Cambium PTP 650 Series User Guide

System Release 650-01-00

Cambium Networks

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Contents

About This User Guide

This guide describes the planning, installation, configuration and operation of the Cambium PTP 650 Series of point-to-point wireless Ethernet bridges. It is intended for use by the system designer, system installer and system administrator.

For radio network design, refer to the following chapters:

- Chapter 1: Product description
- Chapter 2: System hardware
- Chapter 3: System planning
- Chapter 4: Legal and regulatory information

For radio equipment installation, refer to the following chapter:

- Chapter 5: Installation

For system configuration, monitoring and fault-finding, refer to the following chapters:

- Chapter 6: Configuration and alignment
- Chapter 7: Operation
- Chapter 8: Troubleshooting

Contacting Cambium Networks

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Purpose

Cambium Networks Point-To-Point (PTP) documents are intended to instruct and assist personnel in the operation, installation and maintenance of the Cambium PTP equipment and ancillary devices. It is recommended that all personnel engaged in such activities be properly trained.

Cambium disclaims all liability whatsoever, implied or express, for any risk of damage, loss or reduction in system performance arising directly or indirectly out of the failure of the customer, or anyone acting on the customer's behalf, to abide by the instructions, system parameters, or recommendations made in this document.

Cross references

References to external publications are shown in italics. Other cross references, emphasized in blue text in electronic versions, are active links to the references.

This document is divided into numbered chapters that are divided into sections. Sections are not numbered, but are individually named at the top of each page, and are listed in the table of contents.

Feedback

We appreciate feedback from the users of our documents. This includes feedback on the structure, content, accuracy, or completeness of our documents. Send feedback to support@cambiumnetworks.com.

Important regulatory information

The PTP 650 product is certified as an unlicensed device in frequency bands where it is not allowed to cause interference to licensed services (called primary users of the bands).

Radar avoidance

In countries where radar systems are the primary band users, the regulators have mandated special requirements to protect these systems from interference caused by unlicensed devices. Unlicensed devices must detect and avoid co-channel operation with radar systems.

The PTP 650 provides detect and avoid functionality for countries and frequency bands requiring protection for radar systems.

Installers and users must meet all local regulatory requirements for radar detection. To meet these requirements, users must install a license key for the correct country during commissioning of the PTP 650. If this is not done, installers and users may be liable to civil and criminal penalties.

Contact the Cambium helpdesk if more guidance is required.

USA and Canada specific information

The USA Federal Communications Commission (FCC) has asked manufacturers to implement special features to prevent interference to weather radar systems that operate in the band 5600 MHz to 5650 MHz. These features must be implemented in all products able to operate outdoors in the band 5470 MHz to 5725 MHz.

Manufacturers must ensure that such radio products cannot be configured to operate outside of FCC rules; specifically it must not be possible to disable or modify the radar protection functions that have been demonstrated to the FCC.

In order to comply with these FCC requirements, Cambium supplies variants of the PTP 650 for operation in the USA or Canada. These variants are only allowed to operate with license keys that comply with FCC/IC rules. In particular, operation of radio channels overlapping the band 5600-5650 MHz is not allowed and these channels are permanently barred.

In addition, other channels may also need to be barred when operating close to weather radar installations.

Note

To ensure compliance with FCC rules (KDB 443999: Interim Plans to Approve UNII Devices Operating in the 5470 - 5725 MHz Band with Radar Detection and DFS Capabilities), follow Avoidance of weather radars (USA only) on page 3-20.

Other variants of the PTP 650 are available for use in the rest of the world, but these variants are not supplied to the USA or Canada except under strict controls, when they are needed for export and deployment outside the USA or Canada.

Specific expertise and training required for professional installers

To ensure that the PTP 650 is installed and configured in compliance with the requirements of Industry Canada and the FCC, installers must have the radio engineering skills and training described in this section. This is particularly important when installing and configuring a PTP 650 system for operation in the 5.4 GHz UNII band.

Avoidance of weather radars

The installer must be familiar with the requirements in FCC KDB 443999. Essentially, the installer must be able to:

- Access the FCC data base of weather radar location and channel frequencies.
- Use this information to correctly configure the product (using the GUI) to avoid operation on channels that should be barred according to the guidelines that are contained in the KDB and explained in detail in this user guide.

External antennas

When using a connectorized version of the product (as compared to the version with an integrated antenna), the conducted transmit power may need to be reduced to ensure the regulatory limit on transmitter EIRP is not exceeded. The installer must have an understanding of how to compute the effective antenna gain from the actual antenna gain and the feeder cable losses.

The range of permissible values for maximum antenna gain and feeder cable losses are included in this user guide together with a sample calculation. The product GUI automatically applies the correct conducted power limit to ensure that it is not possible for the installation to exceed the EIRP limit, when the appropriate values for antenna gain and feeder cable losses are entered into the GUI.

Ethernet networking skills

The installer must have the ability to configure IP addressing on a PC and to set up and control products using a web browser interface.

Lightning protection

To protect outdoor radio installations from the impact of lightning strikes, the installer must be familiar with the normal procedures for site selection, bonding and grounding. Installation guidelines for the PTP 650 can be found in Chapter 2: System hardware and Chapter 5: Installation.

Training

The installer needs to have basic competence in radio and IP network installation. The specific requirements applicable to the PTP 650 should be gained by reading Chapter 5: Installation and Chapter 6: Configuration and alignment and by performing sample set ups at base workshop before live deployments.

Problems and warranty

Reporting problems

If any problems are encountered when installing or operating this equipment, follow this procedure to investigate and report:

1. Search this document and the software release notes of supported releases.
2. Visit the support website.
3. Ask for assistance from the Cambium product supplier.
4. Gather information from affected units, such as any available diagnostic downloads.
5. Escalate the problem by emailing or telephoning support.

Repair and service

If unit failure is suspected, obtain details of the Return Material Authorization (RMA) process from the support website.

Hardware warranty

Cambium's standard hardware warranty is for one (1) year from date of shipment from Cambium Networks or a Cambium distributor. Cambium Networks warrants that hardware will conform to the relevant published specifications and will be free from material defects in material and workmanship under normal use and service. Cambium shall within this time, at its own option, either repair or replace the defective product within thirty (30) days of receipt of the defective product. Repaired or replaced product will be subject to the original warranty period but not less than thirty (30) days.

To register PTP products or activate warranties, visit the support website. For warranty assistance, contact the reseller or distributor.

Caution

Using non-Cambium parts for repair could damage the equipment or void warranty. Contact Cambium for service and repair instructions.

Portions of Cambium equipment may be damaged from exposure to electrostatic discharge. Use precautions to prevent damage.

Security advice

Cambium Networks systems and equipment provide security parameters that can be configured by the operator based on their particular operating environment. Cambium recommends setting and using these parameters following industry recognized security practices. Security aspects to be considered are protecting the confidentiality, integrity, and availability of information and assets. Assets include the ability to communicate, information about the nature of the communications, and information about the parties involved.

In certain instances Cambium makes specific recommendations regarding security practices, however the implementation of these recommendations and final responsibility for the security of the system lies with the operator of the system.

Warnings, cautions, and notes

The following describes how warnings and cautions are used in this document and in all documents of the Cambium Networks document set.

Warnings

Warnings precede instructions that contain potentially hazardous situations. Warnings are used to alert the reader to possible hazards that could cause loss of life or physical injury. A warning has the following format:

Warning

Warning text and consequence for not following the instructions in the warning.

Cautions

Cautions precede instructions and are used when there is a possibility of damage to systems, software, or individual items of equipment within a system. However, this damage presents no danger to personnel. A caution has the following format:

Caution

Caution text and consequence for not following the instructions in the caution.

Notes

A note means that there is a possibility of an undesirable situation or provides additional information to help the reader understand a topic or concept. A note has the following format:

Note

Note text.

Caring for the environment

The following information describes national or regional requirements for the disposal of Cambium Networks supplied equipment and for the approved disposal of surplus packaging.

In EU countries

The following information is provided to enable regulatory compliance with the European Union (EU) directives identified and any amendments made to these directives when using Cambium equipment in EU countries.

Disposal of Cambium equipment

European Union (EU) Directive 2002/96/EC Waste Electrical and Electronic Equipment (WEEE)

Do not dispose of Cambium equipment in landfill sites. For disposal instructions, refer to http://www.cambiumnetworks.com/support

Disposal of surplus packaging

Do not dispose of surplus packaging in landfill sites. In the EU, it is the individual recipient's responsibility to ensure that packaging materials are collected and recycled according to the requirements of EU environmental law.

In non-EU countries

In non-EU countries, dispose of Cambium equipment and all surplus packaging in accordance with national and regional regulations.

Chapter 1: Product description

This chapter provides a high level description of the PTP 650 product. It describes in general terms the function of the product, the main product variants and the main hardware components. The following topics are described in this chapter:

- Overview of the PTP 650 on page 1-2 introduces the key features, typical uses, product variants and components of the PTP 650.
- Wireless operation on page 1-6 describes how the PTP 650 wireless link is operated, including modulation modes, power control and spectrum management.
- Ethernet bridging on page 1-15 describes how the PTP 650 controls Ethernet data, in both the customer data and system management networks.
- System management on page 1-23 introduces the PTP 650 management system, including the web interface, installation, configuration, security, alerts and upgrades.

Overview of the PTP 650

This section introduces the key features, typical uses, product variants and components of the PTP 650.

Purpose

Cambium PTP 650 Series Bridge products are designed for Ethernet bridging over point-to-point microwave links in unlicensed and lightly-licensed frequency bands between 4.9 GHz and 5.8 GHz. Users must ensure that the PTP 650 Series complies with local operating regulations.

The PTP 650 Series acts as a transparent bridge between two segments of the operator's network. In this sense, it can be treated as a virtual wired connection between two points. The PTP 650 Series forwards 802.3 Ethernet frames destined for the other part of the network and filters frames it does not need to forward. The system is transparent to higher-level protocols such as VLANs and Spanning Tree.

Key features

The PTP 650 is a high performance wireless bridge for Ethernet traffic with a maximum throughput of 450 Mbps. It is capable of operating in line-of-sight (LOS), near-LOS and non-LOS propagation condition. Its maximum LOS range is 200 km.

The PTP 650 operates in unlicensed and lightly-licensed frequency bands between 4.9 and 5.8 GHz. It has a very high spectral efficiency of 10 bps/Hz and supports a channel bandwidth of up to 45 MHz. The integrated ODU has its own flat plate antenna. The connectorized ODU is designed for use with an external antenna.

The wireless link is TDD based and supports both symmetric and asymmetric configurations.

From a network point-of-view, the PTP 650 wireless link is a transparent Layer 2 bridge. It supports up to three Gigabit Ethernet ports. Two ports support twisted pair Gigabit Ethernet. One of them is capable of providing power via standard 802.3at PoE to an external device such as a video surveillance camera or a wireless access point. The third port accepts either a twisted pair or fibre GE SFP module.

PTP 650 has extensive quality of service (QoS) classification capability and supports up to eight levels of queues. Management of the unit may be via the same interface as the bridged traffic (in-band management) or on a separate port (out-of-band local management).

Table 1 gives a summary of the main PTP 650 characteristics.

Table 1 Main characteristics of the PTP 650 Series

Characteristic	Value
Topology	PTP
Wireless link condition	LOS, near LOS or non-LOS
Range	Up to 200 km
Duplexing	TDD (symmetric and asymmetric)
Connectivity	Ethernet
Operating frequencies	4.9 to 5.8 GHz
Channel bandwidth	10, 20, 40 or 45 MHz
High spectral efficiency	Up to 10 bps/Hz
Data rate	Up to 450 Mbps (45 MHz channel BW)

Frequency bands

The PTP 650 ODU can be configured by the user to operate in the following bands:

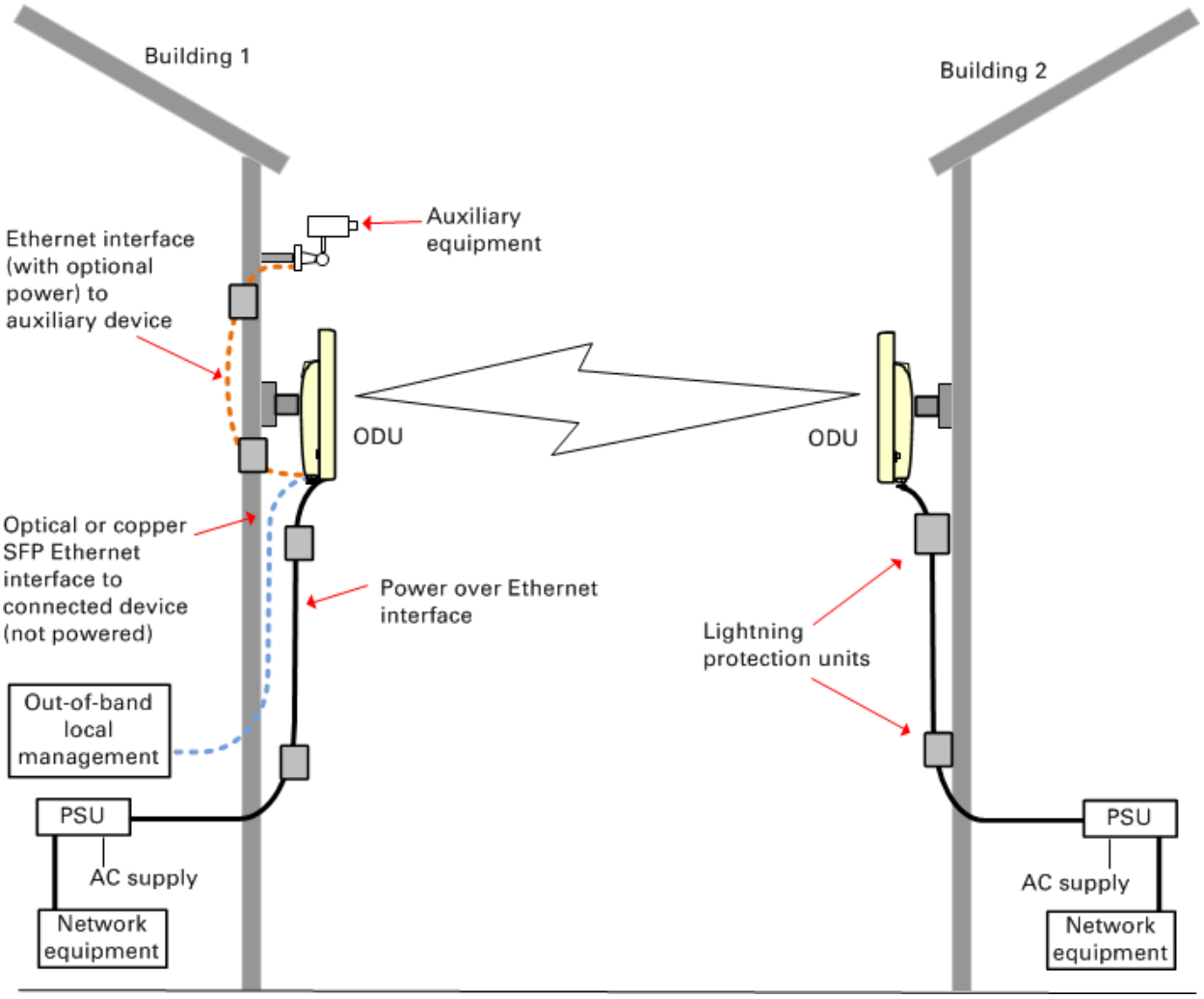
- 4900 to 4990 MHz
- 5470 to 5725 MHz
- 5725 to 5875 MHz

Typical bridge deployment

The PTP 650 is an "all outdoor" solution consisting of a wireless bridge between two sites. Each site installation consists of an integrated or connectorized outdoor unit (ODU) and a power injector (PSU) (Figure 1). The ODU provides the following interfaces:

- PSU port: This provides proprietary power over Ethernet and connection to the management and/or data networks via 100BASE-TX or 1000BASE-T Ethernet. In the basic configuration, this is the only Ethernet connection to the ODU.
- SFP port: This provides an optical or copper Gigabit Ethernet interface for out-of-band local management, user data or user data with in-band management.
- Aux port: This provides an optional power and 100BASE-TX or 1000BASE-T Ethernet connection to an IEEE803.2at device such as a video camera or wireless access point.

Figure 1 PTP 650 typical bridge deployment



Hardware overview

The main hardware components of the PTP 650 are as follows:

- Outdoor unit (ODU): The ODU is a self-contained transceiver unit that houses both radio and networking electronics. The ODU is supplied in the following product variants:
  - Integrated or Connectorized: The ODU may be either Integrated (attached to its own flat plate antenna) or connectorized (without an antenna).
  - FCC/IC, EU or RoW: These variants are for deployment in the USA and Canada, the EU and the rest of the world respectively.
- Power supply unit (PSU): There is a choice of two PSUs:
  - The AC Power Injector is suitable for installations without an auxiliary device.
  - The AC+DC power injector is required when powering from a DC supply or when the PSU is needed to operate at extreme temperatures.
- Antennas and antenna cabling: Connectorized ODUs require external antennas connected using RF cable.
- Ethernet cabling: All configurations require a copper Ethernet Cat5e connection from the ODU (PSU port) to the PSU. Advanced configurations may also require one or both of the following:
  - A copper or optical Ethernet connection from the ODU (SFP port) to network terminating equipment or another device.
  - A copper Ethernet Cat5e connection from the ODU (Aux port) to an auxiliary device.
- Lightning protection unit (LPU): LPUs are installed in the PSU and Aux copper drop cables to provide transient voltage surge suppression.
- Ground cables: ODU, LPUs and outdoor copper Ethernet cables are bonded to the site grounding system using ground cables.

For more information about these components, including interfaces, specifications and Cambium part numbers, refer to Chapter 2: System hardware.

Wireless operation

This section describes how the PTP 650 wireless link is operated, including modulation modes, power control and security.

Time division duplexing

TDD cycle

PTP 650 links operate using Time Division Duplexing (TDD). They use a TDD cycle in which the ODUs alternately transmit and receive TDD bursts. The TDD cycle is illustrated in Figure 2. The steps in the cycle are as follows:

1. The TDD master transmits a burst to the TDD slave.
2. A delay occurs as the master-slave burst propagates over the link.
3. The slave receives the burst from the master.
4. The slave processes the master-slave burst.
5. The slave transmits a burst to the master.
6. A delay occurs as the slave-master burst propagates over the link.
7. The master receives the burst from the slave.
8. The master transmits the next burst to the slave.

TDD frame parameters

The TDD burst duration varies depending on the following:

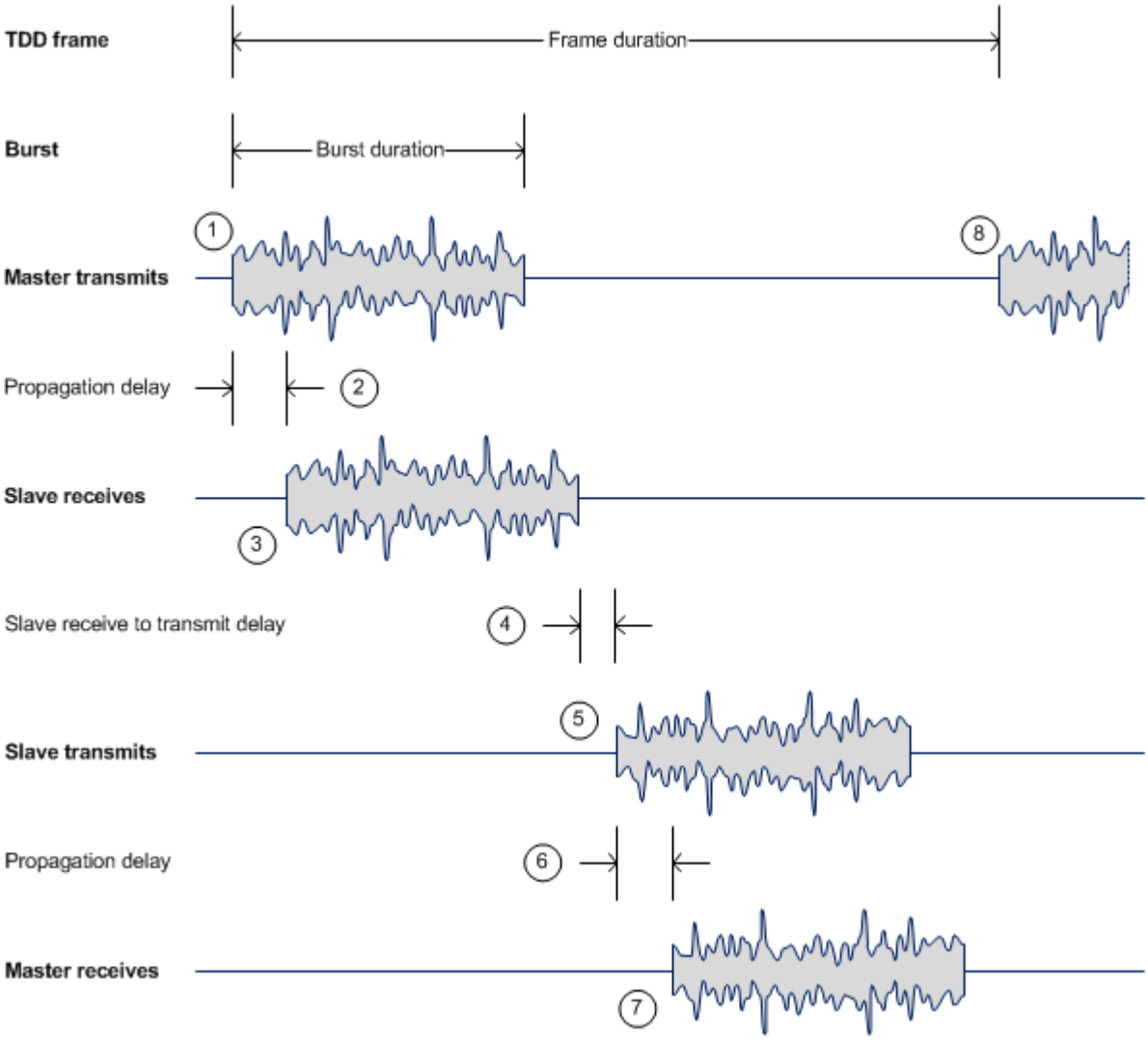
- Channel bandwidth
- Link range
- Link optimization mode
- Link symmetry
- Offered traffic loading.

The TDD frame duration varies depending on the following:

- TDD burst duration master-slave.
- TDD burst duration slave-master.
- Link range.

The propagation delay in Step 2 is necessarily equal to the propagation delay in Step 6, and is determined solely by the link range. There may be added delays between rx and tx on the master and slave to minimize interference, as set up by the link planner or installer.

Figure 2 TDD cycle



Channel selection

The PTP 650 series links are capable of transmitting and receiving on the same channel or on different channels. In other words, the slave-master direction may use a different channel from the master-slave direction. Independent selection of transmit and receive frequencies can be useful in planned networks or for countering interference.

When links operate in radar avoidance regions, each unit monitors its transmit channel for the presence of radar signals. Therefore, the transmit and receive channels are always identical.

Link mode optimization

Link mode optimization allows the PTP 650 link to be optimized according to the type of traffic that will be bridged. The link supports two modes, IP Traffic and TDM Traffic.

IP traffic

IP Traffic mode is optimized to provide the maximum possible link capacity. IP Traffic mode is an appropriate choice where applications in the bridged networks provide some measure of reliable transmission, and where very low latency is not critical. IP mode supports both fixed and adaptive link symmetry (see Link symmetry on page 1-8).

TDM traffic

TDM Traffic mode is optimized to provide the lowest possible latency. TDM Traffic mode additionally implements a more conservative approach to adaptive modulation, leading to lower error rates in fading channels at the expense of slightly lower link capacity. TDM Traffic mode is an appropriate choice for delay intolerant data without reliable transmission (for example voice over IP data).

Link symmetry

The PTP 650 series provides four configuration options for apportioning the available capacity between the two link directions.

- **Symmetric –** The Master and Slave have equal capacity. The PTP 650 series achieves this by allocating an equal Burst Duration for the Master and the Slave.
- **2:1 –** The capacity in the direction Master to Slave is twice that of the direction Slave to Master. The PTP 650 series achieves this by setting the Burst Duration of the Master to twice that of the Slave.
- **1:2 –** The capacity in the direction Slave to Master is twice that of the direction Master to Slave. The PTP 650 series achieves this by setting the Burst Duration of the Slave to twice that of the Master.
- **Adaptive –** This is only available on the Full variant. The capacity allocated to a given link direction is dependent on the offered level of network traffic in both link directions. If the level of offered traffic in both directions is equally high or equally low, the PTP 650 will allocate equal capacity to both directions. If however the offered level of traffic is greater in one direction, it is allocated a greater proportion of the overall link capacity. The PTP 650 series achieves this by increasing (or decreasing) the duration of the Transmit Burst in a given link direction as the offered level of network traffic increases (or decreases) in this same direction. This is done independently for the two directions.

Adaptive mode is not available in the following configurations:

- When link mode optimization is set to TDM Traffic (see Link mode optimization on page 1-8).
- In regions where radar avoidance is operational (see Radar avoidance on page 1-12).
- When the ODU is not a Full variant.

OFDM and channel bandwidth

The PTP 650 series transmits using Orthogonal Frequency Division Multiplexing (OFDM). This wideband signal consists of many equally spaced sub-carriers. Although each sub carrier is modulated at a low rate using conventional modulation schemes, the resultant data rate from the sub-carriers is high. OFDM works exceptionally over a Non-Line-of-Sight (NLoS) channel.

The channel bandwidth of the OFDM signal is configurable to one of the following values: 10, 20, 40 and 45 MHz. Higher bandwidths provide greater link capacity at the expense of using more spectrum. Systems configured for a narrower channel bandwidth provide better receiver sensitivity and can also be an appropriate choice in deployments where the amount of free spectrum is limited.

Each channel is offset in center frequency from its neighboring channel by 10 or 5 MHz.

Note

The Channel Bandwidth must be configured to the same value at both ends of the link. Not all channel bandwidths are available in all regulatory bands.

Spectrum management

The spectrum management feature of the PTP 650 Series monitors the available wireless spectrum and directs both ends of the wireless link to operate on a channel with a minimum level of co-channel and adjacent channel interference.

Spectrum management measurements

The PTP 650 Series performs two mean signal measurements per TDD cycle, per channel. This mean measurement represents the mean received signal power for the 40 microsecond measurement period.

The Spectrum Management algorithm collects measurements equally from all channels in the operating band. This process is called the Channel Availability Check (CAC). The CAC uses a round-robin channel selection process to collect an equal amount of measurements from each channel. The CAC measurement process is not altered by the channel barring process. Measurements are still collected for all channels irrespective of the number of barred channels.

Measurement analysis

Spectrum Management uses statistical analysis to process the received peak and mean measurement. The statistical analysis is based on a fixed, one minute, measurement quantization period. Spectrum Management collects data for the specified quantization period and only at the end of the period is the statistical analysis performed.

Statistical summary

The display of statistical measurement on the spectrum management page always shows a statistical summary of all channel measurement. The statistical summary is controlled by the Statistics Window attribute. This attribute defaults to a value of twenty minutes, which means that the mean and percentile values displayed for each channel are calculated over the 20 minute period. All channel decisions are made using the values computed over the statistics window period.

Spectrum management in fixed frequency mode

The transmit and receive frequencies can be fixed in a PTP 650 wireless link. Once fixed frequency mode is configured, the spectrum management software will not attempt to move the wireless link to a channel with lower co-channel and adjacent-channel interference. Therefore this mode of operation is only recommended for deployments where the installer has a good understanding of the prevailing interference environment. Care must also be taken to ensure that the frequency allocations at each end of the link are compatible.

Fixed frequency mode is not available in regions where radar detection is required by the regulations.

Adaptive modulation

The PTP 650 series can transport data over the wireless link using a number of different modulation modes ranging from 256QAM 0.81 to BPSK 0.63. For a given channel bandwidth and TDD frame structure, each modulation mode transports data at a fixed rate. Also, the receiver requires a minimum signal to noise ratio in order to successfully demodulate a given modulation mode. Although the more complex modulations such as 256QAM 0.81 will transport data at a much higher rate than the less complex modulation modes, the receiver requires a much higher signal to noise ratio.

The PTP 650 series provides an adaptive modulation scheme where the receiver constantly monitors the quality of the received signal and notifies the far end of the link of the optimum modulation mode with which to transmit. In this way, optimum capacity is achieved at all times. This is one of a number of features which allows the PTP 650 to operate in challenging non-line of sight radio channels.

Note

PTP LINKPlanner includes an estimate of mean data rate, the data rate provided by each modulation and the percentage of time spent in each modulation mode.

MIMO

Multiple-Input Multiple-Output (MIMO) techniques provide protection against fading and increase the probability that the receiver will decode a usable signal. When the effects of MIMO are combined with those of OFDM techniques and a high link budget, there is a high probability of a robust connection over a non-line-of-sight path.

The PTP 650 transmits two signals on the same radio frequency, one of which is vertically polarized and the other horizontally polarized. Depending on the channel conditions, the PTP 650 will adapt between two modes of operation:

- **Dual Payload**: When the radio channel conditions allow, the PTP 650 will transmit two different and parallel data streams, one on the vertical channel and one on the horizontal channel. This doubles the capacity of the PTP 650.
- **Single Payload**: As the radio channel becomes more challenging, the PTP 650 has the ability to detect this and switch to a mode which transmits the same data stream on both vertical and horizontal channels. This provides polar diversity and is another key feature which allows the PTP 650 to operate in challenging non- line of sight radio channels.

Lower order modulations (BPSK 0.63 up to QPSK 0.87) only operate in single payload mode. Higher order modulations (16QAM 0.63 to 256QAM 0.81) are available in single payload mode and dual payload mode. The switching between modes is automatically controlled by the adaptive modulation feature described in Adaptive modulation on page 1-10.

Note

The system automatically chooses between dual and single payload to try to increase the capacity of a link. However the user can disable the dual payload mode, forcing the more robust option of single payload.

Dynamic spectrum optimization

The PTP 650 series uses an interference mitigation technique known as Dynamic Spectrum Optimization (DSO). Both the Master and Slave continually monitor for interference on all channels and then select the best frequency of operation. This is a dynamic process where the PTP 650 can continually move channels in response to changes in interference. Two modes of operation are available:

- First mode: the two link directions are forced to select the same frequency, determined by the Master.
- Second mode: the frequency of operation can be determined independently for each direction. This mode is not permitted in radar regions.

Radar avoidance

In regions where protection of radars is part of the local regulations, the PTP 650 must detect interference from radar-like systems and avoid co-channel operation with these systems.

To meet this requirement, the PTP 650 implements the following features:

- The radar detection algorithm will always scan a usable channel for 60 seconds for radar interference before making the channel an available channel.
- This compulsory channel scan will mean that there is at least 60 seconds service outage every time radar is detected and that the installation time is extended by at least 60 seconds even if no radar is found.
- When operating on a channel, the spectrum management algorithm implements a radar detection function which looks for impulsive interference on the operating channel. If impulsive interference is detected, spectrum management will mark the current operating channel as having detected radar (unavailable channel) and initiate a channel hop to an available channel. The previous operating channel will remain in the unavailable state for thirty minutes after the impulsive interference pulse was detected.
- After the thirty minutes have expired the channel will be returned to the usable channel pool.

There is a secondary requirement for bands requiring radar avoidance. Regulators have mandated that products provide a uniform loading of the spectrum across all devices. In general, this prevents operation with fixed frequency allocations. However:

- ETSI regulations do allow frequency planning of networks (as that has the same effect of spreading the load across the spectrum).
- The FCC does allow channels to be barred if there is actually interference on them.

Note

Fixed frequency allocation is not recommended in radar avoidance regions, as any radar detection would cause a system outage of at least 30 minutes.

Encryption

The PTP 650 supports optional encryption for data transmitted over the wireless link. The encryption algorithm used is the Advanced Encryption Standard (AES) with 128-bit and 256-bit key size. AES is a symmetric encryption algorithm approved by U.S. Government organizations (and others) to protect sensitive information. The AES implementation in PTP 650 is approved to FIPS-197. Encryption is enabled through the purchase of an upgrade.

License keys and regulatory bands

The PTP 650 license key specifies the country of operation for the ODU, and lists the regulatory bands that are licensed by regulators in that country. If a license key provides access to more than one regulatory band, PTP 650 provides a choice between the available bands. In each regulatory band, PTP 650 sets the following aspects of wireless operation to comply with the applicable regulations:

- Maximum transmit power
- Radar avoidance
- Transmit power reduction in edge channels
- Frequency range
- Channel plan

The country of operation (and thus the supported regulatory bands) can be changed by generating a new license key at the License Key Generator page of the Cambium web-site, and entering the new license key using the Installation Wizard.

Caution

To avoid possible enforcement action by the country regulator, always operate links in accordance with local regulations.

PTP networks

Using Dynamic Spectrum Optimization

The Dynamic Spectrum Optimization (DSO) feature allows a PTP 650 unit to select wireless channels for a lower level of radio frequency (RF) interference. This approach is appropriate where the network consists of a small number of PTP links, or where the RF interference is predominantly from equipment belonging to other operators.

Using frequency planning

Networks will benefit from the use of fixed channel allocations if (a) the network consists of multiple PTP links, and (b) RF interference predominantly arises from equipment in the same network.

Frequency planning is the exercise of assigning operating channels to PTP units so as to minimize RF interference between links. Frequency planning must consider interference from any PTP unit to any other PTP unit in the network. Low levels of interference normally allow for stable operation and high link capacity.

The frequency planning task is made more straightforward by use of the following techniques:

- Using several different channels
- Separating units located on the same mast
- Using high performance (directional) external antennas

For help with planning networks, refer to Chapter 3: System planning, or contact your Cambium distributor or re-seller.

Ethernet bridging

This section describes how the PTP 650 processes Ethernet data, in both the customer and system management networks.

Ethernet ports

The PTP 650 Series ODU has three Ethernet ports:

- **Main PSU**: The Main PSU port provides a copper Ethernet interface for 100BASE-TX and 1000BASE-T, and accepts power from the AC+DC Enhanced Power Injector or the AC Power Injector to the ODU using a proprietary power over Ethernet (PoE) method.
- **Aux:** The Aux port provides a copper Ethernet interface for 100BASE-TX and 1000BASE-T, and supplies power from the ODU to external equipment using standards-based power over Ethernet (PoE) complying with IEEE 802.3at.
- **SFP:** The SFP port is a small format pluggable receptacle accepting copper or optical plug-in modules supplied as part of the SFP module kits on page 2-27.

Each of the three Ethernet ports can be allocated for customer data or network management in the following ways:

- **Disabled:** The port is not in use for customer data or network management.
- **Data Only**: The port is connected to the customer data network only.
- **Data and In-Band Management**: The port is connected to the customer data network and to the management agent of the local ODU
- **Out-of-Band Local Management**: The port is connected directly to the management agent of the local ODU.

Port allocation is subject to the following rules:

- One port should be allocated to Data Only or Data and In-Band Management
- The remaining ports should be allocated to Disabled or Out-of-Band Local Management

Further examples of port allocation are provided in Chapter 3: System planning.

