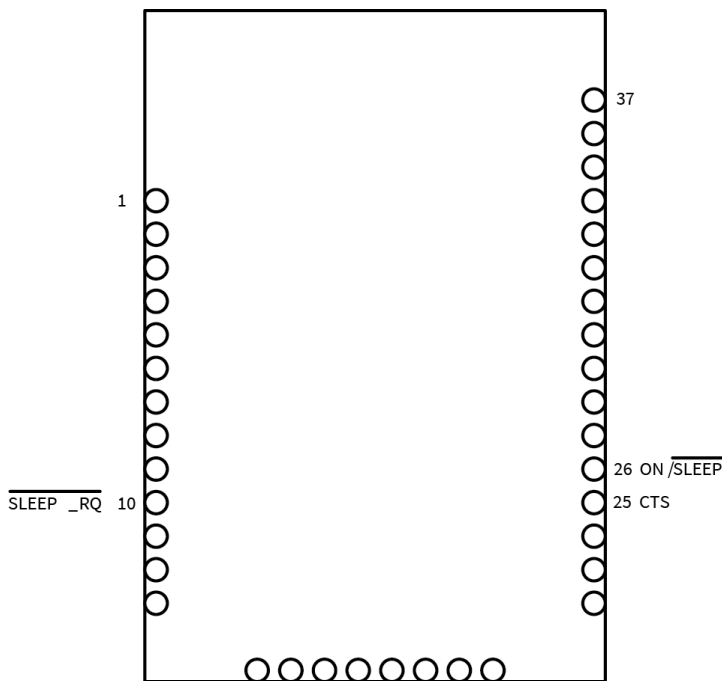
When the device asserts (high) SLEEP_RQ, it finishes any transmit or receive operations for the current packet that is processing and enters a low power state. For example, if the device has not joined a network and SLEEP_RQ is asserted (high), it sleeps once the current join attempt completes (that is, when scanning for a valid network completes). The device wakes from pin sleep when the SLEEP_RQ pin is de-asserted (low).

Devices with SPI functionality can use the SPI_SSEL pin instead of **D8** for pin sleep control. If **D8 = 0** and **P7 = 1**, SPI_SSEL takes the place of SLEEP_RQ and functions as described above. In order to use SPI_SSEL for sleep control while communicating on the UART, the other SPI pins must be disabled (set **P5**, **P6**, and **P8** to **0**). See [Low power operation](#) for information on using SPI_SSEL for sleep control while communicating over SPI.

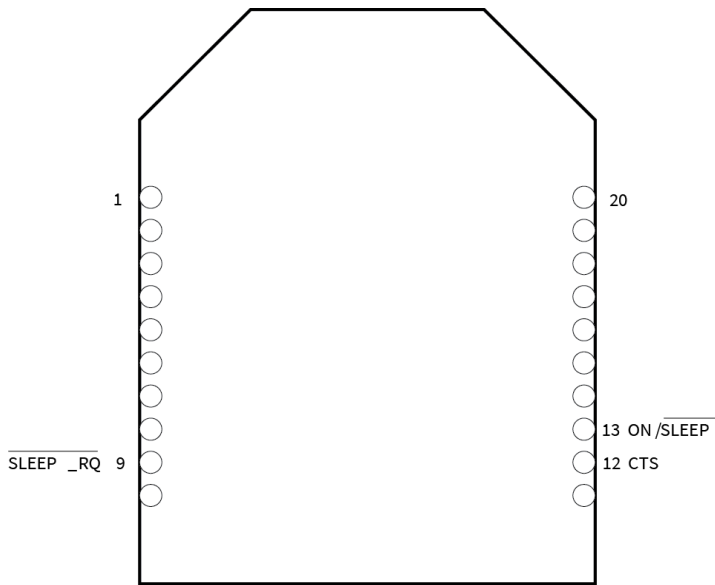
Sleep pin diagrams

The following figures show the device's sleep pins.

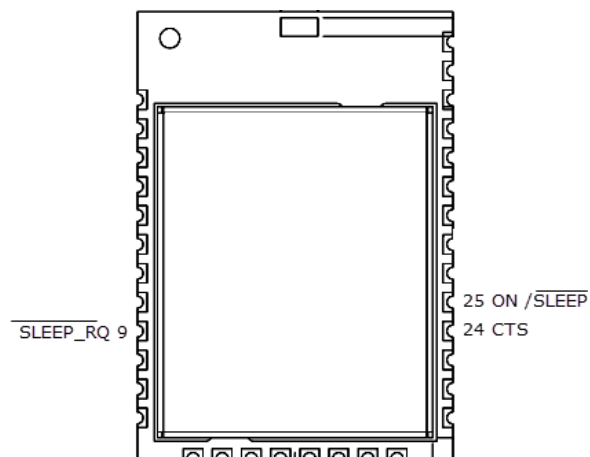
Surface-mount sleep pins



Through-hole sleep pins

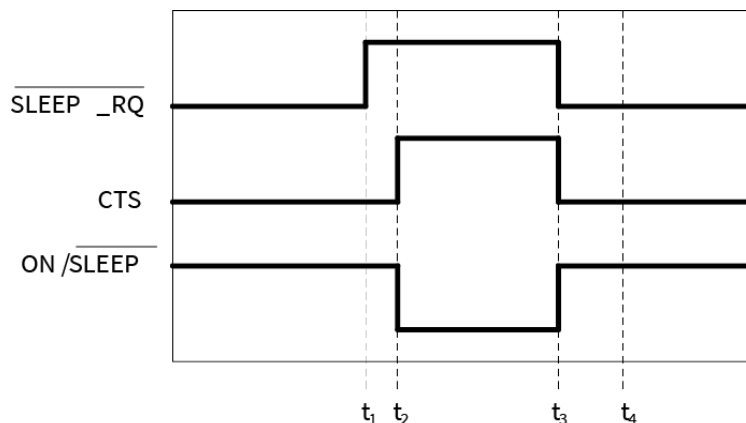


Micro sleep pins



Sleep pin waveform

The following figure show the pin sleep waveforms:



In the previous figure, t_1 , t_2 , t_3 and t_4 represent the following events:

- t_1 - Time when Sleep_RQ is asserted (high)
- t_2 - Time when the device enters sleep ($\overline{\text{CTS}}$ state change only if hardware flow control is enabled)
- t_3 - Time when Sleep_RQ is de-asserted (low) and the device wakes
- t_4 - Time when the module sends a poll request to its parent

The time between t_1 and t_2 varies depending on the state of the module. In the worst case scenario, if the end device is trying to join a network, or if it is waiting for an acknowledgment from a data transmission, the delay could be up to a few seconds. The time between t_3 and t_4 is 1-2 ms for a regular device and about 6 ms for a PRO device.

When the XBee3 Zigbee RF Module is awake and is joined to a network, it sends a poll request to its parent to see if the parent has any buffered data. The end device continues to send poll requests every 100 ms while it is awake.

Demonstration of pin sleep

Parent and remote devices must be configured to buffer data correctly and to use adequate transmission timeouts. For more information, see [Router/Coordinator configuration](#).

Cyclic sleep

Cyclic sleep allows the device to sleep for a specified time and wake for a short time to poll its parent for any buffered data messages before returning to sleep again. Enable cyclic sleep mode by setting the **SM** command to 4 or 5. **SM5** is a slight variation of **SM4** that allows the device to wake up prematurely by asserting the Sleep_RQ pin. In **SM5**, the XBee device can wake after the sleep period expires, or if a high-to-low transition occurs on the Sleep_RQ pin. Setting **SM** to 4 disables the pin wake option.

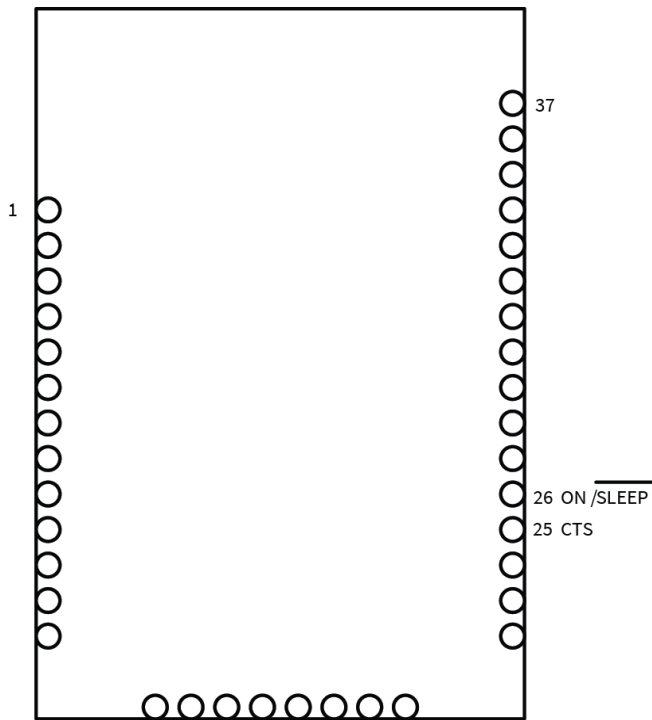
In cyclic sleep, the device sleeps for a specified time, and then wakes and sends a poll request to its parent to discover if the parent has any pending data for the end device. If the parent has buffered data for the end device, or if it receives serial data, the device remains awake for a time. Otherwise, it enters sleep mode immediately.

When the device wakes, it asserts (high) the On/Sleep line, and de-asserted (low) when the device sleeps. If you enable hardware flow control (**D7** command), the CTS pin asserts (low) when the device wakes and can receive serial data, and de-assert (high) when the device sleeps.

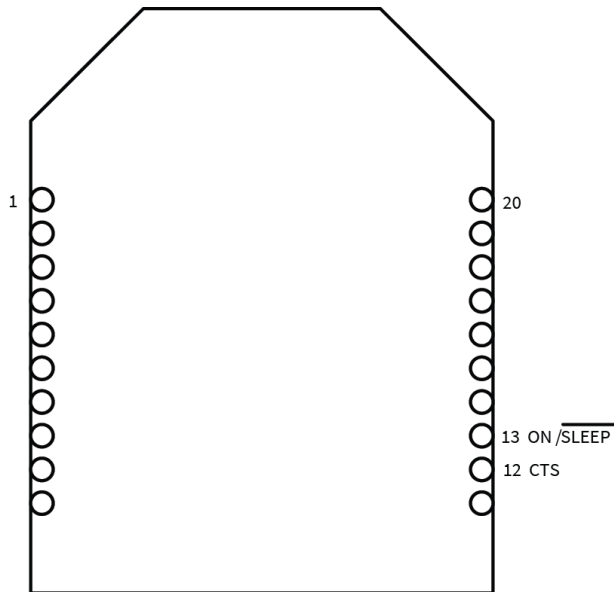
Cyclic sleep pin diagrams

The following figure shows the device's cyclic sleep pins.

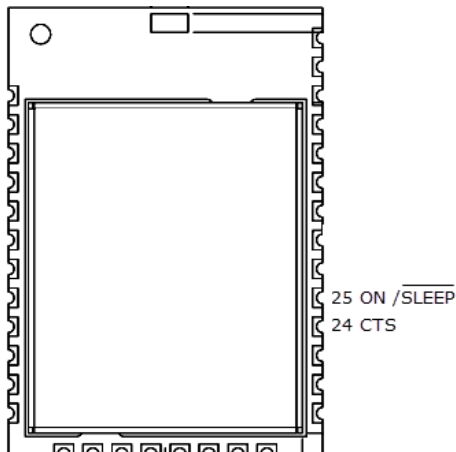
Surface-mount cyclic sleep pins



Through-hole cyclic sleep pins

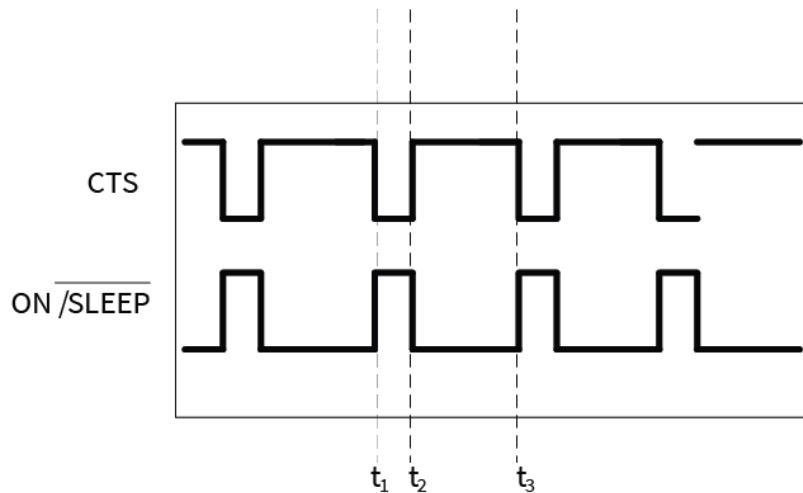


Micro cyclic sleep pins



Cyclic sleep pin waveform

The following figure shows the cyclic sleep waveforms.



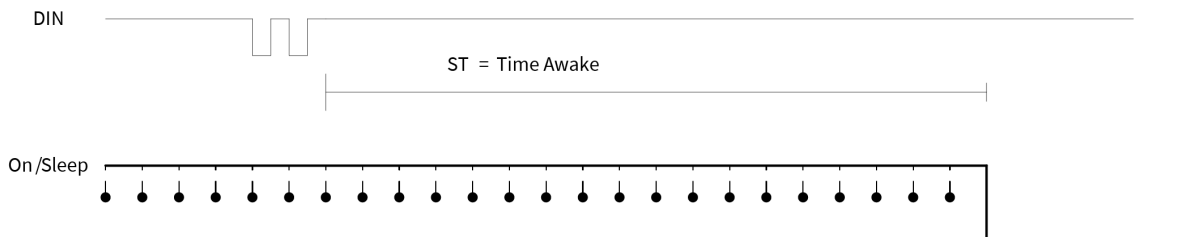
In the figure above, t_1 , t_2 , and t_3 represent the following events:

- t_1 - Time when the device wakes from cyclic sleep
- t_2 - Time when the device returns to sleep
- t_3 - Later time when the device wakes from cyclic sleep

The wake time and sleep time are configurable with software commands.

Wake time (until sleep)

In cyclic sleep mode (**SM = 4 or 5**), if the device receives serial or RF data, it starts a sleep timer (time until sleep). Any data received serially or over the RF link restarts the timer. Set the sleep timer value with [ST \(Cyclic Sleep Wake Time\)](#). While the device is awake, it sends poll request transmissions every 100 ms to check its parent for buffered data messages. The device returns to sleep when the sleep timer expires, or if it receives [SI command](#) as shown in the following image.



A cyclic sleep end device enters sleep mode when no serial or RF data is received for ST time.

Legend
 On/Sleep —————
 Transmitting Poll Request - - - - ●

Sleep period

Configure the sleep period based on the **SP**, **SN**, and **SO** commands. The following table lists the behavior of these commands.

Command	Range	Description
SP	0x20 - 0xAF0 (x 10 ms) (320 - 28,000 ms)	Configures the sleep period of the device.
SN	1 - 0xFFFF	Configures the number of sleep periods multiplier.
SO	0 - 0xFF	Defines options for sleep mode behavior. 0x02 - Always wake for full ST time 0x04 - Enable extended sleep (sleep for full (SP * SN) time)

The device supports both a [Short cyclic sleep](#) and an [Extended cyclic sleep](#) that make use of these commands. These two modes allow the sleep period to be configured according to the application requirements.

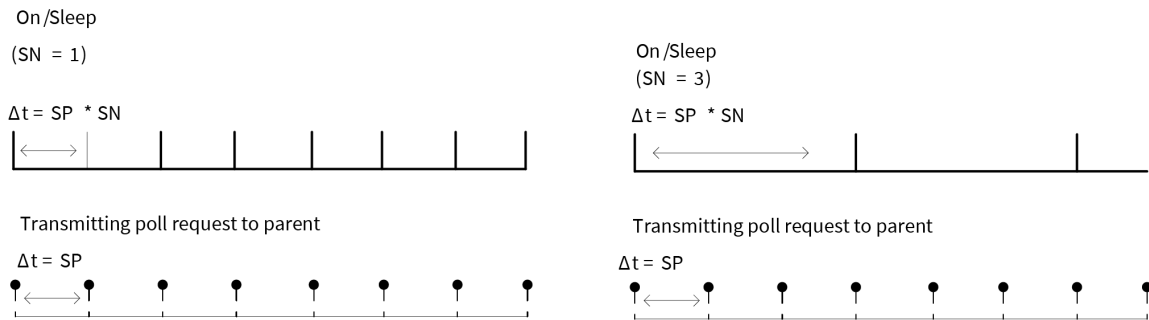
Short cyclic sleep

In short cyclic sleep mode, define the sleep behavior of the device by the **SP** and **SN** commands, and the **SO** command must be set to 0x00 (default) or 0x02. In short cyclic sleep mode, the **SP** command defines the sleep period and you can set it for up to 28 seconds. When the device enters short cyclic sleep, it remains in a low power state until the **SP** time has expired.

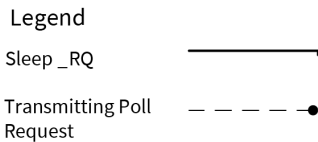
After the sleep period expires, the XBee3 Zigbee RF Module sends a poll request transmission to its parent to determine if the parent has any buffered data waiting for the end device. Since router and coordinator devices can buffer data for end device children up to 30 seconds, the **SP** range (up to 28 seconds) allows the end device to poll regularly enough to receive buffered data. If the parent has data for the end device, the end device starts its sleep timer (**ST**) and continues polling every 100 ms to receive data. If the end device wakes and finds that its parent has no data for it, the end device can return to sleep immediately.

Use the **SN** command to control when the On/Sleep line is asserted (high). If you **SN** to 1 (default), the On/Sleep line sets high each time the device wakes from sleep. Otherwise, if **SN** is greater than 1, the On/Sleep line only sets high if RF data is received, or after **SN** wake cycles occur. This allows an external device to remain powered off until it receives RF data, or until a number of sleep periods have expired (**SN** sleep periods). This mechanism allows the device to wake at regular intervals to poll its

parent for data without waking an external device for an extended time (**SP** * **SN** time) as shown in the following figure.



Setting $SN > 1$ allows the device to silently poll for data without asserting On/Sleep. If RF data is received when polling, On/Sleep will immediately assert.



Note **SP** controls the packet buffer time on routers and coordinators. Set **SP** on all router and coordinator devices to match the longest end device **SP** time. For more information, see [Router/Coordinator configuration](#).

Extended cyclic sleep

In extended cyclic sleep operation, an end device can sleep for a multiple of **SP** time which can extend the sleep time up to several days. Configure the sleep period using the **SP** and **SN** commands. The total sleep period is equal to $(SP * SN)$ where **SP** is measured in 10ms units. The **SO** command must be set correctly to enable extended sleep.

Since routers and coordinators can only buffer incoming RF data for their end device children for up to 30 seconds, if an end device sleeps longer than 30 seconds, devices in the network need some indication when an end device is awake before they can send data to it. End devices that use extended cyclic sleep should send a transmission (such as an **I/O** sample) when they wake to inform other devices that they are awake and can receive data. We recommended that extended sleep end devices set **SO** to wake for the full **ST** time to provide other devices with enough time to send messages to the end device.

Similar to short cyclic sleep, end devices running in this mode return to sleep when the sleep timer expires, or when they receive the **SI** command.

Deep sleep

The following are preconditions for maintaining low current draw during sleep:

- You must maintain the supply voltage within a valid operating range (2.1 to 3.6 V for the XBee, 3.0 to 3.6 V for the XBee-PRO (S2), 2.7 to 3. V for the XBee-PRO S2B).
- Each GPIO input line with a pullup resistor which is driven low draws about 100 uA current through the internal pullup resistor.

- If circuitry external to the XBee drives such input lines low, then the current draw rises above expected deep sleep levels.
- Each GPIO input line that has no pullup or pull-down resistor (is floating) has an indeterminate voltage which can change over time and temperature in an indeterminate manner.

Recommended sleep current measurements

Properly measuring the sleep current helps to accurately estimate battery life requirements. To ensure that you take proper measurements without upsetting the normal operation of the unit under test, read the following steps.

When you measure sleep currents, it can cause problems with the devices because the equipment that measures very low currents accurately requires a large resistor in series with the power supply. This large resistor starves current from the device during a momentary wake cycle, forcing the voltage to drop to brownout levels rapidly. This voltage drop places the device in a state that may require a reset to resolve the problem.

Achieve the lowest sleep current

To achieve the lowest sleep current, you must disable brownout detectors during sleep modes. Even if the measurement equipment automatically changes current ranges, it is often too slow and cannot keep up with the necessary sudden short bursts. During long cyclic sleep periods, the device can wake every 10 to 30 seconds to reset timers and perform other necessary steps. These wake times are small and you may not notice them when measuring sleep currents.

Compensate for switching time

To compensate for the switching time of the equipment you must temporarily add an additional large cap when you need measurements to allow for short pulses of current draw (see the following schematic for details). A cap of 100 uF is enough to handle 1.5 milliseconds with 20 mA of current. You can increase or decrease the capacitor based on the switching time of the measurement circuitry and the momentary on time of the unit. Measure the leakage current of the additional cap to verify that it does not skew the low current reading. The capacitor averages the spike in current draw. The actual magnitude of the current spike is no longer visible, but you can account for the total energy consumed by integrating the current over time and multiplying by the voltage.

Internal pin pull-ups

Internal pull-up/down resistors only apply to GPIO lines that are configured as disabled (0) or digital input (3). Use [PR \(Pull-up/Down Resistor Enable\)](#) to enable them on a per-pin basis and use [PD \(Pull Up/Down Direction\)](#) to determine the direction.

Internal pin pull-ups can pull excess current and cause the sleep current readings to be higher than desired if you drive or float the pull-ups.

- Disable all pull-ups for input lines that have a low driven state during sleep.
- Enable pull-ups for floating lines or inputs that do not connect to other circuitry.

If you use an analog-to-digital converter (ADC) to read the analog voltage of a pin, it may not be possible to stop all leakage current unless you can disconnect the voltage during sleep. Each floating input that is not at a valid high or low level can cause leakage depending on the temperature and charge buildup that you may not observe at room temperature.

Transmit RF data

An end device may transmit data when it wakes from sleep and has joined a network. End devices transmit directly to their parent and then wait for an acknowledgment to be received. The parent performs any required address and route discoveries to help ensure the packet reaches the intended destination before reporting the transmission status to the end device.

Receiving RF data

After waking from sleep, an end device sends a poll request to its parent to determine if the parent has any buffered data for it. In pin sleep mode, the end device polls every 100 ms while the Sleep_RQ pin is de-asserted (low). In cyclic sleep mode, the end device will only poll once before returning to sleep unless the sleep timer (**ST**) is started (serial or RF data is received). If the sleep timer is started, the end device will continue to poll every 100 ms until the sleep timer expires.

This firmware includes an adaptive polling enhancement where, if an end device receives RF data from its parent, it sends another poll after a very short delay to check for more data. The end device continues to poll at a faster rate as long as it receives data from its parent. This feature greatly improves data throughput to end devices. When the end device no longer receives data from its parent, it resumes polling every 100 ms.

I/O sampling

End devices can be configured to send one or more I/O samples when they wake from sleep. To enable I/O sampling on an end device, the IR command must be set to a non-zero value, and at least one analog or digital I/O pin must be enabled for sampling (**D0 - D9, P0 - P4** commands). If I/O sampling is enabled, an end device sends an I/O sample when it wakes and starts the **ST** timer. It will continue sampling at the **IR** rate until the sleep timer (**ST**) has expired. For more information, see [Analog and digital I/O lines](#).

Wake end devices with the Commissioning Pushbutton

If you use [D0 \(DIO0/AD0/Commissioning Button Configuration\)](#) to enable the Commissioning Pushbutton functionality, a high-to-low transition on the AD0/DIO0 pin (Micro pin 31/SMT pin 33/TH pin 20) causes an end device to wake for 30 seconds. For more information, see [Commissioning pushbutton and associate LED](#).

Parent verification

Since an end device relies on its parent to maintain connectivity with other devices in the network, XBee end devices include provisions to verify the connection with its parent. End devices monitor the link with their parent when sending poll messages and after a power cycle or reset event as described below.

When an end device wakes from sleep, it sends a poll request to its parent. In cyclic sleep, if the end device does not receive RF or serial data and the sleep timer is not started, it polls one time and returns to sleep for another sleep period. Otherwise, the end device continues polling every 100ms. If the parent does not send an acknowledgment response to three consecutive poll request transmissions, the end device assumes the parent is out of range, and attempts to find a new parent. After a power-up or reset event, the end device does an orphan scan to locate its parent. If the parent does not send a response to the orphan scan, the end device attempts to find a new parent.

Rejoining

Once all devices have joined a Zigbee network, disable the permit-joining attribute disabled such that new devices are no longer allowed to join the network. You can enable permit-joining later as needed for short times. This provides some protection in preventing other devices from joining a live network. If an end device cannot communicate with its parent, the end device must be able to join a new parent to maintain network connectivity. However, if permit-joining is disabled in the network, the end device will not find a device that is allowing new joins.