Note

The PTP 650 provides flexible interconnection of customer data and network management using several Ethernet ports, but it does not contain a general-purpose Ethernet switch, and it is not possible to forward traffic between the Ethernet ports of the same ODU.

Customer data network

Transparent Ethernet service

The PTP 650 Series provides an Ethernet service between one of the Ethernet ports at a local ODU and one of the Ethernet ports at an associated remote ODU. The Ethernet service is based on conventional layer two transparent bridging, and is equivalent to the Ethernet Private Line (EPL) service defined by the Metro Ethernet Forum (MEF).

The service is transparent to untagged frames, standard VLAN frames, priority-tagged frames, provider bridged frames, Q-in-Q frames and provider backbone bridged frames. In each case, the service preserves MAC addresses, VLAN ID, Ethernet priority and Ethernet payload in the forwarded frame. The maximum frame size for bridged frames in the customer network is 9600 bytes.

Note

There is no requirement for the customer data network to be connected to the same Ethernet port at both ends of a wireless link. For example, it is possible to connect the Main PSU port to the customer data network at one end of the link and to connect the Aux port to the customer data network at the other end of the link.

Layer two control protocols

The PTP 650 Series is transparent to layer two control protocols (L2CP) including:

- Spanning tree protocol (STP), rapid spanning tree protocol (RSTP)
- Multiple spanning tree protocol (MSTP)
- Link aggregation control protocol (LACP)
- Link OAM, IEEE 802.3ah
- Port authentication, IEEE 802.1X
- Ethernet local management interface (E-LMI), ITU-T Q.933.
- Link layer discovery protocol (LLDP)
- Multiple registration protocol (MRP)
- Generic attribute registration protocol (GARP)

The PTP 650 Series does not generate or respond to any L2CP traffic.

Quality of service for bridged Ethernet traffic

The PTP 650 Series supports eight traffic queues for Ethernet frames waiting for transmission over the wireless link. Ethernet frames are classified by inspection of the Ethernet priority code point in the outermost VLAN tag, the Differentiated Services Code Point (DSCP) in an IPv4 or IPv6 header, or the Traffic Class in an MPLS header.

PTP 650 provides a configurable mapping between Ethernet, IP or MPLS priority and transmission queue, together with a simple way to restore a default mapping based on the recommended default in IEEE 802.1Q-2005. Untagged frames, or frames with an unknown network layer protocol, can be separately classified.

Scheduling for transmission over the wireless link is by strict priority. In other words, a frame at the head of a given queue is transmitted only when all higher priority queues are empty.

Fragmentation

The PTP 650 Series minimizes latency and jitter for high-priority Ethernet traffic by fragmenting Ethernet frames before transmission over the wireless link. The fragment size is selected automatically according to channel bandwidth and modulation mode of the wireless link. Fragments are reassembled on reception, and incomplete Ethernet frames are discarded.

Wireless link down alert

The PTP 650 Series provides an optional indication of failure of the wireless link by means of a brief disconnection of the copper data port or the optical data port allocated to the customer data network. The Wireless link down alert can be used to trigger protection switching by Spanning Tree Protocol (STP) or Ethernet Automatic Protection Switching (EAPS) and other higher layer protocols in a redundant network.

Lowest Ethernet Modulation Mode

The PTP 650 ODU can be configured to discard Ethernet frames when the modulation mode is lower than the configured Lowest Ethernet Modulation Mode.

This feature is likely to be useful in networks that have alternate routes, for example in a ring or mesh topology where EAPS or RSTP is used to resolve loops. In this application, Lowest Ethernet Modulation Mode should be set to ensure that an active link will provide at least the minimum necessary capacity for high-priority constant bit rate traffic such as voice over IP or TDM pseudo wire. An active link will be blocked when the capacity falls below the minimum required, triggering a routing change in associated Ethernet switches to bring alternate links into use.

Lowest Ethernet Modulation Mode should normally be set to BPSK 0.63 Single in simply connected tree networks or other topologies that do not have alternative routes.

Network management

IPv4 and IPv6 interfaces

The PTP 650 ODU contains an embedded management agent with IPv4 and IPv6 interfaces. Network management communication is exclusively based on IP and associated higher layer transport and application protocols. The default IPv4 address of the management agent is 169.254.1.1. There is no default IPv6 address. The PTP 650 does not require use of supplementary serial interfaces.

MAC address

The management agent end-station MAC address is recorded on the enclosure and is displayed on the Status web page. The MAC address is not configurable by the user.

VLAN membership

The management agent can be configured to transmit and receive either untagged, priority-tagged, C-tagged (IEEE 802.1Q) or S-tagged (IEEE 802.1ad) frames. C-tagged and S-tagged frames must be single tagged. The VLAN ID can be 0 (priority tagged) or in the range 1 to 4094.

Ethernet and DHCP priority

The management agent transmits IPv4 and IPv6 management packets with a configurable DHCP value in the range 0 to 63. If the management agent is configured to operate in a management VLAN, the Ethernet frames will be transmitted with a configurable Ethernet priority in the range 0 to 7. The same DHCP and Ethernet priorities are assigned to all management packets generated by the agent. Management frames are multiplexed with customer data frames of the same priority for transmission at the wireless port.

Access to the management agent

The management agent can be reached from any Ethernet port at the local ODU that is allocated to either Data and In-Band Management or Out-of-Band Local Management.

If the wireless link is established, the management agent can also be reached from the remote ODU via an Ethernet port that is allocated to Data and In-Band Management.

Management frames are processed by the management agent if (a) the destination MAC address in the frame matches the ODU MAC address, and (b) the VLAN ID in the frame matches the VLAN configuration of the management agent.

If Local Packet Filtering is enabled, unicast frames forwarded to the management agent as in-band management are filtered, that is, not forwarded in the customer data network.

The Port Allocation options described in Ethernet ports on page 1-15 allow for several combinations of in-band and out-of-band local management as shown in Figure 3, Figure 4 and Figure 5.

Figure 3 shows a single port allocated to Data and In-Band Management. The in-band management might be connected to a network management center or to a management terminal of an installer or technician.

Figure 3 In-band management

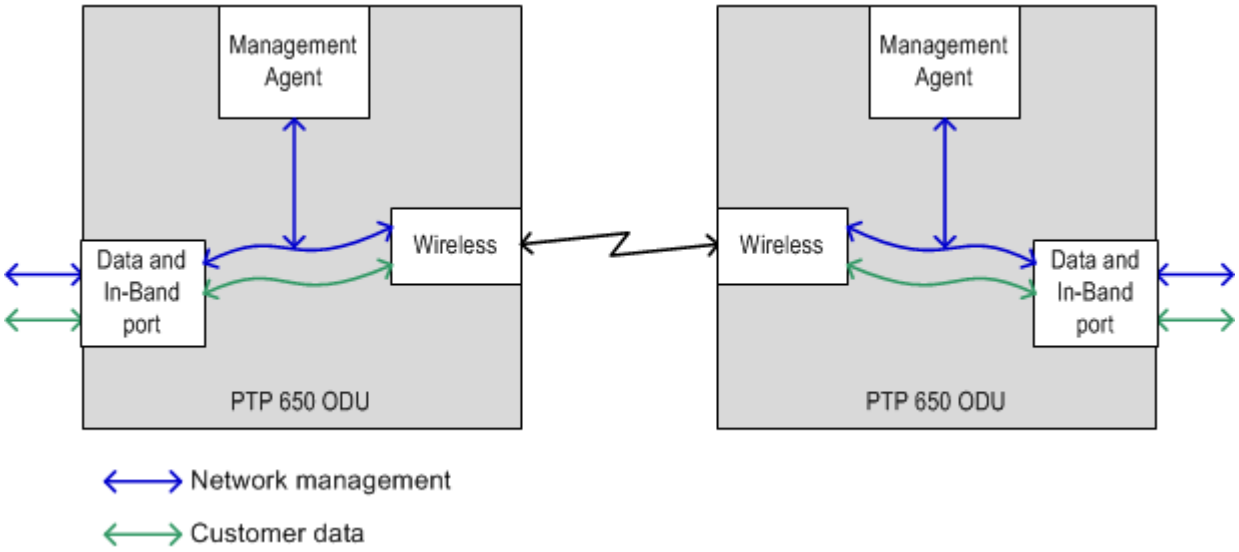


Figure 4 shows one port allocated to Data Only and one allocated to Out-of-Band Local Management. The local management network (shown in red) is isolated from the customer data network (shown in green). Management frames are not forwarded over the wireless link. The connection to the management agent is solely through the management port of the local ODU.

Figure 4 Out-of-band local management

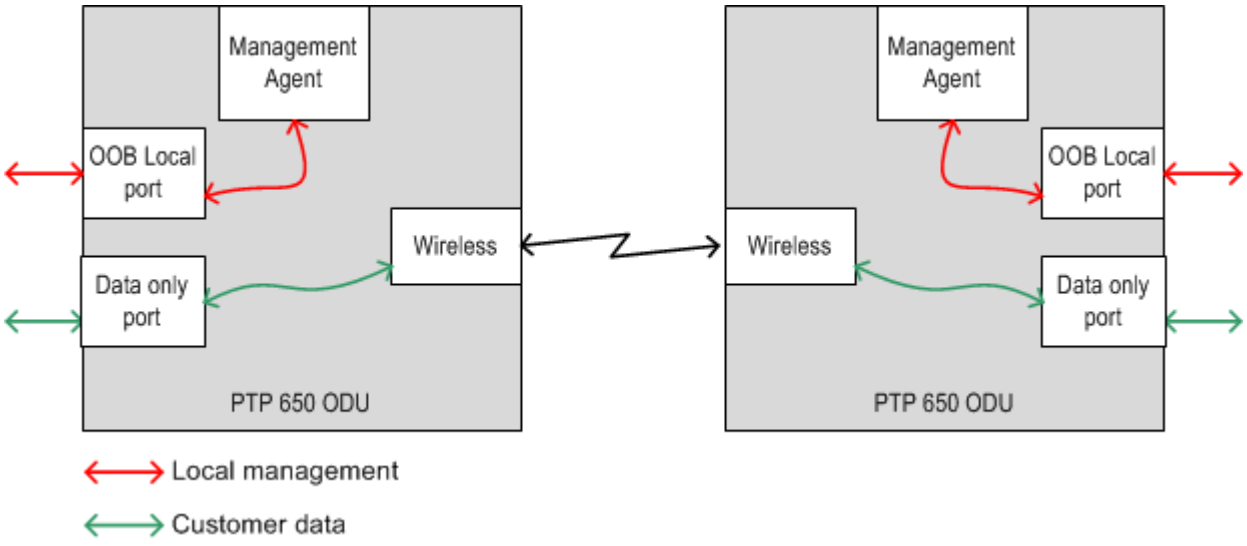
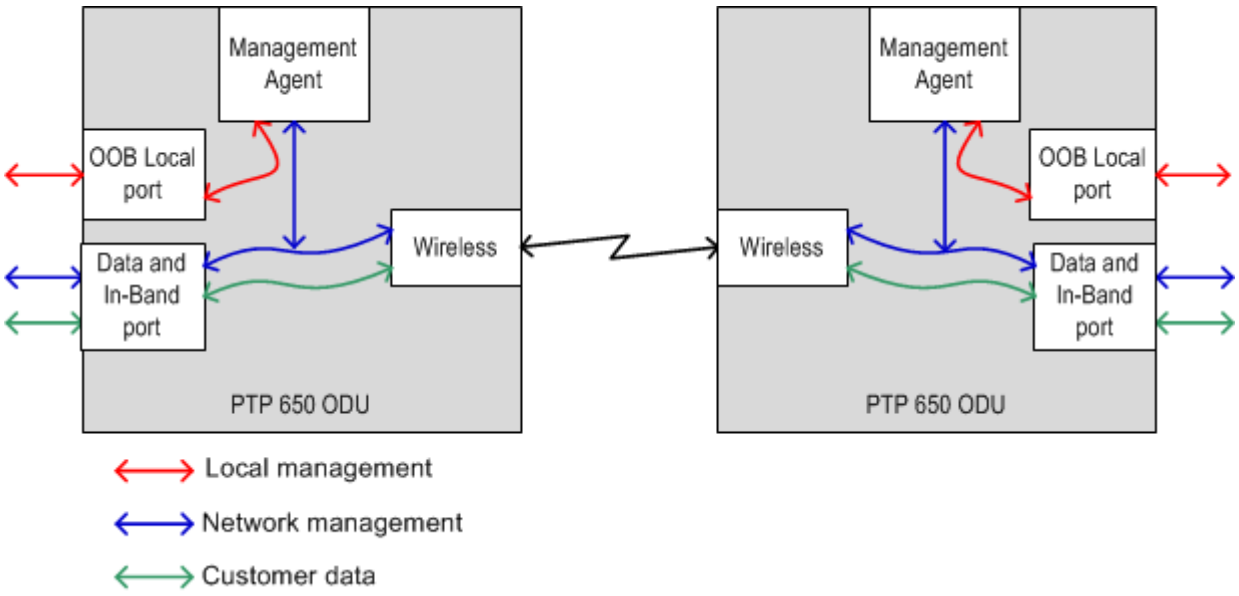


Figure 5 shows a combination of in-band and out-of-band local management. Here, the out-of-band local port might be used to connect a management terminal of an installer or technician, whilst the in-band management is connected to a network management center.

Figure 5 IB and OOB local management



MAC address and IP address of the management agent

The MAC address and IP address used by the management agent will be the same at each port that is allocated to In-Band Management or Out-Of-Band Local Management. The management agent does not provide the function of a dual-homed or multi-homed host. Network designers should take care to ensure that the ODU will not be connected to more than one IP network.

Further examples of useful port allocation schemes are provided in Chapter 3: System planning.

Source address learning

If Local Packet Filtering is enabled, the PTP 650 learns the location of end stations from the source addresses in received management frames. The agent filters transmitted management frames to ensure that the frame is transmitted at the appropriate Ethernet port, or over the wireless link as required to reach the reach the correct end station. If the end station address is unknown, then management traffic is transmitted at each of Ethernet port enabled for management and over the wireless link.

Ethernet loopback mode

PTP 650 provides a local Ethernet loopback function that can be used to loop traffic between the Aux Port and one of the other Ethernet ports.

Loopback is intended to assist in the commissioning of a camera or other auxiliary device collocated with the PTP 650 ODU. For example, when setting up a camera which will ultimately be connected to the wireless bridge, it may be useful to loop the data back to a second local interface, to assist in the positioning and alignment of the camera.

When ports are configured for Ethernet local loopback, they are temporarily disconnected from their allocated function and connected together internally within the PTP 650 ODU. Out-of-band local management is disconnected from the management agent, and the In-band management path will also be un-available if one of the loopback ports has been allocated for Data and in-band management. In this case, it will not be possible to manage the ODU from a local Ethernet port. For this reason the Ethernet loopback is always disabled when the ODU is rebooted or power-cycled, restoring the previous port configuration and any associated management paths.

During loopback operation, the same frame size restrictions that apply to management traffic are present, jumbo frames are not supported and the maximum frame size is restricted to 1536 bytes.

Loopback is able to loop between Ethernet ports operating at different line rates if required, and it is possible to configure a Loopback between ports operating at 1000BASE-T/LX/SX and 100BASE-TX if needed.

Protocol model

Ethernet bridging behavior at each end of the wireless link is equivalent to a two-port, managed, transparent MAC bridge where the two ports are Ethernet Port and Wireless Port.

Frames are transmitted at the Wireless port over a proprietary point-to-point circuit-mode link layer between ends of the PTP 650 link. Ethernet frames received at the Ethernet port, or generated internally within the management agent, are encapsulated within a lightweight MAC layer for transmission over the wireless link.

Protocol layers involved in bridging between Ethernet and wireless interfaces are shown in Figure 6. Protocol layers involved in bridging between external interfaces and the management agent are shown in Figure 7. In these figures, the layers have the meanings defined in IEEE 802.1Q-2005.

Figure 6 Protocol layers between Ethernet and wireless interfaces

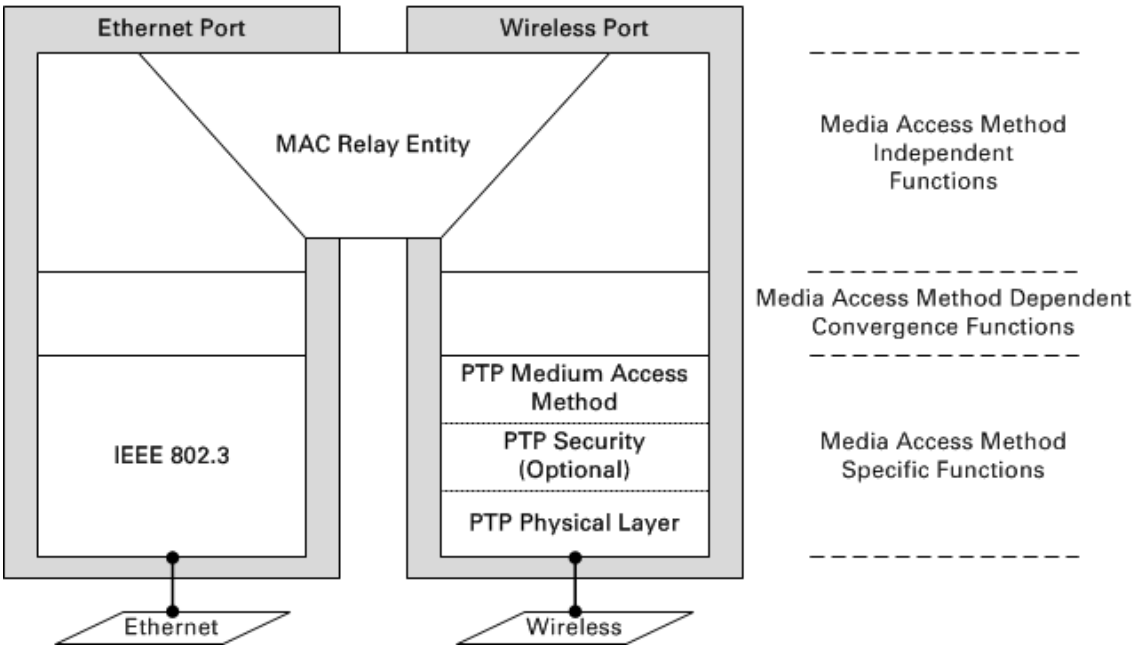
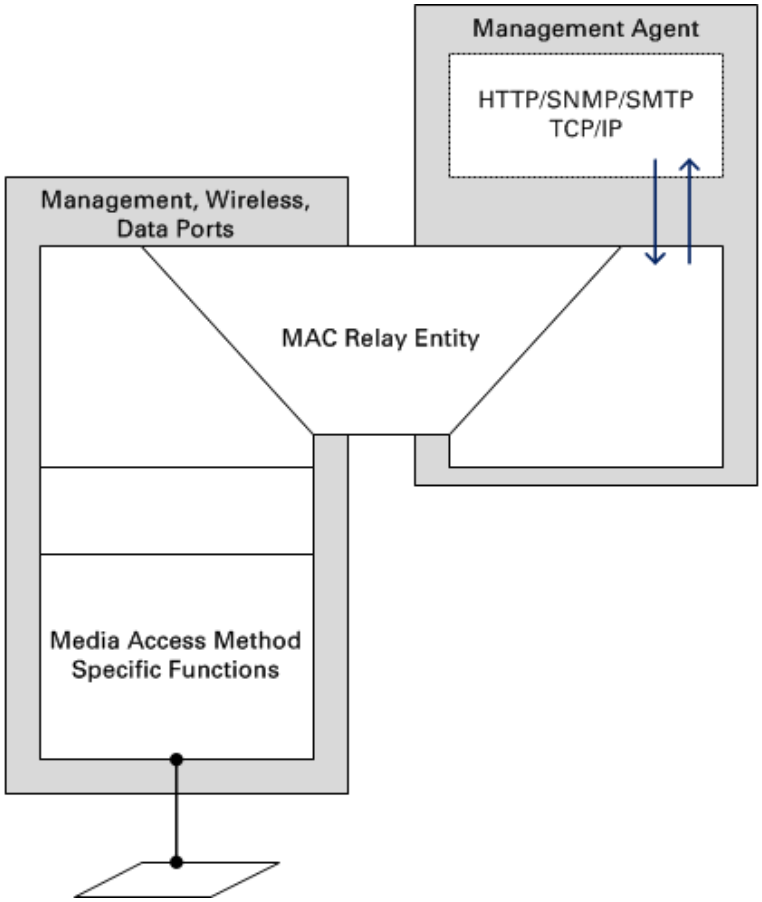


Figure 7 Protocol layers between external interfaces and the management agent



System management

This section introduces the PTP 650 management system, including the web interface, installation, configuration, alerts and upgrades.

Management agent

PTP 650 equipment is managed through an embedded management agent. Management workstations, network management systems or PCs can be connected to this agent using a choice of in-band or out-of-band local modes. These modes are described in detail in Network management on page 1-18.

The management agent includes a dual IPv4/IPv6 interface at the management agent. The IP interface operates in the following modes:

- IPv4 only (default)
- IPv6 only
- Dual IPv4/IPv6

In the dual IPv4/IPv6 mode, the IP interface is configured with an IPv4 address and an IPv6 address and can operate using both IP versions concurrently. This dual mode of operation is useful when a network is evolving from IPv4 to IPv6.

The management agent supports the following application layer protocols (regardless of the management agent IP mode):

- Hypertext transfer protocol (HTTP)
- HTTP over transport layer security (HTTPS/TLS)
- RADIUS authentication
- TELNET
- Simple network management protocol (SNMP)
- Simple mail transfer protocol (SMTP)
- Simple network time protocol (SNTP)
- System logging (syslog)

Note

PTP 650 supports a single public key certificate for HTTPS. This certificate must be based on an IPv4 or IPv6 address as the Common Name. The Dual IPv4/IPv6 interface should not normally be used when HTTPS is required.

IPv6

The PTP 650 management agent supports the following IPv6 features:

Neighbor discovery

PTP 650 supports neighbor discovery for IPv6 as specified in RFC 4861 including:

- Neighbor un-reachability detection (NUD),
- Sending and receiving of neighbor solicitation (NS) and neighbor advertisement (NA) messages,
- Processing of redirect functionality.

PTP 650 sends router solicitations, but does not process router advertisements.

Path MTU discovery and packet size

PTP 650 supports path MTU discovery as specified in RFC 1981, and packet fragmentation and reassembly as specified in RFC 2460 and RFC 5722.

ICMP for IPv6

PTP 650 supports ICMPv6 as specified in RFC 4443. PTP 650 does not support RFC 4884 (multi-part messages).

Addressing

The PTP 650 management agent is compatible with the IPv6 addressing architecture specified in RFC 4291. PTP 650 allows static configuration of the following:

- Global unicast address
- IPv6 prefix length
- IPv6 default router.

PTP 650 additionally assigns an automatically configured Link Local address using stateless address auto-configuration (SLAAC) as specified in RFC 4862. PTP 650 does not assign a global unicast IP address using SLAAC.

PTP 650 responds on the standard management agent interfaces (HTTP, HTTPS, syslog, Telnet, SNMP, SMTP, SNTP) using the global unicast address.

Privacy extensions

PTP 650 does not support the privacy extensions specified in RFC 4941.

DHCPv6

PTP 650 does not support address assignment using DHCPv6. The address of the management agent must be configured statically.

Multicast listener discovery for IPv6

The PTP 650 management agent supports Multicast Listener Discovery version 1 (MLDv1) as specified in RFC 2710.

PTP 650 does not support Multicast Listener Discovery version 2 (MLDv2).

Textual representation of IPv6 addresses

PTP 650 allows users to input text-based IP addresses in any valid format defined in RFC 5952. IPv6 addresses are automatically converted by PTP 650 to the preferred compressed form, apart from those using the prefix length on the same line as the address, such as **2000::1/64**.

Security

PTP 650 does not support IP security (IPsec).

Web server

The PTP 650 management agent contains a web server. The web server supports the HTTP and HTTPS/TLS interfaces.

Web-based management offers a convenient way to manage the PTP 650 equipment from a locally connected computer or from a network management workstation connected through a management network, without requiring any special management software. The web-based interfaces are the only interfaces supported for installation of PTP 650.

Web pages

The web-based management interfaces provide comprehensive web-based fault, configuration, performance and security management functions organized into the following web-pages and groups:

- **Home:** The Home web-page reports Wireless Link Status and basic information needed to identify the link. The Home page additionally lists all active alarm conditions.
- **Status:** The Status web-page reports the detailed status of the PTP 650.
- **System:** These web-pages are used for configuration management, including IP and Ethernet, AES encryption keys, quality of service and software upgrade. The System pages additionally provide detailed counters and diagnostic measurements used for performance management.

- **Installation:** The Installation Wizard is used to install license keys, configure the PTP 650 wireless interface and to arm the unit ready for alignment.
- **Management:** These web-pages are used to configure the network management interfaces.
- **Security:** The Security Wizard is used to configure the HTTPS/TLS interface and other security parameters such as the AES wireless link encryption key and the key of keys for encrypting CSPs on the ODU. The Security Wizard is disabled until AES encryption is enabled by license key.
- **Change Password**: The Change Password web page changes the web interface password of the active user. The User Accounts page is also used to change passwords.
- **Logout:** Allows a user to log out from the web-based interface.

Transport layer security

The HTTPS/TLS interface provides the same set of web-pages as the HTTP interface, but allows HTTP traffic to be encrypted using Transport Layer Security (TLS). PTP 650 uses AES encryption for HTTPS/TLS. Operation of HTTPS/TLS is enabled by purchase of an optional AES upgrade.

HTTPS/TLS requires installation of a private key and a public key certificate where the common name of the subject in the public key certificate is the IP address or host name of the PTP 650 unit. PTP 650 supports certificates with 2048-bit key size.

HTTPS/TLS operation is configured through the web-based interfaces using the Security Wizard.

Details of the security material needed for HTTPS/TLS are provided in Security planning on page 3-33.

Note

The PTP 650 has no default public key certificate, and Cambium Networks is not able to generate private keys or public key certificates for specific network applications.

Note

PTP 650 supports a single public key certificate for HTTPS. This certificate must be based on an IPv4 or IPv6 address as the Common Name. Any attempt to use HTTPS without a certificate for the associated IP address will not be secure, and will trigger browser security warnings. It follows from this that the Dual IPv4/IPv6 interface should not normally be used when HTTPS is required.

User account management

PTP 650 allows a network operator to configure a policy for login attempts, the period of validity of passwords and the action taken on expiry of passwords.

Identity-based user accounts

The PTP 650 web-based interface provides two methods of authenticating users:

- Role-based user authentication allows the user, on entry of a valid password, to access all configuration capabilities and controls. This is the default method.
- Identity-based user authentication supports up to 10 users with individual usernames and passwords.

When identity-based user accounts are enabled, a security officer can define from one to ten user accounts, each of which may have one of the three possible roles:

- Security officer.
- System administrator.
- Read only.

Identity-based user accounts are enabled in the Local User Accounts page of the web-based interface.

Password complexity

PTP 650 allows a network operator to enforce a configurable policy for password complexity. Password complexity configuration additionally allows a pre-determined best practice configuration to be set.

SNMP control of passwords

PTP 650 allows the role-based and identity-based passwords for the web-based interface to be updated using the proprietary SNMP MIB. This capability is controlled by the SNMP Control of Passwords, and is disabled by default.

SNMP Control of Passwords can be used together with SNMPv3 to provide a secure means to update passwords from a central network manager. However, password complexity rules are not applied.

RADIUS authentication

PTP 650 supports remote authentication for users of the web interface using the Remote Authentication Dial-In User Service (RADIUS) with one of the following authentication methods:

- Challenge Handshake Authentication Protocol (CHAP)
- Microsoft CHAP Version 2 (MS-CHAPv2)

PTP 650 supports connections to primary and secondary RADIUS servers. The RADIUS interface is configured through the RADIUS Authentication page of the web-based interfaces.

PTP 650 RADIUS supports the standard Service Type attribute to indicate authentication roles of System Administrator and Read Only together with a vendor specific attribute to indicate authentication roles of Security Officer, System Administrator, and Read Only.

Remote authentication can be used in addition to local authentication, or can be used as a replacement for local authentication. If remote and local authentications are used together, PTP 650 checks log in attempts against locally stored user credentials before submitting a challenge and response for remote authentication. Remote authentication is not attempted if the username and password match locally stored credentials, or fails against the local database.

RADIUS is only available when PTP 650 is configured for Identity-based User Accounts. For more information, refer to Planning for RADIUS operation on page 3-39.

SNMP

The management agent supports fault and performance management by means of an SNMP interface. The management agent is compatible with SNMP v1, SNMP v2c, and SNMPv3 using the following Management Information Bases (MIBs):

- RFC-1493. BRIDGE-MIB. dot1dBase group.
- RFC-2233. IF-MIB. Interfaces group, and ifXTable table.
- RFC-3411. SNMP-FRAMEWORK-MIB. snmpEngine group.
- RFC-3412. SNMP-MPD-MIB. snmpMPDStats group.
- RFC-3413. SNMP-TARGET-MIB. snmpTargetObjects group and SNMP-NOTIFICATION-MIB snmpNotifyTable table.
- RFC-3414. SNMP-USER-BASED-SM-MIB. usmStats group and usmUser group.
- RFC-3415. SNMP-VIEW-BASED-ACM-MIB vacmMIBObjects group.
- RFC-3418. SNMPv2-MIB. System group, SNMP group, and set group.
- RFC-3826. SNMP-USM-AES-MIB. usmAesCfb128Protocol OID.
- RFC-4293 IP-MIB, ipForwarding, ipAdEntAddr, ipAdEntIfIndex, ipAdEntNetMask
- PTP 650 Series proprietary MIB.

Simple Network Time Protocol (SNTP)

The clock supplies accurate date and time information to the system. It can be set to run with or without a connection to a network time server (SNTP). It can be configured to display local time by setting the time zone and daylight saving in the Time web page.

If an SNTP server connection is available, the clock can be set to synchronize with the server time at regular intervals. For secure applications, the PTP 650 can be configured to authenticate received NTP messages using an MD5 signature.

SNMPv3 security

SNMP Engine ID

PTP 650 supports four different formats for SNMP Engine ID:

- MAC address
- IPv4 address
- Configurable text string
- IPv6 address

SNMPv3 security configuration is re-initialized when the SNMP Engine ID is changed.

User-based security model

PTP 650 supports the SNMPv3 user-based security model (USM) for up to 10 users, with MD5, SHA-1, DES and (subject to the license key) AES protocols in the following combinations:

- No authentication, no privacy,
- MD5, no privacy,
- SHA-1, no privacy,
- MD5, DES,
- SHA-1, DES,
- MD5, AES,
- SHA-1, AES.

Use of AES privacy requires the PTP 650 AES upgrade described in AES license on page 1-32.

View-based access control model

PTP 650 supports the SNMPv3 view-based access control model (VACM) with a single context. The context name is the empty string. The context table is read-only, and cannot be modified by users.

Access to critical security parameters

The SNMPv3 management interface does not provide access to critical security parameters (CSPs) of PTP 650. It is not possible to read or modify AES keys used to encrypt data transmitted at the wireless interface. Neither is it possible to read or modify security parameters associated with TLS protection of the web-based management interface. The recovery mode option to zeroize CSPs does not affect SNMPv3 configuration.

MIB-based management of SNMPv3 security

PTP 650 supports a standards-based approach to configuring SNMPv3 users and views through the SNMP MIB. This approach provides maximum flexibility in terms of defining views and security levels appropriate for different types of user.

PTP 650 provides a default SNMPv3 configuration. This initial configuration is not secure, but it provides the means by which a secure configuration can be created using SNMPv3.

The secure configuration should be configured in a controlled environment to prevent disclosure of the initial security keys necessarily sent as plaintext, or sent as encrypted data using a predictable key. The initial security information should not be configured over an insecure network.

The default configuration is restored when any of the following occurs:

- All ODU configuration data is erased.
- All SNMP users are deleted using the SNMP management interface.
- The SNMP Engine ID Format has been changed.
- The SNMP Engine ID Format is Internet Address AND the Internet Address has been changed.
- The SNMP Engine ID Format is Text String AND the text string has been changed.
- The SNMP Engine ID Format is MAC Address AND configuration has been restored using a file saved from a different unit.
- SNMPv3 Security Management is changed from web-based to MIB-based.

The default user configuration is specified in SNMPv3 default configuration (MIB-based) on page 3-37.

PTP 650 creates the `initial` user and template users with localized authentication and privacy keys derived from the passphrase string 123456789. Authentication keys for the templates users are fixed and cannot be changed. Any or all of the template users can be deleted.

The default user `initial` is created with a view of the entire MIB, requiring authentication for SET operations. There is no access for template users.

Note

VACM grants access for requests sent with more than the configured security level.

The default user `initial` will have read/write access to the whole of the MIB. This is described in further detail in View-based access control model on page 1-29. The template users have no access to the MIB in the default configuration. User `initial` will normally be used to create one or more additional users with secret authentication and privacy keys, and with appropriate access to the whole of the MIB or to particular views of the MIB according to the operator's security policy. New users must be created by cloning template users. The user `initial` may then be deleted to prevent access using the well-known user name and keys. Alternatively, the keys associated with `initial` may be set to some new secret value.

Web-based management of SNMPv3 security

PTP 650 supports an alternative, web-based approach for configuring SNMPv3 security. In this case, the web-based interface allows users to specify SNMPv3 users, security levels, privacy and authentication protocols, and passphrases. Web-based management will be effective for many network applications, but the capabilities supported are somewhat less flexible than those supported using the MIB-based security management.

Selection of web-based management for SNMPv3 security disables the MIB-based security management.

Web-based management of SNMPv3 security allows for two security roles:

- Read Only
- System Administrator

Read Only and System Administrator users are associated with fixed views allowing access to the whole of the MIB, excluding the objects associated with SNMPv3 security. System Administrators have read/write access as defined in the standard and proprietary MIBs.

Web-based management of SNMPv3 security allows an operator to define the security levels and protocols for each of the security roles; all users with the same role share a common selection of security level and protocols.

Web-based security configuration is re-initialized when any of the following occurs:

- All ODU configuration data is erased.
- The SNMP Engine ID Format has been changed.
- The SNMP Engine ID Format is Internet Address and the Internet Address has been changed.
- The SNMP Engine ID Format is Text String and the text string has been changed.
- The SNMP Engine ID Format is MAC Address and configuration has been restored using a file saved from a different unit.
- SNMPv3 Security Management is changed from MIB-based to web-based.

Additionally, all SNMP user accounts are disabled when the authentication protocol, the privacy protocol, or the security level is changed.

Downgrade of the license key

A possible lockout condition exists if a user downgrades the PTP 650 license key so as to disable the AES capability when SNMPv3 users are configured with AES privacy and VACM is configured to require privacy. In this case, recovery is by either (a) restoring the correct license key, or (b) using recovery mode to erase all configuration and entering new configuration.

Option (b) will cause default users and access configuration to be re-created.

System logging (syslog)

PTP 650 supports the standard syslog protocol to log important configuration changes, status changes and events. The protocol complies with RFC 3164.

PTP 650 creates syslog messages for configuration changes to any attribute that is accessible via the web-based interface, or via the enterprise MIB at the SNMP interface.

PTP 650 additionally creates syslog messages for changes in any status variable displayed in the web-based interface.

PTP 650 creates syslog messages on a number of events (for example successful and unsuccessful attempts to log in to the web-based interface).

PTP 650 can be configured to send syslog messages to one or two standard syslog servers.

Additionally, PTP 650 logs event notification messages locally. Locally-stored event messages survive reboot of the unit, and are overwritten only when the storage capacity is exhausted (approximately 2000 messages). The locally stored events can be reviewed using the web-based user interface.

Only users with Security Officer role are permitted to configure the syslog client. Users with Security Officer, System Administrator or Read Only roles are permitted to review the locally logged event messages.

AES license

PTP 650 provides optional encryption using the Advanced Encryption Standard (AES). Encryption is not available in the standard PTP 650 system.

AES upgrades are supplied as an access key purchased from your Cambium Point-to-Point distributor or solutions provider. The access key authorizes AES operation for one ODU. Two access keys are needed to operate AES on a link. The upgrade is applied by entering an access key together with the MAC address of the target ODU into the PTP License Key Generator web page, which may be accessed from the support website.

The License Key Generator creates a new license key that is delivered by email. The license key must be installed on the ODU. When the license key is installed, the ODU must be rebooted before AES can be enabled. Once applied, the AES upgrade is bound to a single ODU and is not transferrable.

AES encryption may be used in the following ways:

- At the wireless port to encrypt data transmitted over the wireless link.
- At the SNMP management interface in the SNMPv3 mode.
- At the HTTPS/TLS management interface.
- At the RADIUS interface when PEAP (MS-CHAPv2) is used as the authentication method.

Two levels of encryption are available to purchase:

- 128-bit: This allows an operator to encrypt all traffic sent over the wireless link using 128-bit encryption.
- 256-bit: This allows an operator to encrypt traffic using either 128-bit or 256-bit encryption.

Encryption must be configured with the same size key in each direction.

AES encryption at the PTP 650 wireless port is based on pre-shared keys. An identical key must be entered at each end of the link.

AES encryption for SNMPv3 or TLS is always based on a 128-bit key, regardless of level enabled in the PTP 650 license key.

Critical security parameters

Critical security parameters (CSPs) are as follows:

- Key of keys.
- AES encryption keys for the wireless interface.
- Private key for the HTTPS/TLS interface.
- Entropy value for the HTTPS/TLS interface.
- User account passwords for the web-based interface.

CSPs can be erased (zeroized) using the Zeroize CSPs page of the web-based interface or by selecting the Zeroize CSPs option in Recovery mode.

Login information

PTP 650 optionally provides details of the most recent successful login, and the most recent unsuccessful login attempt, for each user of the web-based interface.

Capability upgrades

ODUs are shipped with “Lite” data throughput capability, that is, up to 125 Mbps. Cambium Networks supply capability upgrades to upgrade ODUs to “Mid” (up to 250 Mbps) or “Full” (up to 450 Mbps) capability. ODUs are shipped without AES encryption capability. Cambium Networks supply capability upgrades to upgrade ODUs to128-bit or 256-bit AES Encryption.

Capability upgrades are purchased from Cambium and supplied as access keys. The user then enters the access key into the PTP License Key Generator web page on the support website.

The License Key Generator creates a new license key and delivers it by email. The user then installs the license key using the ODU web interface. License keys are bound to a single ODU and are not transferrable.

Full capability trial period

A full capability trial period is available for units that are licensed for “Lite” (up to 125 Mbps) or “Mid” (up to 250 Mbps) data throughput capability. This trial allows the ODU to operate with “Full” capability (up to 450 Mbps) during a 60 day period, reverting to the Lite or Mid capability afterwards. The trial period can be started, paused and resumed from the web interface.

Software upgrade

The management agent supports application software upgrade using either the web-based interface or the SNMP interface.

PTP 650 software images are digitally signed, and the ODU will accept only images that contain a valid Cambium Networks PTP digital signature. The ODU always requires a reboot to complete a software upgrade.

Note

Obtain the application software and this user guide from the support website BEFORE warranty expires.

Caution

ODU software version must be the same at both ends of the link. Limited operation may sometimes be possible with dissimilar software versions, but such operation is not supported by Cambium Networks.

Recovery mode

The PTP 650 recovery mode provides a means to recover from serious configuration errors including lost or forgotten passwords and unknown IP addresses.

Recovery mode also allows new main application software to be loaded even when the integrity of the existing main application software image has been compromised. The most likely cause of an integrity problem with the installed main application software is where the power supply has been interrupted during an earlier software upgrade.

The ODU operates in recovery mode in the following circumstances:

- When a checksum error occurs for the main application software image.
- When a power on, power off, power on cycle is applied to the ODU with the power off period being around 5sec.

Recovery mode supports a single IPv4 interface, with IP address 169.254.1.1. Recovery mode does not support IPv6.

Note

When Recovery has been entered through a power on/off/on cycle, the ODU will revert to normal operation if no web access has been made to the unit within 30 seconds. This prevents the unit remaining inadvertently in recovery following a power outage.

Recovery mode options

Options in recovery mode (IPv4 only) are as follows:

- Load new main application software.
- Reset all configuration data. This option resets IP and Ethernet configuration, and erases (zeroizes) critical security parameters.
- Reset IP and Ethernet configuration.
- Erase (zeroize) critical security parameters.
- Reboot with existing software and configuration.

Note

If recovery mode has been entered because of a checksum error, after a 30 second wait the ODU will attempt to reboot with existing software and configuration.

The recovery software image is installed during manufacture of the ODU and cannot be upgraded by operators.

Chapter 2: System hardware

This chapter describes the hardware components of a PTP 650 link.

The following topics are described in this chapter:

Outdoor unit (ODU)

ODU description

The ODU is a self-contained transceiver unit that houses both radio and networking electronics. The ODU is supplied in two configurations: integrated (attached to its own flat plate antenna) () or connectorized (without an antenna) (Figure 8). The connectorized ODU is designed to work with externally mounted antennas that have higher gains than the integrated antenna. Connectorized units can cope with more difficult radio conditions.

Figure 8 PTP 650 Series ODUs (integrated and connectorized)

ODU part numbers

One ODU is required for each link end. Order ODUs and ODU kits from Cambium Networks (Table 2 and Table 3).

Note

To determine when to install connectorized units and to calculate their impact on link performance and regulatory limits, see Planning for connectorized units on page 3-25.

To select antennas, RF cables and connectors for connectorized units, see Antennas and antenna cabling on page 2-13.

Choose the correct regional variant: one is for use in regions where FCC or IC licensing restrictions apply (FCC/IC), one is for use in ETSI countries (EU), and the other is for the rest of the world (RoW).

Individual ODUs

Each of the parts listed in Table 2 includes the following items:

- One integrated or connectorized ODU.
- With connectorized ODUs only: one connectorized ODU mounting bracket (Figure 9). Integrated ODUs, when sold individually, are supplied without mounting brackets.

Table 2 ODU part numbers

Cambium description	Cambium part number
PTP 650 (4.9 to 6.05 GHz) Integrated ODU (FCC/IC)	C050065B001
PTP 650 (4.9 to 6.05 GHz) Connectorized ODU (FCC/IC)	C050065B002
PTP 650 (4.9 to 6.05 GHz) Integrated ODU (RoW)	C050065B003
PTP 650 (4.9 to 6.05 GHz) Connectorized ODU (RoW)	C050065B004
PTP 650 (4.9 to 6.05 GHz) Integrated ODU (EU)	C050065B005
PTP 650 (4.9 to 6.05 GHz) Connectorized ODU (EU)	C050065B006

ODU kits

Each of the parts listed in Table 3 includes the following additional items:

- One integrated or connectorized ODU.
- One integrated or connectorized ODU mounting bracket (Figure 9), as appropriate.
- One PSU of the type stated in the Cambium description.
- One line cord, either US (FCC/IC) or EU (EU and RoW).

Table 3 ODU kit part numbers

Cambium description	Cambium part number
PTP 650 Connectorized END with AC Supply (FCC/IC)	C050065H007
PTP 650 Connectorized END with AC+DC Enhanced Supply (FCC/IC)	C050065H008
PTP 650 Integrated END with AC Supply (FCC/IC)	C050065H009
PTP 650 Integrated END with AC+DC Enhanced Supply (FCC/IC)	C050065H010
PTP 650 Connectorized END with AC Supply (RoW)	C050065H011
PTP 650 Connectorized END with AC+DC Enhanced Supply (RoW)	C050065H012
PTP 650 Integrated END with AC Supply (RoW)	C050065H013
PTP 650 Integrated END with AC+DC Enhanced Supply (RoW)	C050065H014
PTP 650 Connectorized END with AC Supply (EU)	C050065H017
PTP 650 Connectorized END with AC+DC Enhanced Supply (EU)	C050065H018
PTP 650 Integrated END with AC Supply (EU)	C050065H019
PTP 650 Integrated END with AC+DC Enhanced Supply (EU)	C050065H020

Accessories

Spare ODU port blanking plugs are available from Cambium Networks (Table 4).

Table 4 ODU accessory part numbers

Cambium description	Cambium part number
PTP 650 Series Blanking Plug Pack (Qty 10)	N000065L036

ODU mounting brackets

The integrated and connectorized mounting brackets (Figure 9) are used to mount the ODU on poles with diameters in the range 50 to 75 mm (2 to 3 inches). The extended mounting bracket (Figure 9) is used for mounting an integrated or connectorized ODU on poles with a diameter of either 90 mm (3.5 inches) or 115 mm (4.5 inches).

Before ordering ODU mounting brackets, be aware of the following:

- Individual integrated ODUs are supplied without a mounting bracket (Table 2).
- Individual connectorized ODUs are supplied with a connectorized mounting bracket (Table 2).
- ODUs in kits are supplied with an integrated or connectorized bracket, as appropriate (Table 3).

If separate ODU mounting brackets are required, order them from Cambium Networks (Table 5).

Figure 9 ODU mounting brackets (integrated, connectorized and extended)

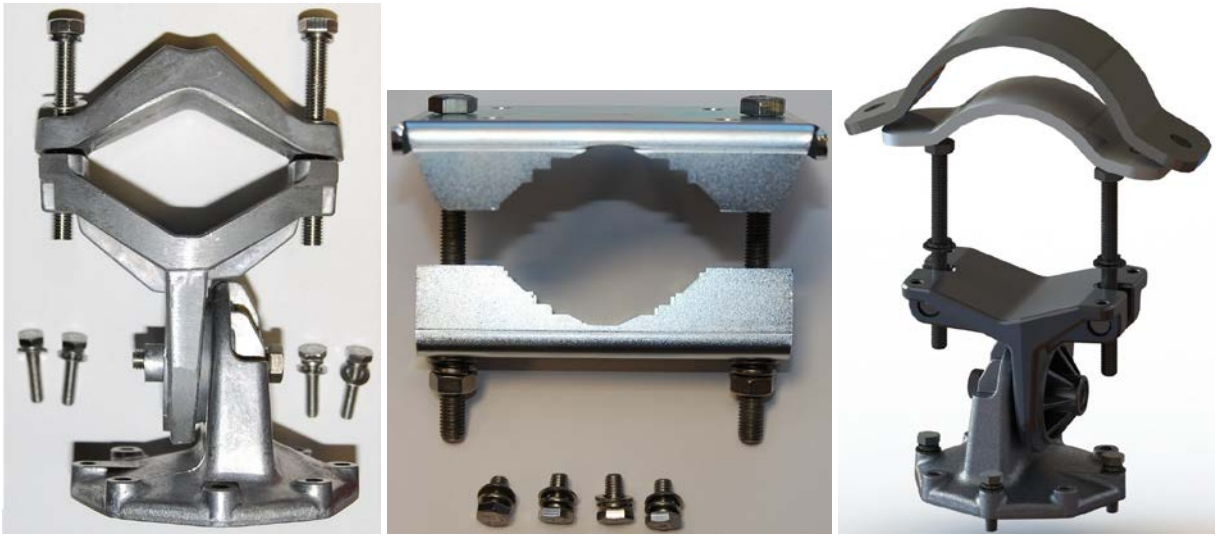


Table 5 ODU mounting bracket part numbers

Pole diameter	ODU type	Cambium description	Cambium part number
From 50 to 75 mm (2 to 3 inches)	Integrated	PTP 650 Mounting Bracket (integrated)	N000065L031
	Connectorized	PTP 650 Mounting Bracket (connectorized)	N000065L032
Either 90 mm (3.5 inches) or 115 mm (4.5 inches)	Integrated and connectorized	Extended Diameter Mast mounting kit 3.5" and 4.5"	N000065L030

ODU interfaces

The PSU, AUX and SFP ports are on the rear of the integrated and connectorized ODUs (Figure 10). These interfaces are described in Table 6. Each of the PSU, AUX and SFP ports can be configured to disable Ethernet traffic or to carry the following Ethernet traffic:

- Wireless bridge data
- Wireless bridge data and in-band management
- Out-of-band local management
- Local loop-back between any two ports

Figure 10 ODU rear interfaces

Table 6 ODU rear interfaces

Port name	Connector	Interface	Description
PSU	RJ45	POE input	Proprietary power over Ethernet (POE).
		100/1000BASE-T Ethernet	Management and/or data.
AUX	RJ45	100/1000BASE-T Ethernet with 802.3at compliant POE out capability	Auxiliary Ethernet port which can be used, for example, to connect and power a video camera or wireless access point.
SFP	SFP	Optical or Copper Gigabit Ethernet	OOB management, user data, user data with IB management, ODU-to-ODU. Plug-in SFP module must be purchased separately.

The front of the connectorized ODU (Figure 11) provides N type female connectors for RF cable interfaces to antennas with horizontal (H) and vertical (V) polarization.

Figure 11 Connectorized ODU antenna interfaces

ODU specifications

The PTP 650 ODU conforms to the specifications listed in Table 7.

Table 7 ODU specifications

Category	Specification
Dimensions	Integrated: 370 mm (14.5 in) x 370 mm (14.5 in) x 95 mm (3.75 in) Connectorized: 305 mm (12 in) x 305 mm (12 in) x 105 mm (4.01 in)
Weight	Integrated: 5.5 Kg (12.1 lbs) including bracket Connectorized: 4.3 Kg (9.1 lbs) including bracket
Temperature	-40°C (-40°F) to +60°C (140°F)
Wind loading	200 mph (323 kph) maximum. See ODU wind loading on page 3-11.
Humidity	100% condensing
Waterproofing	IP66, IP67
UV exposure	10 year operational life (UL746C test evidence)
Static discharge	See Electromagnetic compatibility (EMC) compliance on page 4-23

Power supply units (PSU)

PSU description

The PSU is an indoor unit that is connected to the ODU and network terminating equipment using Cat5e cable with RJ45 connectors. It is also plugged into an AC or DC power supply so that it can inject Power over Ethernet (POE) into the ODU. Choose one of the following PSUs (Figure 12):

- The AC Power Injector (left) accepts an AC input supply only.
- The AC+DC Enhanced Power Injector (right) accepts both AC and DC input, tolerates a greater temperature range, and allows the ODU to support a device on the Aux port, such as a video camera or wireless access point. It also allows the ODU to provide DC power output.

Figure 12 PSU 650 PSUs

Caution

The PSU ODU ports are designed to connect only to PTP 650 ODUs or LPUs. Do not connect any other equipment, as damage may occur.

Do not connect the PIDU Plus PTP 300/500/600 Series to the PTP 650 ODU or LPU.

Note

Each of the ODU kits listed in Table 3 includes one PSU and one US or EU line cord as stated in the Cambium description.

PSU part numbers

Order PSUs and (for AC power) line cords from Cambium Networks (Table 8).

Table 8 Power supply component part numbers

Cambium description	Cambium part number
PTP 650 AC Power Injector	N000065L001
PTP 650 AC+DC Enhanced Power Injector	C000065L002
US Line Cord Fig 8	N000065L003
UK Line Cord Fig 8	N000065L004
EU Line Cord Fig 8	N000065L005
Australia Line Cord Fig 8	N000065L006

AC Power Injector interfaces

The AC Power Injector interfaces are shown in Figure 13 and described in Table 9.

Figure 13 AC Power Injector interfaces

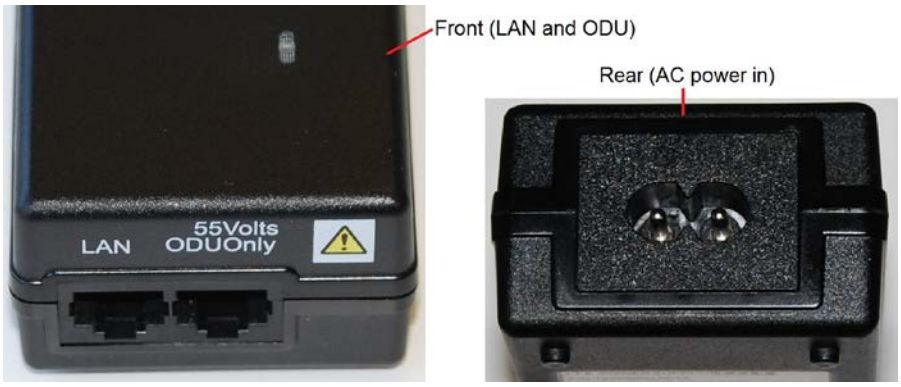


Table 9 AC Power Injector interface functions

Interface	Function
AC power in	AC power input (main supply).
ODU	RJ45 socket for connecting Cat5e cable to ODU.
LAN	RJ45 socket for connecting Cat5e cable to network.
Power (green) LED	Power supply detection

AC+DC Enhanced Power Injector interfaces

The AC+DC Enhanced Power Injector interfaces are shown in Figure 14 and described in Table 10.

Figure 14 AC+DC Enhanced Power Injector interfaces

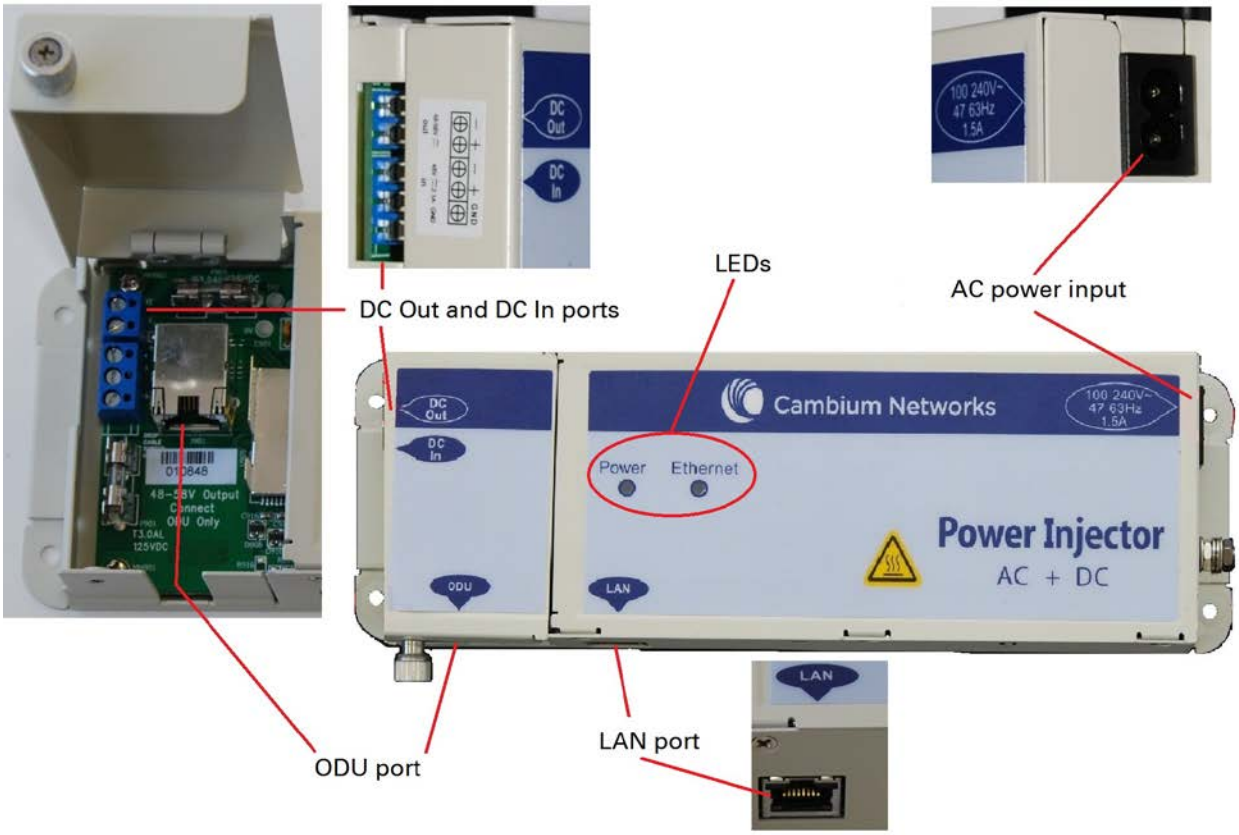


Table 10 AC+DC Enhanced Power Injector interface functions

Interface	Function
100-240V 47-63Hz 1.5A	AC power input (main supply).
DC In	Alternative DC power supply input.
DC Out	DC power output to a second PSU (for power supply redundancy).
ODU	RJ45 socket for connecting Cat5e cable to ODU.
LAN	RJ45 socket for connecting Cat5e cable to network.
Power (green) LED	Power supply detection
Ethernet (yellow) LED	Ethernet traffic detection

PSU specifications

The PTP 650 AC Power Injector conforms to the specifications listed in Table 11.

The PTP 650 AC+DC Enhanced Power Injector conforms to the specifications listed in Table 12.

Table 11 AC Power Injector specifications

Category	Specification
Dimensions	137 mm (5.4 in) x 56 mm (2.2 in) x 38 mm (1.5 in)
Weight	0.240 Kg (0.5 lbs)
Temperature	0°C to +40°C
Humidity	90% non-condensing
Waterproofing	Not waterproof
Altitude	Sea level to 5000 meters (16000 ft)
AC Input	Min 90 V AC, 57 – 63 Hz, max 264 V AC, 47 – 53 Hz.
DC output voltage to the ODU	55V +/- 5%
AC connector	IEC-320-C8
Efficiency	Better than 85%, efficiency level 'V'
Over Current Protection	Hiccup current limiting, trip point set between 120% to 150% of full load current
Hold up time	At least 10 milliseconds

Table 12 AC+DC Enhanced Power Injector specifications

Category	Specification
Dimensions	250 mm (9.75 in) x 40 mm (1.5 in) x 80 mm (3 in)
Weight	0.864 Kg (1.9 lbs)
Temperature	-40°C (-40°F) to +60°C (140°F)
Humidity	0 to 90% non-condensing
Waterproofing	Not waterproof
AC Input	90-264 V AC, 47-60 Hz
Alternative DC Input	37-60 V DC
DC Output Voltage	For mains input: 58 V, +2V, -0V For DC input: Output voltage at maximum rated output current, not more than 1.5 V below the DC input voltage. Maximum length of DC output cable: 3 meters.
AC Input connector	IEC-320-C8
DC Output current	1.7A
Efficiency	Better than 84%
Over Current Protection	Hiccup current limiting, trip point set between 120% to 150% of full load current
Hold up time	At least 20 milliseconds
Power factor	Better than 0.9

Antennas and antenna cabling

Antenna requirements

Each connectorized ODU requires one external antenna (normally dual-polar), or if spatial diversity is required, each ODU requires two antennas. These antennas are not supplied by Cambium Networks.

For connectorized units operating in the USA or Canada 5.4 GHz or 5.8 GHz bands, choose external antennas from those listed in FCC and IC approved antennas on page 2-14. Do not install any other antennas. For links in other countries, the listed antennas are advisory, not mandatory.

Note

To determine when to install connectorized units and to calculate their impact on link performance and regulatory limits, see Planning for connectorized units on page 3-25.

RF cable and connectors

RF cable of type CNT-400 is required for connecting the ODU to the antenna. N type male connectors are required for connecting the RF cables to the connectorized ODU. Two connectors are required per ODU. Use weatherproof connectors, preferably ones that are supplied with adhesive lined heat shrink sleeves that are fitted over the interface between the cable and connector. Order RF cable and N type male connectors from Cambium Networks (Table 13).

Table 13 RF cable and connector part numbers

Cambium description	Cambium part number
50 Ohm Braided Coaxial Cable - 75 meter	30010194001
50 Ohm Braided Coaxial Cable - 500 meter	30010195001
RF CONNECTOR,N,MALE,STRAIGHT FOR CNT-400 CABLE	09010091001

Note

To select the correct connectors for the antenna end of the RF cable, refer to the antenna manufacturer's instructions.

Antenna accessories

Connectorized ODUs require the following additional components:

- Cable grounding kits: Order one cable grounding kit for each grounding point on the antenna cables. Refer to Cable grounding kit on page 2-22 for specifications and part numbers.
- Self-amalgamating and PVC tape: Order these items to weatherproof the RF connectors.
- Lightning arrestors: When the connectorized ODU is mounted indoors, lightning arrestors (not PTP 650 LPUs) are required for protecting the antenna RF cables at building entry. One arrestor is required per antenna cable. One example of a compatible lightning arrestor is the Polyphaser LSXL-ME or LSXL (not supplied by Cambium Networks).

FCC and IC approved antennas

For connectorized units operating in the USA or Canada, choose external antennas from Table 14 (5.4 GHz) or Table 15 (5.8 GHz). These are approved by the FCC for use with the product and are constrained by the following limits for single- or dual-polarization parabolic dish antennas:

- 5.4 GHz - 34.9 dBi per polarization or antenna.
- 5.8 GHz - up to 37.7 dBi per polarization or antenna.

Caution

Antennas not included in these tables are strictly prohibited for use with the PTP 650 in the specified bands.

Caution

This radio transmitter (IC certification number 109AO-50650) has been approved by Industry Canada to operate with the antenna types listed below with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Le présent émetteur radio (Numéro de certification IC 109AO-50650) a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés ci-dessous et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur.

Table 14 Antennas permitted for deployment in USA/Canada – 5.4 GHz

Manufacturer	Antenna type	Nominal gain (dBi)	Parabolic dish	Cambium part number
Andrew	Andrew 4-foot Dual-Pol Parabolic, PX4F-52	34.9	Y	RDG4453B
Andrew	Andrew 4-foot Parabolic, P4F-52	34.9	Y	RDH4524A
Gabriel	Gabriel 4-foot Standard QuickFire Parabolic, QF4-52-N	34.8	Y	
Gabriel	Gabriel 4-foot Standard QuickFire Parabolic, QF4-52-N-RK	34.8	Y	
RadioWaves	Radio Waves 4-foot Parabolic, SP4-5.2	34.8	Y	
Gabriel	Gabriel 4-foot Standard Dual QuickFire Parabolic, QFD4-52-N	34.7	Y	
Gabriel	Gabriel 4-foot Standard Dual QuickFire Parabolic, QFD4-52-N-RK	34.7	Y	
RadioWaves	Radio Waves 4-foot Dual-Pol Parabolic, HPD4-5.2NS	34.7	Y	RDH4510B
Gabriel	Gabriel 4-foot High Performance QuickFire Parabolic, HQF4-52-N	34.4	Y	
RadioWaves	Radio Waves 4-foot Dual-Pol Parabolic, SPD4-5.2	34.4	Y	RDH4505B
Gabriel	Gabriel 4-foot High Performance Dual QuickFire Parabolic, HQFD4-52-N	34.3	Y	
RFS	RFS 4-foot HP Parabolic, SDF4-52AN	33.9	Y	
RFS	RFS 4-foot Parabolic, SPF4-52AN	33.9	Y	
Andrew	Andrew 3-foot Dual-Pol Parabolic, PX3F-52	33.4	Y	
Andrew	Andrew 3-foot Parabolic, P3F-52	33.4	Y	
StellaDoradus	StellaDoradus 4-foot Single-Pol, 56 PSD113	32.4	Y	
RadioWaves	Radio Waves 3-foot Dual-Pol Parabolic, HPD3-5.2NS	32.3	Y	RDH4509B
RadioWaves	Radio Waves 3-foot Parabolic, SP3-5.2	31.4	Y	RDH4513B
Gabriel	Gabriel 2.5-foot Standard QuickFire Parabolic, QF2.5-52-N	31.2	Y	
Gabriel	Gabriel 2.5-foot Standard Dual QuickFire Parabolic, QFD2.5-52-N	31.1	Y	

Manufacturer	Antenna type	Nominal gain (dBi)	Parabolic dish	Cambium part number
RadioWaves	Radio Waves 3-foot Dual-Pol Parabolic, SPD3-5.2	31.1	Y	RDH4504B
Andrew	Andrew 2-foot Dual-Pol Parabolic, PX2F-52	29.4	Y	
Andrew	Andrew 2-foot Parabolic, P2F-52	29.4	Y	
MTI	MTI 3-foot Single-Pol, MT-487000/N	29	Y	
RadioWaves	Radio Waves 2-foot Parabolic, SP2-5.2	29	Y	
RadioWaves	Radio Waves 2-foot Dual-Pol Parabolic, HPD2-5.2NS	28.8	Y	RDH4508B
Gabriel	Gabriel 2-foot Standard QuickFire Parabolic, QF2-52-N	28.5	Y	
Gabriel	Gabriel 2-foot Standard QuickFire Parabolic, QF2-52-N-RK	28.5	Y	
MTI	MTI 2-foot Dual-Pol, MT-486013/N	28.5	Y	
MTI	MTI 2-foot Single-Pol, MT-466009/N	28.5	Y	
Gabriel	Gabriel 2-foot Standard Dual QuickFire Parabolic, QFD2-52-N	28.4	Y	
Gabriel	Gabriel 2-foot Standard Dual QuickFire Parabolic, QFD2-52-N-RK	28.4	Y	
Gabriel	Gabriel 2-foot High Performance QuickFire Parabolic, HQF2-52-N	28.2	Y	
Gabriel	Gabriel 2-foot High Performance Dual QuickFire Parabolic, HQFD2-52-N	28.1	Y	
RadioWaves	Radio Waves 2-foot Dual-Pol Parabolic, SPD2-5.2	28.1	Y	RDH4503B
RFS	RFS 2-foot Parabolic, SPF2-52AN	27.9	Y	
StellaDoradus	StellaDoradus 2-foot Single-Pol, 56 PSD61	27	Y	
MTI	MTI 15 inch Dual-Pol Flat Panel, MT-485025/NVH	23	N	
Andrew	Andrew 1.25-foot Flat Panel Dual, UBXP375-4-1	21	N	
Andrew	Andrew 1-foot Flat Panel Single, UBP300-4-1	21	N	
Laird	60 Sectorized (Dual-Pol)	17	N	

Manufacturer	Antenna type	Nominal gain (dBi)	Parabolic dish	Cambium part number
Laird	90 Sectorized (Dual-Pol)	17	N	
KPPA	OMNI (Dual-Pol)	13	N	

Table 15 Antennas permitted for deployment in USA/Canada – 5.8 GHz

Manufacturer	Antenna type	Nominal gain (dBi)	Parabolic dish	Cambium part number
Gabriel	Gabriel 6-foot Standard Dual QuickFire Parabolic, QFD6-52-N	37.7	Y	
Gabriel	Gabriel 6-foot Standard QuickFire Parabolic, QF6-52-N	37.7	Y	
RadioWaves	Radio Waves 6-foot Dual-Pol Parabolic, HPD6-5.2NS	37.7	Y	RDH4511B
RadioWaves	Radio Waves 6-foot Parabolic, SP6-2/5	37.7	Y	
RadioWaves	Radio Waves 6-foot Parabolic, SP6-5.2	37.7	Y	
Andrew	Andrew 6-foot Dual-Pol Parabolic, PX6F-52	37.6	Y	
Andrew	Andrew 6-foot Parabolic, P6F-52	37.6	Y	RDH4525A
RadioWaves	Radio Waves 6-foot Dual-Pol Parabolic, SPD6-5.2	37.5	Y	RDH4506B
Gabriel	Gabriel 6-foot High Performance QuickFire Parabolic, HQF6-52-N	37.4	Y	
RFS	RFS 6-foot HP Parabolic, SDF6-52AN	37.4	Y	
RFS	RFS 6-foot Parabolic, SPF6-52AN	37.4	Y	
Gabriel	Gabriel 6-foot High Performance Dual QuickFire Parabolic, HQFD6-52-N	37.3	Y	
Andrew	Andrew 4-foot Dual-Pol Parabolic, PX4F-52	34.9	Y	RDG4453B
Andrew	Andrew 4-foot Parabolic, P4F-52	34.9	Y	RDH4524A
Gabriel	Gabriel 4-foot Standard QuickFire Parabolic, QF4-52-N	34.8	Y	
Gabriel	Gabriel 4-foot Standard QuickFire Parabolic, QF4-52-N-RK	34.8	Y	
RadioWaves	Radio Waves 4-foot Parabolic, SP4-5.2	34.8	Y	

Manufacturer	Antenna type	Nominal gain (dBi)	Parabolic dish	Cambium part number
Gabriel	Gabriel 4-foot Standard Dual QuickFire Parabolic, QFD4-52-N	34.7	Y	
Gabriel	Gabriel 4-foot Standard Dual QuickFire Parabolic, QFD4-52-N-RK	34.7	Y	
RadioWaves	Radio Waves 4-foot Dual-Pol Parabolic, HPD4-5.2NS	34.7	Y	RDH4510B
RadioWaves	Radio Waves 4-foot Parabolic, SP4-2/5	34.6	Y	
Gabriel	Gabriel 4-foot High Performance QuickFire Parabolic, HQF4-52-N	34.4	Y	
RadioWaves	Radio Waves 4-foot Dual-Pol Parabolic, SPD4-5.2	34.4	Y	RDH4505B
Gabriel	Gabriel 4-foot High Performance Dual QuickFire Parabolic, HQFD4-52-N	34.3	Y	
RFS	RFS 4-foot HP Parabolic, SDF4-52AN	33.9	Y	
RFS	RFS 4-foot Parabolic, SPF4-52AN	33.9	Y	
Andrew	Andrew 3-foot Dual-Pol Parabolic, PX3F-52	33.4	Y	
Andrew	Andrew 3-foot Parabolic, P3F-52	33.4	Y	
StellaDoradus	StellaDoradus 4-foot Single-Pol, 56 PSD113	32.4	Y	
RadioWaves	Radio Waves 3-foot Dual-Pol Parabolic, HPD3-5.2NS	32.3	Y	RDH4509B
RadioWaves	Radio Waves 3-foot Parabolic, SP3-2/5	31.4	Y	
RadioWaves	Radio Waves 3-foot Parabolic, SP3-5.2	31.4	Y	RDH4513B
Gabriel	Gabriel 2.5-foot Standard QuickFire Parabolic, QF2.5-52-N	31.2	Y	
Gabriel	Gabriel 2.5-foot Standard Dual QuickFire Parabolic, QFD2.5-52-N	31.1	Y	
RadioWaves	Radio Waves 3-foot Dual-Pol Parabolic, SPD3-5.2	31.1	Y	RDH4504B
Andrew	Andrew 2-foot Dual-Pol Parabolic, PX2F-52	29.4	Y	
Andrew	Andrew 2-foot Parabolic, P2F-52	29.4	Y	
MTI	MTI 3-foot Single-Pol, MT-487000/N	29	Y	

Manufacturer	Antenna type	Nominal gain (dBi)	Parabolic dish	Cambium part number
RadioWaves	Radio Waves 2-foot Parabolic, SP2-5.2	29	Y	
RadioWaves	Radio Waves 2-foot Dual-Pol Parabolic, HPD2-5.2NS	28.8	Y	RDH4508B
Gabriel	Gabriel 2-foot Standard QuickFire Parabolic, QF2-52-N	28.5	Y	
Gabriel	Gabriel 2-foot Standard QuickFire Parabolic, QF2-52-N-RK	28.5	Y	
MTI	MTI 2-foot Dual-Pol, MT-486013/N	28.5	Y	
MTI	MTI 2-foot Single-Pol, MT-466009/N	28.5	Y	
Gabriel	Gabriel 2-foot Standard Dual QuickFire Parabolic, QFD2-52-N	28.4	Y	
Gabriel	Gabriel 2-foot Standard Dual QuickFire Parabolic, QFD2-52-N-RK	28.4	Y	
RadioWaves	Radio Waves 2-foot Parabolic, SP2-2/5	28.3	Y	
Gabriel	Gabriel 2-foot High Performance QuickFire Parabolic, HQF2-52-N	28.2	Y	
Gabriel	Gabriel 2-foot High Performance Dual QuickFire Parabolic, HQFD2-52-N	28.1	Y	
RadioWaves	Radio Waves 2-foot Dual-Pol Parabolic, SPD2-5.2	28.1	Y	RDH4503B
RFS	RFS 2-foot Parabolic, SPF2-52AN	27.9	Y	
StellaDoradus	StellaDoradus 2-foot Single-Pol, 56 PSD61	27	Y	
RFS	RFS 1-foot Flat Panel, MA0528-23AN	23	N	
Andrew	Andrew 1.25-foot Flat Panel Dual, UBXP375-4-1	21	N	
Andrew	Andrew 1-foot Flat Panel Single, UBP300-4-1	21	N	
Laird	60 Sectorized (Dual-Pol)	17	N	
Laird	90 Sectorized (Dual-Pol)	17	N	
KPPA	OMNI (Dual-Pol)	13	N	

Ethernet cabling

Ethernet standards and cable lengths

All configurations require a copper Ethernet connection from the ODU (PSU port) to the PSU. Advanced configurations may also require one or both of the following:

- A copper Ethernet connection from the ODU (Aux port) to an auxiliary device.
- An optical or copper Ethernet connection from the ODU (SFP port) to network terminating equipment or a linked ODU.