To overcome this problem, Zigbee supports rejoining, where an end device can obtain a new parent in the same network even if joining is not enabled. When an end device joins using rejoining, it performs a PAN ID scan to discover nearby networks. If a network is discovered that has the same 64-bit PAN ID as the end device, it joins the network by sending a rejoin request to one of the discovered devices. The device that receives the rejoin request sends a rejoin response if it can allow the device to join the network (that is, the child table is not full). You can use the rejoin mechanism to allow a device to join the same network even if permit-joining is disabled.

To enable rejoining, set **NJ** to less than 0xFF on the device joining. If **NJ** < 0xFF, the device assumes the network is not allowing joining and first tries to join a network using rejoining. If multiple rejoining attempts fail, or if **NJ** = 0xFF, the device attempts to join using association.

Router/Coordinator configuration

XBee routers and coordinators may require some configuration to ensure the following are set correctly.

- RF Packet buffering timeout
- Child poll timeout
- Transmission timeout

The value of these timeouts depends on the sleep time used by the end devices.

RF packet buffering timeout

When a router or coordinator receives an RF data packet intended for one of its end device children, it buffers the packet until the end device wakes and polls for the data, or until a packet buffering timeout occurs. Use the **SP** command to set the timeout. The actual timeout is $(1.2 * SP)$, with a minimum timeout of 1.2 seconds and a maximum of 30 seconds. Since the packet buffering timeout is set slightly larger than the **SP** setting, set **SP** the same on routers and coordinators as it is on cyclic sleep end devices. For pin sleep devices, set **SP** as long as the pin sleep device can sleep, up to 30 seconds.

Note In pin sleep and extended cyclic sleep, end devices can sleep longer than 30 seconds. If end devices sleep longer than 30 seconds, parent and non-parent devices must know when the end device is awake in order to reliably send data. For applications that require sleeping longer than 30 seconds, end devices should transmit an **I/O** sample or other data when they wake to alert other devices that they can send data to the end device.

Child poll timeout

Router and coordinator devices maintain a timestamp for each end device child indicating when the end device sent its last poll request to check for buffered data packets. If an end device does not send a poll request to its parent for a certain period of time, the parent assumes the end device has moved out of range and removes the end device from its child table. This allows routers and coordinators to

be responsive to changing network conditions. You can issue the **NC** command at any time to read the number of remaining (unused) child table entries on a router or coordinator.

Set the child poll timeout with the **SP** and **SN** commands. **SP** and **SN** should be set such that **SP * SN** matches the longest expected sleep time of any end devices in the network. The device calculates the actual timeout as $(3 * SP * SN)$, with a minimum of five seconds. For networks consisting of pin sleep end devices, set the **SP** and **SN** values on the coordinator and routers so the **SP * SN** matches the longest expected sleep period of any pin sleep device. The three multiplier ensures the end device will not be removed unless 3 sleep cycles pass without receiving a poll request. You can set the poll timeout up to two months.

Adaptive polling

PO command determines the regular polling rate. However, if RF data has been recently received by an end device, it is likely that more RF data could be on the way. Therefore, the end device polls at a faster rate, gradually decreasing its adaptive poll rate until polling resumes at the regular rate as defined by the **PO** command.

Transmission timeout

When you are sending RF data to a remote router, because routers are always on, the timeout is based on the number of hops the transmission may traverse. Set the timeout using **NH** (**Maximum Unicast Hops**). For more information, see [Transmission, addressing, and routing](#).

Since end devices may sleep for lengthy periods of time, the transmission timeout to end devices also allows for the sleep period of the end device. When sending data to a remote end device, the transmission timeout is calculated using the **SP** and **NH** commands. If the timeout occurs with no acknowledgment received, the source device re-sends the transmission until it receives an acknowledgment, up to two more times.

The transmission timeout per attempt is:

$$3 * ((\text{unicast router timeout}) + (\text{end device sleep time}))$$

$$3 * ((50 * \mathbf{NH}) + (1.2 * \mathbf{SP})), \text{ where } \mathbf{SP} \text{ is measured in 10 ms units.}$$

Short sleep periods

Pin and cyclic sleep devices that sleep less than 30 seconds can receive data transmissions at any time since their parent devices are able to buffer data long enough for the end devices to wake and poll to receive the data. Set **SP** the same on all devices in the network. If end devices in a network have more than one **SP** setting, set **SP** on the routers and coordinators to match the largest **SP** setting of any end device. This ensure the RF packet buffering, poll timeout, and transmission timeouts are set correctly.

Extended sleep periods

Pin and cyclic sleep devices that might sleep longer than 30 seconds cannot receive data transmissions reliably unless you take certain design approaches. Specifically, the end devices should use I/O sampling or another mechanism to transmit data when they wake to inform the network they can receive data. **SP** and **SN** should be set on routers and coordinators such that **(SP * SN)** matches the longest expected sleep time. This configures the poll timeout so end devices are not expired from the child table unless routers and coordinators do not receive a poll request for 3 consecutive sleep periods.

As a general rule, **SP** and **SN** should be set the same on all devices in almost all cases.

Sleep examples

Some sample XBee configurations to support different sleep modes follow. In Command mode, issue each command with a leading **AT** and no = sign, for example, **ATSM4**. In the API, the two byte command is used in the command field, and parameters are populated as binary values in the parameter field.

Example 1: Configure a device to sleep for 20 seconds, but set SN such that the On/sleep line will remain de-asserted for up to 1 minute.

The following settings should be configured on the end device.

- **SM** = 4 (cyclic sleep) or 5 (cyclic sleep, pin wake).
- **SP** = 0x7D0 (2000 decimal). This causes the end device to sleep for 20 seconds since **SP** is measured in units of 10 ms.
- **SN** = 3. (With this setting, the On/Sleep pin asserts once every 3 sleep cycles, or when it receives RF data) **SO** = 0.

Set all router and coordinator devices on the network **SP** to match **SP** on the end device. This set the RF packet buffering times and transmission timeouts correctly.

Since the end device wakes after each sleep period (**SP**), you can set the **SN** command to 1 on all routers and the coordinator.

Example 2: Configure an end device to sleep for 20 seconds, send 4 I/O samples in 2 seconds, and return to sleep.

Because **SP** is measured in 10 ms units, and **ST** and **IR** are measured in 1 ms units, configure an end device with the following settings:

- **SM** = 4 (cyclic sleep) or 5 (cyclic sleep, pin wake).
- **SP** = 0x7D0 (2000 decimal). This causes the end device to sleep for 20 seconds.
- **SN** = 1.
- **SO** = 0.
- **ST** = 0x7D0 (2000 decimal). This sets the sleep timer to 2 seconds.
- **IR** = 0x258 (600 decimal). Set **IR** to a value greater than (2 seconds / 4) to get 4 samples in 2 seconds. The end device sends an I/O sample at the **IR** rate until the sleep timer has expired.

You must enable at least one analog or digital I/O line for I/O sampling to work. To enable AD1/DIO1 (Micro pin 30/SMT pin 32/TH pin 19) as a digital input line, you must set the following:

D1 = 3

Set all router and coordinator devices on the network **SP** to match **SP** on the end device. This ensures that RF packet buffering times and transmission timeouts are set correctly.

Example 3: configure a device for extended sleep: to sleep for 4 minutes.

- **SP** and **SN** must be set such that $SP * SN = 4$ minutes. Since **SP** is measured in 10 ms units, use the following settings to obtain 4 minute sleep.
- **SM** = 4 (cyclic sleep) or 5 (cyclic sleep, pin wake) **SP** = 0x7D0 (2000 decimal, or 20 seconds).
- **SN** = 0x0B (12 decimal).
- **SO** = 0x04 (enable extended sleep).

With these settings, the module sleeps for **SP** * **SN** time, or (20 seconds * 12) = 240 seconds = 4 minutes.

For best results, the end device should send a transmission when it wakes to inform the coordinator (or network) when it wakes. It should also remain awake for a short time to allow devices to send data to it. The following are recommended settings.

- **ST** = 0x7D0 (2 second wake time)
- **SO** = 0x06 (enable extended sleep and wake for ST time)
- **IR** = 0x800 (send 1 I/O sample after waking). Enable at least one analog or digital I/O sample enabled for I/O sampling.

With these settings, the end device wakes after 4 minutes and sends 1 I/O sample. It then remains awake for 2 seconds before returning to sleep.

Set **SP** and **SN** to the same values on all routers and coordinators that could potentially allow the end device to join. This ensures the parent does not timeout the end device from its child table too quickly.

The **SI** command can optionally be sent to the end device to cause it to sleep before the sleep timer expires.

Analog and digital I/O lines

XBee Zigbee firmware supports a number of analog and digital I/O pins that are configured through software commands. Analog and digital I/O lines can be set or queried.

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I/O configuration

To enable an analog or digital I/O function on one or more XBee3 Zigbee RF Module pin, you must issue the appropriate configuration command with the correct parameter. After issuing the configuration command, you must apply changes on the device for the I/O settings to take effect. The available I/O lines are DIO0 through DIO19. Not every pin supports every function, so refer to the relevant AT command (**D0** - **D9**, **P0** - **P9**) to know the limits and capabilities of each I/O pin.

Pin command parameter	Description
0	Disabled (Floating or pulled up/down)
1	Peripheral control (varies depending on the pin)
2	ADC - Analog input
3	Digital input (see the information following the table)
4	Digital output, low (0 V)
5	Digital output, high (3.3 V)
>6	Alternative peripheral control

When an I/O pin is configured as either disabled (0) or a digital input (3), the pin can be configured for three different states:

- Floating
- Pulled-up
- Pulled-down

A floating input is appropriate if the pin is attached to an output that always drives the line. In this case, a pull-up or pull-down resistor draws more current.

A pulled-up input is useful where there might not always be an external source to drive the pin and it is desirable to have the line read high in the absence of an external driver.

Likewise, a pulled-down input is useful when there is not always an external source to drive the pin and it is desirable to have the line read low in the absence of an external driver.

Two commands are available to configure the input type:

- **PR** determines whether or not to pull an input. If the corresponding bit in **PR** is set, the signal pulls. If it is clear, then the signal floats.
- **PD** determines the pull direction. It only applies when the corresponding bit in **PR** is set. Set the bit in **PD** to enable an internal pull-up resistor; clear it to enable an internal pull-down resistor.

I/O sampling

The XBee3 Zigbee RF Modules have the ability to monitor and sample analog and digital I/O lines. I/O samples can be read locally or transmitted to a remote device to provide an indication of the current I/O line states. You must enable API mode on the receiving device to send I/O samples out the serial port. If you do not enable this mode, the device discards the remote I/O samples.

There are three ways to obtain I/O samples, either locally or remotely:

- Queried Sampling (**IS**)
- Periodic Sampling (**IR**)
- Change Detection Sampling (**IC**)

I/O sample data is formatted as shown in the following table:

Bytes	Name	Description
1	Sample Sets	Number of sample sets in the packet (always set to 1).
2	Digital Channel Mask	Indicates which digital I/O lines have sampling enabled. Each bit corresponds to one digital I/O line on the device. bit 0 = DIO0 bit 1 = DIO1 bit 2 = DIO2 bit 3 = DIO3 bit 4 = DIO4 bit 5 = ASSOC/DIO5 bit 6 = RTS/DIO6 bit 7 = CTS/DIO7 bit 8 = SLP_RQ/DIO8 bit 9 = ON_SLP/DIO9 bit 10 = RSSI/DIO10 bit 11 = PWM/DIO11 bit 12 = DIO12 bit 13 = DOUT/DIO13 bit 14 = DIN/DIO14 For example, a digital channel mask of 0x002F means DIO0,1,2,3, and 5 are enabled as digital I/O.
1	Analog Channel Mask	Indicates which lines have analog inputs enabled for sampling. Each bit in the analog channel mask corresponds to one analog input channel. bit 0 = AD0 bit 1 = AD1 bit 2 = AD2 bit 3 = AD3 bit 7 = Supply Voltage
Variable	Sampled Data Set	A sample set consisting of 1 sample for each enabled ADC and/or DIO channel. If any digital I/O lines are enabled, the first two bytes of the data set indicate the state of all enabled digital I/O. Only digital channels that are enabled in the Digital Channel Mask bytes have any meaning in the sample set. If no digital I/O are enabled on the device, these 2 bytes will be omitted. Following the digital I/O data (if any), each enabled analog channel returns 2 bytes. The data starts with AIN0 and continues sequentially for each enabled analog input channel up to AIN3, and the supply voltage (if enabled) at the end.

I/O examples

Example 1: Configure the following I/O settings on the XBee

Configure AD1/DIO1 as a digital input with pullup resistor enabled Configure AD2/DIO2 as an analog input.

Configure DIO4 as a digital output, driving high.

To configure AD1/DIO1 as an input, issue the **D1** command with a parameter of 3 (“ATD13”). To enable pull-up resistors on the same pin, issues the **PR** command with bit 3 set (for example, PR8, PR1FFF, and so on).

Issue the **D2** command with a parameter of 2 to enable the analog input (“D22”). Finally, set DIO4 as an output, driving high by issuing the **D4** command with a parameter value of 5 (“D45”).

After issuing these commands, apply the changes before the module I/O pins update to the new states. Issue the **AC** or **CN** commands to apply changes (for example, AC).

Example 2: Calculate the PWM counts for a packet received with an RSSI of -84 dBm

- $RSSI = -84 = 0xAC = 172$ decimal (unsigned)
- $PWM\ counts = (41 * 172) - 5928$
- $PWM\ counts = 1124$

With a total of 2400 counts, this yields an ON time of $(1124 / 2400) = 46.8\%$

Example 3: Configure the RSSI/PWM pin to operate for 2 seconds after each received RF packet

First, make sure the RSSI/PWM functionality is enabled by reading the **P0** (P-zero) command. It should be set to 1 (default).

To configure the duration of the RSSI/PWM output, set the **RP** command. To achieve a 2 second PWM output, set **RP** to 0x14 (20 decimal, or 2 seconds) and apply changes using the **AC** command.

After applying changes, all received RF data packets set the RSSI timer for 2 seconds.

The sampled data set includes 2 bytes of digital I/O data only if one or more I/O lines on the device are configured as digital I/O. If no pins are configured as digital I/O, these 2 bytes are omitted. Pins are configured as digital I/O by setting them to a value of 3, 4, or 5.

The digital I/O data is only relevant if the same bit is enabled in the digital I/O mask.

Analog samples are returned as 10-bit values. The device scales the analog reading such that 0x0000 represents 0 V, and 0x3FF = 1.25 V (The analog inputs on the device cannot read more than 1.25 V.). The device returns analog samples in order starting with AD0 and finishing with AD3, and the supply voltage. Only enabled analog input channels return data.

To convert the A/D reading to mV, do the following:

$$AD(mV) = (A/D\ reading * 1250mV) / 1023$$

The reading in the sample frame represents voltage inputs of 1192.57 and 356.8 mV for AD0 and AD1 respectively.

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After applying changes, all received RF data packets set the RSSI timer for 2 seconds.

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To convert the A/D reading to mV, do the following:

$$AD(mV) = (A/D\ reading * 1250mV) / 1023$$

The reading in the sample frame represents voltage inputs of 1192.57 and 356.8 mV for AD0 and AD1 respectively.

Queried sampling

You can send the **IS** command to a device locally, or to a remote device using the API remote command frame (for more information, see [API Operation](#)). When you send the IS command, the receiving device samples all enable digital I/O and analog input channels and return an I/O sample. If

you send the **IS** locally, the device sends the I/O sample out the serial port. If the **IS** command was received as a remote command, the I/O sample is sent over-the-air to the device that sent the **IS** command.

If you issue the **IS** command in Command mode, the device returns a carriage return-delimited list containing the fields listed in [I/O sampling](#). If you issue the **IS** command in API mode, an API command response contains the same information.

The following table shows an example of the fields in an **IS** response.

Example	Sample AT Response
0x01	[1 sample set]
0x0C0C	[Digital Inputs: DIO 2, 3, 10, 11 enabled]
0x03	[Analog Inputs: A/D 0, 1 enabled]
0x0408	[Digital input states: DIO 3, 10 high, DIO 2, 11 low]
0x03D0	[Analog input ADIO 0= 0x3D0]
0x0124	[Analog input ADIO 1=0x120]

Periodic I/O sampling

Periodic sampling allows a device to take an I/O sample and transmit it to a remote device at a periodic rate. Use the **IR** command to set the periodic sample rate.

- To disable periodic sampling, set **IR** to **0**.
- For all other **IR** values, the firmware samples data when **IR** milliseconds elapse and the sample data transmits to a remote device.

The **DH** and **DL** commands determine the destination address of the I/O samples.

You can set **DH** and **DL** to **0** to transmit to the coordinator, or to the 64-bit address of the remote device (**SH** and **SL**).

Only devices with API operating mode enabled send I/O data samples out their serial interface. Devices that are in Transparent mode (**AP = 0**) discard the I/O data samples they receive. You must configure at least one pin as a digital or ADC input to generate sample data.

A device with sleep enabled transmits periodic I/O samples at the **IR** rate until the **ST** time expires and the device can resume sleeping.

Change detection sampling

You can configure devices to transmit a data sample immediately whenever a monitored digital I/O pin changes state. The **IC** command is a bitmask used to set which digital I/O lines to monitor for a state change. If one or more bits in **IC** is set, the device transmits an I/O sample as soon as it observes a state change in one of the monitored digital I/O lines. Use **DH** and **DL** to specify the 64-bit address to transmit change detection samples.

We do not recommend using change detection if sleep is enabled. Change detection is edge-triggered, and the change must occur while the module is awake to generate an I/O sample.

RSSI PWM

The XBee3 Zigbee RF Module features an RSSI/PWM pin (Micro pin 7/SMT pin 7/TH pin 6) that, if enabled, adjusts the PWM output to indicate the signal strength of the last received packet. Use [P0 \(DIO10/RSSI Configuration\)](#) to enable the RSSI pulse width modulation (PWM) output on the pin. If **P0** is set to 1, the RSSI/PWM pin outputs a pulse width modulated signal where the frequency adjusts based on the received signal strength of the last packet. Otherwise, for all other **P0** settings, use the pin for general purpose **IO**.

When a data packet is received, if you set **P0** to enable the RSSI/PWM feature, the RSSI PWM output adjusts based on the RSSI of the last packet. The RSSI/PWM output is enabled for a time based on the **RP** command. Each time the device receives an RF packet, the RSSI/PWM output adjusts based on the RSSI of the new packet, and resets the RSSI timer. If the RSSI timer expires, the RSSI/PWM pin drives low. RP is measured in 100 ms units and defaults to a value of 40 (4 seconds).

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Networking commands

This section lists the AT commands that are used during a form and join attempt.

Note Any changes you make to this section will cause the device to leave and rejoin or form a new network.

CE (Device Role)

Determines whether the device should form or join a network.

When forming a network, the device acts as a Zigbee network coordinator it is unless using a distributed trust center security model (**EO** bit 1 is not set) where it forms the network as a route.

Parameter range

0 - 1

Value	Description
0	Join Network
1	Form Network (SM must be 0 to set CE to 1)

Default

0

ID (Extended PAN ID)

The preconfigured Extended PAN ID used when forming or joining a network.

ID restricts joining to only networks with a matching **OP** value. If **ID** is set to 0, the device attempt to join any open network.

When forming a network (**CE**=1), **ID** preconfigures the Extended PAN ID used to form the network. When you set **ID** to 0, a random Extended PAN ID is generated.

Parameter range

0 - 0xFFFFFFFFFFFFFFFF

Default

0

II (Initial 16-bit PAN ID)

The preconfigured 16-bit PAN ID used when forming a network. Use this command to replace a coordinator node on an existing network.

When you set **II** to the default value (recommended) the module forms a network on a random 16-bit PAN ID.

Range

0 - 0xFFFF

Default

0xFFFF

ZS (Zigbee Stack Profile)

Set or read the initial Zigbee stack profile used by the device. This parameter must be the same on all devices joining the same network. If XBee devices are the only type of radio on your network, leave **ZS** at the default value of 0; a non-zero value allows third-party Zigbee devices to join.

If operating in Command mode, any changes to **ZS** is made active only when Command mode exits (via timeout or [CN \(Exit Command mode\)](#)). Changing **ZS** causes all current parameters to be written to persistent storage and the module restarts; this is equivalent to issuing **WR** and **FR** commands.

When the device restarts as a result of changing **ZS** or **BT**, no modem status is generated. $\overline{\text{CTS}}$ will also de-assert during this period, so flow control is advised. If hardware flow control is not being used, a 1-second delay after exiting Command mode (or applying changes if using API) may be necessary to avoid data loss.

Parameter range

0 - 2

Value	Description
0	Digi Proprietary
1	Zigbee 2006 (legacy)
2	Zigbee-PRO (third-party)

Default

0

CR (Conflict Report)

The number of PAN ID conflict reports that must be received by the network manager within one minute to trigger a PAN ID change.

A corrupt beacon can cause a report of a false PAN ID conflict.

A higher value reduces the chance of a false PAN ID change.

Parameter range

1 - 0x3F

Default

3

NJ (Node Join Time)

Configure the amount of time the local device's join window is open for. The join window specified by **NJ** only affects the window for the local node and does not affect the timing of the rest of the network. This value can be changed at run time without requiring a Coordinator or Router to restart.

Zigbee 3.0 does not allow the network to be always open for joining; modules that attempt to join when the join window is closed will report an **AI** value of 0x23. The join window can optionally be

persistently opened by setting **NJ** = **0xFF**, but this causes the device to operate outside of the Zigbee 3.0 specifications.

The join window opens under the following conditions:

- **NJ** parameter value is changed and applied.
- Local device is power cycled.
- Local device forms a network (**CE**=1).
- Commissioning button is enabled (**DO**=1) and is physically pressed twice.
- A **CB2** AT command is issued.

If you set **NJ** to 0, the join window will always be closed; this is the recommended setting for secure networks. When configured with this setting, using a **CB2** AT command or pressing the commissioning button twice opens the join window for one minute.

Note When a device is rejoining a network, the join window does not need to be open. However, if the rejoin attempt fails six times, the module attempts to join by association which requires an open joining window.

Parameter range

0 - 0xFF (seconds)

Default

0xFE (254 seconds)

DJ (Disable Joining)

Prevent a local device from joining a network.

This parameter does not affect end devices that are already joined to a network. It only prevents those devices from joining another network.

Note This parameter is not written to flash with the **WR** command and reverts to default after a power cycle.

Parameter range

0 - 1

Value	Description
0	Enable Joining
1	Disable Joining

Default

1

NW (Network Watchdog Timeout)

Set the network watchdog timeout used to ensure that a coordinator is active on the network.

If **NW** is set > 0, the router monitors communication from the coordinator (or data collector) and leaves the network if it cannot communicate with the coordinator for 3 **NW** periods. The device resets

the timer each time it receives or sends data to a coordinator, or if it receives a many-to-one broadcast.

Parameter range

0 - 0x64FF [x 1 minute](up to approximately 18 days)

Default

0 (disabled)

JV (Coordinator Join Verification)

Used during join and rejoin attempts to determine if a coordinator is present on the target network.

If **JV = 1**, a router or end device verifies the coordinator is on its operating channel when joining or coming up from a power cycle. If a coordinator is not detected, the router or end device leaves its current channel and attempts to join a new PAN. If **JV = 0**, the router or end device continues operating on its current channel even if a coordinator is not detected.

Parameter range

0 - 1

Value	Description
0	No coordinator verification
1	Coordinator verification enabled

Default

0

JN (Join Notification)

Broadcast Join Notification upon successful join attempt.

If enabled, the device transmits a broadcast node identification packet on power up and when joining. This action blinks the Associate LED rapidly on all devices that receive the transmission, and sends an API frame out the serial port of API devices.

Digi recommends you disable this feature for large networks to prevent excessive broadcasts.

Parameter range

0 - 1

Parameter	Description
0	Disabled
1	Broadcast notification to network upon joining

Default

0

DO (Miscellaneous Device Options)

A bitfield that contains advanced device options that do not have dedicated AT commands.

Leave unused bits clear so future device options are not inadvertently enabled during a firmware update.

Bit field:

Bit	Description
0	Reserved.
1	Reserved.
2	Reserved.
3	Reserved.
4	Disable Tx packet extended timeout.
5	Disable ACK for end device I/O sampling.
6	Enable High-RAM concentrator.
7	Use coordinator verification to find new network when network watchdog triggers.

Parameter range

0 - 0xFF

Default

0x40

DC (Joining Device Controls)

A bitfield that contains advanced joining device controls that do not have dedicated AT commands. These options only apply to joining devices (**CE**=0).

Leave unused bits clear so future device controls are not inadvertently enabled during a firmware update.

Bit field:

Bit	Description
0	Generate a preconfigured link key using device's install code (KY is ignored). Enabling this option requires the joining device be registered to the trust center.
1	Ignore NWK leave requests after joining.
2	Enable verbose join information.
3	Join network with best response (strongest signal) instead of first responder.
4 - 15	Reserved

Parameter range

0 - 0xFFFF

Default

0

CB (Commissioning Pushbutton)

Use **CB** to simulate Commissioning Pushbutton presses in software.

You can issue **CB** even if the Commissioning Button functionality is disabled (**DO** is not set to **1**).

Set the parameter value to the number of button presses that you want to simulate. For example, send **CB1** to perform the action of pressing the Commissioning Pushbutton once.