Table 16 specifies, for each type of PSU and power supply, the maximum permitted PSU drop cable length.

Table 17 specifies, for Aux and copper SFP interfaces, the Ethernet standards supported and the maximum permitted drop cable lengths.

Note

For optical SFP interfaces, the Ethernet standards supported and maximum permitted cable lengths are specified in SFP module kits on page 2-27.

Table 16 PSU drop cable length restrictions

Type of PSU installed	Power supply to PSU	Ethernet supported (*1)	Power output to auxiliary device	Maximum cable length (*2)
AC Power Injector	AC mains	100BASE-TX 1000BASE-T	No	100 m (330 ft)
AC+DC Enhanced power injector	AC mains	No (*3)	No	300 m (990 ft)
	48 V dc	No (*3)	No	300 m (990 ft)
	AC mains	100BASE-TX 1000BASE-T	Yes	100 m (330 ft)
	48 V dc	100BASE-TX 1000BASE-T	Yes	100 m (330 ft)

(*1) 10BASE-T is not supported by PTP 650.

(*2) Maximum length of Ethernet cable from ODU to network terminating equipment via PSU.

(*3) Ethernet is provided via optical SFP interface.

Table 17 Aux and copper SFP Ethernet standards and cable length restrictions

ODU drop cable	Power over Ethernet	Ethernet supported (*1)	Maximum cable length (*2)
Aux – auxiliary device	POE to auxiliary device	100BASE-TX 1000BASE-T	100 m (330 ft)
	None	100BASE-TX	100 m (330 ft)
SFP (copper) – linked device	None	100BASE-TX	100 m (330 ft)

(*1) 10BASE-T is not supported by PTP 650.

(*2) Maximum length of Ethernet cable from the ODU to the linked device.

Outdoor copper Cat5e Ethernet cable

For copper Cat5e Ethernet connections from the ODU to the PSU, LPUs and other devices, use Cat5e cable that is gel-filled and shielded with copper-plated steel, for example Superior Essex type BBDGe. This is known as “drop cable” (Figure 15).

Caution

Always use Cat5e cable that is gel-filled and shielded with copper-plated steel. Alternative types of drop cable are not supported by Cambium Networks.

Order Superior Essex type BBDGe cable from Cambium Networks (Table 18). Other lengths of this cable are available from Superior Essex.

Figure 15 Outdoor drop cable

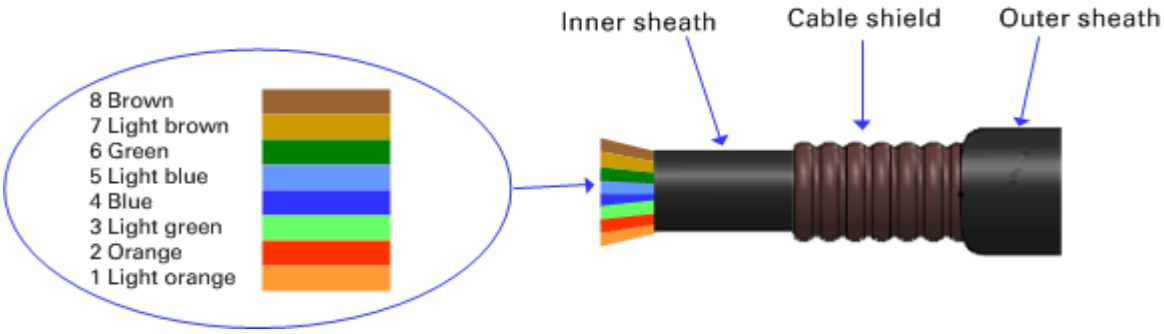


Table 18 Drop cable part numbers

Cambium description	Cambium part number
1000 ft Reel Outdoor Copper Clad CAT5E	WB3175
328 ft (100 m) Reel Outdoor Copper Clad CAT5E	WB3176

Cable grounding kit

Copper drop cable shields must be bonded to the grounding system in order to prevent lightning creating a potential difference between the structure and cable, which could cause arcing, resulting in fire risk and damage to equipment. Optical cables do not require grounding.

One grounding kit (Figure 16) is required for each grounding point on the PSU, Aux and copper SFP drop cables. Order cable grounding kits from Cambium Networks (Table 19).

Caution

To provide adequate protection, all grounding cables must be a minimum size of 10 mm^2 csa (8AWG), preferably 16 mm^2 csa (6AWG), or 25 mm^2 csa (4AWG).

Figure 16 Cable grounding kit

Table 19 Cable grounding kit part numbers

Cambium description	Cambium part number
Cable Grounding Kits For 1/4" And 3/8" Cable	01010419001

Lightning protection unit (LPU) and grounding kit

PTP 650 LPUs provide transient voltage surge suppression for PTP 650 installations. Each PSU or Aux drop cable requires two LPUs, one near the ODU and the other near the linked device, usually at the building entry point (Table 20).

Table 20 LPU and grounding kit contents

Lightning protection units (LPUs) LPU grounding point nuts and washers 	ODU to top LPU drop cable (600 mm) EMC strain relief cable glands 
U-bolts, nuts and washers for mounting LPUs 	ODU to top LPU ground cable (M6-M6) 
Bottom LPU ground cable (M6-M10) 	ODU to ground cable (M6-M10 

One LPU and grounding kit (Table 20) is required for the PSU drop cable connection to the ODU. If the ODU is to be connected to an auxiliary device, one additional LPU and grounding kit is required for the Aux drop cable. Order the kits from Cambium Networks (Table 21).

Table 21 LPU and grounding kit part number

Cambium description	Cambium part number
PTP 650 LPU and Grounding Kit	C000065L007

Note

PTP 650 LPUs are not suitable for installation on SFP copper Cat5e Ethernet interfaces. For SFP drop cables, obtain suitable surge protectors from a specialist supplier.

SFP optical Ethernet interfaces do not require surge protectors.

RJ45 connectors and spare glands

RJ45 connectors are required for plugging Cat5e cables into ODUs, LPUs, PSUs and other devices. Order RJ45 connectors and crimp tool from Cambium Networks (Table 22).

Note

The RJ45 connectors and crimp tool listed in Table 22 work with Superior Essex type BBDGe cable (as supplied by Cambium Networks). They may not work with other types of cable.

The ODU is supplied with one environmental sealing gland for the drop cable. However, this is not suitable when surge protection is required: EMC glands must be used instead. EMC strain relief cable glands (quantity 5) are included in the LPU and grounding kit (Figure 17). These are identified with a black sealing nut. If extra glands are required, order them from Cambium Networks (in packs of 10) (Table 22).

One long EMC strain relief gland (Figure 21) is included in each SFP module kit. This is longer than the standard cable gland as it must house an SFP module plugged into the ODU.

Figure 17 Cable gland

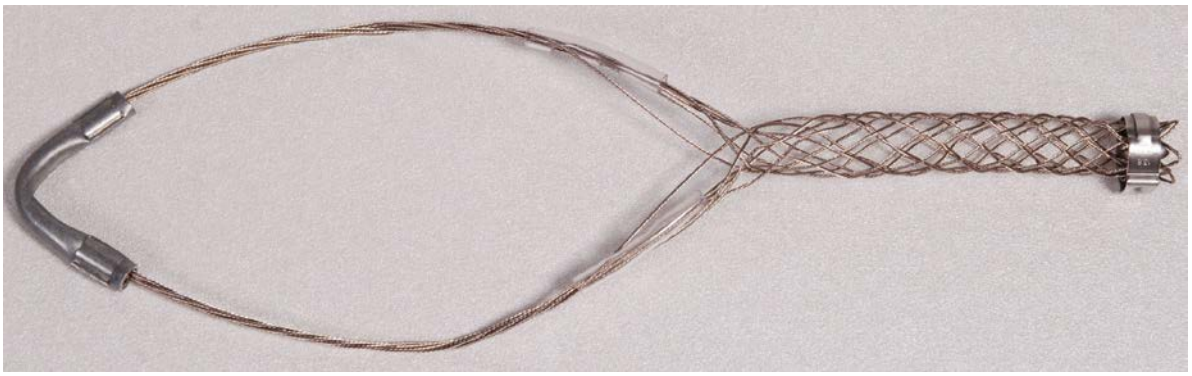
Table 22 RJ45 connector and spare gland part numbers

Cambium description	Cambium part number
Tyco/AMP, Mod Plug RJ45, 100 pack	WB3177
Tyco/AMP Crimp Tool	WB3211
RJ-45 Spare Grounding Gland - PG16 size (Qty. 10)	N000065L033

Cable hoisting grip

One or more grips are required for hoisting the drop cable up to the ODU without damaging the gland or RJ45 plug (Figure 18). They are not supplied by Cambium Networks.

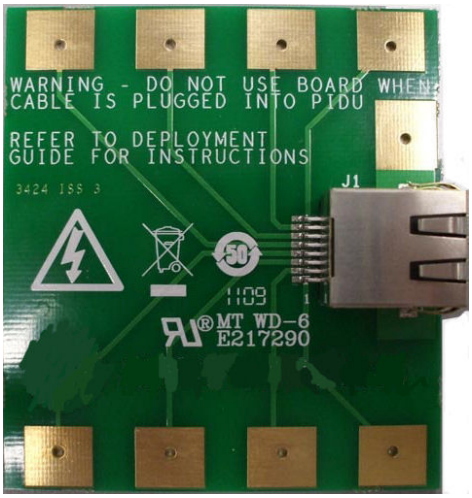
Figure 18 Cable hoisting grip



Drop cable tester

The drop cable tester is an optional item for testing the resistances between the RJ45 pins of the drop cable (Figure 19). Order it by completing the order form on the support website (see Contacting Cambium Networks on page 1).

Figure 19 Drop cable tester



Indoor Cat5e cable

To connect the PSU to network terminating equipment, use indoor Cat5e cable. The ODU network connection implements automatic MDI/MDI-X sensing and pair swapping, allowing connection to networking equipment that requires cross-over cables (MDI-X networks) or straight-through cables (MDI Networks).

SFP module kits

SFP module kits allow connection of a PTP 650 Series ODU to a network over a Gigabit Ethernet interface in one of the following full-duplex modes:

- Optical Gigabit Ethernet: 1000BaseLX or 1000BaseSX
- Copper Gigabit Ethernet: 100BASE-TX or 1000BASE-T

Order SFP module kits from Cambium Networks (Table 23).

Table 23 SFP module kit part numbers

Cambium description	Cambium part number
PTP 650 Optical 1000BaseLX Ethernet SFP Module	C000065L008
PTP 650 Optical 1000BaseSX Ethernet SFP Module	C000065L009
PTP 650 Twisted Pair 1000BASE-T Ethernet SFP Module	C000065L010

To compare the capabilities of the two optical SFP modules, refer to Table 24 and Table 25.

Table 24 Optical 1000BaseLX Ethernet SFP Module (part number C000065L008)

Core/ cladding (microns)	Mode	Bandwidth at 1310 nm (MHz/km)	Maximum length of optical interface	Insertion loss (dB)
62.5/125	Multi	500	550 m (1800 ft)	1.67
50/125	Multi	400	550 m (1800 ft)	0.07
50/125	Multi	500	550 m (1800 ft)	1.19
10/125	Single	N/A	5000 m (16400 ft)	0.16

Table 25 Optical 1000BaseSX Ethernet SFP Module (part number C000065L009)

Core/ cladding (microns)	Mode	Bandwidth at 850 nm (MHz/km)	Maximum length of optical interface	Insertion loss (dB)
62.5/125	Multi	160	220 m (720 ft)	2.38
62.5/125	Multi	200	275 m (900 ft)	2.6
50/125	Multi	400	500 m (1640 ft)	3.37
50/125	Multi	500	550 m (1800 ft)	3.56

The upgrade kits contain the following components:

- Optical or copper SFP transceiver module (Figure 20)
- Long EMC strain relief cable gland (Figure 21)
- The *PTP 650 Series SFP Interface Upgrade Guide*
- License key instructions and unique Access Key

Figure 20 Optical or copper SFP transceiver module

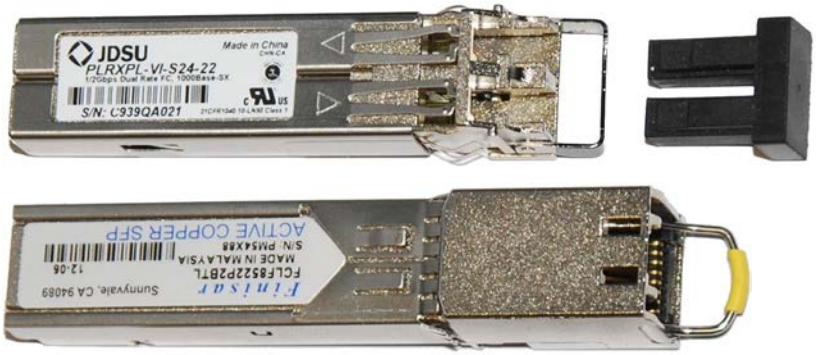
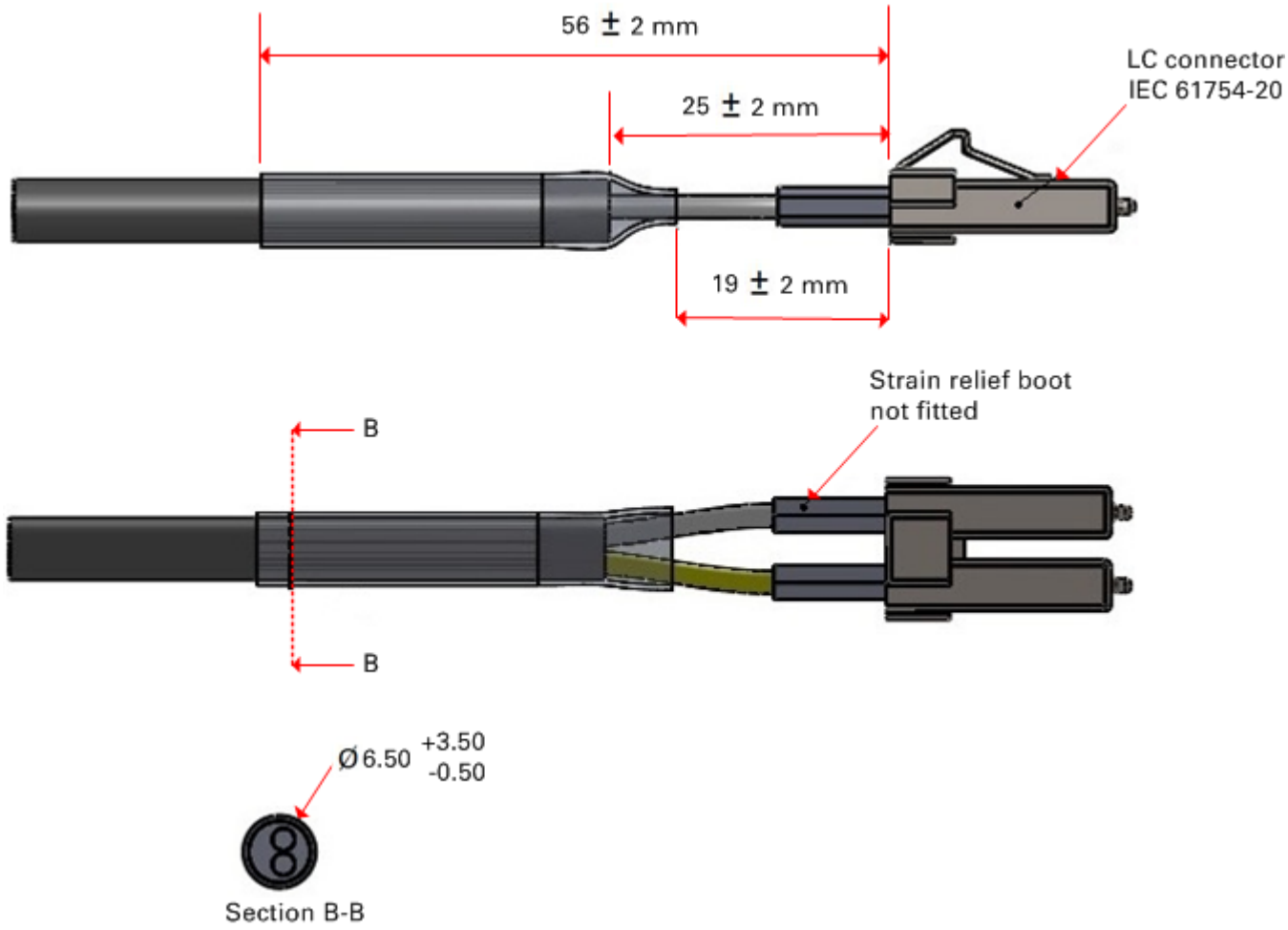


Figure 21 Long cable gland

Optical cable and connectors

Order an optical cable with LC connectors from a specialist fabricator, quoting the specification shown in Figure 22. It must be the correct length to connect the ODU to the other device. LC connectors should be supplied with dust caps to prevent dust build up.

Figure 22 Optical optic cable and connector specification



Chapter 3: System planning

This chapter provides information to help the user to plan a PTP 650 link.

The following topics are described in this chapter:

- Typical deployment on page 3-2 contains diagrams illustrating typical PTP 650 site deployments.
- Site planning on page 3-8 describes factors to be considered when planning the proposed link end sites, including grounding, lightning protection and equipment location.
- Radio spectrum planning on page 3-16 describes how to plan PTP 650 links to conform to the regulatory restrictions that apply in the country of operation.
- Link planning on page 3-21 describes factors to be taken into account when planning links, such as range, path loss and throughput.
- Planning for connectorized units on page 3-25 describes factors to be taken into account when planning to use connectorized ODUs with external antennas in PTP 650 links.
- Data network planning on page 3-27 describes factors to be considered when planning PTP 650 data networks.
- Network management planning on page 3-31 describes how to plan for PTP 650 links to be managed remotely using SNMP.
- Security planning on page 3-33 describes how to plan for PTP 650 links to operate in secure mode.
- System threshold, output power and link loss on page 3-41 contains tables that specify the system threshold (dBm), output power (dBm) and maximum link loss (dB) per channel bandwidth and modulation mode.
- Data throughput capacity tables on page 3-47 contains tables and graphs to support calculation of the data rate capacity that can be provided by PTP 650 configurations.

Typical deployment

This section contains diagrams illustrating typical PTP 650 site deployments.

ODU with POE interface to PSU

In the basic configuration, there is only one Ethernet interface, a copper Cat5e power over Ethernet (POE) from the PSU to the ODU (PSU port), as shown in the following diagrams: mast or tower installation (Figure 23), wall installation (Figure 24) and roof installation (Figure 25).

Figure 23 Mast or tower installation

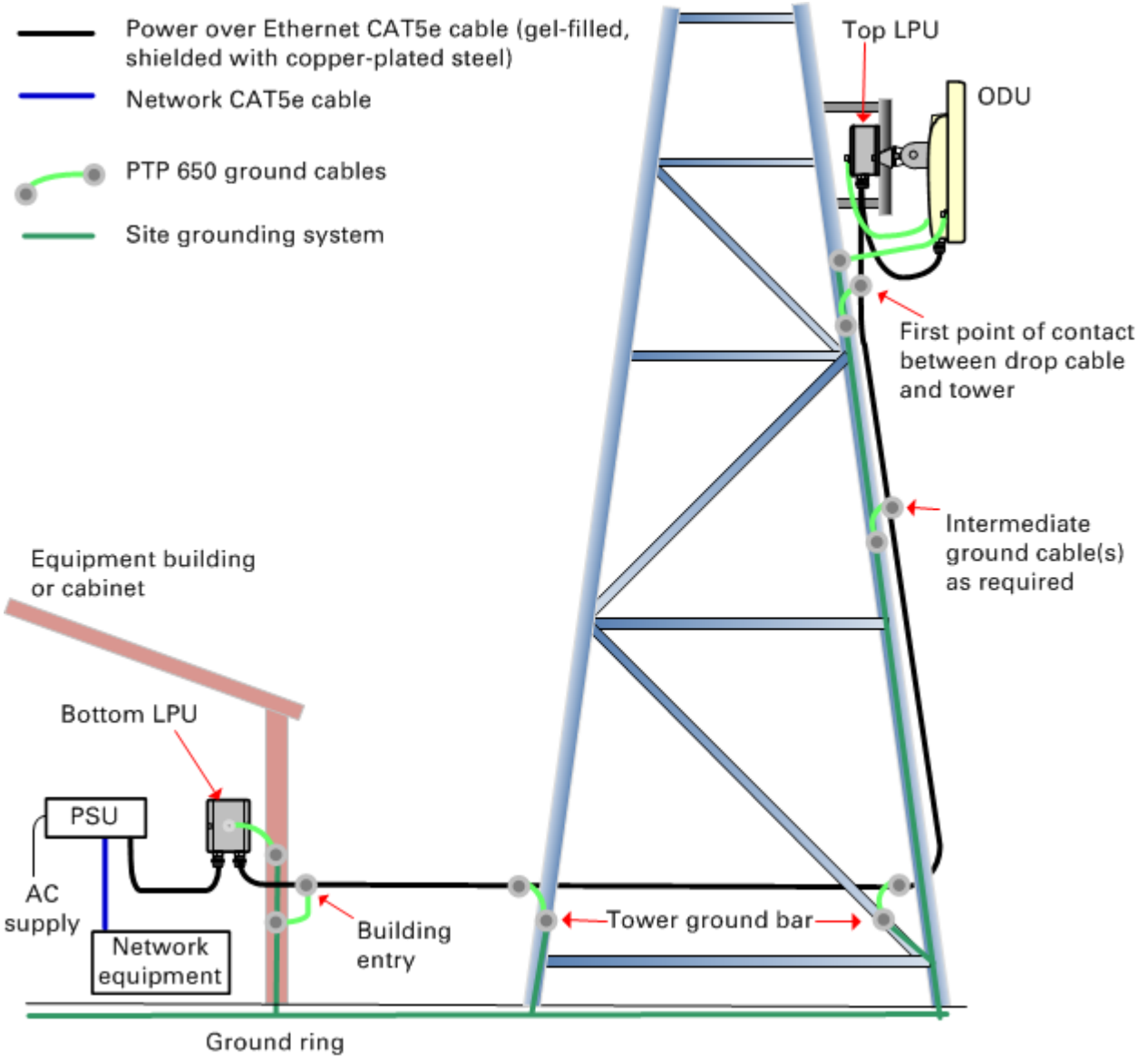


Figure 24 Wall installation

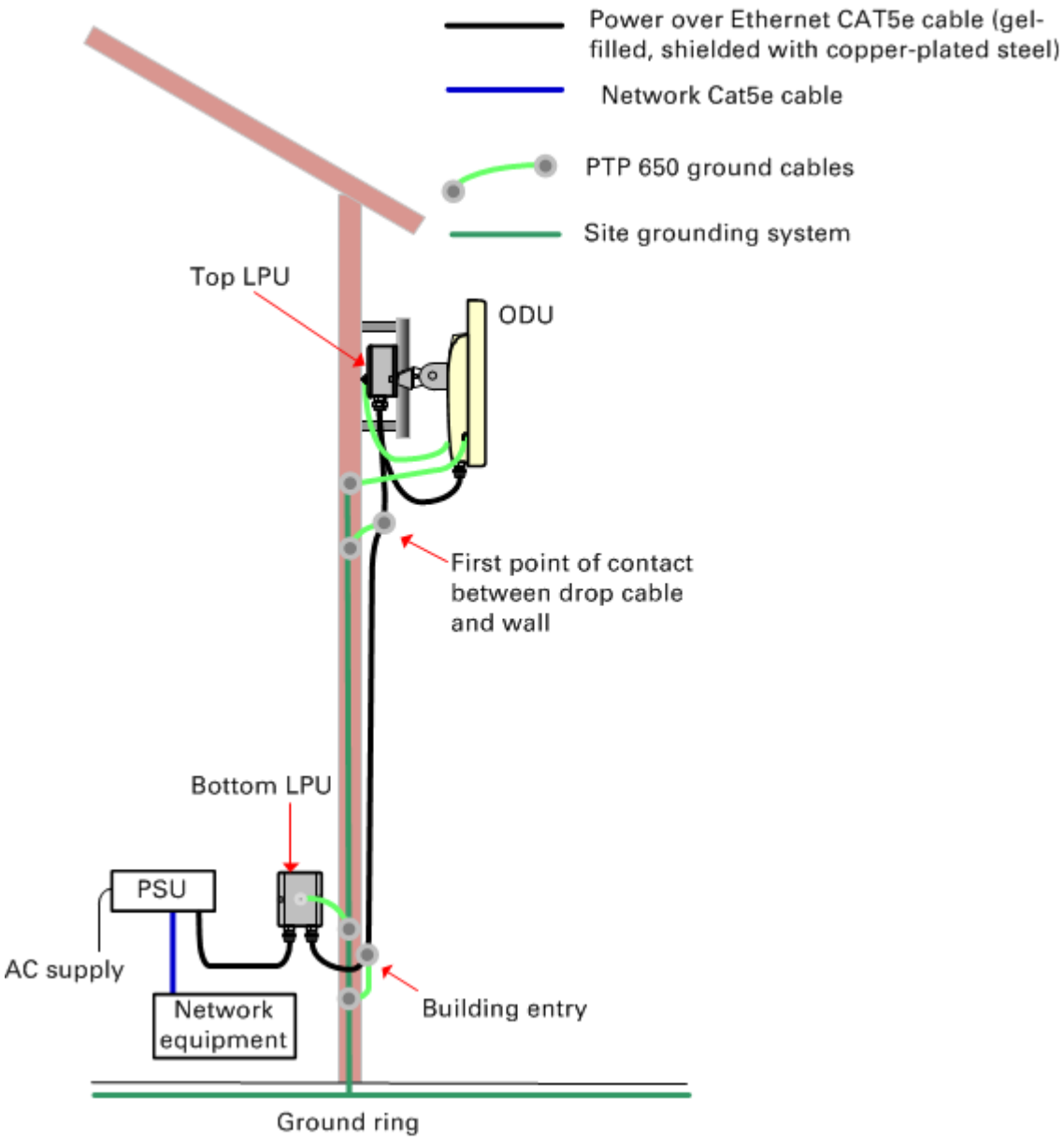
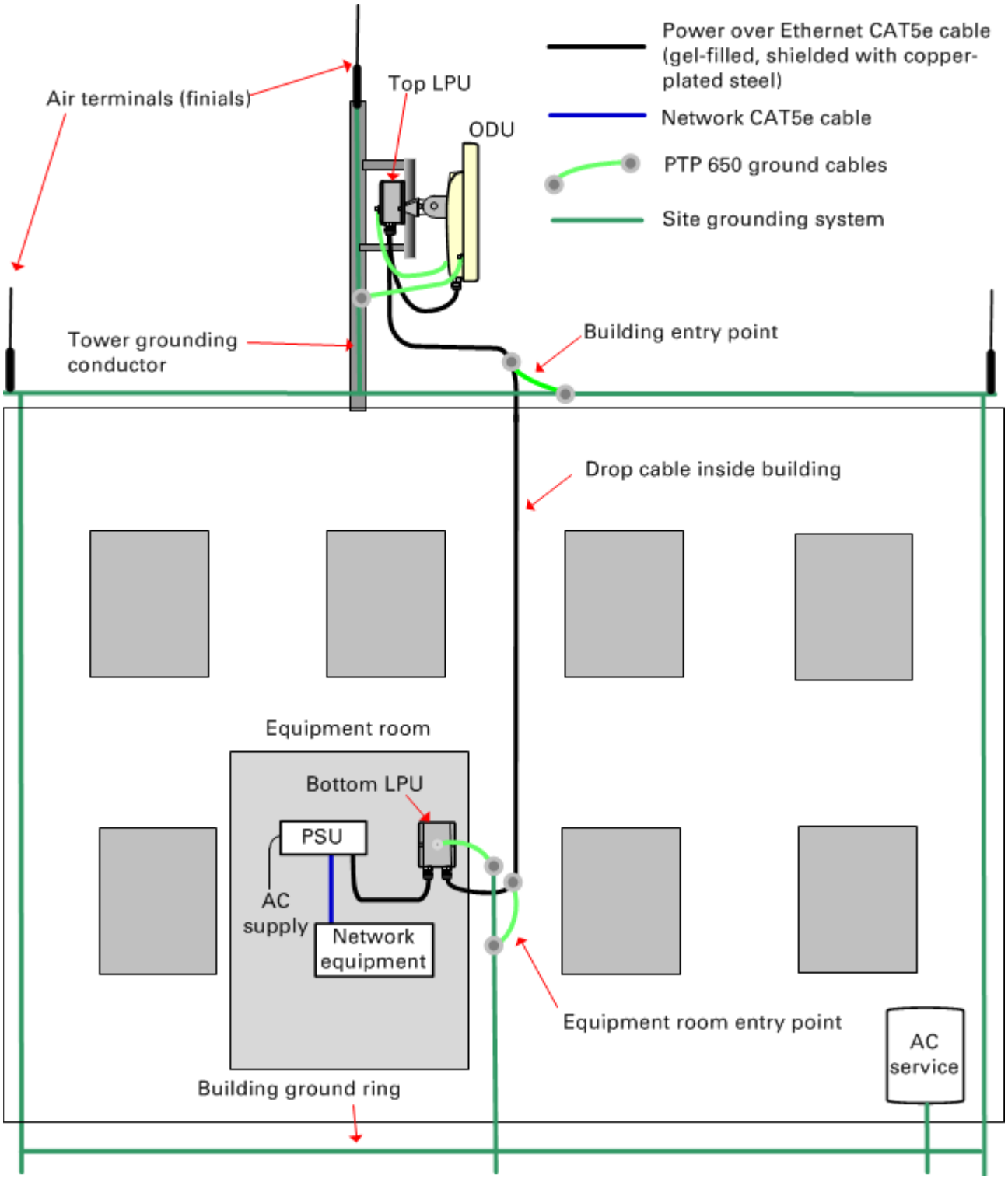


Figure 25 Roof installation



SFP and Aux Ethernet interfaces

There may be one or two additional Ethernet interfaces connected to the ODU: one to the SFP port (copper or optical) and one to the Aux port, as shown in the following diagrams:

- ODU with copper SFP and PSU interfaces – Figure 26
- ODU with optical SFP and PSU interfaces – Figure 27
- ODU with Aux and PSU interfaces – Figure 28

Figure 26 ODU with copper SFP and PSU interfaces

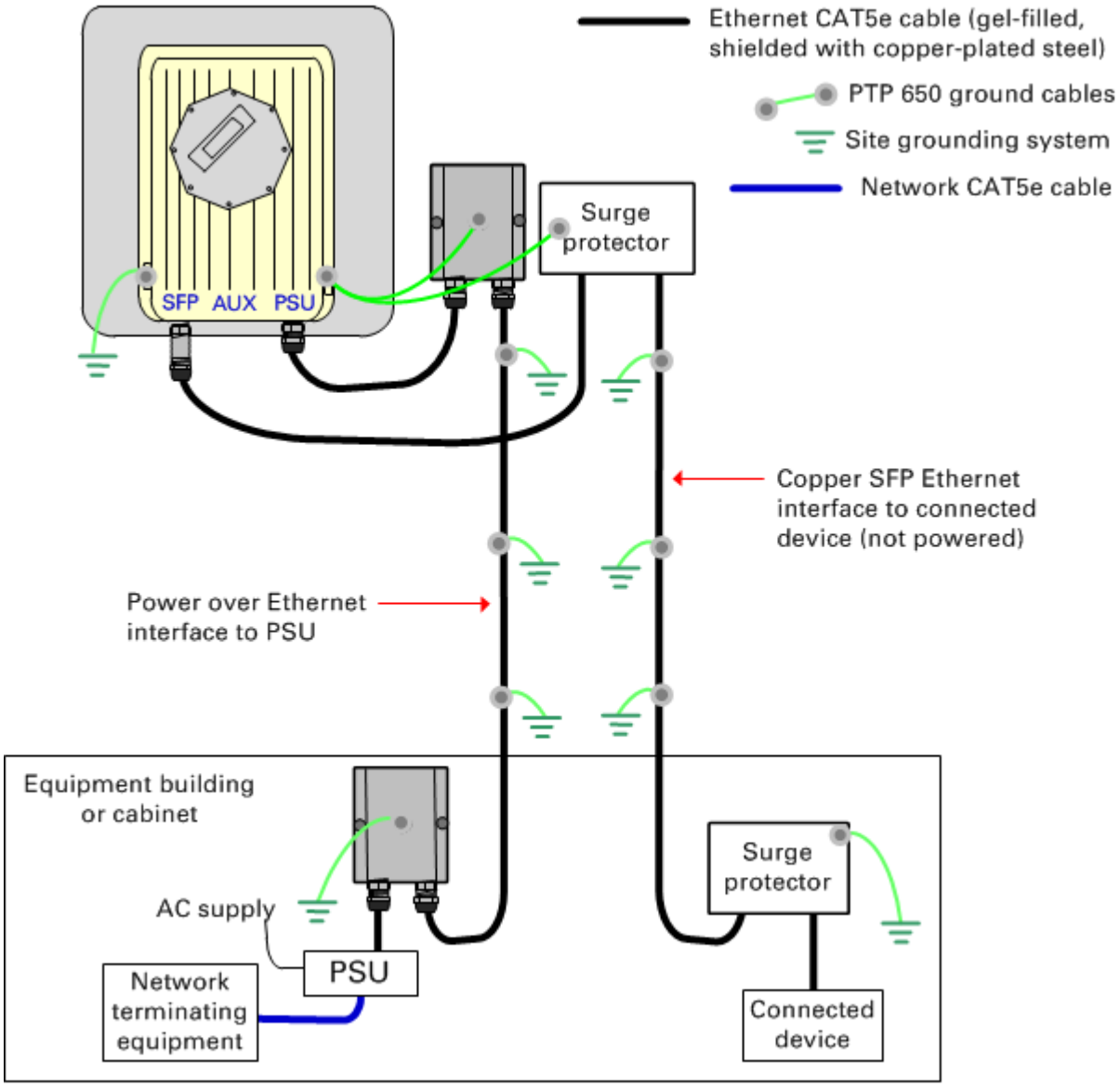


Figure 27 ODU with optical SFP and PSU interfaces

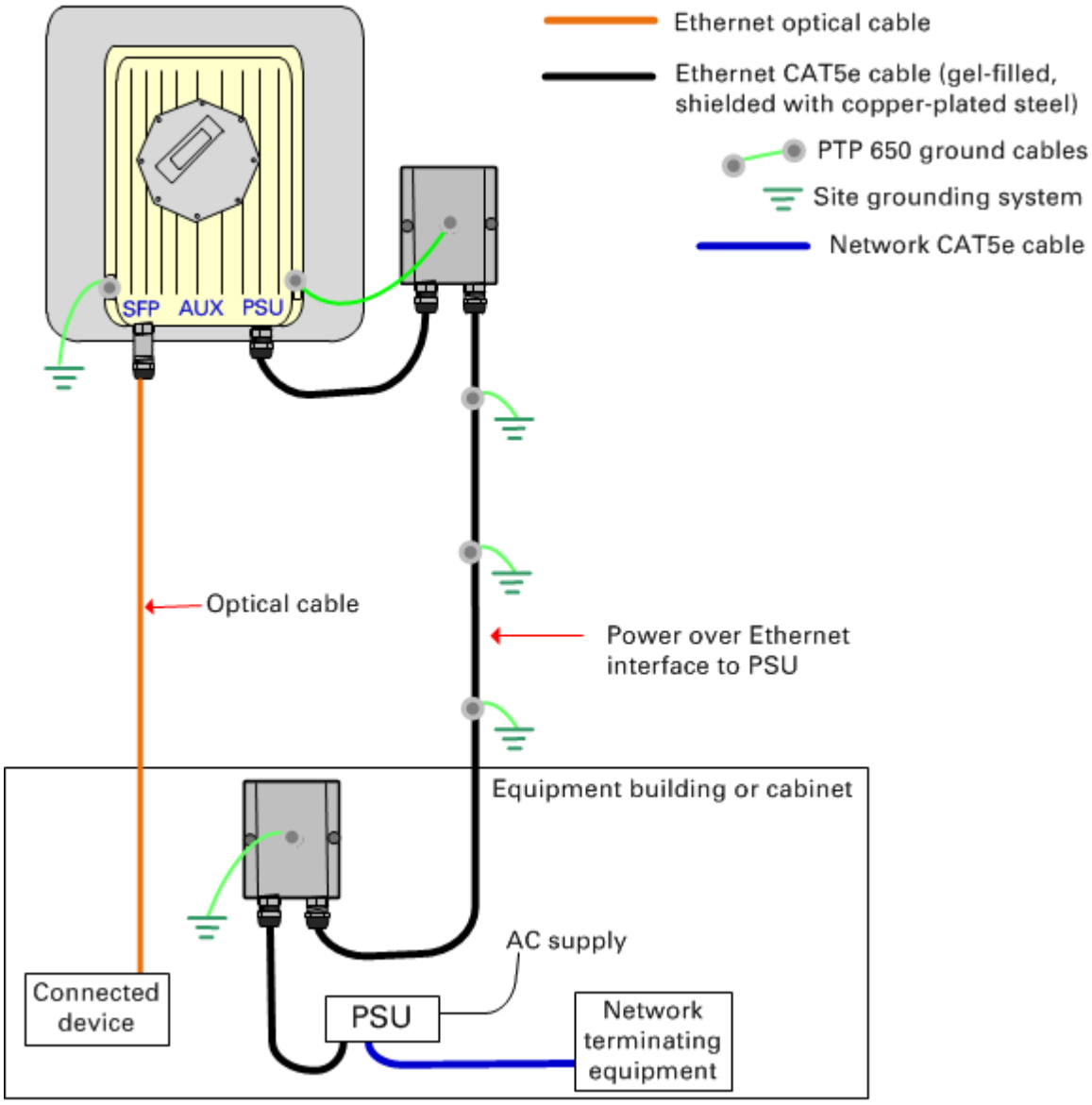
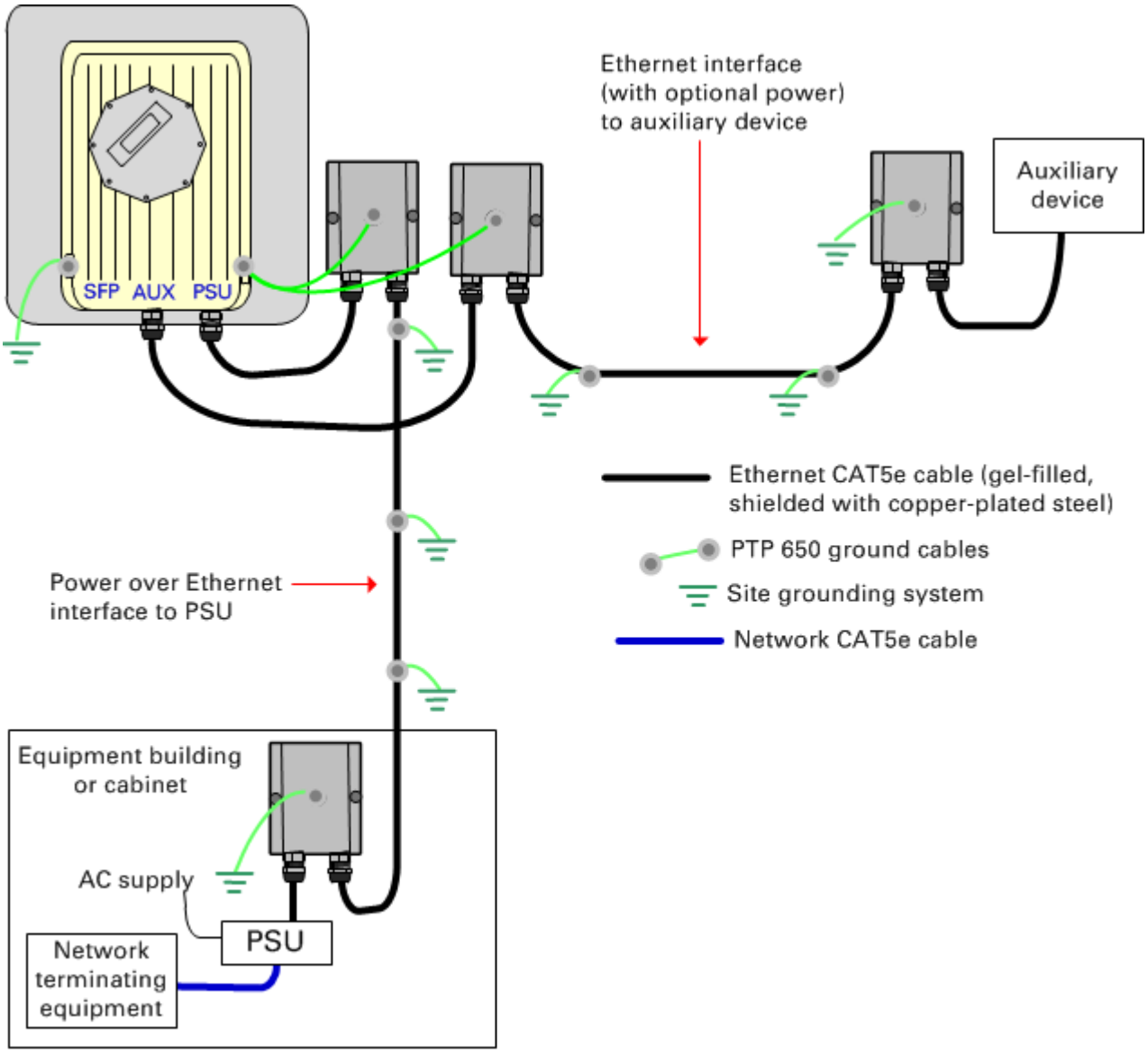


Figure 28 ODU with Aux and PSU interfaces



Site planning

This section describes factors to be considered when planning the proposed link end sites, including grounding, lightning protection and equipment location.

Grounding and lightning protection

Warning

Electro-magnetic discharge (lightning) damage is not covered under warranty. The recommendations in this guide, when followed correctly, give the user the best protection from the harmful effects of EMD. However 100% protection is neither implied nor possible.

Structures, equipment and people must be protected against power surges (typically caused by lightning) by conducting the surge current to ground via a separate preferential solid path. The actual degree of protection required depends on local conditions and applicable local regulations. To adequately protect a PTP 650 installation, both ground bonding and transient voltage surge suppression are required.

Full details of lightning protection methods and requirements can be found in the international standards IEC 61024-1 and IEC 61312-1, the U.S. National Electric Code ANSI/NFPA No. 70-1984 or section 54 of the Canadian Electric Code.

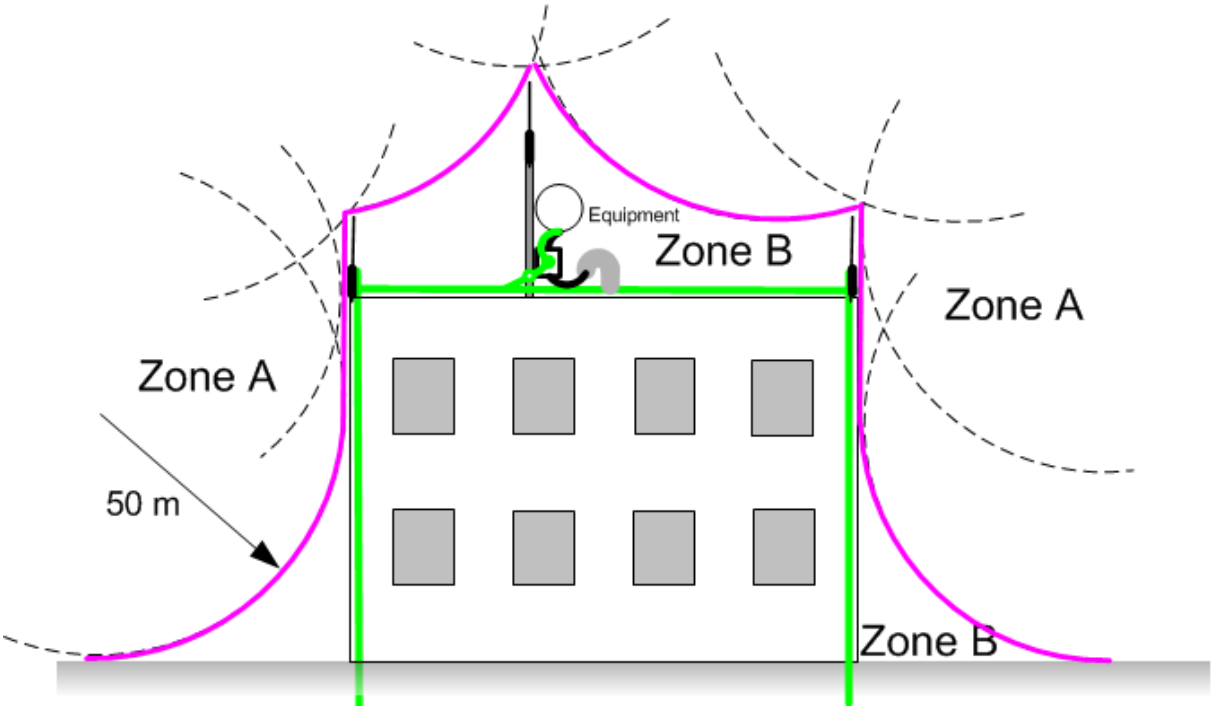
Note

International and national standards take precedence over the requirements in this guide.

Lightning protection zones

Use the rolling sphere method (Figure 29) to determine where it is safe to mount equipment. An imaginary sphere, typically 50 meters in radius, is rolled over the structure. Where the sphere rests against the ground and a strike termination device (such as a finial or ground bar), all the space under the sphere is considered to be in the zone of protection (Zone B). Similarly, where the sphere rests on two finials, the space under the sphere is considered to be in the zone of protection.

Figure 29 Rolling sphere method to determine the lightning protection zones



Assess locations on masts, towers and buildings to determine if the location is in Zone A or Zone B:

- Zone A: In this zone a direct lightning strike is possible. Do not mount equipment in this zone.
- Zone B: In this zone, direct EMD (lightning) effects are still possible, but mounting in this zone significantly reduces the possibility of a direct strike. Mount equipment in this zone.

Warning

Never mount equipment in Zone A. Mounting in Zone A may put equipment, structures and life at risk.

Site grounding system

Confirm that the site has a correctly installed grounding system on a common ground ring with access points for grounding PTP 650 equipment.

If the outdoor equipment is to be installed on the roof of a high building (Figure 25), confirm that the following additional requirements are met:

- A grounding conductor is installed around the roof perimeter to form the main roof perimeter lightning protection ring.
- Air terminals are installed along the length of the main roof perimeter lightning protection ring, typically every 6.1m (20ft).
- The main roof perimeter lightning protection ring contains at least two down conductors connected to the grounding electrode system. The down conductors should be physically separated from one another, as far as practical.

ODU and external antenna location

Find a location for the ODU (and external antenna for connectorized units) that meets the following requirements:

- The equipment is high enough to achieve the best radio path.
- People can be kept a safe distance away from the equipment when it is radiating. The safe separation distances are defined in Calculated distances and power compliance margins on page 4-25.
- The equipment is lower than the top of the supporting structure (tower, mast or building) or its lightning air terminal.
- If the ODU is connectorized, select a mounting position that gives it maximum protection from the elements, but still allows easy access for connecting and weatherproofing the cables. To minimize cable losses, select a position where the antenna cable lengths can be minimized. If diverse or two external antennas are being deployed, it is not necessary to mount the ODU at the midpoint of the antennas.

ODU wind loading

Ensure that the ODU and the structure on which it is mounted are capable of withstanding the prevalent wind speeds at a proposed PTP 650 site. Wind speed statistics should be available from national meteorological offices.

The ODU and its mounting bracket are capable of withstanding wind speeds of up to 323 kph (200 mph).

Wind blowing on the ODU will subject the mounting structure to significant lateral force. The magnitude of the force depends on both wind strength and surface area of the ODU. Wind loading is estimated using the following formulae:

Force (in kilogrammes) = $0.1045aV^2$

Where:	Is:
a	surface area in square meters
V	wind speed in meters per second

Force (in pounds) = $0.0042Av^2$

Where:	Is:
A	surface area in square feet
v	wind speed in miles per hour

Applying these formulae to the PTP 650 ODU at different wind speeds, the resulting wind loadings are shown in Table 26 and Table 27.

Table 26 ODU wind loading (Kg)

Type of ODU	Max surface area (square meters)	Wind speed (meters per second)				
		30	40	50	60	70
Integrated	0.130	12 Kg	22 Kg	34 Kg	49 Kg	66 Kg
Connectorized	0.093	9 Kg	16 Kg	24 Kg	35 Kg	48 Kg

Table 27 ODU wind loading (lb)

Type of ODU	Max surface area (square feet)	Wind speed (miles per hour)				
		80	100	120	140	150
Integrated	1.36	37 lb	57 lb	82 lb	146 lb	229 lb
Connectorized	1.00	27 lb	42 lb	61 lb	108 lb	168 lb

Note

For a connectorized ODU, add the wind loading of the external antenna to that of the ODU. The antenna manufacturer should be able to quote wind loading.

PSU DC power supply

If using the DC input on the AC+DC power injector, ensure that the DC power supply meets the following requirements:

- The voltage and polarity must be correct and must be applied to the correct PSU terminals.
- The power source must be rated as Safety Extra Low Voltage (SELV).
- The power source must be rated to supply at least 1.5A continuously.
- The power source cannot provide more than the Energy Hazard Limit as defined by IEC/EN/UL60950-1, Clause 2.5, Limited Power (The Energy Hazard Limit is 240VA).

PSU location

Find a location for the PSU (AC Power Injector or AC+DC Enhanced Power Injector) that meets the following requirements:

- The AC+DC Enhanced Power Injector can be mounted on a wall or other flat surface. The AC Power Injector can be mounted on a flat surface.
- The PSU is kept dry, with no possibility of condensation, flooding or rising damp.
- The PSU is located in an environment where it is not likely to exceed its operational temperature rating, allowing for natural convection cooling.
- The PSU can be connected to the ODU drop cable and network terminating equipment.

Find a location for the AC+DC Enhanced power injector where it can be connected to a mains or DC power supply. The use of DC supplies of less than 55V will reduce the usable distance between the PSU and ODU.

Drop cable grounding points

To estimate how many grounding kits are required for each drop cable, refer to the site installation diagrams (Figure 23 , Figure 24 and Figure 25) and use the following criteria:

- The drop cable shield must be grounded near the ODU at the first point of contact between the drop cable and the mast, tower or building.
- The drop cable shield must be grounded at the building entry point.

For mast or tower installations (Figure 23), use the following additional criteria:

- The drop cable shield must be grounded at the bottom of the tower, near the vertical to horizontal transition point. This ground cable must be bonded to the tower or tower ground bus bar (TGB), if installed.
- If the tower is greater than 61 m (200 ft) in height, the drop cable shield must be grounded at the tower midpoint, and at additional points as necessary to reduce the distance between ground cables to 61 m (200 ft) or less.
- In high lightning-prone geographical areas, the drop cable shield must be grounded at spacing between 15 to 22 m (50 to 75 ft). This is especially important on towers taller than 45 m (150 ft).

For roof installations (Figure 25), use the following additional criteria:

- The drop cable shield must be bonded to the building grounding system at its top entry point (usually on the roof).
- The drop cable shield must be bonded to the building grounding system at the entry point to the equipment room.

LPU location

Find a location for the top LPU that meets the following requirements:

- There is room to mount the LPU, either on the ODU mounting bracket or on the mounting pole below the ODU.
- The drop cable length between the ODU and top LPU must not exceed 600 mm.
- There is access to a metal grounding point to allow the ODU and top LPU to be bonded in the following ways: top LPU to ODU; ODU to grounding system.

Find a location for the bottom LPU that meets the following requirements:

- The bottom LPU can be connected to the drop cable from the ODU.
- The bottom LPU is within 600 mm (24 in) of the point at which the drop cable enters the building, enclosure or equipment room within a larger building.
- The bottom LPU can be bonded to the grounding system.

Multiple LPUs

If two or three drop cables are connected to the ODU, the PSU and Aux drop cables each require their own top LPU, and the copper SFP drop cable requires a top surge protector, not a PTP 650 LPU (Figure 30). Optical cables do not require LPUs or ground cables (Figure 31).

The copper SFP drop cable requires a bottom surge protector, not a PTP 650 LPU (Figure 32).

The Aux drop cable may require an LPU near the auxiliary device.

Figure 30 ODU with PSU, Aux and copper SFP interfaces

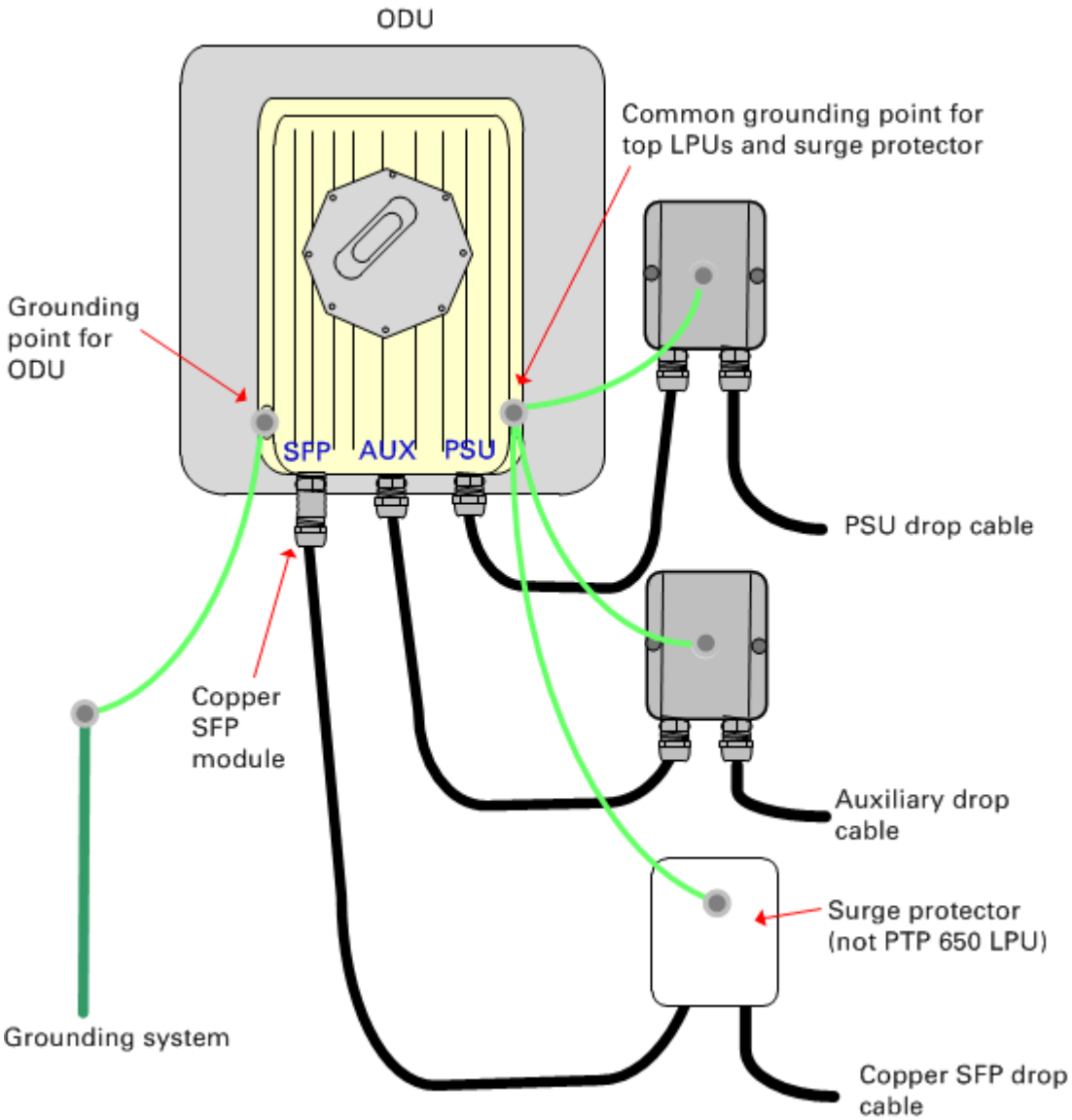


Figure 31 ODU with PSU, Aux and optical SFP interfaces

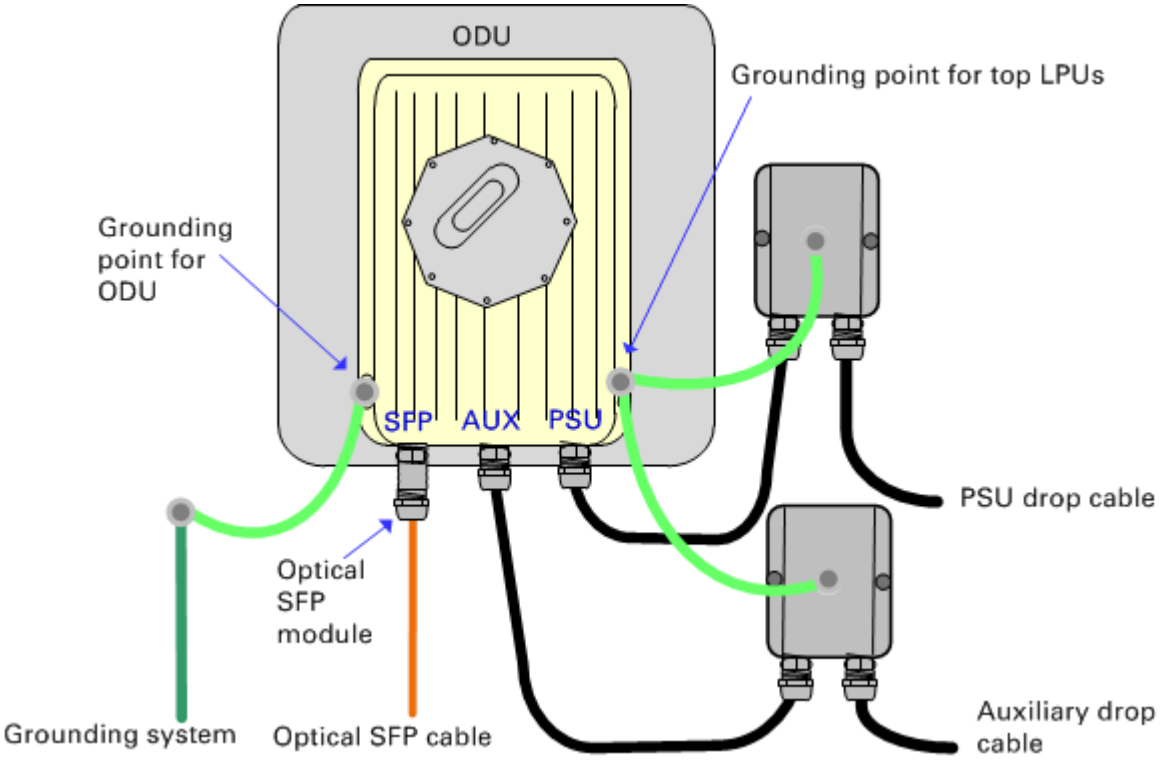
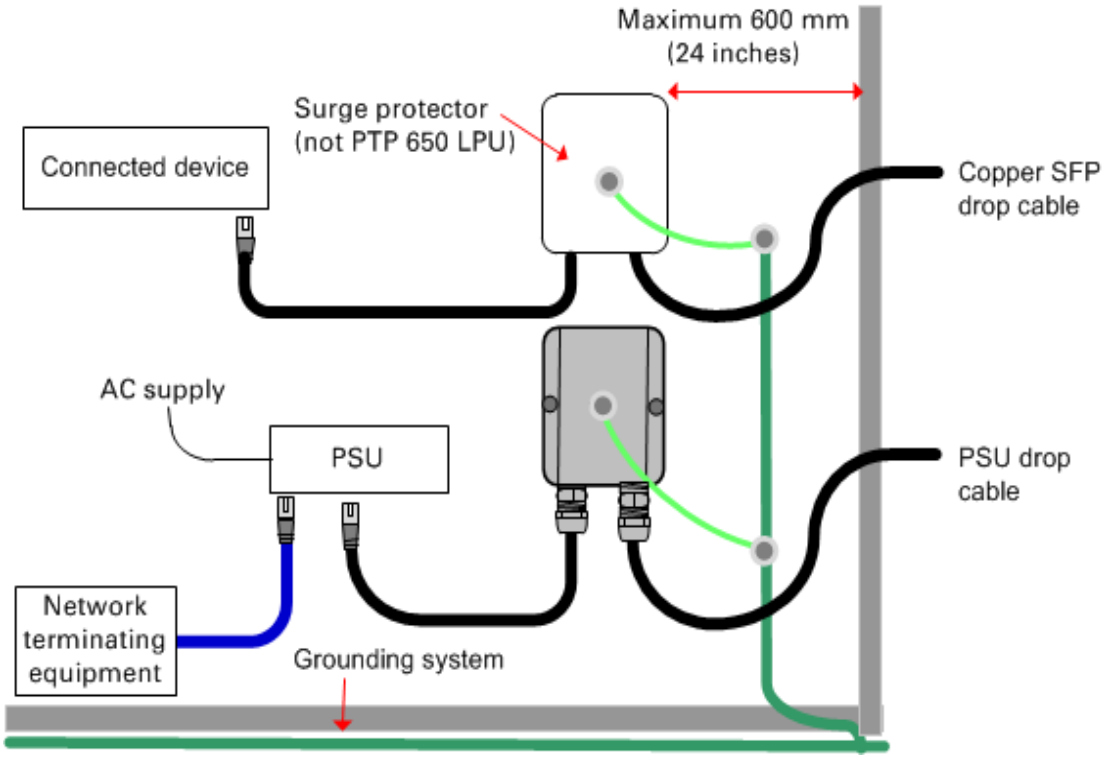


Figure 32 Bottom LPU and surge protector



Radio spectrum planning

This section describes how to plan PTP 650 links to conform to the regulatory restrictions that apply in the country of operation.

Caution

It is the responsibility of the user to ensure that the PTP product is operated in accordance with local regulatory limits.

Note

Contact the applicable radio regulator to find out whether or not registration of the PTP 650 link is required.

General wireless specifications

Table 28 lists the wireless specifications that apply to all PTP 650 frequency bands. Table 29 lists the wireless specifications that are specific to a single frequency band.

Table 28 PTP 650 wireless specifications (all variants)

Item	Specification
Channel selection	Manual selection (fixed frequency). Dynamic frequency selection (DFS or DFS with DSO) is available in radar avoidance regions.
Manual power control	To avoid interference to other users of the band, maximum power can be set lower than the default power limit.
Integrated antenna type	Flat plate antenna
Duplex schemes	Symmetric fixed, asymmetric fixed and, for the Full variant only, adaptive TDD.
Range	Optical Line-of-Sight: 200 km (125 miles). Non-Line-of-Sight: 10 km (6 miles).
Over-the-air encryption	AES 128-bit or 256-bit.
Weather sensitivity	Sensitivity at higher modes may be reduced by adjusting the Adaptive Modulation Threshold.
Error Correction	FEC

Table 29 PTP 650 wireless specifications (per frequency band)

Item	4.9 GHz	5.4 GHz	5.8 GHz
RF band (GHz)	4.900 -4.990	5.470 -5.725	5.725 -5.875
Channel bandwidth	10, 20 MHz	10, 20, 40, 45 MHz	10, 20, 40, 45 MHz
Typical receiver noise	6 dB	6 dB	6 dB
Typical antenna gain (integrated)	23 dBi	23 dBi	23 dBi
Antenna beamwidth (integrated)	8°	8°	8°

Regulatory limits

Many countries impose EIRP limits (Allowed EIRP) on products operating in the bands used by the PTP 650 Series. For example, in the 5.4 GHz and 5.8 GHz bands, these limits are calculated as follows:

- In the 5.4 GHz band (5470 MHz to 5725 MHz), the EIRP must not exceed the lesser of 30 dBm or (17 + 10 x Log Channel width in MHz) dBm.
- In the 5.8 GHz band (5725 MHz to 5875 MHz), the EIRP must not exceed the lesser of 36 dBm or (23 + 10 x Log Channel width in MHz) dBm.

Some countries (for example the USA) impose conducted power limits on products operating in the 5.8 GHz band.

Conforming to the limits

Ensure the link is configured to conform to local regulatory requirements by installing license keys for the correct country. In the following situations, the license key does not prevent operation outside the regulations:

- When using connectorized ODUs with external antennas, the regulations may require the maximum transmit power to be reduced.
- When installing 5.4 GHz links in the USA, it may be necessary to avoid frequencies used by Terminal Doppler Weather Radar (TDWR) systems. For more information, refer to Avoidance of weather radars (USA only) on page 3-20.

Available spectrum

The available spectrum for operation depends on the regulatory band. When configured with the appropriate license key, the unit will only allow operation on those channels which are permitted by the regulations.

Note

In Italy, general authorization is required for any 5.4 GHz radio link that is used outside the operator's own premises. It is the responsibility of the installer or operator to have the link authorized. Details may be found at:

http://www.sviluppoeconomico.gov.it/index.php?option=com_content&view=article&idmenu=672&idarea1=593&andor=AND&idarea2=1052&id=68433&sectionid=1,16&viewType=1&showMenu=1&showCat=1&idarea3=0&andorcat=AND&partebassaType=0&idareaCalendario1=0&MvediT=1&idarea4=0&showArchiveNewsBotton=0&directionidUser=0

The form to be used for general authorization may be found at:

http://www.sviluppoeconomico.gov.it/images/stories/mise_extra/Allegato%20n19.doc

Certain regulations have allocated certain channels as unavailable for use:

- ETSI has allocated part of the 5.4 GHz band to weather radar.
- UK and some other European countries have allocated part of the 5.8 GHz band to Road Transport and Traffic Telematics (RTTT) systems.

The number and identity of channels barred by the license key and regulatory band is dependent on the channel bandwidth and channel raster selected.

Barred channels are indicated by a "No Entry" symbol displayed on the Spectrum Management web page (Spectrum management in radar avoidance mode on page 7-27).

Channel bandwidth

Select the required channel bandwidth for the link. The selection depends upon the regulatory band selected.

The wider the channel bandwidth, the greater the capacity. As narrower channel bandwidths take up less spectrum, selecting a narrow channel bandwidth may be a better choice when operating in locations where the spectrum is very busy.

Both ends of the link must be configured to operate on the same channel bandwidth.

Frequency selection

Regions without mandatory radar detection

In regions that do not mandate DFS, choose **DSO** or **Fixed Frequency**:

- **Dynamic Spectrum Optimization (DSO)**: In this mode, the unit monitors the spectrum looking for the channel with the lowest level of interference. Statistical techniques are used to select the most appropriate transmit and receive channels. The unit can be configured such that it operates in DSO mode, but does not operate on selected channels. This allows a frequency plan to be implemented in cases where multiple links are installed in close proximity.
- **Fixed Frequency**: In this mode, the unit must be configured with a single fixed transmit frequency and a single fixed receive frequency. These may set to the same value or to different values. This mode should only be considered in exceptional circumstances, for example where it is known that are no sources of interference on the selected channels.