Parameter range

1, 2, 4

Parameter	Description
1	If disassociated: <ul style="list-style-type: none"> ■ Join Network. If associated: <ul style="list-style-type: none"> ■ Wake device for 30 seconds, if sleeping. ■ Send Node Identification broadcast.
2	Enable joining for 1 minute (or NJ seconds if NJ is not 0 or 0xFF).
4	Restore device configuration to default and leave the network.

Default

N/A

NR (Network Reset)

Resets network layer parameters on one or more modules within a PAN. Responds immediately with an **OK** then causes a network restart. The device loses all network configuration and routing information.

If **NR** = 0: Resets network layer parameters on the node issuing the command.

If **NR** = 1: Sends broadcast transmission to reset network layer parameters on all nodes in the PAN.

Note **NR** and **NR0** both perform the same function and may be used interchangeably.

Parameter range

0 - 1

Default

N/A

Operational Network Parameters commands

The following read-only AT commands provide information about the attached Zigbee network.

AI (Association Indication)

Read information regarding last node join request. Query **AI** during a join attempt to identify the current state.

You can also enable Verbose Joining (**DC=4**) to debug a join attempt in real-time.

Status code	Meaning
0x00	Successfully formed or joined a Zigbee network.
0x21	Scan found no PANs.
0x22	Scan found no valid PANs based on SC and ID settings.
0x23	Valid PAN found, but joining is currently disabled.
0x24	No joinable beacons were found.
0x27	Join attempt failed.
0x2A	Failed to start coordinator.
0x2B	Checking for existing coordinator.
0x40	Secure Join - Successfully attached to network, waiting for new link key.
0x41	Secure Join - Successfully received new link key from the trust center.
0x44	Secure Join - Failed to receive new link key from the trust center.
0xAB	Attempted to join a device that did not respond.
0xAD	Secure Join - a network security key was not received from the trust center.
0xAF	Secure Join - a preconfigured key is required to join the network.
0xFF	Initialization time; no association status has been determined yet.

Parameter range

0 - 0xFF [read-only]

Default

N/A

OP (Operating Extended PAN ID)

Read the 64-bit extended PAN ID of the attached network. The **OP** value reflects the operating 64-bit extended PAN ID where the device is running.

Parameter range

1 - 0xFFFFFFFFFFFFFFFF

Default

N/A

OI (Operating 16-bit PAN ID)

Read the 16-bit PAN ID of the attached network. The **OI** value reflects the actual 16-bit PAN ID where the device is running.

Parameter range

0 - 0xFFFF [read-only]

Default

N/A

CH (Operating Channel)

Read the channel number of the attached network. Channels are represented as IEEE 802.15.4 channel numbers.

A value of 0 means the device has not joined a PAN and is not operating on any channel.

Parameter range

0, 0x0B - 0x1A (Channels 11 through 26) [read-only]

Default

N/A

NC (Number of Remaining Children)

Read the number of remaining end device children that can join the device. If **NC** returns 0, the device is at capacity and cannot allow any more end device children to join.

Parameter range

0 - 0x14 (20 child devices)

Default

N/A

Security commands

The following AT commands are used to set the initial security parameters.

Note Configure these parameters prior to forming/joining a network. Changing these parameters may cause the node to leave any currently attached network.

EE (Encryption Enable)

Set or read the encryption enable setting of the local device.

Parameter range

0 - 1

Parameter	Description
0	Encryption Disabled
1	Encryption Enabled

Default

0

EO (Encryption Options)

A bitfield that contains advanced encryption options that do not have dedicated AT commands. These options are only applicable when encryption is enabled (**EE = 1**).

Leave unused bits clear so future encryption options are not inadvertently enabled during a firmware update.

Bit field:

Bit	Description
0	Send/receive NWK keys in the clear (unsecure).
1	1 = Centralized Trust Center. 0 = Distributed Trust Center.
2	Use EUI64-hashed link keys (used on centralized trust center only).
3	Emit join notification frames (used on centralized trust center only).
4	Allow joining using well-known default link keys (unsecure).
5 - 15	Reserved.

Parameter range

0 - 0xFF

Default

2

KY (Link Key)

The preconfigured link key used during network formation and joining. This is a write-only parameter.

On a forming node (**CE=1**):

KY acts as the preconfigured global link key of the trust center. If you set **KY** to 0, a random link key will be generated and used to form the network; this requires joining devices to be registered to the trust center using a 0x24 registration API frame.

On a joining node (**CE=0**):

KY is the preconfigured link key used during joining; it must either match the **KY** value set on the trust center or be registered with the trust center via 0x24 registration frame. If you set **KY** to 0 on a joining node, an unsecure well-known default link key will be used. **EO** bit 4 must be set on the trust center for unsecure devices configured in this way to join.

Parameter range

0 - 0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF [write-only]

Default

0

NK (Trust Center Network Key)

The network key used by the trust center to encrypt network traffic. If you set **NK** to 0 (recommended), a random network key is used. **NK** is not used by joining nodes, as the network key is securely obtained as part of the join process. This is a write-only parameter.

If operating with a centralized trust center (**EE=1, EO=2**), **NK** can be changed to rotate the network key, which will be distributed to every device on the network. In a distributed trust center, every router has a copy of the network key, so it cannot be changed after the network is formed.

Parameter range

0 - 0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF [write-only]

Default

0

KT (Trust Center Link Key Registration Timeout)

When registering a joining device using a 0x24 registration API frame, this parameter determines the length of time the key table entry persists before expiring.

This timeout is separate from the **NJ** join time. The join window does not open when a device is registered to the trust center.

Parameter range

0x1E - 0xFFFF (seconds)

Default

0x12C (500 Seconds)

I? (Install Code)

The install code is a random key assigned to every Zigbee 3.0 device at the factory. This install code can be used to securely register a device to a trust center using a 0x24 registration frame and option bit.

For the install code to be used by the joining device, **DC** bit 0 must be set on the joiner.

Parameter range

0 - 0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF [read-only]

Default

Set in the factory.

Zigbee Addressing commands

The following AT commands are used for communication with a Zigbee network after association.

SH (Serial Number High)

Displays the upper 32 bits of the unique IEEE 64-bit extended address assigned to the XBee in the factory.

This value is read-only and it never changes.

Parameter range

0x0013A200 - 0x0013A2FF [read-only]

Default

Set in the factory

SL (Serial Number Low)

Displays the lower 32 bits of the unique IEEE 64-bit RF extended address assigned to the XBee in the factory.

This value is read-only and it never changes.

Parameter range

0x0013A200 - 0x0013A2FF [read-only]

Default

Set in the factory

MY (16-bit Network Address)

Reads the 16-bit network address of the device, which is randomly assigned by the network upon association.

A value of 0xFFFFE means the device has not joined a Zigbee network.

Parameter range

0 - 0xFFFF [read-only]

Default

0 - 0xFFFFE

MP (16-bit Parent Network Address)

Read the 16-bit network address of the device's parent. A value of 0xFFFFE means the device does not have a parent.

Read the 16-bit network address of the device's parent.

If MP=0xFFFFE, the device is not an End Device or is not currently associated with a parent.

Parameter range

0 - 0xFFFFE [read-only]

Default

0xFFFFE

DH (Destination Address High)

Set or read the upper 32 bits of the 64-bit destination address.

When you combine **DH** with **DL**, it defines the 64-bit destination address that the device uses for outgoing data transmissions in transparent mode (**AP=0**) and I/O sampling. This destination address corresponds to the serial number (**SH + SL**) of the target device.

Reserved Zigbee network addresses:

- **0x000000000000FFFF** is a broadcast address.
- **0x0000000000000000** addresses the network coordinator.

Parameter range

0 - 0xFFFFFFFF

Default

0

DL command

Set or display the lower 32 bits of the 64-bit destination address.

When you combine **DH** with **DL**, it defines the 64-bit destination address the device uses for outgoing data transmissions in transparent mode (**AP = 0**) and I/O sampling. This destination address corresponds to the serial number (**SH + SL**) of the target device.

Reserved Zigbee network addresses:

- **0x000000000000FFFF** is a broadcast address.
- **0x0000000000000000** addresses the network coordinator.

Parameter range

0 - 0xFFFFFFFF

Default

0

NI (Node Identifier)

A human-friendly name for the device. Use this string with network discovery commands in order to easily identify devices on the network.

Use the **ND** (Network Discovery) command with this string as an argument to filter network discovery results.

Use the **DN** (Discover Node) command with this string as an argument to resolve the 64-bit address of a node with a matching **NI** string.

Parameter range

A string of case-sensitive ASCII printable characters from 0 to 20 bytes in length. A carriage return or a comma automatically ends the command.

Default

0x20 (an ASCII space character)

NH (Maximum Unicast Hops)

This parameter determines the timeout value used for unicast transmissions from the local device.

The timeout is computed as $(50 * \mathbf{NH}) + 100$ ms. A unicast transmission that does not receive an acknowledgement within the timeout period is reported as a failed transmission.

The default unicast timeout of 1.6 seconds ($\mathbf{NH}=0x1E$) is enough time for data and the acknowledgment to traverse approximately 8 hops.

If \mathbf{BH} (Broadcast Hops) = 0, \mathbf{NH} is used to set the maximum number of hops across the network when sending a broadcast transmission. \mathbf{NH} is also used to set the maximum number of hops for broadcast if $\mathbf{BH} > \mathbf{NH}$.

Parameter range

0 - 0xFF

Default

0x1E

BH (Broadcast Hops)

The number of hops that broadcast transmissions from the local device traverse. Unlike \mathbf{NH} , this parameter is a fixed number of hops and not used in timeout calculations.

Parameter range

0 - 0x1E

Default

0

AR (Aggregate Routing Notification)

Set or read the periodic time for broadcasting aggregate route messages. Setting \mathbf{AR} enables many-to-one routing from the broadcasting device using the concentrator mode determined by \mathbf{DO} Bit 6.

Set \mathbf{AR} to 0x00 to send only one broadcast.

Set \mathbf{AR} to 0xFF to stop sending broadcasts (many-to-one routing will still be enabled until a network reset occurs).

Parameter range

0 - 0xFF (x10 sec)

Default

0xFF (disabled)

DD (Device Type Identifier)

Stores the Digi device type identifier value. Use this value to differentiate between multiple types of devices (for example, sensors or lights).

If you change \mathbf{DD} , \mathbf{RE} (Restore Defaults) will not restore defaults. The only way to get \mathbf{DD} back to default values is to explicitly set it to defaults.

This command can optionally be included in network discovery responses by setting bit 1 of \mathbf{NO} .

Parameter range

0 - 0xFFFFFFFF

Default

0x120000

Note 0x120000 denotes Digi XBee3 hardware.

ND (Network Discovery)

Discovers and reports all of the devices it finds on a network. The command reports the following information after a jittered time delay (based on the local device's **NT** value).

```
PARENT_NETWORK ADDRESS<CR> (2 Bytes) (always 0xFFFE)
DEVICE_TYPE<CR> (1 Byte: 0 = Coordinator, 1 = Router, 2 = End Device)
STATUS<CR> (1 Byte: Reserved)
PROFILE_ID<CR> (2 Bytes)
MANUFACTURER_ID<CR> (2 Bytes)
<CR>
```

After (**NT** * 100) milliseconds, the command ends by returning a <CR>.

If you send **ND** through a local API frame, each network node returns a separate Local or Remote AT Command Response API packet, respectively. The data consists of the previously listed bytes without the carriage return delimiters. The **NI** string ends in a "0x00" null character because it is a variable length.

ND also accepts a **NI** (Node Identifier) as a parameter (optional). In this case, only a device that matches the supplied identifier responds after a jittered time delay. If there are no matching devices, the command returns an "ERROR".

The radius of the **ND** command is set by the **BH** command.

A status code of 1=ERROR will be returned if the transmit queue is full. That means there are already four messages queued for transmission. The application is trying to send messages faster than the device can process the requests. The application may either try again later, be redesigned to send messages at a slower rate, or wait for a Tx Status response for a prior message before attempting to send another.

For more information about the options that affect the behavior of the **ND** command, see [NO \(Network Discovery Options\)](#).

Parameter range

20-byte printable ASCII string

Default

N/A

DN (Discover Node)

Resolves an **NI** (Node identifier) string to a physical address (case sensitive).

The following events occur after **DN** discovers the destination node:

When **DN** is sent in Command mode:

1. The device sets **DL** and **DH** to the address of the device with the matching **NI** string.
2. The receiving device returns OK (or ERROR).
3. The device exits Command mode to allow for immediate communication. If an ERROR is received, then Command mode does not exit.

When **DN** is sent as a local [AT Command Frame - 0x08](#):

1. The receiving device returns the 16-bit network and 64-bit extended addresses in an API Command Response frame..
2. If there is no response from a module within (**NT** * 100) milliseconds or you do not specify a parameter (by leaving it blank), the receiving device returns an ERROR message.

Parameter range

Up to 20-byte printable ASCII string

Default

N/A

NT (Node Discover Timeout)

Sets or displays the amount of time a base node waits for responses from other nodes when using the **ND** (Node Discover) command.

When you issue the **ND** command, the transmission includes the **NT** value to provide all remote devices with a response timeout. Remote devices wait a random time, less than **NT**, before sending their response to avoid collisions.

Parameter range

0x20 - 0xFF (x 100 ms)

Default

0x3C (6 seconds)

NO (Network Discovery Options)

A bitfield that contains advanced network discovery options that do not have dedicated AT commands. These options only affect the behavior of the local device when you issue an **ND** command or when sending a node identification.

Parameter range

0 - 3

Option	Description
0	Append the DD (Digi Device Identifier) value to ND responses and node identification frames.
1	Local device sends ND response when the ND is issued.

Default

0x0

NP (Maximum Packet Payload Bytes)

Reads the maximum number of RF payload bytes that you can send in a transmission based on current parameter settings.

Using APS encryption (API transmit option bit enabled), reduces the maximum payload size by 9 bytes.

Using source routing (**AR** < 0xFF), further reduces the maximum payload size depending on how many hops are traversed.

Note **NP** returns a hexadecimal value. For example, if **NP** returns 0x54, this is equivalent to 84 bytes.

Parameter range

[read-only]

Default

N/A

Zigbee addressing commands

The following AT commands adjust the advanced communication settings that affect outgoing data transmissions.

TO (Transmit Options)

The bitfield that configures the advanced options used for outgoing data transmissions for a device operating in transparent mode (**AP**=0).

When operating in API mode, if the Transmit Options field in the API frame is 0, the **TO** parameter value will be used instead.

Parameter range

0 - 0xFF

Bit field:

Unused bits must be set to 0. These bits may be logically ORed together:

Bit	Meaning
0	Disabled retries and route repair.
5	Enable APS end-to-end encryption (if EE = 1).
6	Use extended timeout.

Default

0

SE (Source Endpoint)

Sets or displays the application layer source endpoint value used for data transmissions.

This command only affects outgoing transmissions in transparent mode (**AP**=0).

0xE8 is the Digi data endpoint used for outgoing data transmissions.

0xE6 is the Digi device object endpoint used for configuration and commands.

Parameter range

0 - 0xFF

Default

0xE8

DE (Destination Endpoint)

Sets or displays the application layer destination endpoint used for data transmissions.

This command only affects outgoing transmissions in transparent mode (**AP=0**).

0xE8 is the Digi data endpoint used for outgoing data transmissions.

0xE6 is the Digi device object endpoint used for configuration and commands.

Parameter range

0 - 0xFF

Default

0xE8

CI (Cluster ID)

Sets or displays the application layer Cluster ID value used for data transmissions.

This command only affects outgoing transmissions in transparent mode (**AP = 0**).

0x11 is a transparent data cluster ID.

0x12 is a loopback cluster ID.

Parameter range

0 - 0xFFFF

Default

0x11 (Transparent data cluster ID)

RF interfacing commands

The following AT commands affect the RF interface of the device.

PL (TX Power Level)

Sets or displays the power level at which the device transmits conducted power.

Note If operating on channel 26 (**CH = 0x1A**), output power will be capped and cannot exceed 8 dBm regardless of the **PL** setting.

Parameter range

0 - 4

Setting	XBee3-PRO	XBee3 non-PRO
0	-5 dBm	-5 dBm
1	+3 dBm	-1 dBm
2	+8 dBm	+2 dBm
3	+15 dBm	+5 dBm
4	+19 dBm	+8 dBm

Default

4

PP (Power at PL4)

Read the maximum allowed dBm power level when device is configured with **PL = 4**.

Use this command to determine if the module is a PRO or non-PRO variant. The value the command returns will be in hex representation (PRO = **0x14** and Non-PRO = **0x8**).

Parameter range

0x08 - 0x14 [read-only]

Default

N/A

SC (Scan Channels)

The channels used when an active scan is performed by the local device.

An active scan is performed any time a network is formed or prior to a join attempt. You can force an active scan by issuing an **AS** command.

Parameter range

1 - 0xFFFF (bit field)

Bit field mask:

Bit	IEEE 802.15.4 channel
0	11
1	12
2	13
3	14
4	15
5	16
6	17

Bit	IEEE 802.15.4 channel
7	18
8	19
9	20
10	21
11	22
12	23
13	24
14	25
15	26

Note Avoid channel 26. The output power is capped at 8 dBm on this channel.

Default

0x7FFF (channels 11 through 25)

SD (Scan Duration)

Sets or displays the length of time the device will linger on a channel during an active scan.

Scan Time is measured as:

$$([\# \text{ of channels to scan}] * (2 \wedge \text{SD}) * 15.36 \text{ ms}) + (38 \text{ ms} * [\# \text{ of channels to scan}]) + 20 \text{ ms}$$

Use the **SC** (Scan Channels) command to set the number of channels to scan.

Note SD influences the time the MAC listens for beacons or runs an energy scan on a given channel. The **SD** time is not an accurate estimate of the router/end device joining time requirements. Zigbee joining includes additional overhead comprising beacon processing on each channel, and sending a join request that extends the actual joining time.

Parameter range

0 - 7 (exponent)

Default

3

AS (Active Scan)

Forces an active scan of the neighborhood for beacon responses. The **AS** command cannot be issued remotely.

An Active scan returns a multi-line response with each field separated by a carriage return:

AS_type – unsigned byte = Always returns 2, indicating the protocol is Zigbee

Channel – unsigned byte

PAN – unsigned word in big endian format

Extended PAN – eight unsigned bytes in bit endian format

Allow Join – unsigned byte – 1 indicates join is enabled, 0 that it is disabled

Stack Profile – unsigned byte

LQI – Link Quality Indicator - unsigned byte, higher values are better

RSSI – Relative Signal Strength Indicator - signed byte, lower values are better

Each field in the AS response is separated by a carriage return (0x0D character).

An additional carriage return separates multiple beacons.

Two additional carriage returns indicate the end of the Active Scan.

If using API Mode, no <CR>'s are returned and a separate response frame is generated for each PanDescriptor. For more information, see [Operate in API mode](#).

Parameter range

N/A

Default

N/A

ED (Energy Detect)

Measures the detected energy on each IEEE 802.15.4 channel.

In Transparent mode (**AP**=0), a comma follows each value with the list ending with a carriage return.

The values returned reflect the detected energy level in units of -dBm. Convert an **ED** response of 49, 3A, and so on, to decimal to become -73 dBm, -58 dBm, and so on.

Parameter range

1 - 0xFF (x1 ms)

Default

0x10 (16 ms)

DB command

This command reports the received signal strength of the last received RF data packet or APS acknowledgment. The **DB** command only indicates the signal strength of the last hop. It does not provide an accurate quality measurement for a multihop link.

The **DB** command value is measured in -dBm. For example, if **DB** returns 0x50, then the RSSI of the last packet received was -80 dBm. Set **DB** to 0 to clear the current value.

Parameter range

0 - 0xFF

Default

N/A

Serial interfacing commands

The following commands affect the UART serial interface.

BD (UART Baud Rate)

This command configures the serial interface baud rate for communication between the UART port of the device and the host.

The device interprets any value between 0x12C and 0x0EC400 as a custom baud rate. Custom baud rates are not guaranteed and the device attempts to find the closest achievable baud rate. After setting a non-standard baud rate, query **BD** to find the actual operating baud rate before applying changes.

The following table provides some example **BD** parameters sent versus the parameters stored.

Parameter range

Standard baud rates: 0x0 - 0x0A

Non-standard baud rates: 0x12C - 0x0EC400

Parameter	Description
0x0	1200 baud
0x1	2400 baud
0x2	4800 baud
0x3	9600 baud
0x4	19200 baud
0x5	38400 baud
0x6	57600 baud
0x7	115200 baud
0x8	230,400 baud
0x9	460,800 baud
0xA	921,600 baud

Default

0x03 (9600 baud)

NB (Parity)

Set or read the serial parity settings for UART communications.

Parameter range

0 - 2

Parameter	Description
0	No parity
1	Even parity
2	Odd parity

Default

0

SB (Stop Bits)

Sets or displays the number of stop bits for UART communications.

Parameter range

0 - 1

Parameter	Configuration
0	One stop bit
1	Two stop bits

Default

0

AP (API Enable)

Determines the API mode for the UART interface.

Parameter range

0 - 2

Parameter	Description
0	API disabled (operate in Transparent mode)
1	API enabled
2	API enabled (with escaped control characters)

Default

0

AO (API Options)

Configure the serial output options for received API frames. The current options select the type of receive API frame to send out the UART for received RF data packets.

Leave unused bits clear so future API options are not inadvertently enabled during a firmware update.

Bit field

Bit	Description
0	0 = Native API output (0x90 frame type). 1 = Explicit API output (0x91 frame type).

Bit	Description
1	Unsupported ZDO request pass-through.
2	Supported ZDO request pass-through.
3	Binding request pass-through.

Parameter range

0 - 0xFF

Default

0

RO (Packetization Timeout)

Set or read the number of character times of inter-character silence required before transmission begins when operating in Transparent mode. Only use **RO** when the device is operating in Transparent mode (**AP** = 0).

Set **RO** to 0 to transmit characters as they arrive instead of buffering them into one RF packet.

The **RO** command only applies to Transparent mode, it does not apply to API mode.

Parameter range

0 - 0xFF (x character times)

Default

3

D6 (DIO6/RTS)

Sets or displays the DIO6/ $\overline{\text{RTS}}$ configuration (Micro pin 27/SMT pin 29/TH pin 16).

Parameter range

0, 1, 3 - 5

Parameter	Description
0	Disabled
1	$\overline{\text{RTS}}$ flow control
3	Digital input
4	Digital output, low
5	Digital output, high

Default

0

D7 (DIO7/CTS)

Sets or displays the DIO7/ $\overline{\text{CTS}}$ configuration (Micro pin 24/SMT pin 25/TH pin 12).

Parameter range

0, 1, 3 - 7

Parameter	Description
0	Disabled
1	$\overline{\text{CTS}}$ flow control
3	Digital input
4	Digital output, low
5	Digital output, high
6	RS-485 enable, low Tx
7	RS-485 enable, high Tx

Default

1

P3 (DIO13/DOUT Configuration)

Sets or displays the DIO13/DOUT configuration (Micro pin 3/SMT pin 3/TH pin 2).

Parameter range

0, 1, 3 - 5

Parameter	Description
0	Disabled
1	UART DOUT
2	N/A
3	Digital input
4	Digital output, low
5	Digital output, high

Default

1

P4 (DIO14/DIN Configuration)

Sets or displays the DIO14/DIN configuration (Micro pin 4/SMT pin 4/TH pin 3).

Parameter range

0, 1, 3 - 5

Parameter	Description
0	Disabled
1	UART DIN
2	N/A
3	Digital input
4	Digital output, low
5	Digital output, high

Default

1

Command mode options

The following commands affect how [Command mode](#) operates.

CN (Exit Command mode)

Executable command. **CN** immediately exits Command mode and applies pending changes.

Parameter range

N/A

Default

N/A

CT (Command Mode Timeout)

Sets or displays the Command mode timeout parameter. If the local device enters Command mode and does not receive any valid AT commands within this time period, Command mode silently exits.

Parameter range

2 - 0x28F

Default

0x64 (10 seconds)

GT (Guard Times)

Set the required period of silence before and after the command sequence characters of the Command mode sequence, **GT + CC + GT** (including spaces). The period of silence prevents inadvertently entering Command mode if a data stream in Transparent mode includes the **CC** character. For more information, see [Enter Command mode](#).

Parameter range

0x2 - 0xCE4 (x 1 ms)

Default

0x3E8 (one second)

CC (Command Character)

Sets or displays the character value used to break from data mode to Command mode. . The command character must be sent three times in succession while observing the minimum guard time (**GT**) of silence before and after this sequence.

The default value (**0x2B**) is the ASCII code for the plus (+) character. You must enter it three times within the guard time to enter Command mode. To enter Command mode, there is also a required period of silence before and after the command sequence characters of the Command mode sequence (**GT + CC + GT**). The period of silence prevents inadvertently entering Command mode. For more information, see [Enter Command mode](#).

Parameter range

0 - 0xFF

Default

0x2B (the ASCII plus character: +)

MicroPython commands

The following commands relate to using MicroPython on the XBee3 Zigbee RF Module.

PS (Python Startup)

Sets whether or not the XBee3 Zigbee RF Module runs the stored Python code at startup.

Range

0 - 1

Parameter	Description
0	Do not run stored Python code at startup.
1	Run stored Python code at startup.

Default

0

PY (MicroPython Command)

Interact with the XBee3 Zigbee RF Module using MicroPython. **PY** is a command with sub-commands. These sub-commands are arguments to **PY**.

PYC(Code Report)

You can store compiled code in flash using the **Ctrl-F** command from the MicroPython REPL; refer to the [Digi MicroPython Programming Guide](#). The **PYC** sub-command reports details of the stored code. In Command mode, it returns three lines of text, for example:

```
source: 1662 bytes (hash=0xC3B3A813)
bytecode: 619 bytes (hash=0x0900DBCE)
compiled: 2017-05-09T15:49:44
```

The messages are:

- **source**: the size of the source code used to generate the bytecode and its 32-bit hash.
- **bytecode**: the size of bytecode stored in flash and its 32-bit hash. A size of **0** indicates that there is no stored code.
- **compiled**: a compilation timestamp. A timestamp of **2000-01-01T00:00:00** indicates that the clock was not set during compilation.

In API mode, **PYC** returns five 32-bit big-endian values:

- source size
- source hash
- bytecode size
- bytecode hash
- timestamp as seconds since 2000-01-01T00:00:00

PYD (Delete Code)

PYD interrupts any running code, erases any stored code and then does a soft-reboot on the MicroPython subsystem.

PYV (Version Report)

Report the MicroPython version.

PY^ (Interrupt Program)

Sends **KeyboardInterrupt** to MicroPython. This is useful if there is a runaway MicroPython program and you have filled the stdin buffer. You can enter Command mode (**+++**) and send **ATPY^** to interrupt the program.

Default

N/A

BLE commands

The following AT commands are BLE commands.

BL (Bluetooth Address)

BL reports the EUI-48 Bluetooth device address. Due to standard XBee AT Command processing, leading zeroes are not included in the response when in Command mode.

Parameter range

N/A

Default

N/A

BT (Bluetooth Enable)

BT enables or disables the Bluetooth functionality.

Note When Bluetooth is enabled, the XBee3 Zigbee RF Module cannot be in Sleep mode. If the device is configured to allow Sleep mode and you enable Bluetooth, the XBee3 Zigbee RF Module will not enter sleep.

Parameter range

Bit	Description
0	Bluetooth functionality is disabled.
1	Bluetooth functionality is enabled.

Default

0

\$\$ (SRP Salt)

Note You should only use this command if you have already [configured a password](#) on the XBee device and the salt corresponds to the password.

The Secure Remote Password (SRP) Salt is a 32-bit number used to create an encrypted password for the XBee3 Zigbee RF Module. Use the **\$\$** command in conjunction with the **\$V**, **\$W**, **\$X**, and **\$Y** verifiers. Together, the command and the verifiers authenticate the client for the BLE API Service without storing the XBee password on the XBee3 Zigbee RF Module.

Configure the salt in the **\$\$** command. In the **\$V**, **\$W**, **\$X**, and **\$Y** verifiers, you specify the 128-byte verifier value, where each command represents 32 bytes of the total 128-byte verifier value.

Note The XBee3 Zigbee RF Module does not allow for **0** to be valid salt. If the value is **0**, SRP is disabled and you are not able to authenticate using Bluetooth.

Parameter range

0 - FFFFFFFF

Default

0

\$V, \$W, \$X, \$Y commands (SRP Salt verifier)

Use the **\$V**, **\$W**, **\$X**, and **\$Y** verifiers in conjunction with [\\$\\$ \(SRP Salt\)](#) to create an encrypted password for the XBee3 Zigbee RF Module. Together, **\$\$** and the verifiers authenticate the client for the BLE API Service without storing the XBee password on the XBee device.

Configure the sale with the **\$\$** command. In the **\$V**, **\$W**, **\$X**, and **\$Y** verifiers, you specify the 128-byte verifier value, where each command represents 32 bytes of the total 128-byte verifier value.

Parameter range

0 - FFFFFFFF

Default

0

Sleep commands

The following commands enable and configure the low power sleep modes of the device.

SM (Sleep Mode)

Sets or displays the sleep mode of the device.

When **SM** > 0, the device operates as an end device. However, **CE** must be 0 before **SM** can be set to a value greater than 0 to change the device to an end device. Changing a device from a router to an end device (or vice versa) forces the device to leave the network and attempt to join as the new device type when changes are applied.

Parameter range

0, 1, 4, 5

Parameter	Description
0	Sleep disabled (router)
1	Pin hibernate
2	N/A
3	N/A
4	Cyclic sleep enabled
5	Cyclic sleep, pin wake

Default

0

SP (Cyclic Sleep Period)

Sets the duration of sleep time for the end device, up to 28 seconds. Use the **SN** command to extend the sleep time past 28 seconds.

On the parent, this value determines how long the parent buffers a message for the sleeping end device. Set the value to at least equal to the longest **SP** time of any child end device.

Parameter range

0x20 - 0xAF0 x 10 ms (Quarter second resolution)

Default

0x20

ST (Cyclic Sleep Wake Time)

Sets or displays the wake time of a cyclically sleeping end device after receiving serial or RF data.

The wake timer resets each time the device receives serial or RF data. Once the timer expires, an end device may enter low power operation.

Parameter range

1 - 0xFFFF (x 1 ms)

Default

0x1388 (5 seconds)

SN (Number of Cycles Between ON_SLEEP)

Set or read the number of sleep periods value. This command controls the number of sleep periods that must elapse between assertions of the ON_SLEEP line during the wake time if no RF data is waiting for the end device. This command allows a host application to sleep for an extended time if no RF data is present.

Parameter range

1 - 0xFFFF

Default

1

SO (Sleep Options)

A bitfield that contains advanced sleep options that do not have dedicated AT commands.

Leave unused bits clear so future sleep options are not inadvertently enabled during a firmware update.

Parameter range

0 - 0xFF

Bit	Option
0	Reserved.
1	Wake for the entire ST time per wake period.
2	Enable extended cyclic sleep (sleep for the entire SN * SP time, possible data loss).

Default

0

WH (Wake Host Delay)

Sets or displays the wake host timer value. You can use WH to give a sleeping host processor sufficient time to power up after the device asserts the ON_SLEEP line.

If you set **WH** to a non-zero value, this timer specifies a time in milliseconds that the device delays after waking from sleep before sending data out the UART or transmitting an I/O sample. If the device receives serial characters, the **WH** timer stops immediately.

Parameter range

0 - 0xFFFF (x 1 ms)

Default

0

PO command

Set or read the end device poll rate.

Setting this to 0 (default) enables polling at 100 ms (default rate), advancing in 10 ms increments.

Adaptive polling may allow the end device to poll more rapidly for a short time when receiving RF data.

Parameter range

0 - 0x3E8 (x 10 ms)

Default

0

SI command

Executable command. Causes a cyclic sleep device to sleep immediately rather than wait for the **ST** timer to expire.

Note If you issue this command in Command mode, the module remains in Command mode until the **CT** timer expires or you issue a **CN** command.

Parameter

N/A

Default

N/A

I/O settings commands

The following commands configure the various I/O lines available on the XBee3 Zigbee RF Module.

D0 (DIO0/AD0/Commissioning Button Configuration)

Sets or displays the DIO0/AD0/CB configuration (Micro pin 31/SMT pin 33/TH pin 20).

Parameter range

0 - 5

Parameter	Description
0	Disabled
1	Commissioning Pushbutton
2	ADC
3	Digital input
4	Digital output, low
5	Digital output, high

Default

1

D1 (AD1/DIO1/TH_SPI_ATTN Configuration)

Sets or displays the DIO1/AD1 configuration (Micro pin 30/SMT pin 32/TH pin 19).

Parameter range

SMT/MMT: 0, 2 - 5

TH: 0 - 5

Parameter	Description
0	Disabled
1	SPI_ATTN for the through-hole device N/A for the surface-mount device
2	ADC
3	Digital input
4	Digital output, low
5	Digital output, high

Default

0

D2 (DIO2/AD2/TH_SPI_CLK Configuration)

Sets or displays the DIO2/AD2 configuration (Micro pin 29/SMT pin 31/TH pin 18).

Parameter range

SMT/MMT: 0, 2 - 5

TH: 0 - 5

Parameter	Description
0	Disabled
1	SPI_CLK for through-hole devices N/A for surface-mount devices
2	ADC
3	Digital input
4	Digital output, low
5	Digital output, high

Default

0

D3 (DIO3/AD3/TH_SPI_SSEL Configuration)

Sets or displays the DIO3/AD3 configuration (Micro pin 28/SMT pin 30/TH pin 17).

Parameter range

SMT/MMT: 0, 2 - 5

TH: 0 - 5

Parameter	Description
0	Disabled
1	SPI_SSEL for the through-hole device N/A for surface-mount device
2	ADC
3	Digital input
4	Digital output, low
5	Digital output, high

Default

0

D4 (DIO4/TH_SPI_MOSI Configuration)

Sets or displays the DIO4 configuration (Micro pin 23/SMT pin 24/TH pin 11).

Parameter range

SMT/MMT: 0, 3 - 5

TH: 0, 1, 3 - 5

Parameter	Description
0	Disabled
3	Digital input
4	Digital output, low
5	Digital output, high

Default

0

D5 (DIO5/Associate Configuration)

Sets or displays the DIO5 configuration (Micro pin 26/SMT pin 28/TH pin 15).

Parameter range

0, 1, 3 - 5

Parameter	Description
0	Disabled

Parameter	Description
1	Associate LED indicator - blinks when associated
3	Digital input
4	Digital output, default low
5	Digital output, default high

Default

1

D8 (DIO8/DTR/SLP_RQ)

Sets or displays the DIO8/ $\overline{\text{DTR}}$ /SLP_RQ configuration (Micro pin 9/SMT pin 10/TH pin 9).

Parameter range

0, 1, 3 - 5

Parameter	Description
0	Disabled
1	$\overline{\text{DTR}}$ /Sleep Request (used with pin hibernate and cyclic sleep with pin wake)
3	Digital input
4	Digital output, low
5	Digital output, high

Default

1

D9 (DIO9/ON_SLEEP)

Sets or displays the DIO9/ON_ $\overline{\text{SLEEP}}$ configuration (Micro pin 25/SMT pin 26/TH pin 13).

Parameter range

0, 1, 3 - 5

Parameter	Description
0	Disabled
1	Awake/ $\overline{\text{SLEEP}}$ indicator
3	Digital input
4	Digital output, low
5	Digital output, high

Default

1

P0 (DIO10/RSSI Configuration)

Sets or displays the DIO10/RSSI configuration (Micro pin 7/SMT pin 7/TH pin 6).

Parameter range

0 - 5

Parameter	Description
0	Disabled
1	RSSI PWM output
2	PWM0 output
3	Digital input
4	Digital output, low
5	Digital output, high

Default

1

P1 (DIO11 Configuration)

Sets or displays the DIO11 configuration (Micro pin 8/SMT pin 8/TH pin 7).

Parameter range

0, 2 - 5

Parameter	Description
0	Disabled
1	N/A
2	PWM1 output. M1 (PWM1 Duty Cycle) or I/O line passing control the value.
3	Digital input
4	Digital output, low
5	Digital output, high

Default

0

P2 (DIO12/TH_SPI_MISO Configuration)

Sets or displays the DIO12 configuration (Micro pin 5/SMT pin 5/TH pin 4).

Parameter range

SMT/MMT: 0, 3 - 5

TH: 0, 1, 3 - 5

Parameter	Description
0	Disabled
1	SPI_MISO for the through-hole device N/A for the surface-mount and micro device
3	Digital input
4	Digital output, low
5	Digital output, high

Default

0

P5 (DIO15/SPI_MISO Configuration)

Sets or displays the DIO15 configuration (Micro pin 16/SMT pin 17/TH Pin N/A).

Note The DIO15 configuration is not available with the XBee3 through-hole module.

Parameter range

0, 4, 5

Parameter	Description
0	Disabled
1	SPI_MISO
4	Digital output, low
5	Digital output, high

Default

0

P6 (DIO16/SPI_MOSI Configuration)

Sets or displays the DIO16 configuration (Micro pin 15/SMT pin 16/TH Pin N/A).

Note The DIO16 configuration is not available with the XBee3 through-hole module.

Parameter range

0, 4, 5

Parameter	Description
0	Disabled
1	SPI_MOSI
4	Digital output, low
5	Digital output, high

Default

0

P7 (DIO17/SPI_SSEL Configuration)

Sets or displays the DIO17 configuration (Micro pin 14/SMT pin 15/TH Pin N/A).

Note The DIO17 configuration is not available with the XBee3 through-hole module.

Parameter range

0, 4, 5

Parameter	Description
0	Disabled
1	SPI_SSEL
4	Digital output, low
5	Digital output, high

Default

0

P8 (DIO18/SPI_CLK Configuration)

Sets or displays the DIO18 configuration (Micro pin 13/SMT pin 14/TH Pin N/A).

Note The DIO18 configuration is not available with the XBee3 through-hole module.

Parameter range

0, 4, 5

Parameter	Description
0	Disabled
1	SPI_CLK
4	Digital output, low
5	Digital output, high

Default

0

P9 (DIO19/SPI_ATTN Configuration)

Sets or displays the DIO19 configuration (Micro pin 11/SMT pin 12/TH Pin N/A).

Note The DIO19 configuration is not available with the XBee3 through-hole module.

Parameter range

0, 4, 5

Parameter	Description
0	Disabled
1	SPI_ATTN
4	Digital output, low
5	Digital output, high

Default

0

PR (Pull-up/Down Resistor Enable)

The bit field that configures the internal pull-up resistor status for the I/O lines.

- If you set a **PR** bit to 1, it enables the pull-up/down resistor
- If you set a **PR** bit to 0, it specifies no internal pull-up/down resistor.

PR and **PD** only affect lines that are configured as digital inputs (**3**) or disabled (**0**).

The following table defines the bit-field map for **PR** and **PD** commands.

Bit	I/O line	Micro pin	Surface-mount pin	Through-hole pin
0	DIO4	23	24	11
1	DIO3	28	30	17
2	DIO2	29	31	18
3	DIO1	30	32	19
4	DIO0	31	33	20
5	DIO6	27	29	16
6	DIO8	9	10	9
7	DIO14	4	4	3

Bit	I/O line	Micro pin	Surface-mount pin	Through-hole pin
8	DIO5	26	28	15
9	DIO9	25	26	13
10	DIO12	5	5	4
11	DIO10	7	7	6
12	DIO11	8	8	7
13	DIO7	24	25	12
14	DIO13	3	3	2
15	DIO15	16	17	N/A
16	DIO16	15	16	N/A
17	DIO17	14	15	N/A
18	DIO18	13	14	N/A
19	DIO19	11	12	N/A

Parameter range (SMT/Micro)

0 - 0xFFFF (bit field)

Default (SMT/Micro)

0xFFFF

Parameter range (TH)

0 - 0x7FFF (bit field)

Default (TH)

0x7FFF

PD (Pull Up/Down Direction)

The resistor pull direction bit field (1 = pull-up, 0 = pull-down) for corresponding I/O lines that are set by the **PR** command.

If the bit is set, the device uses an internal pull-up resistor. If it is clear, the device uses an internal pull-down resistor. See the **PR** command for the bit order.

See [PR \(Pull-up/Down Resistor Enable\)](#) for the bit mappings.

Parameter range (SMT/Micro)

0 - 0xFFFF (bit field)

Default (SMT/Micro)

0xFFFF

Parameter range (TH)

0 - 0x7FFF (bit field)

Default (TH)

0x7FFF

M0 (PWM0 Duty Cycle)

The duty cycle of the PWM0 line (Micro pin 7/SMT pin 7/TH pin 6).

If [IA \(I/O Input Address\)](#) is set correctly and [P0 \(DIO10/RSSI Configuration\)](#) is configured as PWM0 output, incoming AD0 samples automatically modify the PWM0 value. See [PT \(PWM Output Timeout\)](#).

To configure the duty cycle of PWM0:

1. Enable PWM0 output (**P0** = 2).
2. Change **M0** to the desired value.
3. Apply settings (use **CN** or **AC**).

The PWM period is 64 μ s and there are 0x03FF (1023 decimal) steps within this period. When **M0** = 0 (0% PWM), 0x01FF (50% PWM), 0x03FF (100% PWM), and so forth.

Parameter range

0 - 0x3FF

Default

0

M1 (PWM1 Duty Cycle)

If [IA \(I/O Input Address\)](#) is set correctly and [P1 \(DIO11 Configuration\)](#) is configured as PWM1 output, incoming AD0 samples automatically modify the PWM1 value. See [PT \(PWM Output Timeout\)](#).

To configure the duty cycle of PWM1:

1. Enable PWM1 output (**P1** = 2).
2. Change **M1** to the desired value.
3. Apply settings (use **CN** or **AC**).

The PWM period is 64 μ s and there are 0x03FF (1023 decimal) steps within this period. When **M1** = 0 (0% PWM), 0x01FF (50% PWM), 0x03FF (100% PWM), and so forth.

Parameter range

0 - 0x3FF

Default

0

LT (Associate LED Blink Time)

Set or read the Associate LED blink time. If you use [D5 \(DIO5/Associate Configuration\)](#) to enable the Associate LED functionality (DIO5/Associate pin), this value determines the on and off blink times for the LED when the device has joined the network.

If **LT** = 0, the device uses the default blink rate: 500 ms for a sleep coordinator, 250 ms for all other nodes.

If **LT** = 0, the device uses the default blink rate of 250 ms.

For all other **LT** values, the firmware measures **LT** in 10 ms increments.

Parameter range

0, 0xA - 0xFF (x 10 ms)

Default

0

RP (RSSI PWM Timer)

The PWM timer expiration in 0.1 seconds. **RP** sets the duration of pulse width modulation (PWM) signal output on the RSSI pin. The signal duty cycle updates with each received packet and shuts off when the timer expires.

When **RP** = **0xFF**, the output is always on.

Parameter range

0 - 0xFF (x 100 ms), 0xFF

Default

0x28 (four seconds)

I/O sampling commands

The following AT commands enable or adjust I/O sampling from the local device.

IR (I/O Sample Rate)

Determines the I/O sample rate used to generate outgoing I/O sample data. When the IR value is greater than 0, the device samples and transmits all enabled digital I/O and ADCs every **IR** milliseconds. I/O Samples transmit to the address specified by **DH +DL**.

At least one I/O line must be configured as an input or explicit output for samples to be generated.

Parameter range

0, 0x32 - 0xFFFF (ms)

Default

0

IC (Digital Change Detection)

The bit field that configures which digital I/O pins should be monitored for digital change detection. If the device detects a change on an enabled digital I/O pin, it immediately transmits a digital I/O sample to the address specified by **DH +DL**.

Change Detect is edge-triggered and must occur while the device is awake. If the level transition occurs during a sleep period, the device will not see a change.

Bit field

Bit	I/O line	Device pin
0	DIO0	Micro pin 31/SMT pin 33/TH pin 20
1	DIO1	Micro pin 30/SMT pin 32/TH pin 19
2	DIO2	Micro pin 29/SMT pin 31/TH pin 18
3	DIO3	Micro pin 28/SMT pin 30/TH pin 17
4	DIO4	Micro pin 23/SMT pin 24/TH pin 11
5	DIO5	Micro pin 26/SMT pin 28/TH pin 15
6	DIO6	Micro pin 27/SMT pin 29/TH pin 16
7	DIO7	Micro pin 24/SMT pin 25/TH pin 12
8	DIO8	Micro pin 9/SMT pin 10/TH pin 9
9	DIO9	Micro pin 25/SMT pin 26/TH pin 13
10	DIO10	Micro pin 7/SMT pin 7/TH pin 6
11	DIO11	Micro pin 8/SMT pin 8/TH pin 7

Parameter range

0 - 0xFFFF

Default

0

AV (Analog Voltage Reference)

The analog voltage reference used for A/D sampling.

Parameter range

0 - 2

Parameter	Description
0	1.25 V reference
1	2.5 V reference
2	VDD reference

Default

0

IS (Force Sample)

Immediately forces an I/O sample to be generated. If you issue the command to the local device, the sample data is sent out the local serial interface. If sent remotely, the sample data is returned as a [AT](#)

Command Response frame - 0x88.

If the device receives ERROR as a response to an **IS** query, there are no valid I/O lines to sample.

Parameter range

N/A

Default

N/A

V+ (Supply Voltage Threshold)

Define the supply voltage threshold that appends the supply voltage to outgoing I/O sample frames.

If the measured supply voltage falls below or equal to this threshold, the supply voltage will be appended to outgoing I/O sample frames and set bit 7 of the Analog Channel Mask.

Set **V+** to **0** to not include the supply voltage.

Set **V+** to **1** to always include the supply voltage.

Example

To include a measurement of the supply voltage when it falls below 2.7 V, set **V+** to **2700 = 0xA8A**.

Parameter range

0 - 0xFFFF (in mV)

Default

0

Diagnostic commands

The following read-only commands are diagnostics that provide more information about the device.

VR (Firmware Version)

Reads the firmware version on a device as a 4-digit hex number.

Parameter range

0 - 0xFFFF [read-only]

Default

Set in the firmware

VL (Version Long)

Shows detailed version information including the application build date and time.

Parameter range

Multi-line string [read-only]

Default

N/A

VH (Bootloader Version)

Reads the bootloader version of the device.

Parameter range

N/A

Default

N/A

HV (Hardware Version)

Display the hardware version number of the device.

Parameter range

0 - 0xFFFF [read-only]

Default

Set in firmware

%C (Hardware/Software Compatibility)

Specifies what firmware is compatible with this device's hardware. %C is compared to the to the "compatibility_number" field of the firmware configuration xml file. Firmware with a compatibility number lower than the value returned by %C cannot be loaded onto the board. If an invalid firmware is loaded, the device will not boot until a valid firmware is reloaded.

Parameter range

[read-only]

Default

N/A

%V (Voltage Supply Monitoring)

Reads the voltage on the Vcc pin in mV.

Parameter range

0 - 0xFFFF (in mV) [read only]

Default

N/A

EA (MAC ACK Failure Count)

The number of unicast transmissions that time out awaiting a MAC ACK. This can be up to **RR +1** timeouts per unicast when **RR > 0**.

This count increments whenever a MAC ACK timeout occurs on a MAC-level unicast. When the number reaches **0xFFFF**, the firmware does not count further events.

To reset the counter to any 16-bit unsigned value, append a hexadecimal parameter to the command. This value is volatile (the value does not persist in the device's memory after a power-up sequence).

Parameter range

0 - 0xFFFF

Default

0x0

TP (Temperature)

The current module temperature in degrees Celsius. The temperature is represented in two's complement, as shown in the following example:

1 °C = 0x0001 and -1°C = 0xFFFF

Parameter range

0 - 0xFFFF (Celsius) [read-only]

Default

N/A

CK (Configuration Checksum)

Reads the cyclic redundancy check (CRC) of the current AT command configuration settings to determine if the configuration has changed.

After a firmware update this command may return a different value.

Parameter range

0 - 0xFFFF [read-only]

Default

N/A

FR (Software Reset)

Resets the device. The device responds immediately with an **OK** and performs a reset 100 ms later.

If you issue **FR** while the device is in Command mode, the reset effectively exits Command mode.

Parameter range

N/A

Default

N/A

Memory access commands

This section details the executable commands that provide memory access to the device.

AC (Apply Changes)

This command applies changes to all command parameters configured in Command mode and also applies queued command parameter values set with 0x09 API queued command frames.

Any of the following also applies changes the same as issuing an **AC** command:

- Exiting Command mode with a **CN** command.
- Exiting Command mode via timeout.
- Receiving a 0x08 API command frame.
- Issuing a 0x08 Local AT Command API frame.
- Issuing a remote 0x17 AT Command API frame with option bit 1 set.

Example: Altering the UART baud rate with the **BD** command does not change the operating baud rate until after an **AC** command is received; at this point, the interface immediately changes baud rates.

Parameter range

N/A

Default

N/A

WR (Write)

Immediately writes parameter values to non-volatile flash memory so they persist through a power cycle. Operating network parameters are persistent and do not require a **WR** command for the device to reattach to the network.

Note Once you issue a **WR** command, do not send any additional characters to the device until after you receive the **OK** response. Use the **WR** command sparingly; the device's flash supports a limited number of write cycles.

Parameter range

N/A

Default

N/A

RE (Restore Defaults)

Restore all device parameters to factory defaults but do not apply the parameters.

Parameter range

N/A

Default

N/A

Custom default commands

The following commands are used to assign custom defaults to the device. Send [RE \(Restore Defaults\)](#) to restore custom defaults. You must send these commands as local AT commands, they cannot be set using [Remote AT Command Request frame - 0x17](#).

%F (Set Custom Default)

When **%F** is received, the XBee3 Zigbee RF Module takes the next command received and applies it to both the current configuration and the custom defaults, so that when defaults are restored with [RE \(Restore Defaults\)](#) the custom value is used.

Parameter range

N/A

Default

N/A

!C (Clear Custom Defaults)

Clears all custom defaults. This command does not change the current settings, but only changes the defaults so that [RE \(Restore Defaults\)](#) restores settings to the factory values.