Regions with mandatory radar detection

In regions that mandate DFS, the unit first ensures that there is no radar activity on a given channel for a period of 60 seconds before radiating on that channel. Once a channel has been selected for operation, the unit will continually monitor for radar activity on the operating channel. If detected, it will immediately cease radiating and attempt to find a new channel.

In DFS regions, choose **DFS** or **DFS with DSO**:

- **Dynamic Frequency Selection (DFS)**: Once a channel is selected, the unit will only attempt to find an alternative channel if radar activity has been detected on the operating channel.
- **DFS with DSO**: In addition to switching channels on detection of radar, the unit will also switch to a channel which has a significantly lower level of interference than the current channel of operation. Before radiating on the newly selected channel, the unit must again ensure that there is no radar activity on the new channel for a period of 60 seconds. This mode therefore provides the benefit of switching to a channel with lower interference but at the expense of an outage of approximately 60 to 120 seconds. For this reason, the threshold for switching channels is greater than when DSO is operating in a non-radar region.

Radar avoidance requirements in the 5.4 GHz band are defined as follows:

- For the EU: in specification EN 301-893 V1.6.1.
- For the US: in the specification FCC part 15.407 plus the later requirements covered in **Important Regulatory Information** in this User Guide.
- For Canada: in the specification RSS210 Annex 9 (Issue 8).

Radar avoidance at 5.8 GHz is applicable to EU operation (not FCC/IC) and the requirements are defined in EN 302 502 V1.1.1.

Avoidance of weather radars (USA only)

To comply with FCC rules (KDB 443999: Interim Plans to Approve UNII Devices Operating in the 5470 - 5725 MHz Band with Radar Detection and DFS Capabilities), units which are installed within 35 km (22 miles) of a Terminal Doppler Weather Radar (TDWR) system (or have a line of sight propagation path to such a system) must be configured to avoid any frequency within +30 MHz or –30 MHz of the frequency of the TDWR device. This requirement applies even if the master is outside the 35 km (22 miles) radius but communicates with outdoor clients which may be within the 35 km (22 miles) radius of the TDWRs.

If interference is not eliminated, a distance limitation based on line-of-sight from TDWR will need to be used. Devices with bandwidths greater than 20 MHz may require greater frequency separation.

When planning a link in the USA, visit http://spectrumbridge.com/udia/home.aspx, enter the location of the planned link and search for TDWR radars. If a TDWR system is located within 35 km (22 miles) or has line of sight propagation to the PTP device, perform the following tasks:

- Register the installation on http://spectrumbridge.com/udia/home.aspx.
- Make a list of channel center frequencies that must be barred, that is, those falling within +30 MHz or –30 MHz of the frequency of the TDWR radars.

The affected channels must be barred as described in Barring channels on page 7-31.

Link planning

This section describes factors to be taken into account when planning links, such as range, obstacles path loss and throughput. PTP LINKPlanner is recommended.

PTP LINKPlanner

The Cambium PTP LINKPlanner software and user guide may be downloaded from the support website (see Contacting Cambium Networks on page 1).

PTP LINKPlanner imports path profiles and predicts data rates and reliability over the path. It allows the system designer to try different antenna heights and RF power settings. It outputs an installation report that defines the parameters to be used for configuration, alignment and operation. The installation report can be used to compare the predicted and actual performance of the link.

Range and obstacles

Calculate the range of the link and identify any obstacles that may affect radio performance.

Perform a survey to identify all the obstructions (such as trees or buildings) in the path and to assess the risk of interference. This information is necessary in order to achieve an accurate link feasibility assessment.

The PTP 650 Series is designed to operate in Non-Line-of-Sight (NLoS) and Line-of-Sight (LoS) environments. An NLOS environment is one in which there is no optical line-of-sight, that is, there are obstructions between the antennas.

The PTP 650 Series will operate at ranges from 100 m (330 ft) to 200 km (125 miles), within 3 modes: 0-40 km (0-25 miles), 0-100 km (0-62 miles) and 0-200 km (0-124 miles). Operation of the system will depend on obstacles in the path between the units. Operation at 40 km (25 miles) or above will require a near line-of-sight path. Operation at 100 m (330 ft) could be achieved with one unit totally obscured from the other unit, but with the penalty of transmitting at higher power in a non-optimal direction, thereby increasing interference in the band.

LoS links in radar regions

When planning an LoS link to operate in a radar detection region, ensure that receiver signal level is low enough to allow the PTP 650 to detect radar signals:

- With integrated antennas, the recommended minimum LoS operating range is 110 meters (360 ft) for 5.4 GHz or 185 meters (610 ft) for 5.8 GHz. Shorter operating ranges will lead to excessive receiver signal levels.
- With higher gain connectorized antennas, ensure the predicted receiver signal level (from LINKPlanner) is below -53 dBm (for 5.4 GHz) or below -58 dBm (for 5.8 GHz).

Path loss

Path loss is the amount of attenuation the radio signal undergoes between the two ends of the link. The path loss is the sum of the attenuation of the path if there were no obstacles in the way (Free Space Path Loss), the attenuation caused by obstacles (Excess Path Loss) and a margin to allow for possible fading of the radio signal (Fade Margin). The following calculation needs to be performed to judge whether a particular link can be installed:

$$L_{free\_space} + L_{excess} + L_{fade} + L_{seasonal} < L_{capability}$$

Where:	Is:
L_{free_space}	Free Space Path Loss (dB)
L_{excess}	Excess Path Loss (dB)
L_{fade}	Fade Margin Required (dB)
$L_{seasonal}$	Seasonal Fading (dB)
$L_{capability}$	Equipment Capability (dB)

Adaptive modulation

Adaptive modulation ensures that the highest throughput that can be achieved instantaneously will be obtained, taking account of propagation and interference. When the link has been installed, web pages provide information about the link loss currently measured by the equipment, both instantaneously and averaged. The averaged value will require maximum seasonal fading to be added, and then the radio reliability of the link can be computed. For minimum error rates on TDM links, the maximum modulation mode should be limited to 64QAM 0.75.

For details of the system threshold, output power and link loss for each frequency band in all modulation modes for all available channel bandwidths, refer to System threshold, output power and link loss on page 3-41.

Calculating data rate capacity

The data rate capacity of a PTP link is defined as the maximum end-to-end Ethernet throughput (including Ethernet headers) that it can support. It is assumed that Ethernet frames are 1500 octet. Data rate capacity is determined by the following factors:

- Licensed data throughput capability (ODU variant: Lite, Mid or Full)
- Link Symmetry
- Link Mode Optimization (IP or TDM)
- Modulation Mode
- Channel Bandwidth
- Link Range

Calculation procedure

To calculate the data rate capacity of a PTP 650 link, proceed as follows:

1 Use the tables in Data throughput capacity tables on page 3-47 to look up the data throughput capacity rates (Tx, Rx and Both) for the required combination of:

- Link Symmetry
- Link Mode Optimization
- Modulation Mode
- Channel Bandwidth

The tables contain data rates for PTP 650 Full only.

2 The tables contain data rates for links of zero range. Use the range adjustment graphs in Data throughput capacity tables on page 3-47 to look up the Throughput Factor that must be applied to adjust the data rates for the actual range of the link.

3 Multiply the data rates by the Throughput Factor to give the throughput capacity of the link.

Note

The data rates for adaptive symmetry apply to the most asymmetric case where the link has significant offered traffic in one direction only. The data rates for adaptive symmetry with bidirectional offered traffic are the same as those for link symmetry 1:1 with link optimization IP.

Calculation example

Suppose that the link characteristics are:

- PTP 650 variant = Mid
- Link Symmetry = 1:1
- Link Mode Optimization = TDM
- Modulation Mode = 64QAM 0.92 Dual
- Channel Bandwidth = 10 MHz
- Link Range = 60 km

The calculation procedure for this example is as follows:

1 Use Table 51 to look up the data throughput capacity rates:

Tx = 23 Mbits/s

Rx = 23 Mbits/s

Aggregated = 46 Mbits/s

2 Use Figure 40 to look up the Throughput Factor for 1:1, TDM, 10 MHz, Mid and Link Range 60 km. The factor is 0.86.

3 Multiply the rates from Step 1 by the Throughput Factor from Step 2 to give the throughput capacity of the link:

Tx = 19.8 Mbits/s

Rx = 19.8 Mbits/s

Aggregated = 39.6 Mbits/s

Planning for connectorized units

This section describes factors to be taken into account when planning to use connectorized ODUs with external antennas in PTP 650 links.

When to install connectorized units

The majority of radio links can be successfully deployed with the integrated ODU. However the integrated units may not be sufficient in some areas, for example:

- Where the path is heavily obscured by dense woodland on an NLOS link.
- Where long LOS links (>23 km or >14 miles) are required.
- Where there are known to be high levels of interference.

PTP LINKPlanner can be used to identify these areas of marginal performance.

In these areas, connectorized ODUs and external antennas should be used.

Choosing external antennas

When selecting external antennas, consider the following factors:

- The required antenna gain.
- Ease of mounting and alignment.
- Antenna polarization:
  - For a simple installation process, select one dual-polarization antenna (as the integrated antenna) at each end.
  - To achieve spatial diversity, select two single-polarization antennas at each end. Spatial diversity provides additional fade margin on very long LOS links where there is evidence of correlation of the fading characteristics on Vertical and Horizontal polarizations.

Note

Enter the antenna gain and cable loss into the Installation Wizard, if the country selected has an EIRP limit, the corresponding maximum transmit power will be calculated automatically by the unit.

Note

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (EIRP) is not more than that necessary for successful communication.

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante.

Calculating RF cable length (5.8 GHz FCC only)

The 5.8 GHz band FCC approval for the product is based on tests with a cable loss between the ODU and antenna of not less than 1.2 dB. If cable loss is below 1.2 dB with a 1.3 m (6 ft) diameter external antenna, the connectorized PTP 650 may exceed the maximum radiated spurious emissions allowed under FCC 5.8 GHz rules.

Cable loss depends mainly upon cable type and length. To meet or exceed the minimum loss of 1.2 dB, use cables of the type and length specified in Table 30 (source: Times Microwave). This data excludes connector losses.

Table 30 RF cable lengths required to achieve 1.2 dB loss at 5.8 GHz

RF cable type	Minimum cable length
LMR100	0.6 m (1.9 ft)
LMR200	1.4 m (4.6 ft)
LMR300	2.2 m (7.3 ft)
LMR400	3.4 m (11.1 ft)
LMR600	5.0 m (16.5 ft)

Data network planning

This section describes factors to be considered when planning PTP 650 data networks.

Ethernet interfaces

The PTP 650 Ethernet ports conform to the specifications listed in Table 31.

Table 31 PTP 650 Ethernet bridging specifications

Ethernet Bridging	Specification
Protocol	IEEE802.1; IEEE802.1p; IEEE802.3 compatible
QoS	Eight wireless interface priority queues based on these standards: IEEE 802.1p, IEEE 802.1Q, IEEE 802.1ah, IEEE 802.1ad, DSCP IPv4, DSCP IPv6, MPLS TC
Interfaces	100BASE-TX, 1000BASE-T, 1000BASE-SX, 1000BASE-LX MDI/MDIX auto crossover supported
Max Ethernet frame size	9600 bytes
Service classes for traffic	8 classes

Practical Ethernet rates depend on network configuration and higher layer protocols. Over the air throughput is capped to the rate of the Ethernet interface at the receiving end of the link.

Layer 2 control protocols

PTP 650 identifies L2 control protocols from the Ethernet destination address of bridged frames:

Table 32 Destination address in layer 2 control protocols

Destination address	Protocol
01-80-c2-00-00-00 to 01-80-c2-00-00-0f	IEEE 802.1 bridge protocols
01-80-c2-00-00-20 to 01-80-c2-00-00-2f	IEEE 802.1 Multiple Registration Protocol (MRP)
01-80-c2-00-00-30 to 01-80-c2-00-00-3f	IEEE 802.1ag, Connectivity Fault Management (CFM)
01-19-a7-00-00-00 to 01-19-a7-00-00-ff	Ring Automatic Protection Switching (R-APS)
00-e0-2b-00-00-04	Ethernet Automatic Protection Switching (EAPS)

Ethernet port allocation

Decide how the three Ethernet ports will be allocated to the customer data network, in-band management and out-of-band local management, based on the following rules:

- Ensure that one port is allocated to Data Only or Data and In-Band Management. This port should be associated with the customer data network.
- Ensure that the remaining ports are set to Disabled or Out-of-Band Local Management.
- Ensure that at least one port is allocated for in-band or out-of-band network management. This port should be associated with the management network.

Note

The Main PSU port is always used to supply power to the ODU, even when it is Disabled for the purpose of Ethernet port allocation.

VLAN membership

Decide if the IP interface of the ODU management agent will be connected in a VLAN. If so, decide if this is a standard (IEEE 802.1Q) VLAN or provider bridged (IEEE 802.1ad) VLAN, and select the VLAN ID for this VLAN.

Use of a separate management VLAN is strongly recommended. Use of the management VLAN helps to ensure that the ODU management agent cannot be accessed by customers.

Priority for management traffic

Choose the Ethernet and IP (DSCP) priority for management traffic generated within the ODU management agent. The priority should be selected so as to be consistent with existing policy on priority of management traffic in the network. Use of a high priority is strongly recommended to ensure that management traffic is not discarded if the link is overloaded.

Ensure that the priority assigned to management traffic is consistent with the quality of service scheme configured for bridged Ethernet traffic. If QoS for bridged traffic is based on the IP/MPLS scheme, set the DSCP management priority to map to a high priority queue. If QoS for bridged traffic is based on the Ethernet scheme, set the VLAN management priority to map to a high priority queue.

IP interface

Select the IP version for the IP interface of the ODU management agent. PTP 650 can operate in IPv4 mode, IPv6 mode, or in a dual IPv4/IPv6 mode. Choose one IPv4 address and/or one IPv6 address for the IP interface of the ODU management agent. The IP address or addresses must be unique and valid for the connected network segment and VLAN.

Find out the correct subnet mask (IPv4) or prefix length (IPv6) and gateway IP address for this network segment and VLAN.

Ensure that the design of the data network permits bidirectional routing of IP datagrams between network management systems and the ODUs. For example, ensure that the gateway IP address identifies a router or other gateway that provides access to the rest of the data network.

Quality of service for bridged Ethernet traffic

Decide how quality of service will be configured in PTP 650 to minimize frame loss and latency for high priority traffic. Wireless links often have lower data capacity than wired links or network equipment like switches and routers, and quality of service configuration is most critical at network bottlenecks.

PTP 650 provides eight queues for traffic waiting for transmission over the wireless link. Q0 is the lowest priority queue and Q7 is the highest priority queue. Traffic is scheduled using strict priority; in other words, traffic in a given queue is transmitted when all higher-priority queues are empty.

Layer 2 control protocols

Select the transmission queue for each of the recognised layer 2 control protocols (L2CP). These protocols are essential to correct operation of the Ethernet network, and are normally mapped to a high priority queue. Ethernet frames that match one of the recognized L2CPs are not subject to the Ethernet and IP/MPLS classification described below.

Priority schemes

Select the priority scheme based on Ethernet priority or IP/MPLS priority to match QoS policy in the rest of the data network. Ethernet priority is also known as Layer 2 or link layer priority. IP/MPLS priority is also known as Layer 3 or network layer priority.

Ethernet priority scheme

Ethernet priority is encoded in a VLAN tag. Use the Ethernet priority scheme if the network carries traffic in customer or service provider VLANs, and the priority in the VLAN tag has been set to indicate the priority of each type of traffic. Select a suitable mapping from the Ethernet priority to the eight PTP 650 queues.

An advantage of Ethernet priority is that any VLAN-tagged frame can be marked with a priority, regardless of the higher-layer protocols contained within the frame. A disadvantage of Ethernet priority is that the priority in the frame must be regenerated whenever traffic passes through a router.

IP/MPLS priority scheme

IP priority is encoded in the DSCP value encoded in the ToS field in IPv4 and Traffic Class in IPv6. The DSCP field provides 64 levels of priority. Determine the DSCP values used in the network and select a suitable mapping from these DSCP values to the eight PTP 650 queues.

The advantages of IP priority are that priority in the IP header is normally propagated transparently through a router, also the DSCP field supports a large number of distinct priority code points. A disadvantage of DSCP is that frames receive a single default classification if they contain a network layer protocol other than IPv4 or IPv6. This is controlled by the user setting the Unknown Network Layer Protocol queue value in the same QoS Configuration page under IP/MPLS QoS.

MPLS priority is encoded in the traffic class (TC) field in the outermost MPLS label. Select a suitable mapping from MPLS TC to the eight PTP 650 queues.

"Daisy-chaining" PTP 650 links

When connecting two or more PTP 650 links together in a network (daisy-chaining), do not install direct copper Cat5e connections between the PSUs. Each PSU must be connected to the network terminating equipment using the LAN port. To daisy-chain PTP 650 links, install each ODU-to-ODU link using one of the following solutions:

- A copper Cat5e connection between the Aux ports of two ODUs. For details of the Ethernet standards supported and maximum permitted cable lengths, see Ethernet standards and cable lengths on page 2-20.
- A copper Cat5e connection between the Aux port of one ODU and the SFP port of the next ODU (using a copper SFP module). For details of the Ethernet standards supported and maximum permitted cable lengths, see Ethernet standards and cable lengths on page 2-20.
- Optical connections between the ODUs (SFP ports) using optical SFP modules at each ODU. For details of the Ethernet standards supported and maximum permitted cable lengths, see SFP module kits on page 2-27.

Green Ethernet switches

Do not connect PTP 650 units to Ethernet networking products that control the level of the transmitted Ethernet signal based on the measured length of the Ethernet link, for example Green Ethernet products manufactured by D-Link Corporation. The Ethernet interfaces in these networking products do not work correctly when connected directly to the PTP 650 PSU.

Network management planning

This section describes how to plan for PTP 650 links to be managed remotely using SNMP.

Planning for SNMP operation

The supported notifications are as follows:

- Cold start
- Wireless Link Up/Down
- Channel Change
- DFS Impulse Interference
- Authentication Failure
- Main PSU Port Up Down
- Aux Port Up Down
- SFP Port Up Down

Ensure that the following MIBs are loaded on the network management system.

- RFC-1493. BRIDGE-MIB
- RFC-2233. IF-MIB
- RFC-3411. SNMP-FRAMEWORK-MIB
- RFC-3412. SNMP-MPD-MIB
- RFC-3413. SNMP-TARGET-MIB
- RFC-3414. SNMP-USER-BASED-SM-MIB
- RFC-3415. SNMP-VIEW-BASED-ACM-MIB
- RFC-3418. SNMPv2-MIB
- RFC-3826. SNMP-USM-AES-MIB
- RFC-4293 IP-MIB
- PTP 650 Series proprietary MIB

Note

The proprietary MIBs are provided in the PTP 650 Series software download files in the support website (see Contacting Cambium Networks on page 1).

Supported diagnostic alarms

PTP 650 supports the diagnostic alarms listed in Table 102.

The web-based interface may be used to enable or disable generation of each supported SNMP notification or diagnostic alarm.

Enabling SNMP

Enable the SNMP interface for use by configuring the following attributes in the SNMP Configuration page:

- SNMP State (default disabled)
- SNMP Version (default SNMPv1/2c)
- SNMP Port Number (default 161)

Security planning

This section describes how to plan for PTP 650 links to operate in secure mode.

Planning for SNTP operation

Note

PTP 650 does not have a battery-powered clock, so the set time is lost each time the ODU is powered down. To avoid the need to manually set the time after each reboot, use SNTP server synchronization.

Before starting to configure Simple Network Time Protocol (SNTP):

- Identify the time zone and daylight saving requirements that apply to the system.
- If SNTP server synchronization is required, identify the details of one or two SNTP servers: IP address, port number and server key.
- Decide whether or not to authenticate received NTP messages using an MD5 signature.

Planning for HTTPS/TLS operation

Before starting to configure HTTPS/TLS operation, ensure that the cryptographic material listed in Table 33 is available.

Table 33 HTTPS/TLS security material

Item	Description	Quantity required
Key of Keys	An encryption key generated using a cryptographic key generator. The key length is dictated by the installed license key. License keys with AES-128 will require a key of keys of 128-bits. License keys with AES-256 will require a key of keys of 256-bits. The key output should be in ASCII hexadecimal characters.	Two per link. For greater security, each link end should be allocated a unique Key of Keys.

Item	Description	Quantity required
TLS Private Key and Public Certificates	An RSA private key of size 2048 bytes, generated in either PKCS#1 or PKCS#5 format, unencrypted, and encoded in the ASN.1 DER format. An X.509 certificate containing an RSA public key, generated in either PKCS#1 or PKCS#5 format, unencrypted, and encoded in the ASN.1 DER format. The public key certificate must have Common Name equal to the IPv4 or IPv6 address of the ODU. The public key certificate must form a valid pair with the private key.	Two pairs per link. These items are unique to IP address.
User Defined Security Banner	The banner provides warnings and notices to be read by the user before logging in to the ODU. Use text that is appropriate to the network security policy.	Normally one per link. This depends upon network policy.
Entropy Input	This must be of size 512 bits (128 hexadecimal characters), output from a random number generator.	Two per link. For greater security, each link end should be allocated a unique Entropy Input.
Wireless Link Encryption Key for AES	An encryption key generated using a cryptographic key generator. The key length is dictated by the selected AES encryption algorithm (128 or 256 bits).	One per link. The same encryption key is required at each link end.
Port numbers for HTTP, HTTPS and Telnet	Port numbers allocated by the network.	As allocated by network.

Planning for SNMPv3 operation

SNMP security mode

Decide how SNMPv3 security will be configured.

MIB-based security management uses standard SNMPv3 MIBs to configure the user-based security model and the view-based access control model. This approach provides considerable flexibility, allowing a network operator to tailor views and security levels appropriate for different types of user. MIB-based security management may allow a network operator to take advantage of built-in security management capabilities of existing network managers.

Web-based security management allows an operator to configure users, security levels, privacy and authentication protocols, and passphrases using the PTP 650 web-based management interface. The capabilities supported are somewhat less flexible than those supported using the MIB-based security management, but will be sufficient in many applications. Selection of web-based management for SNMPv3 security disables the MIB-based security management. PTP 650 does not support concurrent use of MIB-based and web-based management of SNMPv3 security.

Web-based management of SNMPv3 security

Initial configuration of SNMPv3 security is available only to HTTP or HTTPS/TLS user accounts with security role of Security Officer.

Identify the minimum security role of HTTP or HTTPS/TLS user accounts that will be permitted access for web-based management of SNMPv3 security. The following roles are available:

- System Administrator
- Security Officer

Identify the format used for SNMP Engine ID. The following formats are available:

- MAC address (default)
- IPv4 address
- Text string
- IPv6 address

If SNMP Engine ID will be based on a text string, identify the text string required by the network management system. This is often based on some identifier that survives replacement of the PTP hardware.

Identify the user names and security roles of initial SNMPv3 users. Two security roles are available:

- Read Only
- System Administrator

Identify the security level for each of the security roles. Three security levels are available: (a) No authentication, no privacy; (b) Authentication, no privacy; (c) Authentication, privacy.

If authentication is required, identify the protocol. Two authentication protocols are available: MD5 or SHA.

If privacy will be used, identify the protocol. Two privacy protocols are available: DES or AES (an AES 128-bit or 256-bit capability upgrade must be purchased).

If authentication or authentication and privacy protocols are required, identify passphrases for each protocol for each SNMP user. It is considered good practice to use different passphrases for authentication and privacy. Passphrases must have length between 8 and 32 characters, and may contain any of the characters listed in Table 34.

Table 34 Permitted character set for SNMPv3 passphrases

Character	Code	Character	Code
<space>	32	;	59
!	33	<	60
“	34	=	61
#	35	>	62
$	36	?	63
%	37	@	64
&	38	A..Z	65..90
'	39	[	91
(	40	\	92
)	41	]	93
*	42	^	94
+	43	_	95
,	44	`	96
-	45	a..z	97..122
.	46	{	123
/	47	|	124
0..9	48..57	}	125
:	58	~	126

Identify up to two SNMP users that will be configured to receive notifications (traps). Identify the Internet address (IPv4 or IPv6) and UDP port number of the associated SNMP manager.

SNMPv3 default configuration (MIB-based)

When SNMPv3 MIB-based Security Mode is enabled, the default configuration for the `usmUserTable` table is based on one initial user and four template users as listed in Table 35.

Table 35 Default SNMPv3 users

Object	Entry 1
Name	initial
SecurityName	initial
AuthProtocol	usmHMACMD5AuthProtocol
PrivProtocol	usmDESPrivProtocol
StorageType	nonVolatile

Object	Entry 2	Entry 3
Name	templateMD5_DES	templateSHA_DES
SecurityName	templateMD5_DES	templateSHA_DES
AuthProtocol	usmHMACMD5AuthProtocol	usmHMACSAHAuthProtocol
PrivProtocol	usmDESPrivProtocol	usmDESPrivProtocol
StorageType	nonVolatile	nonVolatile

Object	Entry 4	Entry 5
Name	templateMD5_AES	templateSHA_AES
SecurityName	templateMD5_AES	templateSHA_AES
AuthProtocol	usmHMACMD5AuthProtocol	usmHMACSHAAuthProtocol
PrivProtocol	usmAESPrivProtocol	usmAESPrivProtocol
StorageType	nonVolatile	nonVolatile

VACM default configuration

The default user `initial` is assigned to VACM group `initial` in the `vacmSecurityToGroupTable` table. The template users are not assigned to a group.

PTP 650 creates default view trees and access as shown in Table 36 and Table 37.

Table 36 Default VACM view trees

Object	Entry 1	Entry 2
ViewName	internet	restricted
Subtree	1.3.6.1	1.3.6.1
Mask	“”	“”
Type	included	included
StorageType	nonVolatile	nonvolatile

Table 37 Default data fill for access table

Object	Entry 1	Entry 2
GroupName	initial	initial
ContextPrefix	“”	“”
SecurityLevel	authNoPriv	noAuthNoPriv
ContextMatch	exact	exact
ReadViewName	internet	restricted
WriteViewName	internet	“”
NotifyViewName	internet	restricted
StorageType	nonVolatile	nonVolatile

Planning for RADIUS operation

Configure RADIUS where remote authentication is required for users of the web-based interface. Remote authentication has the following advantages:

- Control of passwords can be centralized.
- Management of user accounts can be more sophisticated. For example; users can be prompted by a network manager to change passwords at regular intervals. As another example, passwords can be checked for inclusion of dictionary words and phrases.
- Passwords can be updated without reconfiguring multiple network elements.
- User accounts can be disabled without reconfiguring multiple network elements.

Remote authentication has one significant disadvantage in a wireless link product such as PTP 650. If the wireless link is down, a unit on the remote side of the broken link may be prevented from contacting a RADIUS Server, with the result that users are unable to access the web-based interface.

One useful strategy would be to combine RADIUS authentication for normal operation with a single locally-authenticated user account for emergency use.

PTP 650 provides a choice of the following authentication methods:

- CHAP
- MS-CHAPv2

Ensure that the authentication method selected in PTP 650 is supported by the RADIUS server.

RADIUS attributes

If the standard RADIUS attribute session-timeout (Type 27) is present in a RADIUS response, PTP 650 sets a maximum session length for the authenticated user. If the attribute is absent, the maximum session length is infinite.

If the standard RADIUS attribute idle-timeout (Type 28) is present in a RADIUS response, PTP 650 overrides the Auto Logout Timer with this value in the authenticated session.

If the vendor-specific RADIUS attribute auth-role is present in a RADIUS response, PTP 650 selects the role for the authenticated user according to auth-role. The supported values of auth-role are as follows:

- 0: Invalid role. The user is not admitted.
- 1: Read Only
- 2: System Administrator
- 3: Security Officer

If the vendor-specific auth-role attribute is absent, but the standard service-type (Type 6) attribute is present, PTP 650 selects the role for the authenticated user according to service-type. The supported values of service-type are as follows:

- Login(1): Read Only
- Administrative(6): System Administrator
- NAS Prompt(7): Read Only

If the auth-role and service-type attributes are absent, PTP 650 selects the Read Only role.

The auth-role vendor-specific attribute is defined in Table 38.

Table 38 Definition of auth-role vendor-specific attribute

Field	Length	Value	Notes
Type	1	26	Vendor-specific attribute.
Length	1	12	Overall length of the attribute.
Vendor ID	4	17713	The same IANA code used for the SNMP enterprise MIB.
Vendor Type	1	1	auth-role
Vendor Length	1	4	Length of the attribute specific part.
Attribute-Specific	4	0..3	Integer type (32-bit unsigned). Supported values: invalid-role(0), readonly-role(1), system-admin-role(2), security-officer-role(3).

System threshold, output power and link loss

The following tables specify the system threshold (dBm), output power (dBm) and maximum link loss (dB) per channel bandwidth and modulation mode:

- Table 39 - 4.9 GHz - IP mode
- Table 40 - 4.9 GHz - TDM mode
- Table 41 - 5.4 GHz - IP mode
- Table 42 - 5.4 GHz - TDM mode
- Table 43 - 5.8 GHz - IP mode
- Table 44 - 5.8 GHz - TDM mode

Table 39 4.9 GHz - IP mode - threshold, power and link loss

Modulation mode	System threshold (dBm) per channel bandwidth		Output power (dBm)	Maximum link loss (dB) per channel bandwidth	
	10 MHz	20 MHz	All bands	10 MHz	20 MHz
BPSK 0.63 single	-95.7	-92.5	+27	168.7	165.5
QPSK 0.63 single	-90.0	-88.4	+26	163.0	161.4
QPSK 0.87 single	-86.9	-84.8	+26	159.9	157.8
16QAM 0.63 single	-84.7	-82.8	+25	156.7	154.8
16QAM 0.63 dual	-81.8	-79.1	+25	153.8	151.1
16QAM 0.87 single	-80.5	-78.1	+25	152.5	150.1
16QAM 0.87 dual	-77.6	-75.1	+25	149.6	147.1
64QAM 0.75 single	-77.3	-75.0	+24	148.3	146.0
64QAM 0.75 dual	-74.7	-72.1	+24	145.7	143.1
64QAM 0.92 single	-73.2	-70.7	+24	144.2	141.7
64QAM 0.92 dual	-70.2	-67.6	+24	141.2	138.6
256QAM 0.81 single	-69.9	-67.5	+23	138.9	136.5
256QAM 0.81 dual	-66.8	-64.1	+23	135.8	133.1

Table 40 4.9 GHz - TDM mode - threshold, power and link loss

Modulation mode	System threshold (dBm) per channel bandwidth		Output power (dBm)	Maximum link loss (dB) per channel bandwidth	
	10 MHz	20 MHz	All bands	10 MHz	20 MHz
BPSK 0.63 single	-92.5	-93.4	27	165.5	166.4
QPSK 0.63 single	-87.6	-86.1	26	160.6	159.1
QPSK 0.87 single	-84.2	-82.0	26	157.2	155.0
16QAM 0.63 single	-81.6	-79.7	25	153.6	151.7
16QAM 0.63 dual	-78.4	-76.2	25	150.4	148.2
16QAM 0.87 single	-77.4	-75.0	25	149.4	147.0
16QAM 0.87 dual	-74.4	-71.7	25	146.4	143.7
64QAM 0.75 single	-73.5	-71.3	24	144.5	142.3
64QAM 0.75 dual	-71.1	-68.3	24	142.1	139.3
64QAM 0.92 single	-69.6	-67.0	24	140.6	138.0
64QAM 0.92 dual	-66.9	-64.3	24	137.9	135.3
256QAM 0.81 single	-69.4	-67.2	23	138.4	136.2
256QAM 0.81 dual	-64.3	-63.2	23	133.3	132.2

Table 41 5.4 GHz - IP mode - threshold, power and link loss

Modulation mode	System threshold (dBm) per channel bandwidth				Output power (dBm)	Maximum link loss (dB) per channel bandwidth			
	10 MHz	20 MHz	40 MHz	45 MHz	All bands	10 MHz	20 MHz	40 MHz	45 MHz
BPSK 0.63 single	-96.3	-93.4	-90.7	-90.1	27	169.3	166.4	163.7	163.1
QPSK 0.63 single	-90.8	-88.8	-85.7	-85.2	26	163.8	161.8	158.7	158.2
QPSK 0.87 single	-87.2	-85.3	-82.0	-81.2	26	160.2	158.3	155.0	154.2
16QAM 0.63 single	-85.2	-83.2	-79.9	-79.3	25	157.2	155.2	151.9	151.3
16QAM 0.63 dual	-81.9	-79.6	-76.4	-76.2	25	153.9	151.6	148.4	148.2
16QAM 0.87 single	-81.0	-78.7	-75.4	-74.8	25	153.0	150.7	147.4	146.8
16QAM 0.87 dual	-77.9	-75.1	-72.0	-72.1	25	149.9	147.1	144.0	144.1
64QAM 0.75 single	-77.7	-75.7	-72.4	-71.7	24	148.7	146.7	143.4	142.7
64QAM 0.75 dual	-75.1	-72.1	-69.1	-69.1	24	146.1	143.1	140.1	140.1
64QAM 0.92 single	-73.7	-71.5	-68.3	-67.4	24	144.7	142.5	139.3	138.4
64 QAM 0.92 dual	-70.7	-67.9	-64.9	-64.5	24	141.7	138.9	135.9	135.5
256QAM 0.81 single	-70.5	-68.6	-65.4	-64.9	23	139.5	137.6	134.4	133.9
256QAM 0.81 dual	-67.7	-64.9	-61.8	-62.0	23	136.7	133.9	130.8	131.0

Table 42 5.4 GHz - TDM mode - threshold, power and link loss

Modulation mode	System threshold (dBm) per channel bandwidth				Output power (dBm)	Maximum link loss (dB) per channel bandwidth			
	10 MHz	20 MHz	40 MHz	45 MHz	All bands	10 MHz	20 MHz	40 MHz	45 MHz
BPSK 0.63 single	-96.4	-93.5	-90.3	-90.0	27	169.4	166.5	163.3	163.0
QPSK 0.63 single	-87.9	-86.4	-83.2	-82.8	26	160.9	159.4	156.2	155.8
QPSK 0.87 single	-84.8	-82.4	-79.1	-78.7	26	157.8	155.4	152.1	151.7
16QAM 0.63 single	-82.6	-80.0	-76.9	-76.4	25	154.6	152.0	148.9	148.4
16QAM 0.63 dual	-78.7	-76.3	-73.4	-73.0	25	150.7	148.3	145.4	145.0
16QAM 0.87 single	-78.2	-75.6	-72.3	-71.9	25	150.2	147.6	144.3	143.9
16QAM 0.87 dual	-74.8	-72.0	-69.0	-68.9	25	146.8	144.0	141.0	140.9
64QAM 0.75 single	-74.3	-72.0	-68.9	-68.5	24	145.3	143.0	139.9	139.5
64QAM 0.75 dual	-71.3	-68.6	-65.7	-65.6	24	142.3	139.6	136.7	136.6
64QAM 0.92 single	-70.1	-68.0	-65.0	-64.5	24	141.1	139.0	136.0	135.5
64 QAM 0.92 dual	-67.3	-64.6	-61.1	-61.6	24	138.3	135.6	132.1	132.6
256QAM 0.81 single	-70.5	-68.2	-65.0	-64.7	23	139.5	137.2	134.0	133.7
256QAM 0.81 dual	-66.9	-64.1	-61.3	-61.2	23	135.9	133.1	130.3	130.2