Parameter range

N/A

Default

N/A

R1 (Restore Factory Defaults)

Restores factory defaults, ignoring any custom defaults set using [%F \(Set Custom Default\)](#).

Parameter range

N/A

Default

N/A

API Operation

An alternative to Transparent Operation are Application Programming Interface (API) Operations. API operation requires that the device communicate through a structured interface (that is, data is communicated in frames in a defined order). The API specifies how the device sends and receives commands, command responses, and module status messages using a serial port Data Frame.

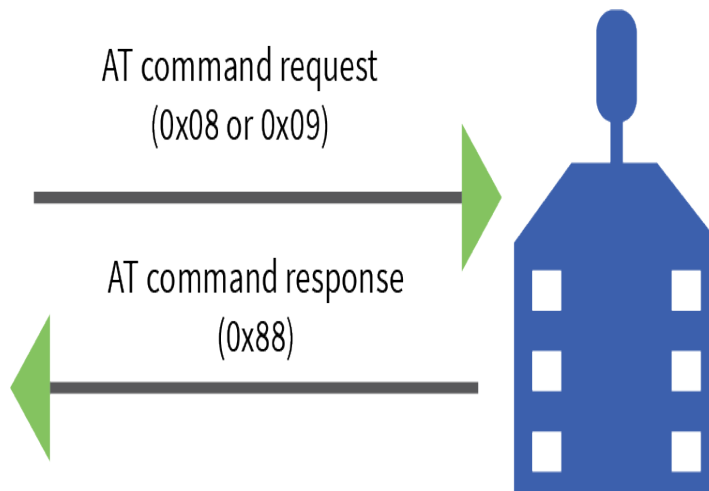
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API serial exchanges

You can use the Frame ID field to correlate between the outgoing frames and associated responses.

AT commands

The following image shows the API frame exchange that takes place at the serial interface when sending an AT command request to read or set a device parameter. You can disable the response by setting the frame ID to 0 in the request.



Transmit and Receive RF data

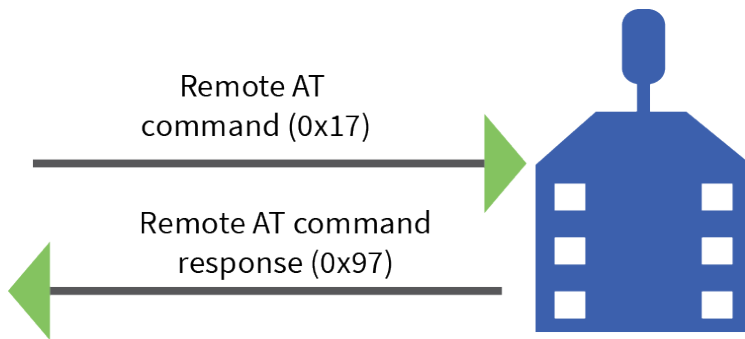
The following image shows the API frames exchange that take place at the UART interface when sending RF data to another device. The transmit status frame is always sent at the end of a data transmission unless the frame ID is set to 0 in the TX request. If the packet cannot be delivered to the destination, the transmit status frame indicates the cause of failure.

The received data frame type (0x90 or 0x91) is determined by the **AO** command.



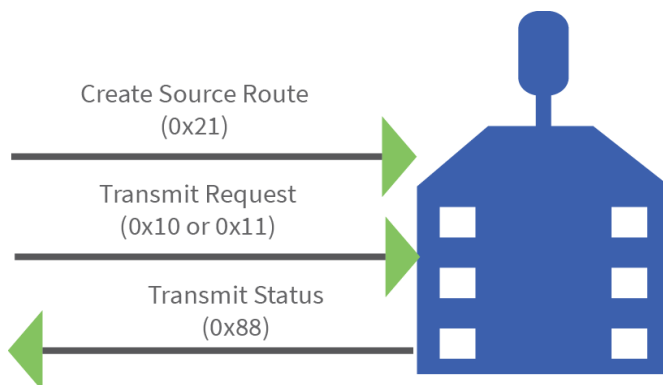
Remote AT commands

The following image shows the API frame exchanges that take place at the serial interface when sending a remote AT command. The device does not send out a remote command response frame through the serial interface if the remote device does not receive the remote command.



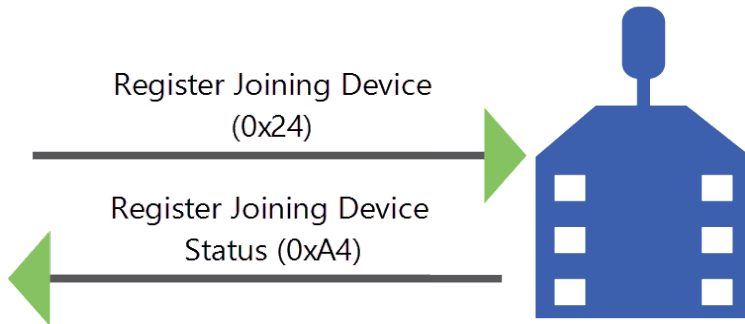
Source routing

The following image shows the API frame exchanges that take place at the serial port when sending a source routed transmission.



Device Registration

The following image shows the API frame exchanges that take place at the serial interface when registering a joining device to a trust center.



API frame format

An API frame consists of the following:

- Start delimiter
- Length
- Frame data
- Checksum

API operation (AP parameter = 1)

This is the recommended API mode for most applications. The following table shows the data frame structure when you enable this mode:

Frame fields	Byte	Description
Start delimiter	1	0x7E
Length	2 - 3	Most Significant Byte, Least Significant Byte
Frame data	4 - number (n)	API-specific structure
Checksum	n + 1	1 byte

Any data received prior to the start delimiter is silently discarded. If the frame is not received correctly or if the checksum fails, the XBee replies with a radio status frame indicating the nature of the failure.

API operation with escaped characters (AP parameter = 2)

Setting API to 2 allows escaped control characters in the API frame. Due to its increased complexity, we only recommend this API mode in specific circumstances. API 2 may help improve reliability if the serial interface to the device is unstable or malformed frames are frequently being generated.

When operating in API 2, if an unescaped 0x7E byte is observed, it is treated as the start of a new API frame and all data received prior to this delimiter is silently discarded. For more information on using this API mode, see the [Escaped Characters and API Mode 2](#) in the Digi Knowledge base.

API escaped operating mode works similarly to API mode. The only difference is that when working in API escaped mode, the software must escape any payload bytes that match API frame specific data, such as the start-of-frame byte (0x7E). The following table shows the structure of an API frame with escaped characters:

Frame fields	Byte	Description	
Start delimiter	1	0x7E	
Length	2 - 3	Most Significant Byte, Least Significant Byte	Characters escaped if needed
Frame data	4 - n	API-specific structure	
Checksum	n + 1	1 byte	

Start delimiter field

This field indicates the beginning of a frame. It is always 0x7E. This allows the device to easily detect a new incoming frame.

Escaped characters in API frames

If operating in API mode with escaped characters (**AP** parameter = 2), when sending or receiving a serial data frame, specific data values must be escaped (flagged) so they do not interfere with the data frame sequencing. To escape an interfering data byte, insert 0x7D and follow it with the byte to be escaped (XORed with 0x20).

The following data bytes need to be escaped:

- 0x7E: start delimiter
- 0x7D: escape character
- 0x11: XON
- 0x13: XOFF

To escape a character:

1. Insert 0x7D (escape character).
2. Append it with the byte you want to escape, XORed with 0x20.

In API mode with escaped characters, the length field does not include any escape characters in the frame and the firmware calculates the checksum with non-escaped data.

Example: escape an API frame

To express the following API non-escaped frame in API operating mode with escaped characters:

Start delimiter	Length	Frame type	Frame Data	Checksum
			Data	
7E	00 0F	17	01 00 13 A2 00 40 AD 14 2E FF FE 02 4E 49 6D	

You must escape the 0x13 byte:

1. Insert a 0x7D.
2. XOR byte 0x13 with 0x20: $13 \oplus 20 = 33$

The following figure shows the resulting frame. Note that the length and checksum are the same as the non-escaped frame.

Start delimiter	Length	Frame type	Frame Data	Checksum
			Data	
7E	00 0F	17	01 00 7D 33 A2 00 40 AD 14 2E FF FE 02 4E 49 6D	

The length field has a two-byte value that specifies the number of bytes in the frame data field. It does not include the checksum field.

Length field

The length field is a two-byte value that specifies the number of bytes contained in the frame data field. It does not include the checksum field.

Frame data

This field contains the information that a device receives or will transmit. The structure of frame data depends on the purpose of the API frame:

Start delimiter	Length		Frame data								Checksum
			Frame type	Data							
1	2	3	4	5	6	7	8	9	...	n	n+1
0x7E	MSB	LSB	API frame type	Data							Single byte

- **Frame type** is the API frame type identifier. It determines the type of API frame and indicates how the Data field organizes the information.
- **Data** contains the data itself. This information and its order depend on the what type of frame that the Frame type field defines.

Multi-byte values are sent big-endian.

Calculate and verify checksums

To test data integrity, the device calculates and verifies a checksum on non-escaped data. To calculate the checksum of an API frame:

1. Add all bytes of the packet, except the start delimiter 0x7E and the length (the second and third bytes).
2. Keep only the lowest 8 bits from the result.
3. Subtract this quantity from 0xFF.

To verify the checksum of an API frame:

1. Add all bytes including the checksum; do not include the delimiter and length.
2. If the checksum is correct, the last two digits on the far right of the sum equal 0xFF.

Example

Consider the following sample data packet: **7E 00 08 08 01 4E 49 58 42 45 45 3B**

Byte(s)	Description
7E	Start delimiter
00 08	Length bytes
08	API identifier
01	API frame ID
4E 49	AT Command
58 42 45 45	Parameter value
3B	Checksum

To calculate the check sum you add all bytes of the packet, excluding the frame delimiter **7E** and the length (the second and third bytes):

7E 00 08 08 **01 4E 49 58 42 45** 45 3B

Add these hex bytes:

$$0x08 + 0x01 + 0x4E + 0x49 + 0x58 + 0x42 + 0x45 + 0x45 = 0x01C4$$

Now take the result of 0x01C4 and keep only the lowest 8 bits which in this example is 0xC4 (the two far right digits). Subtract 0xC4 from 0xFF and you get 0x3B (0xFF - 0xC4 = 0x3B). 0x3B is the checksum for this data packet.

If an API data packet is composed with an incorrect checksum, the XBee3 Zigbee RF Module will consider the packet invalid and will ignore the data.

To verify the check sum of an API packet add all bytes including the checksum (do not include the delimiter and length) and if correct, the last two far right digits of the sum will equal FF.

$$0x08 + 0x01 + 0x4E + 0x49 + 0x58 + 0x42 + 0x45 + 0x45 + 0x3B = 0x01FF$$

Send ZDO commands with the API

Zigbee specifications define Zigbee device objects (ZDOs) as part of the Zigbee device profile. These objects provide functionality to manage and map out the Zigbee network and to discover services on Zigbee devices. ZDOs are typically required when developing a Zigbee product that interoperates in a public profile such as home automation or smart energy, or when communicating with Zigbee devices from other vendors. You can also use the ZDO to perform several management functions such as frequency agility (energy detect and channel changes - Mgmt Network Update Request), discovering routes (Mgmt Routing Request) and neighbors (Mgmt LQI Request), and managing device connectivity (Mgmt Leave and Permit Join Request).

The following table shows some of the more prominent ZDOs with their respective cluster identifier. Each ZDO command has a defined payload. See the *Zigbee device profile* section of the Zigbee specification for details.

ZDO command	Cluster ID
Network Address Request	0x0000
IEEE Address Request	0x0001
Node Descriptor Request	0x0002

ZDO command	Cluster ID
Simple Descriptor Request	0x0004
Active Endpoints Request	0x0005
Match Descriptor Request	0x0006
Mgmt LQI Request	0x0031
Mgmt Routing Request	0x0032
Mgmt Leave Request	0x0034
Mgmt Permit Joining Request	0x0036
Mgmt Network Update Request	0x0038

Use the [Explicit Addressing Command frame - 0x11](#) to send Zigbee device objects commands to devices in the network. Sending ZDO commands with the Explicit Transmit API frame requires some formatting of the data payload field.

When sending a ZDO command with the API, all multiple byte values in the ZDO command (API payload), for example, u16, u32, and 64-bit addresses, must be sent in little endian byte order for the command to be executed correctly on a remote device.

For an API XBee to receive ZDO responses, set [AO \(API Options\)](#) to **1** to enable the explicit receive API frame.

The following table shows how you can use the Explicit API frame to send an “Active Endpoints” request to discover the active endpoints on a device with a 16-bit address of 0x1234.

Frame data fields	Offset	Description
Frame type	3	0x11
Frame ID	4	Identifies the data frame for the host to correlate with a subsequent transmit status. If set to 0 , the device does not send a response out the serial port.
64-bit destination address	5-12	MSB first, LSB last. The 64-bit address of the destination device (big endian byte order). For unicast transmissions, set to the 64-bit address of the destination device, or to 0x0000000000000000 to send a unicast to the coordinator. Set to 0x000000000000FFFF for broadcast.
16-bit destination network address	13	MSB first, LSB last. The 16-bit address of the destination device (big endian byte order). Set to 0xFFFE for broadcast, or if the 16-bit address is unknown.
	14	
Source endpoint	15	Set to 0x00 for ZDO transmissions (endpoint 0 is the ZDO endpoint).
Destination endpoint	16	Set to 0x00 for ZDO transmissions (endpoint 0 is the ZDO endpoint).

Frame data fields	Offset	Description
Cluster ID	17	Set to the cluster ID that corresponds to the ZDO command being sent.
	18	0x0005 = Active Endpoints Request
Profile ID	19-20	Set to 0x0000 for ZDO transmissions (Profile ID 0x0000 is the Zigbee device profile that supports ZDOs).
Broadcast radius	21	Sets the maximum number of hops a broadcast transmission can traverse. If set to 0 , the device sets the transmission radius to the network maximum hops value.
Transmission options	22	All bits must be set to 0.
Data payload	23	The required payload for a ZDO command. All multi-byte ZDO parameter values (u16, u32, 64-bit address) must be sent in little endian byte order.
	24	The Active Endpoints Request includes the following payload: [16-bit NwkAddrOfInterest]
	25	Note The 16-bit address in the API example (0x1234) is sent in little endian byte order (0x3412).

Example

The following example shows how you can use the Explicit API frame to send an “Active Endpoints” request to discover the active endpoints on a device with a 16-bit address of 0x1234.

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x17
Frame type	3	0x11
Frame ID	4	0x01
64-bit destination address	MSB 5	0x00
	6	0x00
	7	0x00
	8	0x00
	9	0x00
	10	0x00
	11	0xFF
	LSB12	0xFF

Frame data fields	Offset	Example
16-bit Destination Network Address	MSB 13	0xFF
	LSB 14	0xFE
Source endpoint	15	0x00
Destination endpoint	16	0x00
Cluster ID	17	0x00
	18	0x05
Profile ID	19	0x00
	20	0x00
Broadcast radius	21	0x00
Transmit options	22	0x00
Data payload - transaction sequence number	23	0x01
Data payload - ZDO payload	24	0x34
	25	0x12
Checksum	29	0xA6

Send Zigbee cluster library (ZCL) commands with the API

The Zigbee cluster library defines a set of attributes and commands (clusters) that can be supported in multiple Zigbee profiles. The ZCL commands are typically required when developing a Zigbee product that will interoperate in a public profile such as home automation or smart energy, or when communicating with Zigbee devices from other vendors. Applications that are not designed for a public profile or for interoperability applications can skip this section.

The following table shows some prominent clusters with their respective attributes and commands.

Cluster (Cluster ID)	Attributes (Attribute ID)	Cluster ID
Basic (0x0000)	Application Version (0x0001) Hardware Version (0x0003) Model Identifier (0x0005)	Reset to defaults (0x00)
Identify (0x0003)	Identify Time (0x0000)	Identify (0x00) Identify Query (0x01)
Time (0x000A)	Time (0x0000) Time Status (0x0001) Time Zone (0x0002)	
Thermostat (0x0201)	Local Temperature (0x0000) Occupancy (0x0002)	Setpoint raise / lower (0x00)

The ZCL defines a number of profile-wide commands that can be supported on any profile, also known as general commands. These commands include the following.

Command (Command ID)	Description
Read Attributes (0x00)	Used to read one or more attributes on a remote device.
Read Attributes Response (0x01)	Generated in response to a read attributes command.
Write Attributes (0x02)	Used to change one or more attributes on a remote device.
Write Attributes Response (0x04)	Sent in response to a write attributes command.
Configure Reporting (0x06)	Used to configure a device to automatically report on the values of one or more of its attributes.
Report Attributes (0x0A)	Used to report attributes when report conditions have been satisfied.
Discover Attributes (0x0C)	Used to discover the attribute identifiers on a remote device.
Discover Attributes Response (0x0D)	Sent in response to a discover attributes command.

Use the [Explicit Addressing Command frame - 0x11](#) to send ZCL commands to devices in the network. Sending ZCL commands with the Explicit Transmit API frame requires some formatting of the data payload field.

When sending a ZCL command with the API, all multiple byte values in the ZCL command (API Payload) (for example, u16, u32, 64-bit addresses) must be sent in little endian byte order for the command to be executed correctly on a remote device.

Note When sending ZCL commands, set the AO command to 1 to enable the explicit receive API frame. This provides indication of the source 64- and 16-bit addresses, cluster ID, profile ID, and endpoint information for each received packet. This information is required to properly decode received data.

The following table shows how the Explicit API frame can be used to read the hardware version attribute from a device with a 64-bit address of 0x0013A200 40401234 (unknown 16-bit address). This example uses arbitrary source and destination endpoints. The hardware version attribute (attribute ID 0x0003) is part of the basic cluster (cluster ID 0x0000). The Read Attribute general command ID is 0x00.

Frame fields	Offset	Description
Frame type	3	
Frame ID	4	Identifies the serial port data frame for the host to correlate with a subsequent transmit status. If set to 0, no transmit status frame will be sent out the serial port.

Frame fields			Offset	Description
64-bit destination address			MSB 5	The 64-bit address of the destination device (big endian byte order). For unicast transmissions, set to the 64-bit address of the destination device, or to 0x0000000000000000 to send a unicast to the coordinator. Set to 0x000000000000FFFF for broadcast.
			6	
			7	
			8	
			9	
			10	
			11	
			LSB 12	
16-bit destination network address			MSB 13	The 16-bit address of the destination device (big endian byte order). Set to 0xFFFE for broadcast, or if the 16-bit address is unknown.
			LSB 14	
Source endpoint			15	Set to the source endpoint on the sending device (0x41 arbitrarily selected).
Destination endpoint			16	Set to the destination endpoint on the remote device (0x42 arbitrarily selected).
Cluster ID			MSB 17	Set to the cluster ID that corresponds to the ZCL command being sent. 0x0000 = Basic Cluster.
			LSB 18	
Profile ID			MSB 19	Set to the profile ID supported on the device (0xD123 arbitrarily selected).
			LSB 20	
Broadcast radius			21	Sets the maximum number of hops a broadcast transmission can traverse. If set to 0, the transmission radius will be set to the network maximum hops value.
Transmit options			22	All bits must be set to 0.
Data payload	ZCL frame header	Frame control	23	Bitfield that defines the command type and other relevant information in the ZCL command. For more information, see the ZCL specification.

Frame fields			Offset	Description
		Transaction sequence number	24	A sequence number used to correlate a ZCL command with a ZCL response. (The hardware version response will include this byte as a sequence number in the response.) The value 0x01 was arbitrarily selected.
		Command ID	25	Since the frame control “frame type” bits are 00, this byte specifies a general command. Command ID 0x00 is a Read Attributes command.
	ZCL payload	Attribute ID	26	The payload for a “Read Attributes” command is a list of Attribute Identifiers that are being read. Note The 16-bit Attribute ID (0x0003) is sent in little endian byte order (0x0300). All multi- byte ZCL header and payload values must be sent in little endian byte order.
			27	0xFF minus the 8 bit sum of bytes from offset 3 to this byte.

Example

In this example, the Frame Control field (offset 23) is constructed as follows:

Name	Bits	Example Value Description
Frame Type	0-1	00 - Command acts across the entire profile.
Manufacturer Specific	2	0 - The manufacturer code field is omitted from the ZCL Frame Header.
Direction	3	0 - The command is being sent from the client side to the server side.
Disable Default Response	4	0 - Default response not disabled.
Reserved	5-7	Set to 0.

For more information, see the *Zigbee Cluster Library* specification.

Frame data fields			Offset	Example
Start delimiter			0	0x7E
Length			MSB 1	0x00
			LSB 2	0x19
Frame type			3	0x11
Frame ID			4	0x01

Frame data fields			Offset	Example
64-bit destination address			MSB 5	0x00
			6	0x13
			7	0xA2
			8	0x00
			9	0x40
			10	0x40
			11	0x12
			LSB12	0x34
16-bit destination network address			MSB 13	0xFF
			LSB 14	0xFE
Source endpoint			15	0x41
Destination endpoint			16	0x42
Cluster ID			MSB 17	0x00
			LSB 18	0x00
Profile ID			MSB 19	0xD1
			LSB 20	0x23
Broadcast radius			21	0x00
Transmit options			22	0x00
Data payload	ZCL frame header	Frame control	23	0x00
		Transaction sequence number	24	0x01
		Command ID	25	0x00
	ZCL payload	Attribute ID	26	0x03
			27	0x00
Checksum			28	0xFA

Send Public Profile Commands with the API

You can use the XBee API using the Explicit Transmit API frame (0x11) to send commands in public profiles such as Smart Energy and Home Automation. Sending public profile commands with the Explicit Transmit API frame requires some formatting of the data payload field. Most of the public profile commands fit into the Zigbee cluster library (ZCL) architecture as described in [Send Zigbee cluster library \(ZCL\) commands with the API](#).

The following table shows how you can use the Explicit API frame to send a demand response and load control message (cluster ID 0x701) in the smart energy profile (profile ID 0x0109) in the revision 14 Smart Energy specification. The device sends a “Load Control Event” message (command ID 0x00) and to a device with 64-bit address of 0x0013A200 40401234 with a 16-bit address of 0x5678. The event starts a load control event for water heaters and smart appliances for a duration of 1 minute, starting immediately.

Note When sending public profile commands, set the **AO** command to 1 to enable the explicit receive API frame. This provides indication of the source 64- and 16-bit addresses, cluster ID, profile ID, and endpoint information for each received packet. This information is required to properly decode received data.

Frame specific data

Frame Fields	Offset	Description
Frame type	3	
Frame ID	4	Identifies the serial port data frame for the host to correlate with a subsequent transmit status. If set to 0, no transmit status frame will be sent out the serial port.
64-bit destination address	MSB 5	The 64-bit address of the destination device (big endian byte order). For unicast transmissions, set to the 64-bit address of the destination device, or to 0x0000000000000000 to send a unicast to the coordinator. Set to 0x000000000000FFFF for broadcast.
	6	
	7	
	8	
	9	
	10	
	11	
16-bit destination network address	MSB 13	The 16-bit address of the destination device (big endian byte order). Set to 0xFFFE for broadcast, or if the 16-bit address is unknown.
	LSB 14	
Source endpoint	15	Set to the source endpoint on the sending device. (0x41 arbitrarily selected).

Frame Fields			Offset	Description
Destination endpoint			16	Set to the destination endpoint on the remote device. (0x42 arbitrarily selected).
Cluster ID			MSB 17	Set to the cluster ID that corresponds to the ZCL command being sent. 0x0701 = Demand response and load control cluster ID
			LSB 18	
Profile ID			MSB 19	Set to the profile ID supported on the device. 0x0109 = Smart Energy profile ID.
			LSB 20	
Broadcast radius			21	Sets the maximum number of hops a broadcast transmission can traverse. If set to 0, the transmission radius will be set to the network maximum hops value.
Transmit options			22	All bits must be set to 0.
Data payload	ZCL frame header	Frame control	23	Bitfield that defines the command type and other relevant information in the ZCL command. For more information, see the ZCL specification.
		Transaction sequence number	24	A sequence number used to correlate a ZCL command with a ZCL response. (The hardware version response will include this byte as a sequence number in the response.) The value 0x01 was arbitrarily selected.
			25	Since the frame control “frame type” bits are 01, this byte specifies a cluster-specific command. Command ID 0x00 in the Demand Response and Load Control cluster is a Load Control Event command. For more information, see the Smart Energy specification.
	ZCL payload - load control event data	Issuer event ID	26	The 4-byte unique identifier. <hr/> Note The 4-byte ID is sent in little endian byte order (0x78563412). <hr/> The event ID in this example (0x12345678) is arbitrarily selected.
			27	
			28	
			29	

Frame Fields			Offset	Description
		Device class	30	This bit encoded field represents the Device Class associated with the Load Control Event. A bit value of 0x0014 enables smart appliances and water heaters. Note The 2-byte bit field value is sent in little endian byte order.
			31	
		Utility enrollment group	32	Used to identify sub-groups of devices in the device-class. 0x00 addresses all groups.
		Start time	33	
			34	
			35	
			36	
		Duration in minutes	37	This 2-byte value must be sent in little endian byte order.
			38	
		Criticality level	39	Indicates the criticality level of the event. In this example, the level is “voluntary”.
		Cooling temperature	40	Requested offset to apply to the normal cooling set point. A value of 0xFF indicates the temperature offset value is not used.
		Heating temperature offset	41	Requested offset to apply to the normal heating set point. A value of 0xFF indicates the temperature offset value is not used.
		Cooling temperature set point	42	Requested cooling set point in 0.01 degrees Celsius. A value of 0x8000 means the set point field is not used in this event.
			43	Note The 0x80000 is sent in little endian byte order.

Frame Fields		Offset	Description
	Heating temperature set point	44	Requested heating set point in 0.01 degrees Celsius. A value of 0x8000 means the set point field is not used in this event.
		45	Note The 0x80000 is sent in little endian byte order.
	Average load adjustment percentage	46	Maximum energy usage limit. A value of 0x80 indicates the field is not used.
	Duty cycle	47	Defines the maximum “On” duty cycle. A value of 0xFF indicates the duty cycle is not used in this event.
	Duty cycle event control	48	A bitmap describing event options.

Example

In this example, the Frame Control field (offset 23) is constructed as follows:

Name	Bits	Example Value Description
Frame Type	0-1	01 - Command is specific to a cluster
Manufacturer Specific	2	0 - The manufacturer code field is omitted from the ZCL Frame Header.
Direction	3	1 - The command is being sent from the server side to the client side.
Disable Default Response	4	0 - Default response not disabled
Reserved	5-7	Set to 0.

For more information, see the Zigbee cluster library specification.

Frame fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x19
Frame type	3	0x11
Frame ID	4	0x01

Frame fields			Offset	Example
64-bit destination address			MSB 5	0x00
			6	0x13
			7	0xA2
			8	0x00
			9	0x40
			10	0x40
			11	0x12
			LSB 12	0x34
16-bit destination network address			MSB 13	0x56
			LSB 14	0x78
Source endpoint			15	0x41
Destination endpoint			16	0x42
Cluster ID			MSB 17	0x07
			LSB 18	0x01
Profile ID			MSB 19	0x01
			LSB 20	0x09
Broadcast radius			21	0x00
Transmit options			22	0x00

Frame fields			Offset	Example
Data payload	ZCL frame header	Frame control	23	0x09
		Transaction sequence number	24	0x01
			25	0x00
	ZCL payload - load control event data	Issuer event ID	26	0x78
			27	0x56
			28	0x34
			29	0x12
		Device class	30	0x14
			31	0x00
		Utility enrollment group	32	0x00
		Start time	33	0x00
			34	0x00
			35	0x00
			36	0x00
		Duration in Minutes	37	0x01
			38	0x00
		Criticality level	39	0x04
		Cooling temperature	40	0xFF
		Heating temperature offset	41	0xFF
		Cooling temperature set point	42	0x00
			43	0x80
		Heating temperature set point	44	0x00
			45	0x80
		Average load adjustment percentage	46	0x80
		Duty cycle	47	0xFF
		Duty cycle event control	48	0x00
Checksum		49	0x5B	

Frame descriptions

The following sections describe the API frames.

AT Command Frame - 0x08	232
AT Command - Queue Parameter Value frame - 0x09	234
Transmit Request frame - 0x10	236
Explicit Addressing Command frame - 0x11	239
Remote AT Command Request frame - 0x17	242
Create Source Route - 0x21	244
Register Joining Device - 0x24	246
BLE Unlock API frame - 0x2C	250
User Data Relay frame - 0x2D	253
AT Command Response frame - 0x88	255
Modem Status frame - 0x8A	257
Transmit Status frame - 0x8B	258
Receive Packet frame - 0x90	260
Explicit Rx Indicator frame - 0x91	262
I/O Data Sample Rx Indicator frame - 0x92	265
Node Identification Indicator frame - 0x95	268
Remote Command Response frame - 0x97	271
Extended Modem Status frame - 0x98	273
Route Record Indicator - 0xA1	280
Register Device Status - 0xA4	281
Many-to-One Route Request Indicator - 0xA3	283
BLE Unlock Response frame - 0xAC	284
User Data Relay Output - 0xAD	284

AT Command Frame - 0x08

Description

Use this frame to query or set command parameters on the local device. This API command applies changes after running the command. You can query parameter values by sending the [AT Command Frame - 0x08](#) with no parameter value field (the two-byte AT command is immediately followed by the frame checksum). Any parameter that is set with this frame type will apply the change immediately. If you wish to queue multiple parameter changes and apply them later, use the [AT Command - Queue Parameter Value frame - 0x09](#) instead.

When a command is queried, a [AT Command Response frame - 0x88](#) is populated with the parameter value that is currently set on the device.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x08
Frame ID	4	Identifies the data frame for the host to correlate with a subsequent response . If set to 0, the device does not send a response.
AT command	5-6	Command name: two ASCII characters that identify the AT command.
Parameter value	7-n	If present, indicates the requested parameter value to set the given register. If no characters are present, it queries the register.

Examples

The following example illustrates an AT Command frame where the device's **NJ** parameter value is queried.

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x0
Frame type	3	0x08
Frame ID	4	0x52

Frame data fields	Offset	Example
AT command	5	0x42 (B)
	6	0x44 (D)
Parameter value (optional)		
Checksum	7	0x0D

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x06
Frame type	3	0x08
Frame ID	4	0x01
AT command	5	0x42 (B)
	6	0x44 (D)
Parameter value (0x04B0 = 1200)	7	0x04
	8	0xB0
Checksum	9	0xBC

AT Command - Queue Parameter Value frame - 0x09

Description

This frame allows you to query or set device parameters. In contrast to the AT Command (0x08) frame, this frame sets new parameter values and does not apply them until you issue either:

- The **AT** Command (0x08) frame
- The **AC** command (as either a 0x08 or 0x09 frame in API mode)

When querying parameter values, the 0x09 frame behaves identically to the 0x08 frame; the response for this command is also an **AT** Command Response frame (0x88).

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x09
Frame ID	4	Identifies the data frame for the host to correlate with a subsequent response. If set to 0 , the device does not send a response.
AT command	5-6	Command name: two ASCII characters that identify the AT command.
Parameter value (BD7 = 115200 baud) (optional)	7-n	If present, indicates the requested parameter value to set the given register. If no characters are present, queries the register.

Example

The following example sends a command to change the baud rate (**BD**) to 115200 baud, but does not apply the changes immediately. The device continues to operate at the previous baud rate until you apply the changes.

Note In this example, you could send the parameter as a zero-padded 2-byte or 4-byte value.

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x05

Frame data fields	Offset	Example
Frame type	3	0x09
Frame ID	4	0x01
AT command	5	0x42 (B)
	6	0x44 (D)
Parameter value (BD7 = 115200 baud)	7	0x07
Checksum	8	0x68

Transmit Request frame - 0x10

Description

This frame causes the device to send payload data as an RF packet to a specific destination.

- For broadcast transmissions, set the 64-bit destination address to **0x000000000000FFFF**. Address the coordinator by either setting the 64-bit address to all 0x00s and the 16-bit address to **0xFFFFE**, or setting the 64-bit address to the coordinator's 64-bit address and the 16-bit address to **0x0000**.
- For all other transmissions, setting the 16-bit address to the correct 16-bit address helps improve performance when transmitting to multiple destinations. If you do not know a 16-bit address, set this field to **0xFFFFE** (unknown). If successful, the Transmit Status frame (0x8B) indicates the discovered 16-bit address.

When transmitting to a broadcast address, the broadcast radius field can be used to determine how many hops should be traversed.

You can read the maximum number of payload bytes with the **NP** command.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x10
Frame ID		Identifies the data frame for the host to correlate with a subsequent response. If set to 0 , the device does not send a response.
64-bit destination address	5-12	The 64-bit address of the destination device. Reserved 64-bit address for the coordinator = 0x0000000000000000 Broadcast = 0x000000000000FFFF
16-bit destination network address	MSB 13	Set to the 16-bit address of the destination device, if known. If the address is unknown or if sending a broadcast, set to 0xFFFFE.
	LSB 14	
Broadcast radius	15	Sets the maximum number of hops a broadcast transmission can occur. If set to 0, the broadcast radius is set to the maximum hops value.

Frame data fields	Offset	Description
Options	16	Bitfield of supported transmission options. Supported values include the following: 0x01 - Disable retries 0x20 - Enable APS encryption (if EE=1) 0x40 - Use the extended transmission timeout for this destination Enabling APS encryption decreases the maximum number of RF payload bytes by 4 (below the value reported by NP). Setting the extended timeout bit causes the stack to set the extended transmission timeout for the destination address. See Transmission, addressing, and routing . All unused and unsupported bits must be set to 0.
RF data	17-n	Data sent to the destination device.

Example

The example shows how to send a transmission to a device if you disable escaping (**AP** = 1), with destination address 0x0013A200 40014011, and payload “TxData1B”.

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x16
Frame type	3	0x10
Frame ID	4	0x01
64-bit destination address	MSB 5	0x00
	6	0x13
	7	0xA2
	8	0x00
	9	0x40
	10	0x0A
	11	0x01
	LSB 12	0x27
16-bit destination network address	MSB 13	0xFF
	LSB 14	0xFE
Broadcast radius	15	0x00
Options	16	0x00

Frame data fields	Offset	Example
RF data	17	0x54
	18	0x78
	19	0x44
	20	0x61
	21	0x74
	22	0x61
	23	0x30
	24	0x41
Checksum	25	0x13

Send a transmission to the coordinator without specifying the coordinator's 64-bit address. The API transmit request frame should look like:

0x7E 0x00 0x16 0x10 0x01 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0xFF

0xFE 0x00 0x00 0x54 0x78 032 0x43 0x6F 0x6F 0x72 0x64 0xFC

Where 0x16 = length (22 bytes excluding checksum).

Explicit Addressing Command frame - 0x11

Description

This frame is similar to Transmit Request (0x10), but it also requires you to specify the application-layer addressing fields: endpoints, cluster ID, and profile ID.

This frame causes the device to send payload data as an RF packet to a specific destination, using specific source and destination endpoints, cluster ID, and profile ID.

- For broadcast transmissions, set the 64-bit destination address to **0x000000000000FFFF** for all devices. Address the coordinator by either setting the 64-bit address to all 0x00s and the 16-bit address to **0xFFFE**, or setting the 64-bit address to the coordinator's 64-bit address and the 16-bit address to **0x0000**.
- For all other transmissions, setting the 16-bit address to the correct 16-bit address helps improve performance when transmitting to multiple destinations. If you do not know a 16-bit address, set this field to 0xFFFE (unknown). If successful, the Transmit Status frame (0x8B) indicates the discovered 16-bit address.

When transmitting to a broadcast address, the broadcast radius field can be used to determine how many hops should be traversed.

You can read the maximum number of payload bytes with the **NP** command.

Note Using source routing reduces the RF payload by two bytes per intermediate hop in the source route.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x11
Frame ID	4	Identifies the data frame for the host to correlate with a subsequent response. If set to 0 , the device does not send a response.
64-bit destination Address	5-12	The 64-bit address of the destination device. Reserved 64-bit address for the coordinator = 0x0000000000000000 Broadcast = 0x000000000000FFFF
16-bit destination Network Address	MSB 13 LSB 14	Set to the 16-bit address of the destination device, if known. Set to 0xFFFE if the address is unknown, or if sending a broadcast.

Frame data fields	Offset	Description
Source Endpoint	15	Source Endpoint for the transmission. 0xE8 is a data endpoint.
Destination Endpoint	16	Destination Endpoint for the transmission. 0xE8 is a data endpoint.
Cluster ID	17 18	Cluster ID used in the transmission. Use 0x11 for data transmissions.
Profile ID	19-20	Profile ID used in the transmission. 0xC105 is the Digi profile ID that should be used to communicate with XBee modules.
Broadcast Radius	21	Sets the maximum number of hops a broadcast transmission can traverse. If set to 0 , the device sets the transmission radius to the network maximum hops value.
Transmission Options	22	Bitfield of supported transmission options. Supported values include the following: 0x01 - Disable retries {newline} 0x04- Indirect Addressing 0x08- Multicast Addressing 0x20 - Enable APS encryption (if EE = 1) 0x40 - Use the extended transmission timeout for this destination Enabling APS encryption decreases the maximum number of RF payload bytes by 4 (below the value reported by NP). Setting the extended timeout bit causes the stack to set the extended transmission timeout for the destination address. See Transmission, addressing, and routing . All unused and unsupported bits must be set to 0 .
Data Payload	23-n	Up to NP bytes per packet. Sent to the destination device.

Example

- 64-bit address: 0x0000 00 00 00 00 00 00 (coordinator)
- Source endpoint: 0xA0
- Destination endpoint: 0xA1
- Cluster ID: 0x1554
- Profile ID: 0xC105
- Payload: TxData

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x1A
Frame type	3	0x11

Frame data fields	Offset	Example
Frame ID	4	0x01
64-bit destination address	MSB 5	0x00
	6	0x00
	7	0x00
	8	0x00
	9	0x00
	10	0x00
	11	0x00
16-bit destination Network Address	LSB12	0x00
	MSB 13	0xFF
Source endpoint	15	0xA0
Destination endpoint	16	0xA1
Cluster ID	17	0x15
	18	0x54
Profile ID	19	0xC1
	20	0x05
Broadcast radius	21	0x00
Transmit options	22	0x00
Data payload	23	0x54
	24	0x78
	25	0x44
	26	0x61
	27	0x74
	28	0x61
Checksum	29	0x3A

Remote AT Command Request frame - 0x17

Description

Used to query or set device parameters on a remote device. For parameter changes on the remote device to take effect, you must apply changes, either by setting the Apply Changes options bit, or by sending an **AC** command to the remote.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x17
Frame ID	4	Identifies the data frame for the host to correlate with a subsequent response. If set to 0 , the device does not send a response.
64-bit destination address	5-12	MSB first, LSB last. Set to the 64-bit address of the destination device. Reserved 64-bit address for the coordinator = 0x0000000000000000 Broadcast = 0x000000000000FFFF. Reserved broadcast address: 0x000000000000FFFF Note Digi highly discourages sending remote AT commands to a broadcast. You will only receive a single acknowledgment despite there being multiple recipients, and there is no assurance that the broadcast will be successfully received by the rest of the network.
16-bit destination address	13-14	MSB first, LSB last. Set to match the 16-bit network address of the destination device, if known. Set to 0xFFFE if the address is unknown, or if sending a broadcast.
Remote command options	15	Bitfield to enable various remote command options. Supported values include: 0x01 - Disable ACK 0x40 - Use the extended transmission timeout for this destination. Setting the extended timeout bit causes the stack to set the extended transmission timeout for the destination address. For more information, see Transmission, addressing, and routing .
AT command	16-17	Command name: two ASCII characters that identify the command.
Command parameter	18-n	If present, indicates the parameter value you request for a given register. If no characters are present, it queries the register.

Example

The following example sends a remote command:

In this example, the 64-bit address of the remote device is 0x0013A200 40401122. The destination 16-bit address is unknown. The **BH** command is being set to 1 on the remote device with the change being applied immediately (equivalent to sending a separate **AC** command).

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x10
Frame type	3	0x17
Frame ID	4	0x01
64-bit destination address	MSB 5	0x00
	6	0x13
	7	0xA2
	8	0x00
	9	0x40
	10	0x40
	11	0x11
	LSB 12	0x22
Reserved	13	0xFF
	14	0xFE
Remote command options	15	0x02 (apply changes)
AT command	16	0x42 (B)
	17	0x48 (H)
Command parameter	18	0x01
Checksum	19	0xF5

Create Source Route - 0x21

Description

This frame creates a source route in the device. A source route specifies the complete route a packet traverses to get from source to destination. For best results, use source routing with many-to-one routing.

There is no response frame for this frame type. Take care when generating source routes. An incorrectly formatted frame will be silently rejected by the radio or cause unexpected results.

Note Both the 64-bit and 16-bit destination addresses are required when creating a source route. These are obtained when the device receives a Route Record Indicator (0xA1) frame.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	
Frame ID	4	This frame type has no response, so the Frame ID is ignored.
64-bit destination address	5-12	MSB first, LSB last. Set to the 64-bit address of the destination device. Reserved 64-bit address for the coordinator = 0x0000000000000000 Broadcast = 0x000000000000FFFF.
16-bit destination network address	13-14	The 16-bit address of the destination node (required).
Route command options	15	Set to 0.
Number of addresses	16	The number of addresses in the source route (excluding source and destination). A route can only traverse across 30 hops. If this number is 0 or exceeds the maximum hop count, the frame is silently discarded and a route will not be created.
Address 1	17	Neighbor of destination
	18	

Frame data fields	Offset	Description
Address 2 (closer hop)	19	Address of intermediate hop
	20	
Address 3	21	Neighbor of source
	22	

Example

You must order intermediate hop addresses starting with the neighbor of the destination and working closer to the source.

Suppose a route is found between A and E as shown in the following example.

A ' B ' C ' D ' E

If device E has the 64-bit and 16-bit addresses of 0x0013A200 40401122 and 0x3344, and if devices B, C, and D have the following 16-bit addresses:

B = 0xAABB C = 0xCCDD D = 0xEEFF

This example shows how to send the Create Source Route frame to establish a source route between A and E.

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x14
Frame type	3	0x21
Frame ID	4	0x00
64-bit destination address	MSB 5	0x00
	6	0x13
	7	0xA2
	8	0x00
	9	0x40
	10	0x40
	11	0x11
	LSB 12	0x22
16-bit destination network address	MSB 13	0x33
	LSB 14	0x44

Frame data fields	Offset	Example
Remote command options	15	0x00
Number of addresses	16	0x03
Address 1	17	0xEE
	18	0xFF
Address 2 (closer hop)	19	0xCC
	20	0xDD
Address 3	21	0xAA
	22	0xBB
Checksum	23	0x01

Register Joining Device - 0x24

Description

Use this frame to securely register a joining device to a trust center. Registration is the process by which a node is authorized to join the network using a preconfigured link key or installation code that is conveyed to the trust center out-of-band (using a physical interface and not over-the-air).

If registering a device with a centralized trust center (**EO** = 2), then the key entry will only persist for **KT** seconds before expiring.

Registering devices in a distributed trust center (**EO** = 0) is persistent and the key entry will never expire unless explicitly removed.

To remove a key entry on a distributed trust center, a 0x24 frame should be issued with a null key (key field is absent from the frame). In a centralized trust center you cannot use this method to explicitly remove the key entries.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x24 Register Joining Device
Frame ID	4	Identifies the data frame for the host to correlate with a subsequent response. If set to 0 , the device does not send a response.
64-bit registrant address	5-12	The 64-bit address of the destination device.
Reserved	13-14	Not used, set to 0xFFFFE.

Frame data fields	Offset	Description
Options	15	0x00 = Key is a Link Key (KY on joining node) 0x01 = Key is an Install Code (I? on joining node, DC must be set to 1 on joiner).
Key	16-n	Up to 16 bytes if entering a link key, up to 18 bytes (16-byte code + 2 byte CRC) if entering an install code.

Example 1

A device needs to join a trust center using a preconfigured link key. This preconfigured link key is unknown to the trust center and must be conveyed out-of-band to the trust center.

The joining node has an **SH+SL** of 0x0013A200 12345678.

The joining node has a **KY** value of 0x012345 which does not match the KY value of the trust center.

The following frame should be sent to the trust center:

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x10
Frame type	3	0x24
Frame ID	4	0x18
64-bit registrant address	MSB 5	0x00
	6	0x13
	7	0xA2
	8	0x00
	9	0x12
	10	0x34
	11	0x56
	LSB 12	0x78
Reserved	MSB 13	0xFF
	LSB 14	0xFE
Options	15	0x00 (Key came from KY)
Key	16	0x01
	17	0x23
	18	0x45
Checksum	19	0x94

Example 2

A device needs to join a trust center using an install code. The link key used to join the network is derived from the install code, which must be conveyed out of band to the trust center.

The joining node has an **SH+SL** of 0x0013A200 87654321.

The joining node has an **I?** value of 0x916720AC233734A86B809CC330B242EC23E and has **DC** set to **1**; this will cause **KY** to be ignored and use the install code to join.

The following frame should be sent to the trust center:

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x1F
Frame type	3	0x24
Frame ID	4	0x43
64-bit registrant address	MSB 5	0x00
	6	0x13
	7	0xA2
	8	0x00
	9	0x87
	10	0x65
	11	0x43
	LSB 12	0x21
Reserved	MSB 13	0xFF
	LSB 14	0xFE
Options	15	0x00 (Key came from I?)

Frame data fields	Offset	Example
Key	16	0x09
	17	0x16
	18	0x72
	19	0x0A
	20	0xC2
	21	0x33
	22	0x73
	23	0x4A
	24	0x86
	25	0xB8
	26	0x09
	27	0xCC
	28	0x33
	29	0x0B
	30	0x24
	31	0x2E
32	0xC2	
33	0x3E	
Checksum	34	0xA5

Example 3

A previously registered device needs to have its registration information removed so that it can no longer securely join the network. This example only applies to a distributed trust center network (**EO** = 0).

The joining node has an **SH+SL** of 0x0013A200 54AB28D3.

Note Removing the key entry will not prevent the module from rejoining the network if it had previously been associated.

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x0D

Frame data fields	Offset	Example
Frame type	3	0x24
Frame ID	4	0xA2
64-bit registrant address	MSB 5	0x00
	6	0x13
	7	0xA2
	8	0x00
	9	0x54
	10	0xAB
	11	0x28
	LSB 12	0xD3
Reserved	MSB 13	0xFF
	LSB 14	0xFE
Options	15	0x00
Key	16	(No key)
Checksum	34	0x8d

BLE Unlock API frame - 0x2C

Description

The XBee3 Zigbee RF Module uses this frame to authenticate a connection on the Bluetooth interface and unlock the processing of AT command frames. This frame is used in conjunction with the [BLE Unlock Response frame - 0xAC](#).

The unlock process is an implementation of the [SRP \(Secure Remote Password\)](#) algorithm using the [RFC5054 1024-bit group](#) and the SHA-256 hash algorithm. The value of *i* is fixed to the username **apiservice**.

Upon completion, each side will have derived a shared session key which is used to communicate in an encrypted fashion with the peer. Additionally, a [Modem Status frame - 0x8A](#) with the status code **0x32 (Bluetooth Connected)** is sent through the UART (if **AP = 1** or **2**). When an unlocked connection is terminated, a Modem Status frame with the status code **0x33 (Bluetooth Disconnected)** is sent through the UART.

The following implementations are known to work with the BLE SRP implementation:

- github.com/cncfanatics/SRP
 You need to modify the hashing algorithm to SHA256 and the values of *N* and *g* to use the RFC5054 1024-bit group.
- github.com/cocagne/csrp
- github.com/cocagne/pysrp

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x2C = Request 0xAC = Response
Step	4	Indicates the phase of authentication and interpretation of payload data. 1 = Client presents <i>A</i> value 2 = Server presents <i>B</i> and <i>salt</i> 3 = Client present <i>M1</i> session key validation value 4 = Server presents <i>M2</i> session key validation value and two 12-byte nonces See the phase tables below for more information. Step values greater than 0x80 indicate error conditions. 0x80 = Unable to offer B (cryptographic error with content, usually due to $A \bmod N == 0$) 0x81 = Incorrect payload length 0x82 = Bad proof of key 0x83 = Resource allocation error 0x84 = Request contained a step not in the correct sequence
Payload	5	Payload structure varies by Step value. Descriptions are in the tables below.

The tables below provide more information about the phase of authentication and interpretation of payload data.

Phase 1 (Client presents A)

If the *A* value is zero, the server will terminate the connection.

Frame data field	Offset in frame	Length
A	5	128 bytes

Phase 2 (Server presents B and salt)

Frame data field	Offset in frame	Length
salt	5	4 bytes
B	9	128 bytes

Phase 3 (Client presents M1)

Frame data field	Offset in frame	Length
M1	5	Hash algorithm digest length (32 bytes for SHA256)

Phase 4 (Server presents M2)

Frame data field	Offset in frame	Length
M2	5	Hash algorithm digest length (32 bytes for SHA256)
TX nonce	37	12-byte (96-bit) random nonce, used as the constant prefix of the counter block for encryption/decryption of data transmitted to the API service by the client
RX nonce	49	12-byte (96-bit) random nonce, used as the constant prefix of the counter block for encryption/decryption of data received by the client from the API service

Upon completion of M2 verification, the session key has been determined to be correct and the API service is unlocked and allows additional API frames to be used. Content from this point is encrypted using AES-256-CTR with the following parameters:

- **Key:** The entire 32-byte session key.
- **Counter:** 128 bits total, prefixed with the appropriate nonce shared during authentication. The initial remaining counter value is 1.
 The counter for data sent into the XBee API Service is prefixed with the TX nonce value (see the **Phase 4** table) and the counter for data sent by the XBee3 Zigbee RF Module to the client is prefixed with the RX nonce value.

Example sequence to perform AT Command XBee API frames over BLE

1. Discover the XBee3 Zigbee RF Module through scanning for advertisements.
2. Create a connection to the GATT Server.
3. Optional, but recommended: request a larger MTU for the GATT connection.
4. Turn on indications for the API Response characteristic.
5. Perform unlock procedure using unlock frames. See [BLE Unlock API frame - 0x2C](#).