Table 43 5.8 GHz - IP mode - threshold, power and link loss

Modulation mode	System threshold (dBm) per channel bandwidth				Output power (dBm)	Maximum link loss (dB) per channel bandwidth			
	10 MHz	20 MHz	40 MHz	45 MHz	All bands	10 MHz	20 MHz	40 MHz	45 MHz
BPSK 0.63 single	-95.8	-92.9	-89.6	-89.4	27	168.8	165.9	162.6	162.4
QPSK 0.63 single	-90.3	-87.9	-85.3	-85.0	26	163.3	160.9	158.3	158.0
QPSK 0.87 single	-87.3	-84.5	-81.4	-81.0	26	160.3	157.5	154.4	154.0
16QAM 0.63 single	-85.2	-82.5	-79.2	-78.9	25	157.2	154.5	151.2	150.9
16QAM 0.63 dual	-81.4	-79.0	-75.7	-75.3	25	153.4	151.0	147.7	147.3
16QAM 0.87 single	-80.6	-77.8	-74.8	-74.6	25	152.6	149.8	146.8	146.6
16QAM 0.87 dual	-77.3	-74.4	-71.4	-71.1	25	149.3	146.4	143.4	143.1
64QAM 0.75 single	-77.3	-74.8	-71.7	-71.4	24	148.3	145.8	142.7	142.4
64QAM 0.75 dual	-74.5	-71.5	-68.5	-68.2	24	145.5	142.5	139.5	139.2
64QAM 0.92 single	-73.4	-70.7	-67.7	-67.5	24	144.4	141.7	138.7	138.5
64 QAM 0.92 dual	-70.0	-67.1	-64.2	-64.0	24	141.0	138.1	135.2	135.0
256QAM 0.81 single	-70.1	-67.4	-64.8	-64.4	23	139.1	136.4	133.8	133.4
256QAM 0.81 dual	-67.0	-64.0	-61.2	-60.8	23	136.0	133.0	130.2	129.8

Table 44 5.8 GHz - TDM mode - threshold, power and link loss

Modulation mode	System threshold (dBm) per channel bandwidth				Output power (dBm)	Maximum link loss (dB) per channel bandwidth			
	10 MHz	20 MHz	40 MHz	45 MHz	All bands	10 MHz	20 MHz	40 MHz	45 MHz
BPSK 0.63 single	-96.4	-92.7	-90.2	-89.6	27	169.4	165.7	163.2	162.6
QPSK 0.63 single	-87.5	-86.0	-83.2	-82.7	26	160.5	159.0	156.2	155.7
QPSK 0.87 single	-84.3	-81.9	-79.0	-78.4	26	157.3	154.9	152.0	151.4
16QAM 0.63 single	-81.9	-79.6	-76.6	-76.2	25	153.9	151.6	148.6	148.2
16QAM 0.63 dual	-78.2	-76.0	-73.0	-72.6	25	150.2	148.0	145.0	144.6
16QAM 0.87 single	-77.7	-75.0	-72.1	-71.6	25	149.7	147.0	144.1	143.6
16QAM 0.87 dual	-74.0	-71.4	-69.0	-68.2	25	146.0	143.4	141.0	140.2
64QAM 0.75 single	-73.8	-71.4	-68.8	-68.2	24	144.8	142.4	139.8	139.2
64QAM 0.75 dual	-70.7	-68.0	-65.7	-64.9	24	141.7	139.0	136.7	135.9
64QAM 0.92 single	-69.8	-67.2	-64.8	-64.2	24	140.8	138.2	135.8	135.2
64 QAM 0.92 dual	-66.7	-63.8	-61.2	-60.3	24	137.7	134.8	132.2	131.3
256QAM 0.81 single	-70.0	-67.3	-64.7	-64.3	23	139.0	136.3	133.7	133.3
256QAM 0.81 dual	-66.2	-63.5	-61.1	-60.3	23	135.2	132.5	130.1	129.3

Data throughput capacity tables

Use the following tables to look up the data throughput rates (Mbits/s) that are achieved when two PTP 650 ODUs are linked and the link distance (range) is 0 km:

PTP 650 variant	Link symmetry	Link optimization	Table
Full	1:1	IP	Table 45
		TDM	Table 46
	2:1	IP	Table 47
		TDM	Table 48
	Adaptive	IP	Table 49
Mid	1:1	IP	Table 50
		TDM	Table 51
	2:1	IP	Table 52
		TDM	Table 53
	Adaptive	IP	Table 54
Lite	1:1	IP	Table 55
		TDM	Table 56
	2:1	IP	Table 57
		TDM	Table 58
	Adaptive	IP	Table 59

Use the following range adjustment graphs to look up the link range and find the throughput factor that must be applied to adjust the 0 km data throughput rates:

Link symmetry	Link optimization	Bandwidth			
		45 MHz	40 MHz	20 MHz	10 MHz
1:1	IP	Figure 33	Figure 34	Figure 35	Figure 36
	TDM	Figure 37	Figure 38	Figure 39	Figure 40
2:1	IP	Figure 41	Figure 42	Figure 43	Figure 44
	TDM	Figure 45	Figure 46	Figure 47	Figure 48
Adaptive	IP	Figure 49	Figure 50	Figure 51	Figure 52

Throughput for link symmetry 2:1 is the same as 1:2, but the Tx and Rx data rates are swapped.

Table 45 Throughput at zero link range (Mbit/s), Full, symmetry 1:1, optimization IP

Modulation mode	45 MHz (Tx/Rx/Aggregate)			40 MHz (Tx/Rx/Aggregate)		
256QAM 0.81 dual	226.1	226.1	452.2	206.3	206.3	412.6
64QAM 0.92 dual	190.5	190.5	381.0	173.8	173.8	347.6
64QAM 0.75 dual	155.7	155.7	311.3	142.0	142.0	284.1
16QAM 0.87 dual	121.1	121.1	242.2	110.5	110.5	221.0
16QAM 0.63 dual	87.1	87.1	174.1	79.4	79.4	158.9
256QAM 0.81 single	113.0	113.0	226.1	103.1	103.1	206.3
64QAM 0.92 single	95.2	95.2	190.5	86.9	86.9	173.8
64QAM 0.75 single	77.8	77.8	155.7	71.0	71.0	142.0
16QAM 0.87 single	60.5	60.5	121.1	55.2	55.2	110.5
16QAM 0.63 single	43.5	43.5	87.0	39.7	39.7	79.4
QPSK 0.87 single	30.3	30.3	60.5	27.6	27.6	55.2
QPSK 0.63 single	21.8	21.8	43.5	19.9	19.9	39.7
BPSK 0.63 single	10.9	10.9	21.8	9.9	9.9	19.9
Modulation mode	**20 MHz (Tx/Rx/Aggregate)**			**10 MHz (Tx/Rx/Aggregate)**		
256QAM 0.81 dual	100.0	100.0	200.1	50.1	50.1	100.2
64QAM 0.92 dual	84.3	84.3	168.6	42.2	42.2	84.4
64QAM 0.75 dual	68.9	68.9	137.8	34.5	34.5	69.0
16QAM 0.87 dual	53.6	53.6	107.2	26.8	26.8	53.7
16QAM 0.63 dual	38.5	38.5	77.0	19.3	19.3	38.6
256QAM 0.81 single	50.0	50.0	100.0	25.0	25.0	50.1
64QAM 0.92 single	42.1	42.1	84.3	21.1	21.1	42.2
64QAM 0.75 single	34.4	34.4	68.9	17.2	17.2	34.5
16QAM 0.87 single	26.8	26.8	53.6	13.4	13.4	26.8
16QAM 0.63 single	19.3	19.3	38.5	9.6	9.6	19.3
QPSK 0.87 single	13.4	13.4	26.8	6.7	6.7	13.4
QPSK 0.63 single	9.6	9.6	19.3	4.8	4.8	9.6
BPSK 0.63 single	4.8	4.8	9.6	2.4	2.4	4.8

Tx/Rx/Aggregate columns contain the transmit, receive and aggregate data rates per bandwidth.

Table 46 Throughput at zero link range (Mbit/s), Full, symmetry 1:1, optimization TDM

Modulation mode	45 MHz (Tx/Rx/Aggregate)			40 MHz (Tx/Rx/Aggregate)		
256QAM 0.81 dual	202.1	202.1	404.1	186.1	186.1	372.1
64QAM 0.92 dual	170.2	170.2	340.5	156.8	156.8	313.5
64QAM 0.75 dual	139.1	139.1	278.2	128.1	128.1	256.2
16QAM 0.87 dual	108.2	108.2	216.5	99.7	99.7	199.3
16QAM 0.63 dual	77.8	77.8	155.6	71.6	71.6	143.3
256QAM 0.81 single	101.0	101.0	202.1	93.0	93.0	186.1
64QAM 0.92 single	85.1	85.1	170.2	78.4	78.4	156.8
64QAM 0.75 single	69.6	69.6	139.1	64.0	64.0	128.1
16QAM 0.87 single	54.1	54.1	108.2	49.8	49.8	99.7
16QAM 0.63 single	38.9	38.9	77.8	35.8	35.8	71.6
QPSK 0.87 single	27.1	27.1	54.1	24.9	24.9	49.8
QPSK 0.63 single	19.4	19.4	38.9	17.9	17.9	35.8
BPSK 0.63 single	9.7	9.7	19.4	9.0	9.0	17.9
Modulation mode	**20 MHz (Tx/Rx/Aggregate)**			**10 MHz (Tx/Rx/Aggregate)**		
256QAM 0.81 dual	96.0	96.0	192.0	49.1	49.1	98.2
64QAM 0.92 dual	80.9	80.9	161.7	41.4	41.4	82.8
64QAM 0.75 dual	66.1	66.1	132.2	33.8	33.8	67.6
16QAM 0.87 dual	51.4	51.4	102.8	26.3	26.3	52.6
16QAM 0.63 dual	37.0	37.0	73.9	18.9	18.9	37.8
256QAM 0.81 single	48.0	48.0	96.0	24.6	24.6	49.1
64QAM 0.92 single	40.4	40.4	80.9	20.7	20.7	41.4
64QAM 0.75 single	33.0	33.0	66.1	16.9	16.9	33.8
16QAM 0.87 single	25.7	25.7	51.4	13.2	13.2	26.3
16QAM 0.63 single	18.5	18.5	37.0	9.5	9.5	18.9
QPSK 0.87 single	12.8	12.8	25.7	6.6	6.6	13.1
QPSK 0.63 single	9.2	9.2	18.5	4.7	4.7	9.5
BPSK 0.63 single	4.6	4.6	9.2	2.4	2.4	4.7

Tx/Rx/Aggregate columns contain the transmit, receive and aggregate data rates per bandwidth.

Table 47 Throughput at zero link range (Mbit/s), Full, symmetry 2:1, optimization IP

Modulation mode	45 MHz (Tx/Rx/Aggregate)			40 MHz (Tx/Rx/Aggregate)		
256QAM 0.81 dual	299.7	149.9	449.6	273.6	136.8	410.5
64QAM 0.92 dual	252.5	126.3	378.8	230.5	115.3	345.8
64QAM 0.75 dual	206.4	103.2	309.6	188.4	94.2	282.6
16QAM 0.87 dual	160.6	80.3	240.8	146.6	73.3	219.8
16QAM 0.63 dual	115.4	57.7	173.1	105.4	52.7	158.0
256QAM 0.81 single	149.9	74.9	224.8	136.8	68.4	205.2
64QAM 0.92 single	126.3	63.1	189.4	115.3	57.6	172.9
64QAM 0.75 single	103.2	51.6	154.8	94.2	47.1	141.3
16QAM 0.87 single	80.3	40.1	120.4	73.3	36.6	109.9
16QAM 0.63 single	57.7	28.9	86.6	52.7	26.3	79.0
QPSK 0.87 single	40.1	20.1	60.2	36.6	18.3	55.0
QPSK 0.63 single	28.9	14.4	43.3	26.3	13.2	39.5
BPSK 0.63 single	14.4	7.2	21.6	13.2	6.6	19.7
Modulation mode	**20 MHz (Tx/Rx/Aggregate)**			**10 MHz (Tx/Rx/Aggregate)**		
256QAM 0.81 dual	133.4	66.7	200.1	66.3	33.2	99.5
64QAM 0.92 dual	112.4	56.2	168.6	55.9	27.9	83.8
64QAM 0.75 dual	91.8	45.9	137.8	45.7	22.8	68.5
16QAM 0.87 dual	71.5	35.7	107.2	35.5	17.8	53.3
16QAM 0.63 dual	51.4	25.7	77.0	25.5	12.8	38.3
256QAM 0.81 single	66.7	33.3	100.0	33.2	16.6	49.8
64QAM 0.92 single	56.2	28.1	84.3	27.9	14.0	41.9
64QAM 0.75 single	45.9	23.0	68.9	22.8	11.4	34.3
16QAM 0.87 single	35.7	17.9	53.6	17.8	8.9	26.6
16QAM 0.63 single	25.7	12.8	38.5	12.8	6.4	19.2
QPSK 0.87 single	17.9	8.9	26.8	8.9	4.4	13.3
QPSK 0.63 single	12.8	6.4	19.3	6.4	3.2	9.6
BPSK 0.63 single	6.4	3.2	9.6	3.2	1.6	4.8

Tx/Rx/Aggregate columns contain the transmit, receive and aggregate data rates per bandwidth.

Table 48 Throughput at zero link range (Mbit/s), Full, symmetry 2:1, optimization TDM

Modulation mode	45 MHz (Tx/Rx/Aggregate)			40 MHz (Tx/Rx/Aggregate)		
256QAM 0.81 dual	280.8	140.4	421.2	257.7	128.9	386.6
64QAM 0.92 dual	236.6	118.3	354.8	217.1	108.6	325.7
64QAM 0.75 dual	193.3	96.7	290.0	177.4	88.7	266.1
16QAM 0.87 dual	150.4	75.2	225.6	138.0	69.0	207.1
16QAM 0.63 dual	108.1	54.1	162.2	99.2	49.6	148.8
256QAM 0.81 single	140.4	70.2	210.6	128.9	64.4	193.3
64QAM 0.92 single	118.3	59.1	177.4	108.6	54.3	162.8
64QAM 0.75 single	96.7	48.3	145.0	88.7	44.4	133.1
16QAM 0.87 single	75.2	37.6	112.8	69.0	34.5	103.5
16QAM 0.63 single	54.1	27.0	81.1	49.6	24.8	74.4
QPSK 0.87 single	37.6	18.8	56.4	34.5	17.3	51.8
QPSK 0.63 single	27.0	13.5	40.5	24.8	12.4	37.2
BPSK 0.63 single	13.5	6.8	20.3	12.4	6.2	18.6
Modulation mode	**20 MHz (Tx/Rx/Aggregate)**			**10 MHz (Tx/Rx/Aggregate)**		
256QAM 0.81 dual	130.6	65.3	195.9	66.3	33.2	99.5
64QAM 0.92 dual	110.1	55.0	165.1	55.9	27.9	83.8
64QAM 0.75 dual	89.9	45.0	134.9	45.7	22.8	68.5
16QAM 0.87 dual	70.0	35.0	104.9	35.5	17.8	53.3
16QAM 0.63 dual	50.3	25.1	75.4	25.5	12.8	38.3
256QAM 0.81 single	65.3	32.7	98.0	33.2	16.6	49.8
64QAM 0.92 single	55.0	27.5	82.5	27.9	14.0	41.9
64QAM 0.75 single	45.0	22.5	67.4	22.8	11.4	34.3
16QAM 0.87 single	35.0	17.5	52.5	17.8	8.9	26.6
16QAM 0.63 single	25.1	12.6	37.7	12.8	6.4	19.2
QPSK 0.87 single	17.5	8.7	26.2	8.9	4.4	13.3
QPSK 0.63 single	12.6	6.3	18.9	6.4	3.2	9.6
BPSK 0.63 single	6.3	3.1	9.4	3.2	1.6	4.8

Tx/Rx/Aggregate columns contain the transmit, receive and aggregate data rates per bandwidth.

Table 49 Throughput at zero link range (Mbit/s), Full, symmetry adaptive, optimization IP

Modulation mode	45 MHz (Tx/Rx/Aggregate)			40 MHz (Tx/Rx/Aggregate)		
256QAM 0.81 dual	407.9	40.8	448.7	367.9	40.9	408.8
64QAM 0.92 dual	343.7	34.4	378.0	310.0	34.4	344.4
64QAM 0.75 dual	280.8	28.1	308.9	253.3	28.1	281.4
16QAM 0.87 dual	218.5	21.8	240.3	197.1	21.9	218.9
16QAM 0.63 dual	157.1	15.7	172.8	141.7	15.7	157.4
256QAM 0.81 single	204.0	20.4	224.3	183.9	20.4	204.4
64QAM 0.92 single	171.8	17.2	189.0	155.0	17.2	172.2
64QAM 0.75 single	140.4	14.0	154.5	126.6	14.1	140.7
16QAM 0.87 single	109.2	10.9	120.2	98.5	10.9	109.5
16QAM 0.63 single	78.5	7.9	86.4	70.8	7.9	78.7
QPSK 0.87 single	54.6	5.5	60.1	49.3	5.5	54.7
QPSK 0.63 single	39.3	3.9	43.2	35.4	3.9	39.3
BPSK 0.63 single	19.6	2.0	21.6	17.7	2.0	19.7
Modulation mode	**20 MHz (Tx/Rx/Aggregate)**			**10 MHz (Tx/Rx/Aggregate)**		
256QAM 0.81 dual	159.4	39.8	199.2	66.3	33.2	99.5
64QAM 0.92 dual	134.3	33.6	167.9	55.9	27.9	83.8
64QAM 0.75 dual	109.7	27.4	137.2	45.7	22.8	68.5
16QAM 0.87 dual	85.4	21.3	106.7	35.5	17.8	53.3
16QAM 0.63 dual	61.4	15.3	76.7	25.5	12.8	38.3
256QAM 0.81 single	79.7	19.9	99.6	33.2	16.6	49.8
64QAM 0.92 single	67.1	16.8	83.9	27.9	14.0	41.9
64QAM 0.75 single	54.9	13.7	68.6	22.8	11.4	34.3
16QAM 0.87 single	42.7	10.7	53.4	17.8	8.9	26.6
16QAM 0.63 single	30.7	7.7	38.4	12.8	6.4	19.2
QPSK 0.87 single	21.3	5.3	26.7	8.9	4.4	13.3
QPSK 0.63 single	15.3	3.8	19.2	6.4	3.2	9.6
BPSK 0.63 single	7.7	1.9	9.6	3.2	1.6	4.8

Tx/Rx/Aggregate columns contain the transmit, receive and aggregate data rates per bandwidth.

Table 50 Throughput at zero link range (Mbit/s), Mid, symmetry 1:1, optimization IP

Modulation mode	45 MHz (Tx/Rx/Aggregate)			40 MHz (Tx/Rx/Aggregate)		
256QAM 0.81 dual	127.0	127.0	254.0	116.0	116.0	232.0
64QAM 0.92 dual	107.0	107.0	214.0	97.0	97.0	194.0
64QAM 0.75 dual	87.0	87.0	174.0	80.0	80.0	160.0
16QAM 0.87 dual	68.0	68.0	136.0	62.0	62.0	124.0
16QAM 0.63 dual	49.0	49.0	98.0	44.0	44.0	88.0
256QAM 0.81 single	63.0	63.0	126.0	58.0	58.0	116.0
64QAM 0.92 single	53.0	53.0	106.0	49.0	49.0	98.0
64QAM 0.75 single	44.0	44.0	88.0	40.0	40.0	80.0
16QAM 0.87 single	34.0	34.0	68.0	31.0	31.0	62.0
16QAM 0.63 single	24.0	24.0	48.0	22.0	22.0	44.0
QPSK 0.87 single	17.0	17.0	34.0	15.0	15.0	30.0
QPSK 0.63 single	12.0	12.0	24.0	11.0	11.0	22.0
BPSK 0.63 single	6.0	6.0	12.0	6.0	6.0	12.0
Modulation mode	**20 MHz (Tx/Rx/Aggregate)**			**10 MHz (Tx/Rx/Aggregate)**		
256QAM 0.81 dual	56.0	56.0	112.0	28.0	28.0	56.0
64QAM 0.92 dual	47.0	47.0	94.0	24.0	24.0	48.0
64QAM 0.75 dual	39.0	39.0	78.0	19.0	19.0	38.0
16QAM 0.87 dual	30.0	30.0	60.0	15.0	15.0	30.0
16QAM 0.63 dual	22.0	22.0	44.0	11.0	11.0	22.0
256QAM 0.81 single	28.0	28.0	56.0	14.0	14.0	28.0
64QAM 0.92 single	24.0	24.0	48.0	12.0	12.0	24.0
64QAM 0.75 single	19.0	19.0	38.0	10.0	10.0	20.0
16QAM 0.87 single	15.0	15.0	30.0	8.0	8.0	16.0
16QAM 0.63 single	11.0	11.0	22.0	5.0	5.0	10.0
QPSK 0.87 single	8.0	8.0	16.0	5.0	5.0	10.0
QPSK 0.63 single	5.0	5.0	10.0	4.8	4.8	9.6
BPSK 0.63 single	4.8	4.8	9.6	2.4	2.4	4.8

Tx/Rx/Aggregate columns contain the transmit, receive and aggregate data rates per bandwidth.

Table 51 Throughput at zero link range (Mbit/s), Mid, symmetry 1:1, optimization TDM

Modulation mode	45 MHz (Tx/Rx/Aggregate)			40 MHz (Tx/Rx/Aggregate)		
256QAM 0.81 dual	113.0	113.0	226.0	104.0	104.0	208.0
64QAM 0.92 dual	95.0	95.0	190.0	88.0	88.0	176.0
64QAM 0.75 dual	78.0	78.0	156.0	72.0	72.0	144.0
16QAM 0.87 dual	61.0	61.0	122.0	56.0	56.0	112.0
16QAM 0.63 dual	44.0	44.0	88.0	40.0	40.0	80.0
256QAM 0.81 single	57.0	57.0	114.0	52.0	52.0	104.0
64QAM 0.92 single	48.0	48.0	96.0	44.0	44.0	88.0
64QAM 0.75 single	39.0	39.0	78.0	36.0	36.0	72.0
16QAM 0.87 single	30.0	30.0	60.0	28.0	28.0	56.0
16QAM 0.63 single	22.0	22.0	44.0	20.0	20.0	40.0
QPSK 0.87 single	15.0	15.0	30.0	14.0	14.0	28.0
QPSK 0.63 single	11.0	11.0	22.0	10.0	10.0	20.0
BPSK 0.63 single	5.0	5.0	10.0	5.0	5.0	10.0
Modulation mode	**20 MHz (Tx/Rx/Aggregate)**			**10 MHz (Tx/Rx/Aggregate)**		
256QAM 0.81 dual	54.0	54.0	108.0	28.0	28.0	56.0
64QAM 0.92 dual	45.0	45.0	90.0	23.0	23.0	46.0
64QAM 0.75 dual	37.0	37.0	74.0	19.0	19.0	38.0
16QAM 0.87 dual	29.0	29.0	58.0	15.0	15.0	30.0
16QAM 0.63 dual	21.0	21.0	42.0	11.0	11.0	22.0
256QAM 0.81 single	27.0	27.0	54.0	14.0	14.0	28.0
64QAM 0.92 single	23.0	23.0	46.0	12.0	12.0	24.0
64QAM 0.75 single	19.0	19.0	38.0	9.0	9.0	18.0
16QAM 0.87 single	14.0	14.0	28.0	7.0	7.0	14.0
16QAM 0.63 single	10.0	10.0	20.0	5.0	5.0	10.0
QPSK 0.87 single	7.0	7.0	14.0	5.0	5.0	10.0
QPSK 0.63 single	5.0	5.0	10.0	4.7	4.7	9.5
BPSK 0.63 single	4.6	4.6	9.2	2.4	2.4	4.7

Tx/Rx/Aggregate columns contain the transmit, receive and aggregate data rates per bandwidth.

Table 52 Throughput at zero link range (Mbit/s), Mid, symmetry 2:1, optimization IP

Modulation mode	45 MHz (Tx/Rx/Aggregate)			40 MHz (Tx/Rx/Aggregate)		
256QAM 0.81 dual	168.0	84.0	252.0	153.0	77.0	230.0
64QAM 0.92 dual	141.0	71.0	212.0	129.0	65.0	194.0
64QAM 0.75 dual	116.0	58.0	174.0	106.0	53.0	159.0
16QAM 0.87 dual	90.0	45.0	135.0	82.0	41.0	123.0
16QAM 0.63 dual	65.0	32.0	97.0	59.0	30.0	89.0
256QAM 0.81 single	84.0	42.0	126.0	77.0	38.0	115.0
64QAM 0.92 single	71.0	35.0	106.0	65.0	32.0	97.0
64QAM 0.75 single	58.0	29.0	87.0	53.0	26.0	79.0
16QAM 0.87 single	45.0	22.0	67.0	41.0	21.0	62.0
16QAM 0.63 single	32.0	16.0	48.0	30.0	15.0	45.0
QPSK 0.87 single	22.0	11.0	33.0	21.0	10.0	31.0
QPSK 0.63 single	16.0	8.0	24.0	15.0	7.0	22.0
BPSK 0.63 single	8.0	5.0	13.0	7.0	5.0	12.0
Modulation mode	**20 MHz (Tx/Rx/Aggregate)**			**10 MHz (Tx/Rx/Aggregate)**		
256QAM 0.81 dual	75.0	37.0	112.0	37.0	19.0	56.0
64QAM 0.92 dual	63.0	31.0	94.0	31.0	16.0	47.0
64QAM 0.75 dual	51.0	26.0	77.0	26.0	13.0	39.0
16QAM 0.87 dual	40.0	20.0	60.0	20.0	10.0	30.0
16QAM 0.63 dual	29.0	14.0	43.0	14.0	7.0	21.0
256QAM 0.81 single	37.0	19.0	56.0	19.0	9.0	28.0
64QAM 0.92 single	31.0	16.0	47.0	16.0	8.0	24.0
64QAM 0.75 single	26.0	13.0	39.0	13.0	6.0	19.0
16QAM 0.87 single	20.0	10.0	30.0	10.0	5.0	15.0
16QAM 0.63 single	14.0	7.0	21.0	7.0	5.0	12.0
QPSK 0.87 single	10.0	5.0	15.0	5.0	4.4	9.4
QPSK 0.63 single	7.0	5.0	12.0	5.0	3.2	8.2
BPSK 0.63 single	5.0	3.2	8.2	3.2	1.6	4.8

Tx/Rx/Aggregate columns contain the transmit, receive and aggregate data rates per bandwidth.

Table 53 Throughput at zero link range (Mbit/s), Mid, symmetry 2:1, optimization TDM

Modulation mode	45 MHz (Tx/Rx/Aggregate)			40 MHz (Tx/Rx/Aggregate)		
256QAM 0.81 dual	157.0	79.0	236.0	144.0	72.0	216.0
64QAM 0.92 dual	132.0	66.0	198.0	122.0	61.0	183.0
64QAM 0.75 dual	108.0	54.0	162.0	99.0	50.0	149.0
16QAM 0.87 dual	84.0	42.0	126.0	77.0	39.0	116.0
16QAM 0.63 dual	61.0	30.0	91.0	56.0	28.0	84.0
256QAM 0.81 single	79.0	39.0	118.0	72.0	36.0	108.0
64QAM 0.92 single	66.0	33.0	99.0	61.0	30.0	91.0
64QAM 0.75 single	54.0	27.0	81.0	50.0	25.0	75.0
16QAM 0.87 single	42.0	21.0	63.0	39.0	19.0	58.0
16QAM 0.63 single	30.0	15.0	45.0	28.0	14.0	42.0
QPSK 0.87 single	21.0	11.0	32.0	19.0	10.0	29.0
QPSK 0.63 single	15.0	8.0	23.0	14.0	7.0	21.0
BPSK 0.63 single	8.0	5.0	13.0	7.0	5.0	12.0
Modulation mode	**20 MHz (Tx/Rx/Aggregate)**			**10 MHz (Tx/Rx/Aggregate)**		
256QAM 0.81 dual	73.0	37.0	110.0	37.0	19.0	56.0
64QAM 0.92 dual	62.0	31.0	93.0	31.0	16.0	47.0
64QAM 0.75 dual	50.0	25.0	75.0	26.0	13.0	39.0
16QAM 0.87 dual	39.0	20.0	59.0	20.0	10.0	30.0
16QAM 0.63 dual	28.0	14.0	42.0	14.0	7.0	21.0
256QAM 0.81 single	37.0	18.0	55.0	19.0	9.0	28.0
64QAM 0.92 single	31.0	15.0	46.0	16.0	8.0	24.0
64QAM 0.75 single	25.0	13.0	38.0	13.0	6.0	19.0
16QAM 0.87 single	20.0	10.0	30.0	10.0	5.0	15.0
16QAM 0.63 single	14.0	7.0	21.0	7.0	5.0	12.0
QPSK 0.87 single	10.0	5.0	15.0	5.0	4.4	9.4
QPSK 0.63 single	7.0	5.0	12.0	5.0	3.2	8.2
BPSK 0.63 single	5.0	3.1	8.1	3.2	1.6	4.8

Tx/Rx/Aggregate columns contain the transmit, receive and aggregate data rates per bandwidth.

Table 54 Throughput at zero link range (Mbit/s), Mid, symmetry adaptive, optimization IP

Modulation mode	45 MHz (Tx/Rx/Aggregate)			40 MHz (Tx/Rx/Aggregate)		
256QAM 0.81 dual	228.0	23.0	251.0	206.0	23.0	229.0
64QAM 0.92 dual	192.0	19.0	211.0	174.0	19.0	193.0
64QAM 0.75 dual	157.0	16.0	173.0	142.0	16.0	158.0
16QAM 0.87 dual	122.0	12.0	134.0	110.0	12.0	122.0
16QAM 0.63 dual	88.0	9.0	97.0	79.0	9.0	88.0
256QAM 0.81 single	114.0	11.0	125.0	103.0	11.0	114.0
64QAM 0.92 single	96.0	10.0	106.0	87.0	10.0	97.0
64QAM 0.75 single	79.0	8.0	87.0	71.0	8.0	79.0
16QAM 0.87 single	61.0	6.0	67.0	55.0	6.0	61.0
16QAM 0.63 single	44.0	5.0	49.0	40.0	5.0	45.0
QPSK 0.87 single	31.0	5.0	36.0	28.0	5.0	33.0
QPSK 0.63 single	22.0	3.9	25.9	20.0	3.9	23.9
BPSK 0.63 single	11.0	2.0	13.0	10.0	2.0	12.0
Modulation mode	**20 MHz (Tx/Rx/Aggregate)**			**10 MHz (Tx/Rx/Aggregate)**		
256QAM 0.81 dual	89.0	22.0	111.0	37.0	19.0	56.0
64QAM 0.92 dual	75.0	19.0	94.0	31.0	16.0	47.0
64QAM 0.75 dual	61.0	15.0	76.0	26.0	13.0	39.0
16QAM 0.87 dual	48.0	12.0	60.0	20.0	10.0	30.0
16QAM 0.63 dual	34.0	9.0	43.0	14.0	7.0	21.0
256QAM 0.81 single	45.0	11.0	56.0	19.0	9.0	28.0
64QAM 0.92 single	38.0	9.0	47.0	16.0	8.0	24.0
64QAM 0.75 single	31.0	8.0	39.0	13.0	6.0	19.0
16QAM 0.87 single	24.0	6.0	30.0	10.0	5.0	15.0
16QAM 0.63 single	17.0	5.0	22.0	7.0	5.0	12.0
QPSK 0.87 single	12.0	5.0	17.0	5.0	4.4	9.4
QPSK 0.63 single	9.0	3.8	12.8	5.0	3.2	8.2
BPSK 0.63 single	5.0	1.9	6.9	3.2	1.6	4.8

Tx/Rx/Aggregate columns contain the transmit, receive and aggregate data rates per bandwidth.

Table 55 Throughput at zero link range (Mbit/s), Lite, symmetry 1:1, optimization IP

Modulation mode	45 MHz (Tx/Rx/Aggregate)			40 MHz (Tx/Rx/Aggregate)		
256QAM 0.81 dual	63.0	63.0	126.0	58.0	58.0	116.0
64QAM 0.92 dual	53.0	53.0	106.0	49.0	49.0	98.0
64QAM 0.75 dual	44.0	44.0	88.0	40.0	40.0	80.0
16QAM 0.87 dual	34.0	34.0	68.0	31.0	31.0	62.0
16QAM 0.63 dual	24.0	24.0	48.0	22.0	22.0	44.0
256QAM 0.81 single	32.0	32.0	64.0	29.0	29.0	58.0
64QAM 0.92 single	27.0	27.0	54.0	24.0	24.0	48.0
64QAM 0.75 single	22.0	22.0	44.0	20.0	20.0	40.0
16QAM 0.87 single	17.0	17.0	34.0	15.0	15.0	30.0
16QAM 0.63 single	12.0	12.0	24.0	11.0	11.0	22.0
QPSK 0.87 single	8.0	8.0	16.0	8.0	8.0	16.0
QPSK 0.63 single	6.0	6.0	12.0	6.0	6.0	12.0
BPSK 0.63 single	5.0	5.0	10.0	5.0	5.0	10.0
Modulation mode	**20 MHz (Tx/Rx/Aggregate)**			**10 MHz (Tx/Rx/Aggregate)**		
256QAM 0.81 dual	28.0	28.0	56.0	14.0	14.0	28.0
64QAM 0.92 dual	24.0	24.0	48.0	12.0	12.0	24.0
64QAM 0.75 dual	19.0	19.0	38.0	10.0	10.0	20.0
16QAM 0.87 dual	15.0	15.0	30.0	8.0	8.0	16.0
16QAM 0.63 dual	11.0	11.0	22.0	5.0	5.0	10.0
256QAM 0.81 single	14.0	14.0	28.0	7.0	7.0	14.0
64QAM 0.92 single	12.0	12.0	24.0	6.0	6.0	12.0
64QAM 0.75 single	10.0	10.0	20.0	5.0	5.0	10.0
16QAM 0.87 single	8.0	8.0	16.0	5.0	5.0	10.0
16QAM 0.63 single	5.0	5.0	10.0	5.0	5.0	10.0
QPSK 0.87 single	5.0	5.0	10.0	5.0	5.0	10.0
QPSK 0.63 single	5.0	5.0	10.0	4.8	4.8	9.6
BPSK 0.63 single	4.8	4.8	9.6	2.4	2.4	4.8

Tx/Rx/Aggregate columns contain the transmit, receive and aggregate data rates per bandwidth.