6. Once unlocked, you may send [AT Command Frame - 0x08](#) frames and receive AT Command Response frames received.
 - a. For each frame to send, form the API Frame, and encrypt through the stream cipher as described in the unlock procedure. See [BLE Unlock API frame - 0x2C](#).
 - b. Write the frame using one or more write operations.
 - c. When successful, the response arrives in one or more indications. If your stack does not do it for you, remember to acknowledge each indication as it is received. Note that you are expected to process these indications and the response data is not available if you attempt to perform a read operation to the characteristic.
 - d. Decrypt the stream of content provided through the indications, using the stream cipher as described in the unlock procedure. See [BLE Unlock API frame - 0x2C](#).

User Data Relay frame - 0x2D

Description

Allows for data to be received on an interface with a designation of the target interface for the data to be output on. The frame can be sent or received from any of the following interfaces: MicroPython (internal interface), UART, and BLE. This frame is used in conjunction with [User Data Relay Output - 0xAD](#).

You can send and receive User Data Relay frames from MicroPython. See [Send and receive User Data Relay frames](#) in the *MicroPython Programming Guide*.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Field name	Field value	Data type	Description
Delimiter	7E		
Length			
Frame type	0x2D	Byte	
Frame ID			Reference identifier
Destination interface		Byte	0 = Serial port (SPI, or UART when in API mode) 1 = BLE 2 = MicroPython
Data		Variable	
Checksum		1 Byte	

Error cases

The Frame ID is used to report error conditions in a method consistent with existing transmit frames. The error codes are mapped to statuses. The following conditions result in an error that is reported in a TX Status frame, referencing the frame ID from the 0x2d request.

- **Invalid interface** (0x7c) : The user specified a destination interface that does not exist.
- **Interface not accepting frames** (0x7d): The destination interface is a valid interface, but is not in a state that can accept data. For example, UART not in API mode, BLE does not have a GATT client connected, or buffer queues are full.

Example use cases

These examples show how to use this frame.

- You can use the frame to send data to an external processor through the XBee UART/SPI via the BLE connection. Use a cellphone to send the frame with UART interface as a target. Data contained within the frame is sent out the UART contained within an Output Frame. The external processor then receives and acts on the frame.
- Use an external processor to output the frame over the UART with the BLE interface as a target. This outputs the data contained in the frame as the Output Frame over the active BLE connection via indication.
- An external processor outputs the Frame over the UART with the Micropython interface as a target. Micropython operates over the data and publishes the data to mqtt topic.

AT Command Response frame - 0x88

Description

A device sends this frame in response to an AT Command (0x08 or 0x09) frame. Some commands send back multiple frames; for example, the **ND** command.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x88
Frame ID	4	The FrameID used in the original AT Command request frame will be populated in the corresponding response. If the FrameID in the AT Command request was 0 , then no response will be generated.
AT command	5-6	Command name: two ASCII characters that identify the command.
Command status	7	0 = OK 1 = ERROR 2 = Invalid command 3 = Invalid parameter 4 = Tx failure
Command data		The register data in binary format. If the host sets the register, the device does not return this field.

Example

If you change the **BD** parameter on a local device with a frame ID of 0x01, and the parameter is valid, the user receives the following response.

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x05
Frame type	3	0x88
Frame ID	4	0x01

Frame data fields	Offset	Example
AT command	5	0x42 (B)
	6	0x44 (D)
Command status	7	0x00 (success)
Command data		(No command data implies the parameter was set rather than queried)
Checksum	8	0xF0

Modem Status frame - 0x8A

Description

Devices send the status messages in this frame in response to specific conditions.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x8A
Status	4	0x00 = Hardware reset 0x01 = Watchdog timer reset 0x02 = Joined network (routers and end devices) 0x03 = Disassociated 0x06 = Coordinator started 0x07 = Network security key was updated 0x0D = Voltage supply limit exceeded 0x11 = Modem configuration changed while join in progress 0x32 = BLE Connect 0x33 = BLE Disconnect 0x80 = Stack error

Note The BLE Connect and BLE Disconnect events are reported over the UART/SPI interface in API mode when a valid Bluetooth connection has been made and API mode has been unlocked, and also when an unlocked connection disconnects.

Example

When a device powers up, it returns the following API frame.

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
LSB 2	LSB 2	0x02
Frame type	3	0x8A
Status	4	0x00 (Hardware reset)
Checksum	5	0x75

Transmit Status frame - 0x8B

Description

When a Transmit Request (0x10, 0x11) completes, the device sends an 0x8B Transmit Status message out of the serial interface. This message indicates if the Transmit Request was successful or if it failed.

Note Broadcast transmissions are not acknowledged and always return a status of 0x00, even if the delivery failed.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x8B
Frame ID	4	The Frame ID of the response will be the same value that was used in the originating Tx request.
16-bit destination address	5	The 16-bit Network Address where the packet was delivered (if successful). If not successful, this address is 0xFFFD (destination address unknown).
	6	
Transmit retry count	7	The number of application transmission retries that occur.
Delivery status	8	0x00 = Success 0x01 = MAC ACK Failure 0x02 = CCA Failure 0x15 = Invalid destination endpoint 0x21 = Network ACK Failure 0x22 = Not Joined to Network 0x23 = Self-addressed 0x24 = Address Not Found 0x25 = Route Not Found 0x26 = Broadcast source failed to hear a neighbor relay the message 0x2B = Invalid binding table index 0x2C = Resource error lack of free buffers, timers, etc. 0x2D = Attempted broadcast with APS transmission 0x2E = Attempted unicast with APS transmission, but EE =0 0x32 = Resource error lack of free buffers, timers, etc. 0x74 = Data payload too large 0x75 = Indirect message unrequested

Frame data fields	Offset	Description
Discovery status	9	0x00 = No Discovery Overhead 0x01 = Address Discovery 0x02 = Route Discovery 0x03 = Address and Route 0x40 = Extended Timeout Discovery

Example

In the following example, the destination device reports that a unicast data transmission was successful with a 16-bit address of 0x7D84. The transmission could have been sent with the 16-bit address set to 0x7D84 or 0xFFFE.

Frame Fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x07
Frame type	3	0x8B
Frame ID	4	0x01
16-bit destination address	5	0x7D
	6	0x84
Transmit retry count	7	0x00
Delivery status	8	0x00 (success)
Discovery status	9	0x01 (address discovery)
Checksum	10	0x71

Receive Packet frame - 0x90

Description

When a device configured with a standard API Rx Indicator ([AO \(API Options\)](#) = 0) receives an RF data packet, it sends it out the serial interface using this message type.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x90
64-bit source address	4-11	The sender's 64-bit address.
16-bit source network address	MSB 12	The sender's 16-bit address.
	LSB 13	
Receive options	14	0x01 - Packet Acknowledged 0x02 - Packet was a broadcast packet 0x20 - Packet encrypted with APS encryption 0x40 - Packet was sent from an end device (if known)
		<hr/> Note Option values can be combined. For example, a 0x20 and a 0x01 show as a 0x21. Other possible values: 0x00, 0x21, 0x22, 0x60, 0x61, 0x62.
Received data	15-n	The RF data that the device receives.

Example

In the following example, a device with a 64-bit address of 0x0013A200 40522BAA sends a unicast data transmission to a remote device with payload RxData. If **AO** = 0 on the receiving device, it sends the following frame out its serial interface.

Frame data fields	Offset	Example
Start delimiter	0	0x7E

Frame data fields	Offset	Example
Length	MSB 1	0x00
	LSB 2	0x12
Frame type	3	0x90
64-bit source address	MSB 4	0x00
	5	0x13
	6	0xA2
	7	0x00
	8	0x40
	9	0x52
	10	0x2B
	LSB 11	0xAA
16-bit source network address	MSB 12	0x7D
	LSB 13	0x84
Receive options	14	(Acknowledged)
Received data	15	0x52
	16	0x78
	17	0x44
	18	0x61
	19	0x74
	20	0x61
Checksum	21	0x0D

Explicit Rx Indicator frame - 0x91

Description

When a device configured with explicit API Rx Indicator ([AO \(API Options\) = 1](#)) receives an RF packet, it sends it out the serial interface using this message type.

Note If a [Transmit Request frame - 0x10](#) is sent to a device with **AO = 1**, the receiving device receives a 0x91 frame with the Source endpoint (SE), Destination endpoint (DE), and Cluster ID (CI) values, and not the values set on the transmitting device in Transparent mode .

The Cluster ID and endpoints must be used to identify the type of transaction that occurred.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x91
64-bit source address	4-11	The sender's 64-bit address. The address reads 0xFFFFFFFFFFFFFFFF (unknown 64-bit address) if the sender's 64-bit address is unknown.
16-bit source network address	12-13	The sender's 16-bit address.
Source endpoint	14	Endpoint of the source that initiates transmission.
Destination endpoint	15	Endpoint of the destination that the message is addressed to.
Cluster ID	16-17	The Cluster ID that the frame is addressed to.
Profile ID	18-19	The Profile ID that the fame is addressed to.
Receive options	20	0x01 – Packet Acknowledged 0x02 – Packet was a broadcast packet 0x20 – Packet encrypted with APS encryption
Received data	21-n	Received RF data.

Example

In the following example, a device with a 64-bit address of 0x0013A200 40522BAA sends a broadcast data transmission to a remote device with payload RxData.

If a device sends the transmission:

- With source and destination endpoints of 0xE0
- Cluster ID = 0x2211
- Profile ID = 0xC105

If **AO = 1** on the receiving device, it sends the following frame out its serial interface.

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x18
Frame type	3	0x91
64-bit source address	MSB 4	0x00
	5	0x13
	6	0xA2
	7	0x00
	8	0x40
	9	0x52
	10	0x2B
	LSB 11	0xAA
16-bit Source Network Address	MSB 12	0x7D
	LSB 13	0x84
Source endpoint	14	0xE0
Destination endpoint	15	0xE0
Cluster ID	16	0x22
	17	0x11
Profile ID	18	0xC1
	19	0x05
Receive options	20	0x02 (Broadcast)

Frame data fields	Offset	Example
Received data	21	0x52
	22	0x78
	23	0x44
	24	0x61
	25	0x74
	26	0x61
Checksum	27	0x52

I/O Data Sample Rx Indicator frame - 0x92

Description

When the device receives an I/O sample frame from a remote device, it sends the sample out the serial port using this frame type (when **AO** = **0**). Only devices running in API mode will send I/O samples out the serial port.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x92
64-bit source address	4-11	The sender's 64-bit address.
16-bit Source network address	12-13	The sender's 16-bit address.
Receive options	14	Bit field: 0x01 = Packet acknowledged 0x02 = Packet is a broadcast packet Ignore all other bits
Number of samples	15	The number of sample sets included in the payload. This field always reports 1 sample.
Digital channel mask ¹	16-17	Bitmask field that indicates which digital I/O lines on the remote have sampling enabled, if any. bit 0 = DIO0 bit 1 = DIO1 bit 2 = DIO2 bit 3 = DIO3 bit 4 = DIO4 bit 5 = DIO5 bit 6 = DIO6 bit 7 = DIO7 bit 8 = DIO8 bit 9 = DIO9 bit 10 = DIO10 bit 11 = DIO11 bit 12 = DIO12 bit 13 = DIO13 bit 14 = DIO14 bit 15 = N/A For example, a digital channel mask of 0x002F means DIOs 0, 1, 2, 3, and 5 are enabled as digital I/O.

Frame data fields	Offset	Description
Analog channel mask	18	Bitmask field that indicates which analog I/O lines on the remote have sampling enabled, if any. bit 0 = AD0/DIO0 bit 1 = AD1/DIO1 bit 2 = AD2/DIO2 bit 3 = AD3/DIO3 bit 7 = Supply Voltage (enabled with V+ command)
Digital samples (if included)	19-20	If the sample set includes any digital I/O lines (Digital channel mask > 0), these two bytes contain samples for all enabled digital I/O lines. DIO lines that do not have sampling enabled return 0. Bits in these two bytes map the same as they do in the Digital channel mask field.
Analog samples (if included)	21-n	If the sample set includes any analog I/O lines (Analog channel mask > 0), each enabled analog input returns a 2-byte value indicating the A/D measurement of that input. Analog samples are ordered sequentially from AD0/DIO0 to AD3/DIO3 and will optionally include supply voltage if enabled with the V+ command.

Example

In this example, the device receives an I/O sample with analog and digital input from a remote device with a 64-bit serial number of 0x0013A20040522BAA and a 16-bit address of 0x7D84.

Given this frame, the following information is known about the I/O lines of the module that sent the sample frame:

Digital Channel Mask:

0x1C = 11100b (DIO2, DIO3, DIO4 are configured as digital input or output)

Digital Sample:

0x14 = 10100b (DIO2 and DIO4 are high, DIO3 is low)

Analog Channel Mask:

0x02 = 0010b (AD1 is configured as an analog input)

Analog Sample:

0x0225 = 549 = (549 * 1.25) / 1023 = 670 mV

Frame fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x14
Frame type	3	0x92

Frame fields	Offset	Example
64-bit source address	MSB 4	0x00
	5	0x13
	6	0xA2
	7	0x00
	8	0x40
	9	0x52
	10	0x2B
	LSB 11	0xAA
16-bit source network address	MSB 12	0x7D
	LSB 13	0x84
Receive options	14	0x01
Number of samples	15	0x01
Digital channel mask	16	0x00
	17	0x1C
Analog channel mask	18	0x02
Digital samples (if included)	19	0x00
	20	0x14
Analog sample	21	0x02
	22	0x25
Checksum	23	0xF5

Node Identification Indicator frame - 0x95

Description

A device receives this frame when:

- it transmits a node identification message to identify itself
- **AO = 0**

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x95
64-bit source address	4-11	MSB first, LSB last. The sender's 64-bit address.
16-bit source network address	12-13	MSB first, LSB last. The sender's 16-bit address.
Receive options	14	0x01 = Packet acknowledged 0x02 = Packet was a broadcast packet
Source 16-bit address	15-16	Set to the 16-bit network address of the remote device. Set to 0xFFFE if unknown.
64-bit network address	17-24	Indicates the 64-bit address of the remote device that transmitted the Node Identification Indicator frame.
NI string	25-26	Node identifier string on the remote device. The NI string is terminated with a NULL byte (0x00).
Device type	29	0 = Coordinator 1 = Router 2 = End Device
Source event	30	1 = Frame sent by node identification pushbutton event (see D0 (DIO0/AD0/Commissioning Button Configuration)) 2 = Frame sent after joining event occurred (see JN (Join Notification)). 3 = Frame sent after power cycle event occurred (see JN (Join Notification)).
Digi Profile ID	31-32	Set to Digi's application profile ID.
Digi Manufacturer ID	33-34	Set to Digi's Manufacturer ID.

Example

If you press the commissioning pushbutton on a remote device with 64-bit address 0x0013A200407402AC and a default **NI** string sends a Node Identification, all devices on the network receive the following node identification indicator:

A remote device with 64-bit address 0x0013A200407402AC and a default **NI** string sends a Node Identification, all devices on the network receive the following node identification indicator:

If you press the commissioning button on a remote router device with 64-bit address 0x0013A20040522BAA, 16-bit address 0x7D84, and default **NI** string, devices on the network receive the node identification indicator.

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x20
Frame type	3	0x95
64-bit source address	MSB 4	0x00
	5	0x13
	6	0xA2
	7	0x00
	8	0x40
	9	0x52
	10	0x2B
	LSB 11	0xAA
16-bit source network address	MSB 12	0x7D
	LSB 13	0x84
Receive options	14	0x02
Source 16-bit address	15	0x7D
	16	0x84

Frame data fields	Offset	Example
64-bit network address	17	0x00
	18	0x13
	19	0xA2
	20	0x00
	21	0x40
	22	0x52
	23	0x2B
	24	0xAA
NI string	25	0x20
	26	0x00
Parent 16-bit address	27	0xFF
	28	0xFE
Device type	29	0x01
Source event	30	0x01
Digi Profile ID	31	0xC1
	32	0x05
Digi Manufacturer ID	33	0x10
	34	0x1E
Checksum	35	0x1B

Remote Command Response frame - 0x97

Description

If a device receives this frame in response to a Remote Command Request (0x17) frame, the device sends an AT Command Response (0x97) frame out the serial interface.

Some commands, such as the **ND** command, may send back multiple frames.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x97
Frame ID	4	This is the same value that is passed into the request. The request is a 0x17 frame.
64-bit source (remote) address	5-12	The long address of the remote device returning this response.
16-bit source (remote) address	13-14	Set to the 16-bit network address of the remote device returning this response. Set to 0xFFFE if unknown.
AT commands	15-16	The name of the command.
Command status	17	0 = OK 1 = ERROR 2 = Invalid Command 3 = Invalid Parameter 4 = Remote Command Transmission Failed
Command data	18-n	The register data in binary format. If you set the register, the device does not return this field.

Example

If a device sends a remote command to a remote device with 64-bit address 0x0013A200 40522BAA to query the **SL** command, and if the frame ID = 0x55, the response would look like the following example.

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x13

Frame data fields	Offset	Example
Frame type	3	0x97
Frame ID	4	0x55
64-bit source (remote) address	MSB 5	0x00
	6	0x13
	7	0xA2
	8	0x00
	9	0x40
	10	0x52
	11	0x2B
	LSB 12	0xAA
16-bit source (remote) address	MSB 13	0x7D
	LSB 14	0x84
AT commands	15	0x53
	16	0x4C
Command status	17	0x00
Command data	18	0x40
	19	0x52
	20	0x2B
	21	0xAA
Checksum	22	0xF4

Extended Modem Status frame - 0x98

Description

If you enable the Verbose Join option (DC4), the device serially transmits trace messages to describe what is happening inside the device during association.

Note This option is provided for diagnostic purposes. Verbose Join messages are disabled while the device is operating in Command mode.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0x98
Status code	4	See the following table for status code descriptions.
Status data	5	The length of this field varies with the Status Code.

Example

A device is attempting to join a network that has joining disallowed. The following frame is emitted that shows the moment that the **AI** value becomes 0x23.

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB1	0x00
	LSB1	0x03
Frame type	3	0x98
Status code	4	0x0B
Status data	5	0x23
Checksum	6	0x39

Status code descriptions

The following table describes the various Verbose Join trace messages in Status Code order. The Transparent mode string column shows the string which appears if you run Verbose Join in Command mode. The Description column gives a more detailed explanation of each particular message. When a message accompanies Status Data, the Status Data column shows how to parse the hexadecimal string into fields. The number of bytes per field appears in parentheses “()”.

Status code	Transparent mode string	Description	Status data	Description
0x00	Rejoin	A join attempt is being started.	rejoinState(1)	The rejoinState is a count of join attempts.
0x01	Stack Status	Shows status and state.	EmberStatus(1)	0x00 - no network 0x01 - joining 0x02 - joined 0x03 - joined (no parent) 0x04 - leaving
			emberNetworkState(1)	0x90 - Network is up and ready to receive/transmit. 0x91 - Network is down and cannot receive/transmit. 0x94 - Join attempt failed. 0x96 - A node's attempt to re-establish contact with the network after moving failed. 0x98 - A join attempt as a router failed due to a Zigbee 2006 versus Zigbee PRO 2007 incompatibility. Try to join as an end device. 0x99 - The network ID has changed. 0x9A - The PAN ID has changed. 0x9B - The channel has changed. 0xAB - No beacons were received in response to a beacon request.

Status code	Transparent mode string	Description	Status data	Description
0x02	Joining	An association request is being made.	radioChannel(1)	channel number ranging from 11 to 26 (0x0B to 0x1A)
			radioTxPower(1)	low level signed byte value for transmit power, values range from 0xC9 to 0x05 inclusive
			panid(2)	16 bit 4med' a network, or a Router/End Device has 'joined' a network.
			extendedPanId(8)	64 bit PAN Identifier for network
0x03	Joined	Joined - Coordinator “Formed:”, Router/End Device “Joined”		
0x04	Beacon Response	Data received from a neighboring node in response to a beacon request	ZS[stackProfile](1)	See ZS (Zigbee Stack Profile) .
			extendedPanId(8)	64 bit PAN Identifier for network
			allowingJoin(1)	0x00 - not permitting joins to its network 0x01 - permitting joins to its network
			radioChannel(1)	channel number ranging from 11 to 26 (0x0B to 0x1A)
			panid(2)	16 bit PAN Identifier for network
			rssi(1)	maximum relative signal strength indicator value measured in units of dBm
			lqi	link quality indicator
0x05	Reject ZS	Not an association candidate because ZS does not match that given in the beacon response.		
0x06	Reject ID	Not an association candidate because configured pan ID does not match that given in the beacon response.		
0x07	Reject NJ	Not an association candidate because it is not allowing joins.		

Status code	Transparent mode string	Description	Status data	Description
0x08	panID Match	JV/NW with search option (DO80) has found a matching network.	panId(2)	16 bit PAN Identifier for network
0x09	Reject LQIRSSI	JV/NW with search option (DO80) candidate rejected because this beacon response is weaker than an earlier beacon response.		
0x0A	Beacon Saved	This beacon response is a suitable candidate for an association request.	radioChannel(1)	channel number ranging from 11 to 26 (0x0B to 0x1A)
			radioTxPower(1)	low level signed byte value for transmit power, values range from 0xC9 to 0x05 inclusive
			panid(2)	16 bit PAN Identifier for network
			extendedPanId(8)	64 bit PAN Identifier for network
0x0B	AI	AI value has changed.	AIStatusCode(1)	See a description of AI (Association Indication)
0x0C	Permit Join	NJ setting (Permit Join Duration) has changed	value(1)	See a description of the NJ (Node Join Time) command.
0x0D	Scanning	Active scanning has begun.	ChannelMask(4)	A 32 bit value driven by the SC setting where bit positions 11 through 26 show which channels are enabled for the upcoming Active Scan. See a description of SC (Scan Channels) .
0x0E	Scan Error	An error occurred during active scan.	StatusCode(1)	
0x0F	Join Request	High level request for a form/join.		
0x10	Reject LQI	Reject because LQI is worse than an already saved beacon	lqi(1)	link quality indicator
0x11	Reject RSSI	Rejected because RSSI is worse than an already saved beacon	rssi(1)	relative signal strength indicator

Status code	Transparent mode string	Description	Status data	Description
0x12	Rejected (cmdL ast)	Rejected because it matches the last associated network.		
0x13	Rejected (cmdS ave)	Rejected because it matches an already saved beacon response.		
0x14	Reject strength	During first/best phase, response is weaker than an already saved beacon response.		
0x16	Reset for DC80	With DC80 enabled, reset if no joinable beacon responses are received within 60s of joining.		
0x18	ScanCh	Scanning on Channel	radioChannel(1)	channel number ranging from 11 to 26 (0x0B to 0x1A)
0x19	Scan Mode	Shows phase of Ordered Association.	mode(1)	0: first/bestcandidate 1: ordered association by extpanid, then by channel
0x1A	Scan Init	Starting a scan	channel(1) TxPower(1)	channel being scanned low level radio transmit power setting
0x1D	Energy Scan - channel mask	Starting energy scan	SC mask(4)	Scan channel mask
0x1E	Energy Scan - energies	Channel Energies observed	Energies(16)	Energy Levels per channel in SC
0x1F	PanIdScan - radio channel	Pan Id Scan starting on channel	channel(1)	Radio Channel
0x20	FormNetwork - parameters	Forming a network	radioChannel(1)	channel number ranging form 11 to 26
			radioTxPower(1)	low level radio transmit power setting
			panid(2)	16 bit PAN identifier for network
			extendedpanid(8)	64 bit PAN identifier for network

Status code	Transparent mode string	Description	Status data	Description
0x21	Discovering KE Endpoint	Looking for Key Establishment Endpoint		
0x22	KE Endpoint	Found Key Establishment Endpoint	Endpoint(1)	Endpoint number

The following example shows a successful association with Verbose Join enabled in AT Command mode.

Note Comments are included with the trace messages to explain the content and are preceded by an ellipsis "...".

```

+++OK
atid3151 OK

...configured pan identifier has been changed atdc10

OK

...and verbose join enabled atac

OK

...applying changes to the configuration V AI - Searching for Parent:FF
...search has started

V AI - Searching for Parent:FF

...and started again

V Scanning:03FFF800

...Channels 11 through 25 are enabled by the SC setting for the Active Search.

V Beacon Rsp:0000000000000042A6010B949AC8FF

...ZS(0), extendedPanId(00000000000042A6), allowingJoin(1), radiochannel(0x0B), panid(949A), rssi(C8), lqi(FF)

V Reject ID

...beacon response's extendedPanId does not match this radio's ID setting of 3151
    
```

V Beacon Rsp:020000000000002AB010C55D2B2DB

...ZS(2), extendedPanId(0000000000002AB), allowingJoin(1), radiochannel(0x0C), panid(55D2), rssi(B2), lqi(DB)

V Reject ZS

...beacon response's ZS does not match this radio's ZS setting of 0x00

V Beacon Rsp:000000000000003151010EE29FDFFF

V Beacon Saved:0E05E29F0000000000003151

...this beacon response is acceptable as a candidate for association

V Joining:0E05E29F0000000000003151

...sending association request

V Stack Status: joined, network up 0290

...we are joined, the network is up, we can send and transmit

V Joined:

V AI - Association Succeeded:00

Route Record Indicator - 0xA1

Description

This frame contains the routing information for a remote device on the network. This route information should be stored in external memory and used in a 0x21 Create Source Route frame to provide a return route for data transmissions; this eliminates the need to perform a route discovery. The frame will be emitted out of the node that is acting as a low RAM concentrator when a unicast data transmission is received from a remote node for the first time. If a previously established route fails, a new 0xA1 Route Record Indicator will be generated with information about the new route.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0xA1
64-bit source (remote) address	4-11	The 64-bit address of the device that initiated the route record.
Source (updater) 16-bit address	12-13	The 16-bit address of the device that initiated the route record.
Receive options	14	0x01 - Packet Acknowledged. 0x02 - Packet was a broadcast.
Number of addresses	15	The number of addresses in the source route (excluding source and destination).
Address 1	16-17	(neighbor of destination)
Address 2 (closer hop)	18-19	Address of intermediate hop
Address n (neighbor of source)	20	Two bytes per 16-bit address.
	21	

Example

Suppose device A is a low RAM concentrator, and device E is sending a unicast message to it.

Device E knows that device A is a low RAM concentrator and will send a route record that traverses multiple hops en route to the concentrator as shown in the following example:

A < B < C < D < E

In this frame, the following route information is provided:

Device E 64-bit address: 0x0013A200 40401122

Device E 16-bit address: 0x3344

Device D 16-bit address: 0xEEFF

Device C 16-bit address: 0xCCDD

Device B 16-bit address: 0xAABB

The concentrator emits the following frame out of the serial port:

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x13
Frame type	3	0xA1
64-bit source (remote) address	MSB 4	0x00
	5	0x13
	6	0xA2
	7	0x00
	8	0x40
	9	0x40
	10	0x11
	11	0x22
Source (updater) 16-bit address	12	0x33
	13	0x44
Receive options	14	0x01
Number of Addresses	15	0x03
Address 1	16	0xEE
	17	0xFF
Address 2 (closer hop)	18	0xCC
	19	0xDD
Address n (neighbor of source)	20	0xAA
	21	0xBB
Checksum	22	0x80

Register Device Status - 0xA4

Description

This frame is sent out of the UART of the trust center as a response to a 0x24 Register Device frame, indicating whether the registration was successful or not.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0xA4 Register Device Status
Frame ID	4	Identifies the data frame for the host to correlate with a subsequent response. It matches the Frame ID of the registration request (0x24).
Status	5	0x00 = Success 0x01 = Key too long 0xB1 = Address not found in the key table 0xB2 = Key is invalid (00 and FF are reserved) 0xB3 = Invalid address 0xB4 = Key table is full 0xFF = Key not found

Example

A device is registered to the trust center using a 0x24 frame with a Frame ID of 0x53. The following status is returned, indicating that the registration was a success.

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x03
Frame type	3	0xA4
Frame ID	4	0x53
Status	5	0x00 (Success)
Checksum	6	0x08

Many-to-One Route Request Indicator - 0xA3

Description

A many-to-one route request is sent as a broadcast message from a concentrator (**AR** < 0xFF).

When a node receives a many-to-one broadcast, it will create a route table entry for the concentrator, preventing the need to do a route discovery when sending data to that destination.

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Frame data fields	Offset	Description
Frame type	3	0xA3
64-bit source (remote) address	4-11	MSB first, LSB last. The 64-bit address of the device that sent the many-to-one route request.
Source 16-bit address	12-13	MSB first, LSB last. The 16-bit address of the device that initiated the many-to-one route request.
Reserved	14	Set to 0.

Example

Suppose a device with a 64-bit address of 0x0013A200 40401122 and 16-bit address of 0x0000 sends a many-to-one route request. All remote routers operating in API mode that receive the many-to-one broadcast send the following example API frame out their serial port.

Frame data fields	Offset	Example
Start delimiter	0	0x7E
Length	MSB 1	0x00
	LSB 2	0x0C
Frame type	3	0xA3

Frame data fields	Offset	Example
64-bit source (remote) address	MSB 4	0x00
	5	0x13
	6	0xA2
	7	0x00
	8	0x40
	9	0x40
	10	0x11
	11	0x22
Source 16-bit address	MSB 12	0x00
	LSB 13	0x00
Reserved	14	0x00
Checksum	22	0xF4

BLE Unlock Response frame - 0xAC

Description

The XBee3 Zigbee RF Module uses [BLE Unlock API frame - 0x2C](#) to authenticate a connection on the Bluetooth interface and unlock the processing of AT command frames. This frame is used in conjunction with the **Response (0xAC)** frame.

For details, see [BLE Unlock API frame - 0x2C](#).

User Data Relay Output - 0xAD

Description

Allows for data to be received on an interface with a designation of the target interface for the data to be output on. The frame can be sent or received from any of the following interfaces: MicroPython (internal interface), UART, and BLE. This frame is used in conjunction with [User Data Relay frame - 0x2D](#).

Format

The following table provides the contents of the frame. For details on frame structure, see [API frame format](#).

Field name	Field value	Data type	Description
Delimiter	7E		

Field name	Field value	Data type	Description
Length			
Frame type	0xAD	Byte	
Source interface		1Byte	
Data		Variable	
Checksum		Variable	

In-depth OTA firmware upgrade process for Zigbee

3.0

The OTA upgrade process is based on the Zigbee Cluster Library specifications; ZCL messages are exchanged between the server and the client using 0x11 explicit addressing API frames with a cluster ID of 0x0019. All multiple byte values in the ZCL command in the payload must be sent in little endian byte order for the command to be executed correctly on the remote device.

For the server to receive the required ZDO responses from the client, set [AO \(API Options\)](#) to **1** to enable the [Explicit Rx Indicator frame - 0x91](#). The client automatically generates the necessary responses regardless of its serial configuration.

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OTA file

The OTA firmware process uses a specific firmware file with a .gbl extension. This file needs to be parsed and divided into 64-byte blocks.

Storage

The OTA firmware image blocks are received and stored in a separate internal flash slot that is allotted exclusively for this purpose. Once all the image bytes are written to the slot, the new image must be validated by the current application before it can be used.

If the new image is deemed invalid, the running Zigbee firmware rejects the image and continues operating with the current, valid application.

ZCL OTA messaging

The following figure provides the messaging sequence between the Server (updater node) and the Client (target node).

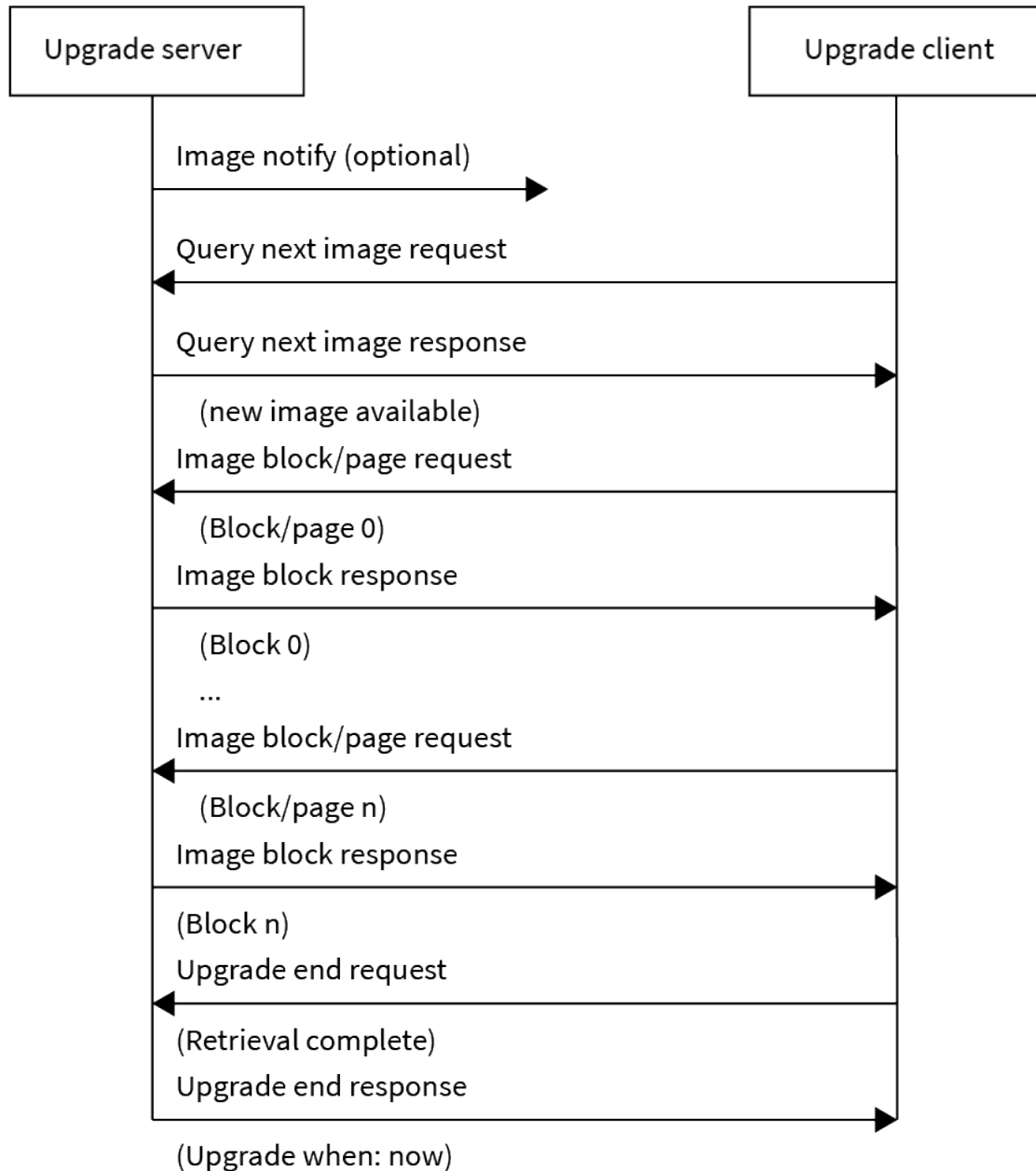


Image Notify

The server sends the Image Notify message to the client informing the device of the presence of an update image. The Image Notify message is sent when the upgrade process is initiated from the server.

Create the Image Notify request

The Image Notify Request is an explicit transmit frame (0x11 type) passed into the server with the following information:

Frame data fields	Offset	Example	Comments
Start delimiter	0	0x7E	
Length	MSB 1	0x00	
	LSB 2	0x21	
Frame Type	3	0x11	
Frame ID	4	0x01	
64-bit destination address	MSB 5	0x00	
	6	0x13	
	7	0xA2	
	8	0xFE	
	9	0x00	
	10	0x00	
	11	0x00	
	LSB 12	0x03	
16-bit destination address	MSB 13	0x28	
	LSB 14	0x2F	
Source Endpoint	15	0xE8	
Destination Endpoint	16	0xE8	
Cluster ID	MSB 17	0x00	
	LSB 18	0x19	
Profile ID	MSB 19	0xC1	
	LSB 20	0x05	
Broadcast radius	21	0x00	
Transmit options	22	0x00	

Frame data fields			Offset	Example	Comments
Data payload	ZCL frame header	Frame control	23	0x09	
		Transaction sequence number	24	0x01	
	ZCL payload	Command ID	25	0x00	Image Notify Command ID
		Payload type	26	0x03	Contains Jitter, Image Type, Firmware Version
		Query jitter	27	0x00	
		Manufacturer ID	LSB 28	0x1E	Digi's Manufacturer ID in Little Endian
			MSB 29	0x10	
		Image type	LSB 30	0x00	Image type should be 0x0000 unless the server doesn't want to update the client
			MSB 31	0x00	
		Firmware version	LSB 32	0x01	Firmware version of the new update file in Little Endian. In this example, the version is 0x1001
			33	0x10	
			34	0x00	
			MSB 35	0x00	
		Checksum			36

Query Next Image request

The client device sends the Query Next Image request message to the server to indicate it is ready to receive a firmware image and is sent as a response to an Image Notify message. The client sends information about the existing firmware version as a part of this message. The server emits the following frame after receiving the request from the client:

Frame data fields	Offset	Example	Comments
Start delimiter	0	0x7E	
Length	MSB 1	0x00	
	LSB 2	0x1E	
Frame Type	3	0x91	

Frame data fields			Offset	Example	Comments
64-bit source address			MSB 4	0x00	
			5	0x13	
			6	0xA2	
			7	0xFE	
			8	0x00	
			9	0x00	
			10	0x00	
			LSB 11	0x03	
16-bit source address			MSB 12	0x28	
			LSB 13	0x2F	
Source Endpoint			14	0xE8	
Destination Endpoint			15	0xE8	
Cluster ID			MSB 16	0x00	
			LSB 17	0x19	
Profile ID			MSB 18	0xC1	
			LSB 19	0x05	
Receive options			20	0x01	
Data payload	ZCL frame header	Frame control	21	0x01	
		Transaction sequence number	22	0x00	

Frame data fields		Offset	Example	Comments
ZCL payload	Command ID	23	0x01	Query Next Image request
	Field control	24	0x00	
	Manufacturer ID	LSB 25	0x1E	
		MSB 26	0x10	
	Image type	LSB 27	0x00	
		MSB 28	0x00	
	Firmware version	LSB 29	0x00	
		30	0x10	
		31	0x00	
		MSB 32	0x00	
Checksum		33	0x71	

Query Next Image response

The server obtains the information sent by the Client in the Query Next Image request and determines if it has a suitable image for the client. It then sends a Query Next Image response with one of the following status messages as appropriate:

- 0x00 - SUCCESS: The server is authorized to upgrade the client with the image.
- 0x98 - NO_IMAGE_AVAILABLE: The server is authorized to update the client but does not have a new OTA update image available.
- 0x7E - NOT_AUTHORIZED: The server is not authorized to update the client.

Frame data fields	Offset	Example	Comments
Start delimiter	0	0x7E	
Length	MSB 1	0x00	
	LSB 2	0x24	
Frame Type	3	0x11	
Frame ID	4	0x01	

Frame data fields	Offset	Example	Comments
64-bit destination address	MSB 5	0x00	
	6	0x13	
	7	0xA2	
	8	0xFE	
	9	0x00	
	10	0x00	
	11	0x00	
	LSB 12	0x03	
16-bit destination address	MSB 13	0x28	
	LSB 14	0x2F	
Source Endpoint	15	0xE8	
Destination Endpoint	16	0xE8	
Cluster ID	MSB 17	0x00	
	LSB 18	0x19	
Profile ID	MSB 19	0xC1	
	LSB 20	0x05	
Broadcast radius	21	0x00	
Transmit options	22	0x00	

Frame data fields			Offset	Example	Comments
Data payload	ZCL frame header	Frame control	23	0x09	
		Transaction sequence number	24	0x01	
	ZCL payload	Command ID	25	0x02	Query Next Image Response
		Status	26	0x00	Success = 0x00 No Image Available = 0x98 Not Authorized = 0x7E
		Manufacturer ID	LSB 27	0x1E	
			MSB 28	0x10	
		Image type	LSB 29	0x00	
			MSB 30	0x00	
		Firmware version	LSB 31	0x01	Firmware version of the new update file in Little Endian. In this example, the version is 0x1001
			32	0x10	
			33	0x00	
			MSB 34	0x00	
	Image Size	LSB 35	0x2E		
		36	0xF3		
37		0x02			
MSB 38		0x00			
Checksum			39	0xE5	

Image Block request

The Client generates Image Block requests to request the server for bytes of the OTA firmware image. Each image block is 64 byte long. The client also sends the file offset as a way to keep the synchronization of every block intact.

The Image Block requests are repeated by the client until all the blocks of the image are successfully obtained. The size of the OTA upgrade image is usually obtained by the client in the Query Next Image response message and hence it knows the exact number of Image Block requests it needs to send.

Frame data fields	Offset	Example	Comments
Start delimiter	0	0x7E	
Length	MSB 1	0x00	
	LSB 2	0x1E	
Frame Type	3	0x91	
64-bit source address	MSB 4	0x00	
	5	0x13	
	6	0xA2	
	7	0xFE	
	8	0x00	
	9	0x00	
	10	0x00	
	LSB 11	0x03	
16-bit source address	MSB 12	0x28	
	LSB 13	0x2F	
Source Endpoint	14	0xE8	
Destination Endpoint	15	0xE8	
Cluster ID	MSB 16	0x00	
	LSB 17	0x19	
Profile ID	MSB 18	0xC1	
	LSB 19	0x05	
Receive options	20	0x01	

Frame data fields			Offset	Example	Comments
Data payload	ZCL frame header	Frame control	21	0x01	
		Transaction sequence number	22	0x01	
	ZCL payload	Command ID	23	0x03	Image Block Request
		Field control	24	0x00	
		Manufacturer ID	LSB 25	0x1E	
			MSB 26	0x10	
		Image type	LSB 27	0x00	
			MSB 28	0x00	
		Firmware version	LSB 29	0x01	
			30	0x10	
			31	0x00	
			MSB 32	0x00	
		File Offset	LSB 33	0x00	0x0 for the first request. Offset by multiples of Image Block size. For example, 0x00000000 for the first request, 0x00000040, 0x00000080 and so on.
			34	0x00	
			35	0x00	
LSB 36	0x00				
Image Block Size	37	0x40			
Checksum			38	0x2D	

Image Block response

The server generates an Image Block response upon receiving an Image Block request command. It responds with a SUCCESS status on being able to retrieve the data for the client. The server uses the file offset sent by the client to determine the location of the requested data within the OTA upgrade image.

If you wish to cancel the update process, send an ABORT (0x95) status.

Frame data fields	Offset	Example	Comments
Start delimiter	0	0x7E	
Length	MSB 1	0x00	
	LSB 2	0x65	
Frame Type	3	0x11	
Frame ID	4	0x01	
64-bit destination address	MSB 5	0x00	
	6	0x13	
	7	0xA2	
	8	0xFE	
	9	0x00	
	10	0x00	
	11	0x00	
	LSB 12	0x03	
16-bit destination address	MSB 13	0x28	
	LSB 14	0x2F	
Source Endpoint	15	0xE8	
Destination Endpoint	16	0xE8	
Cluster ID	MSB 17	0x00	
	LSB 18	0x19	
Profile ID	MSB 19	0xC1	
	LSB 20	0x05	
Broadcast radius	21	0x00	
Transmit options	22	0x00	

Frame data fields			Offset	Example	Comments
Data payload	ZCL frame header	Frame control	23	0x09	
Data payload		Transaction sequence number	24	0x02	
Data payload	ZCL payload	Command ID	25	0x05	Image Block Response
Data payload	ZCL payload	Status	26	0x00	Success = 0x00 Abort = 0x95
Data payload	ZCL payload	Manufacturer ID	LSB 27	0x1E	
Data payload			MSB 28	0x10	
Data payload	ZCL payload	Image type	LSB 29	0x00	
Data payload			MSB 30	0x00	
Data payload	ZCL payload	Firmware version	LSB 31	0x01	
Data payload			32	0x10	
Data payload			33	0x00	
Data payload			MSB 34	0x00	
Data payload	ZCL payload	File Offset	LSB 35	0x00	
Data payload			36	0x00	
Data payload			37	0x00	
Data payload			MSB 38	0x00	
Data payload	ZCL payload	Image Block Size	39	0x40	64 byte blocks
Data payload	ZCL payload	Image Block Data	40-104	0xEB-0x00	An image block of the size mentioned in Image Block Size
Checksum			106	0x4E	

Upgrade End request

The Upgrade End request is generated by the client after it verifies the received firmware image to ensure its integrity and validity. If the image fails any integrity checks, the client sends an Upgrade End request command to the upgrade server with INVALID_IMAGE as the status. If the image passes all integrity checks, the client sends an Upgrade End request command to the upgrade server with SUCCESS as the status.

Frame data fields	Offset	Example	Comments
Start delimiter	0	0x7E	
Length	MSB 1	0x00	
	LSB 2	0x1E	
Frame Type	3	0x91	
64-bit source address	MSB 4	0x00	
	5	0x13	
	6	0xA2	
	7	0xFE	
	8	0x00	
	9	0x00	
	10	0x00	
	LSB 11	0x03	
16-bit source address	MSB 12	0x28	
	LSB 13	0x2F	
Source Endpoint	14	0xE8	
Destination Endpoint	15	0xE8	
Cluster ID	MSB 16	0x00	
	LSB 17	0x19	
Profile ID	MSB 18	0xC1	
	LSB 19	0x05	
Receive options	20	0x01	

Frame data fields			Offset	Example	Comments
Data payload	ZCL frame header	Frame control	21	0x01	
		Transaction sequence number	22	0x30	
	ZCL payload	Command ID	23	0x06	Upgrade End Request
		Status	24	0x00	Success = 0x00 Invalid Image = 0x96 Abort = 0x95 Require More Image = 0x99
		Manufacturer ID	LSB 25	0x1E	
			MSB 26	0x10	
		Image type	LSB 27	0x00	
			MSB 28	0x00	
		Firmware version	LSB 29	0x01	
			30	0x10	
			31	0x00	
			MSB 32	0x00	
	Checksum			38	0x3B

Upgrade End response

If the server receives an Upgrade End request with a SUCCESS status, it generates an Upgrade End response along with the time at which the device should upgrade to the new image.

Frame data fields	Offset	Example	Comments
Start delimiter	0	0x7E	
Length	MSB 1	0x00	
	LSB 2	0x24	
Frame Type	3	0x11	
Frame ID	4	0x01	

Frame data fields	Offset	Example	Comments
64-bit destination address	MSB 5	0x00	
	6	0x13	
	7	0xA2	
	8	0xFE	
	9	0x00	
	10	0x00	
	11	0x00	
	LSB 12	0x03	
16-bit destination address	MSB 13	0x28	
	LSB 14	0x2F	
Source Endpoint	15	0xE8	
Destination Endpoint	16	0xE8	
Cluster ID	MSB 17	0x00	
	LSB 18	0x19	
Profile ID	MSB 19	0xC1	
	LSB 20	0x05	
Broadcast radius	21	0x00	
Transmit options	22	0x00	

Frame data fields			Offset	Example	Comments
Data payload	ZCL frame header	Frame control	23	0x09	
		Transaction sequence number	24	0x01	
	ZCL payload	Command ID	25	0x07	Upgrade End response
		Manufacturer ID	LSB 26	0x1E	
			MSB 27	0x10	
		Image type	LSB 28	0x00	
			MSB 29	0x00	
		Firmware version	LSB 30	0x01	
			31	0x10	
			32	0x00	
			MSB 33	0x00	
		Current Time	LSB 34	0xF0	32 bit unsigned integer Seconds since Epoch
			35	0x1A	
			36	0x53	
			MSB 37	0x21	
Upgrade Time	LSB38	0x00			
	39	0x1B			
	40	0x53			
	MSB 41	0x21			
Checksum			38	0xE5	

Note We use only Image Block requests / responses and not an Image Page Request, which is specified as an optional message type in the ZCL OTA specification.

ZCL OTA cluster status codes

ZCL OTA status code	Value	Description
SUCCESS	0x00	Successful operation
ABORT	0x95	Failed when client or server decides to abort the upgrade process
NOT_AUTHORIZED	0x7E	Server is not authorized to upgrade the client
INVALID_IMAGE	0x96	Invalid OTA upgrade image. For example, the image failed signature validation or CRC.
WAIT_FOR_DATA	0x97	Server does not have data block available yet
NO_IMAGE_AVAILABLE	0x98	No OTA upgrade image available for a particular client
MALFORMED_COMMAND	0x80	The command received is badly formatted or has incorrect parameters
UNSUP_CLUSTER_COMMAND	0x81	Such command is not supported on the device
REQUIRE_MORE_IMAGE	0x99	The client still requires more OTA upgrade image files in order to successfully upgrade

OTA ZCL command	Error status	Error message
Query Next Image		

For better handling, the OTA framework supports Default responses with Error Codes and command IDs. The format of the ZCL payload for a Default response is:

Frame Ctrl	0x00	0 signifies that the ZCL command is global and not cluster specific
Sequence Number	0x00	ZCL sequence number
Command ID	0x0B	Command ID for Default Response commands
ZCL OTA Command	0x00	The Command ID for which the client is sending the status
Status	0x00	ZCL error status

We expect to encounter the following error cases:

Command ID	ZCL OTA command	Status	XCTU message
0x0B Default Response	0x02 Query Next Image Response	0x80	Incorrect Query Next Image Response Format
		0x85	Attempting to upgrade to invalid firmware
		0x89	Image size is too big
		0x8A	Please ensure that the image you are attempting to upgrade has a different version than the current version
		0x01	ZCL OTA Message Out of Sequence
	0x05 Image Block Response	0x80	Incorrect Image Block Response Format
		0x01	ZCL OTA Message Out of Sequence
		0x--	Mismatched Offset
		0x87	Upgrade File Mismatch
	0x08 Upgrade End Response	0x87	Wrong Upgrade File

The status field in the Upgrade End Status has more extensive error defines than in Zigbee, which are:

ZCL OTA command	Status	Error message
0x06 Upgrade End Request	0x94	Client Timed Out
	0x96	Invalid OTA Image
	0x95	Client Aborted Upgrade
	0x05	Storage Erase Failed
	0x87	Contact Tech Support (Highly unlikely to occur)