Table 56 Throughput at zero link range (Mbit/s), Lite, symmetry 1:1, optimization TDM

Modulation mode	45 MHz (Tx/Rx/Aggregate)			40 MHz (Tx/Rx/Aggregate)		
256QAM 0.81 dual	57.0	57.0	114.0	52.0	52.0	104.0
64QAM 0.92 dual	48.0	48.0	96.0	44.0	44.0	88.0
64QAM 0.75 dual	39.0	39.0	78.0	36.0	36.0	72.0
16QAM 0.87 dual	30.0	30.0	60.0	28.0	28.0	56.0
16QAM 0.63 dual	22.0	22.0	44.0	20.0	20.0	40.0
256QAM 0.81 single	28.0	28.0	56.0	26.0	26.0	52.0
64QAM 0.92 single	24.0	24.0	48.0	22.0	22.0	44.0
64QAM 0.75 single	19.0	19.0	38.0	18.0	18.0	36.0
16QAM 0.87 single	15.0	15.0	30.0	14.0	14.0	28.0
16QAM 0.63 single	11.0	11.0	22.0	10.0	10.0	20.0
QPSK 0.87 single	8.0	8.0	16.0	7.0	7.0	14.0
QPSK 0.63 single	5.0	5.0	10.0	5.0	5.0	10.0
BPSK 0.63 single	5.0	5.0	10.0	5.0	5.0	10.0
Modulation mode	**20 MHz (Tx/Rx/Aggregate)**			**10 MHz (Tx/Rx/Aggregate)**		
256QAM 0.81 dual	27.0	27.0	54.0	14.0	14.0	28.0
64QAM 0.92 dual	23.0	23.0	46.0	12.0	12.0	24.0
64QAM 0.75 dual	19.0	19.0	38.0	9.0	9.0	18.0
16QAM 0.87 dual	14.0	14.0	28.0	7.0	7.0	14.0
16QAM 0.63 dual	10.0	10.0	20.0	5.0	5.0	10.0
256QAM 0.81 single	13.0	13.0	26.0	7.0	7.0	14.0
64QAM 0.92 single	11.0	11.0	22.0	6.0	6.0	12.0
64QAM 0.75 single	9.0	9.0	18.0	5.0	5.0	10.0
16QAM 0.87 single	7.0	7.0	14.0	5.0	5.0	10.0
16QAM 0.63 single	5.0	5.0	10.0	5.0	5.0	10.0
QPSK 0.87 single	5.0	5.0	10.0	5.0	5.0	10.0
QPSK 0.63 single	5.0	5.0	10.0	4.7	4.7	9.5
BPSK 0.63 single	4.6	4.6	9.2	2.4	2.4	4.7

Tx/Rx/Aggregate columns contain the transmit, receive and aggregate data rates per bandwidth.

Table 57 Throughput at zero link range (Mbit/s), Lite, symmetry 2:1, optimization IP

Modulation mode	45 MHz (Tx/Rx/Aggregate)			40 MHz (Tx/Rx/Aggregate)		
256QAM 0.81 dual	84.0	42.0	126.0	77.0	38.0	115.0
64QAM 0.92 dual	71.0	35.0	106.0	65.0	32.0	97.0
64QAM 0.75 dual	58.0	29.0	87.0	53.0	26.0	79.0
16QAM 0.87 dual	45.0	22.0	67.0	41.0	21.0	62.0
16QAM 0.63 dual	32.0	16.0	48.0	30.0	15.0	45.0
256QAM 0.81 single	42.0	21.0	63.0	38.0	19.0	57.0
64QAM 0.92 single	35.0	18.0	53.0	32.0	16.0	48.0
64QAM 0.75 single	29.0	14.0	43.0	26.0	13.0	39.0
16QAM 0.87 single	22.0	11.0	33.0	21.0	10.0	31.0
16QAM 0.63 single	16.0	8.0	24.0	15.0	7.0	22.0
QPSK 0.87 single	11.0	6.0	17.0	10.0	5.0	15.0
QPSK 0.63 single	8.0	5.0	13.0	7.0	5.0	12.0
BPSK 0.63 single	5.0	5.0	10.0	5.0	5.0	10.0
Modulation mode	**20 MHz (Tx/Rx/Aggregate)**			**10 MHz (Tx/Rx/Aggregate)**		
256QAM 0.81 dual	37.0	19.0	56.0	19.0	9.0	28.0
64QAM 0.92 dual	31.0	16.0	47.0	16.0	8.0	24.0
64QAM 0.75 dual	26.0	13.0	39.0	13.0	6.0	19.0
16QAM 0.87 dual	20.0	10.0	30.0	10.0	5.0	15.0
16QAM 0.63 dual	14.0	7.0	21.0	7.0	5.0	12.0
256QAM 0.81 single	19.0	9.0	28.0	9.0	5.0	14.0
64QAM 0.92 single	16.0	8.0	24.0	8.0	5.0	13.0
64QAM 0.75 single	13.0	6.0	19.0	6.0	5.0	11.0
16QAM 0.87 single	10.0	5.0	15.0	5.0	5.0	10.0
16QAM 0.63 single	7.0	5.0	12.0	5.0	5.0	10.0
QPSK 0.87 single	5.0	5.0	10.0	5.0	4.4	9.4
QPSK 0.63 single	5.0	5.0	10.0	5.0	3.2	8.2
BPSK 0.63 single	5.0	3.2	8.2	3.2	1.6	4.8

Tx/Rx/Aggregate columns contain the transmit, receive and aggregate data rates per bandwidth.

Table 58 Throughput at zero link range (Mbit/s), Lite, symmetry 2:1, optimization TDM

Modulation mode	45 MHz (Tx/Rx/Aggregate)			40 MHz (Tx/Rx/Aggregate)		
256QAM 0.81 dual	79.0	39.0	118.0	72.0	36.0	108.0
64QAM 0.92 dual	66.0	33.0	99.0	61.0	30.0	91.0
64QAM 0.75 dual	54.0	27.0	81.0	50.0	25.0	75.0
16QAM 0.87 dual	42.0	21.0	63.0	39.0	19.0	58.0
16QAM 0.63 dual	30.0	15.0	45.0	28.0	14.0	42.0
256QAM 0.81 single	39.0	20.0	59.0	36.0	18.0	54.0
64QAM 0.92 single	33.0	17.0	50.0	30.0	15.0	45.0
64QAM 0.75 single	27.0	14.0	41.0	25.0	12.0	37.0
16QAM 0.87 single	21.0	11.0	32.0	19.0	10.0	29.0
16QAM 0.63 single	15.0	8.0	23.0	14.0	7.0	21.0
QPSK 0.87 single	11.0	5.0	16.0	10.0	5.0	15.0
QPSK 0.63 single	8.0	5.0	13.0	7.0	5.0	12.0
BPSK 0.63 single	5.0	5.0	10.0	5.0	5.0	10.0
Modulation mode	**20 MHz (Tx/Rx/Aggregate)**			**10 MHz (Tx/Rx/Aggregate)**		
256QAM 0.81 dual	37.0	18.0	55.0	19.0	9.0	28.0
64QAM 0.92 dual	31.0	15.0	46.0	16.0	8.0	24.0
64QAM 0.75 dual	25.0	13.0	38.0	13.0	6.0	19.0
16QAM 0.87 dual	20.0	10.0	30.0	10.0	5.0	15.0
16QAM 0.63 dual	14.0	7.0	21.0	7.0	5.0	12.0
256QAM 0.81 single	18.0	9.0	27.0	9.0	5.0	14.0
64QAM 0.92 single	15.0	8.0	23.0	8.0	5.0	13.0
64QAM 0.75 single	13.0	6.0	19.0	6.0	5.0	11.0
16QAM 0.87 single	10.0	5.0	15.0	5.0	5.0	10.0
16QAM 0.63 single	7.0	5.0	12.0	5.0	5.0	10.0
QPSK 0.87 single	5.0	5.0	10.0	5.0	4.4	9.4
QPSK 0.63 single	5.0	5.0	10.0	5.0	3.2	8.2
BPSK 0.63 single	5.0	3.1	8.1	3.2	1.6	4.8

Tx/Rx/Aggregate columns contain the transmit, receive and aggregate data rates per bandwidth.

Table 59 Throughput at zero link range (Mbit/s), Lite, symmetry adaptive, optimization IP

Modulation mode	45 MHz (Tx/Rx/Aggregate)			40 MHz (Tx/Rx/Aggregate)		
256QAM 0.81 dual	114.0	11.0	125.0	103.0	11.0	114.0
64QAM 0.92 dual	96.0	10.0	106.0	87.0	10.0	97.0
64QAM 0.75 dual	79.0	8.0	87.0	71.0	8.0	79.0
16QAM 0.87 dual	61.0	6.0	67.0	55.0	6.0	61.0
16QAM 0.63 dual	44.0	5.0	49.0	40.0	5.0	45.0
256QAM 0.81 single	57.0	6.0	63.0	52.0	6.0	58.0
64QAM 0.92 single	48.0	5.0	53.0	43.0	5.0	48.0
64QAM 0.75 single	39.0	5.0	44.0	35.0	5.0	40.0
16QAM 0.87 single	31.0	5.0	36.0	28.0	5.0	33.0
16QAM 0.63 single	22.0	5.0	27.0	20.0	5.0	25.0
QPSK 0.87 single	15.0	5.0	20.0	14.0	5.0	19.0
QPSK 0.63 single	11.0	3.9	14.9	10.0	3.9	13.9
BPSK 0.63 single	5.0	2.0	7.0	5.0	2.0	7.0
Modulation mode	**20 MHz (Tx/Rx/Aggregate)**			**10 MHz (Tx/Rx/Aggregate)**		
256QAM 0.81 dual	45.0	11.0	56.0	19.0	9.0	28.0
64QAM 0.92 dual	38.0	9.0	47.0	16.0	8.0	24.0
64QAM 0.75 dual	31.0	8.0	39.0	13.0	6.0	19.0
16QAM 0.87 dual	24.0	6.0	30.0	10.0	5.0	15.0
16QAM 0.63 dual	17.0	5.0	22.0	7.0	5.0	12.0
256QAM 0.81 single	22.0	6.0	28.0	9.0	5.0	14.0
64QAM 0.92 single	19.0	5.0	24.0	8.0	5.0	13.0
64QAM 0.75 single	15.0	5.0	20.0	6.0	5.0	11.0
16QAM 0.87 single	12.0	5.0	17.0	5.0	5.0	10.0
16QAM 0.63 single	9.0	5.0	14.0	5.0	5.0	10.0
QPSK 0.87 single	6.0	5.0	11.0	5.0	4.4	9.4
QPSK 0.63 single	5.0	3.8	8.8	5.0	3.2	8.2
BPSK 0.63 single	5.0	1.9	6.9	3.2	1.6	4.8

Tx/Rx/Aggregate columns contain the transmit, receive and aggregate data rates per bandwidth.

Figure 33 Range adjustment for PTP 650, symmetry 1:1, optimization IP, bandwidth 45 MHz

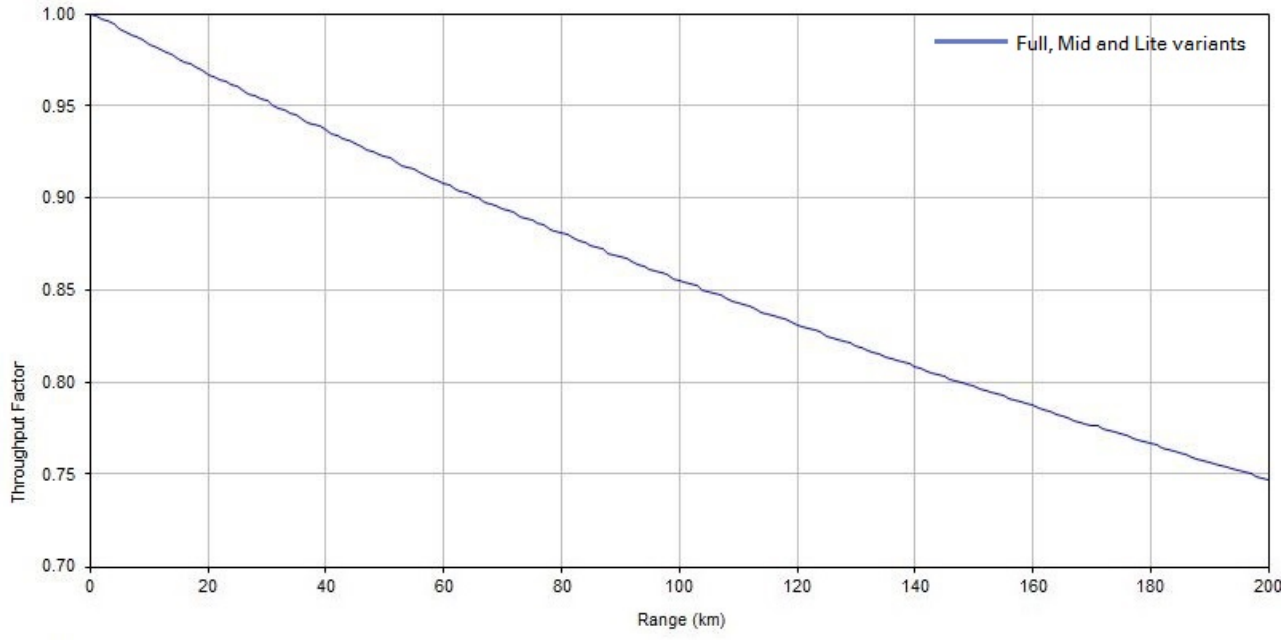


Figure 34 Range adjustment for PTP 650, symmetry 1:1, optimization IP, bandwidth 40 MHz

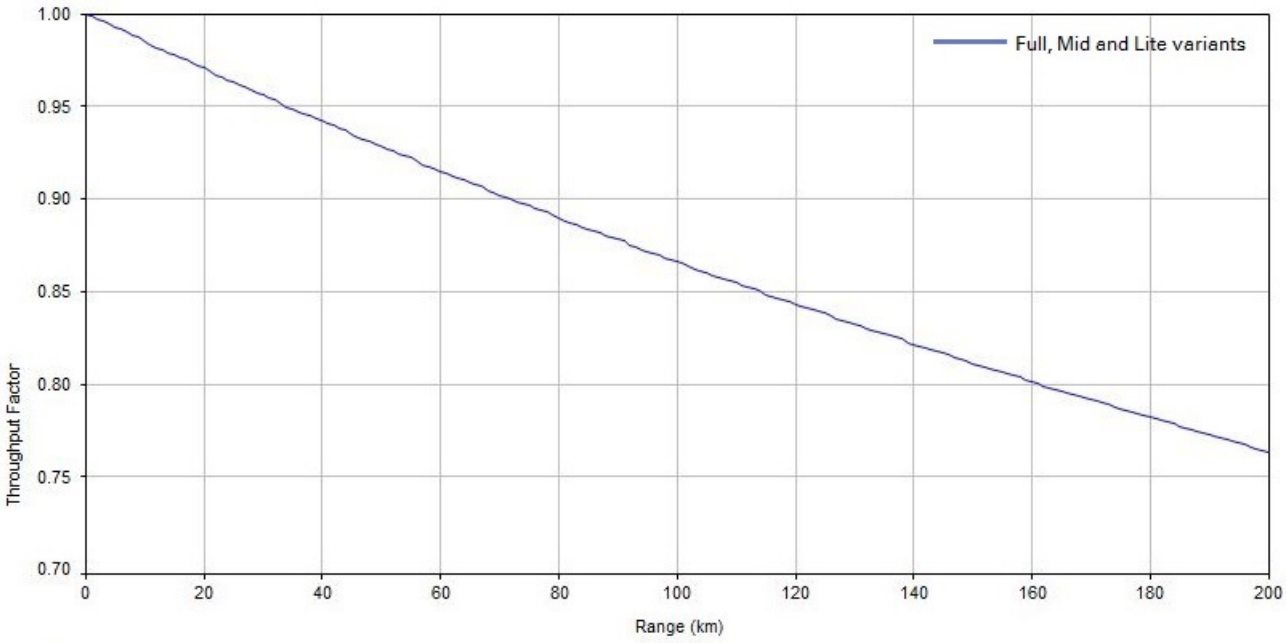


Figure 35 Range adjustment for PTP 650, symmetry 1:1, optimization IP, bandwidth 20 MHz

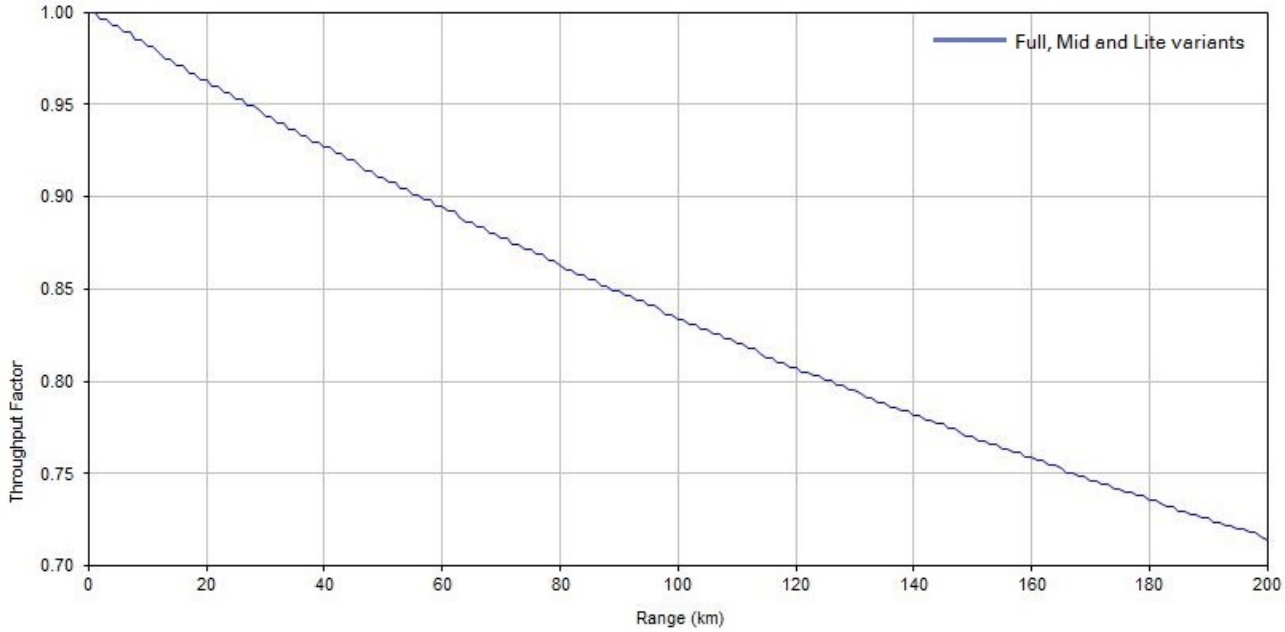


Figure 36 Range adjustment for PTP 650, symmetry 1:1, optimization IP, bandwidth 10 MHz

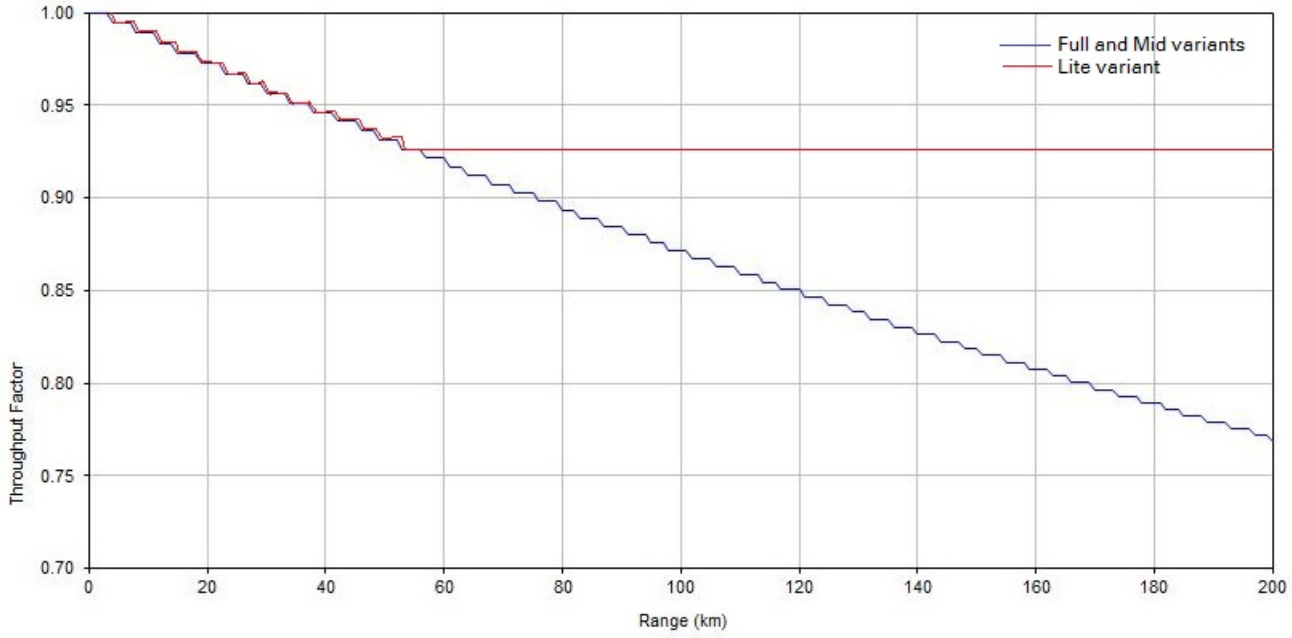


Figure 37 Range adjustment for PTP 650, symmetry 1:1, optimization TDM, bandwidth 45 MHz

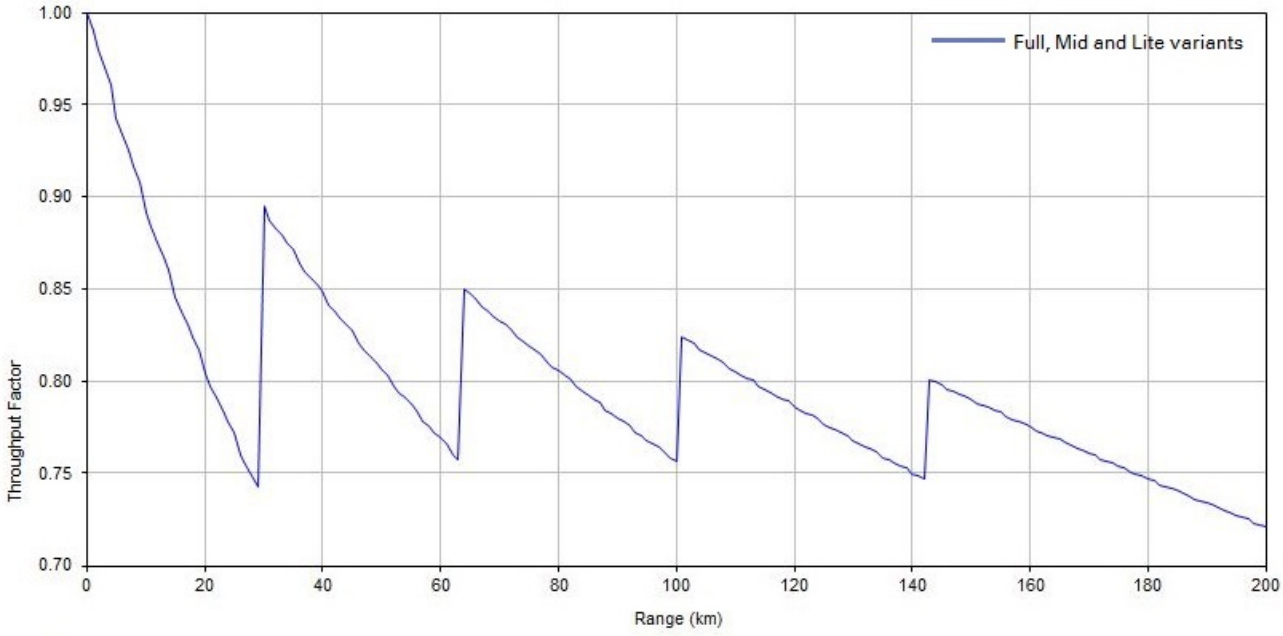


Figure 38 Range adjustment for PTP 650, symmetry 1:1, optimization TDM, bandwidth 40 MHz

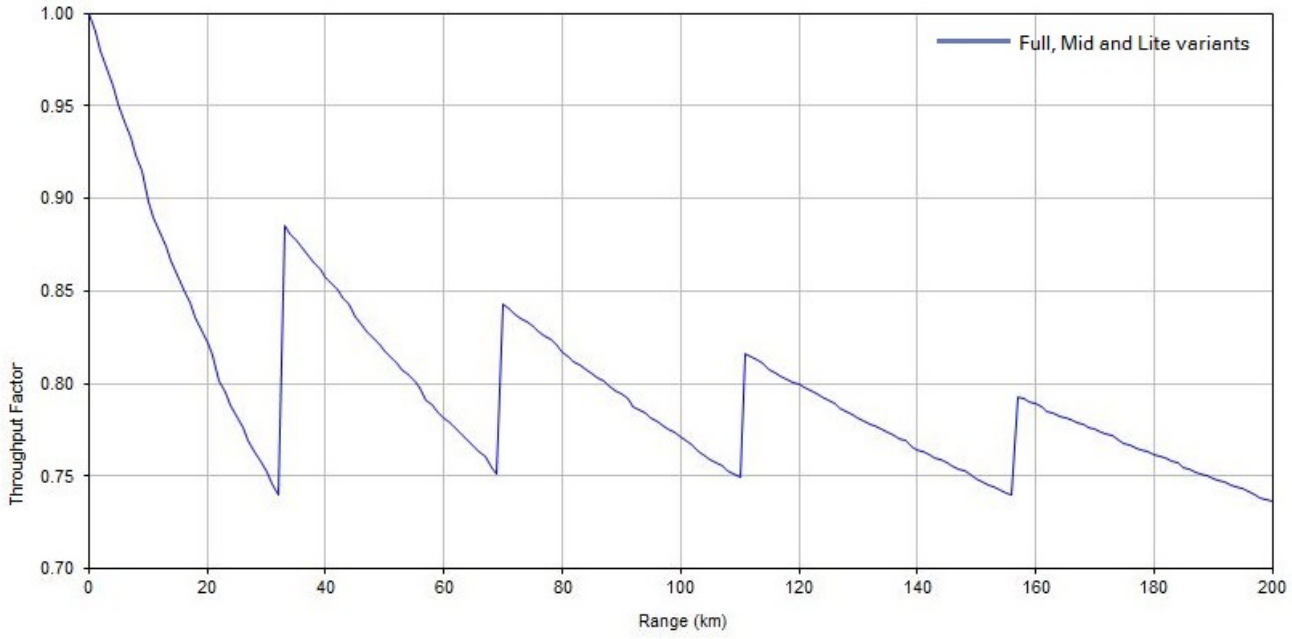


Figure 39 Range adjustment for PTP 650, symmetry 1:1, optimization TDM, bandwidth 20 MHz

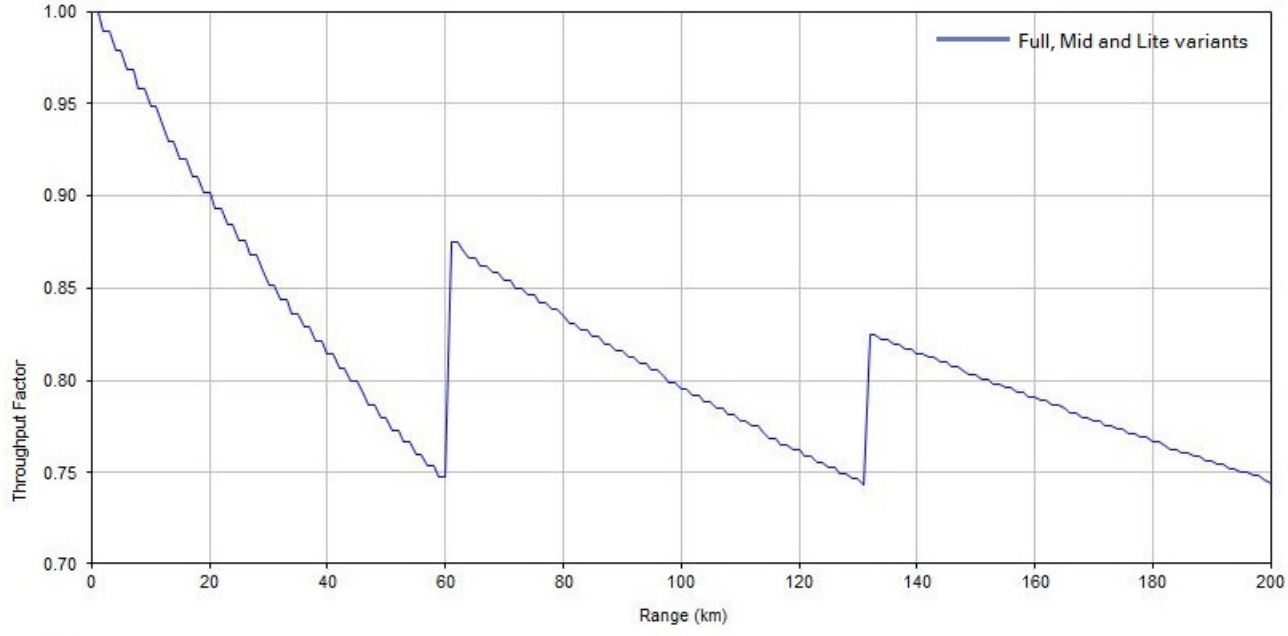


Figure 40 Range adjustment for PTP 650, symmetry 1:1, optimization TDM, bandwidth 10 MHz

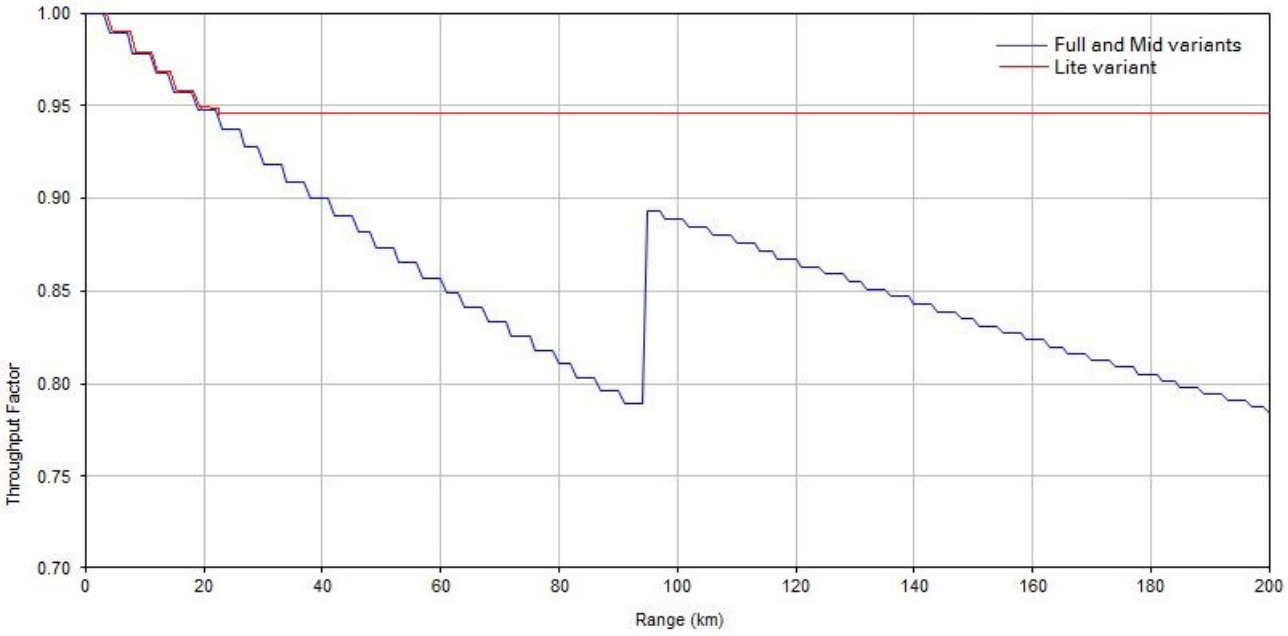


Figure 41 Range adjustment for PTP 650, symmetry 2:1, optimization IP, bandwidth 45 MHz

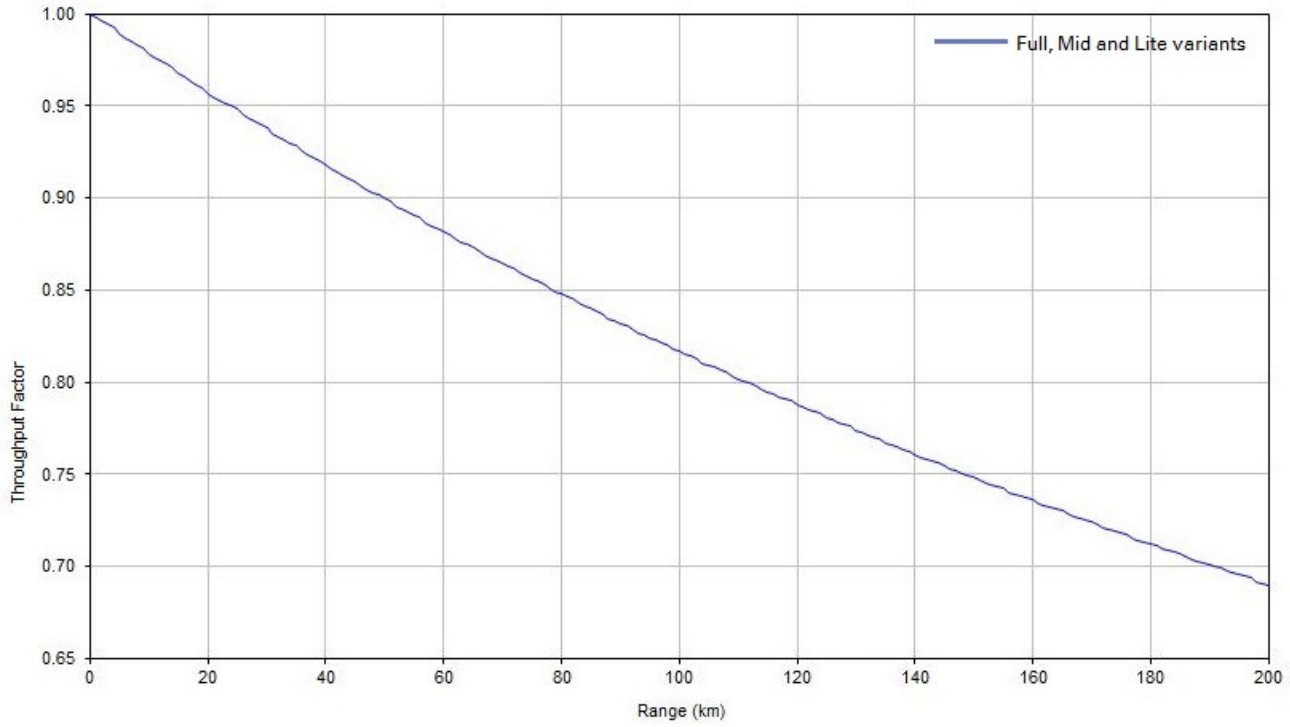


Figure 42 Range adjustment for PTP 650, symmetry 2:1, optimization IP, bandwidth 40 MHz

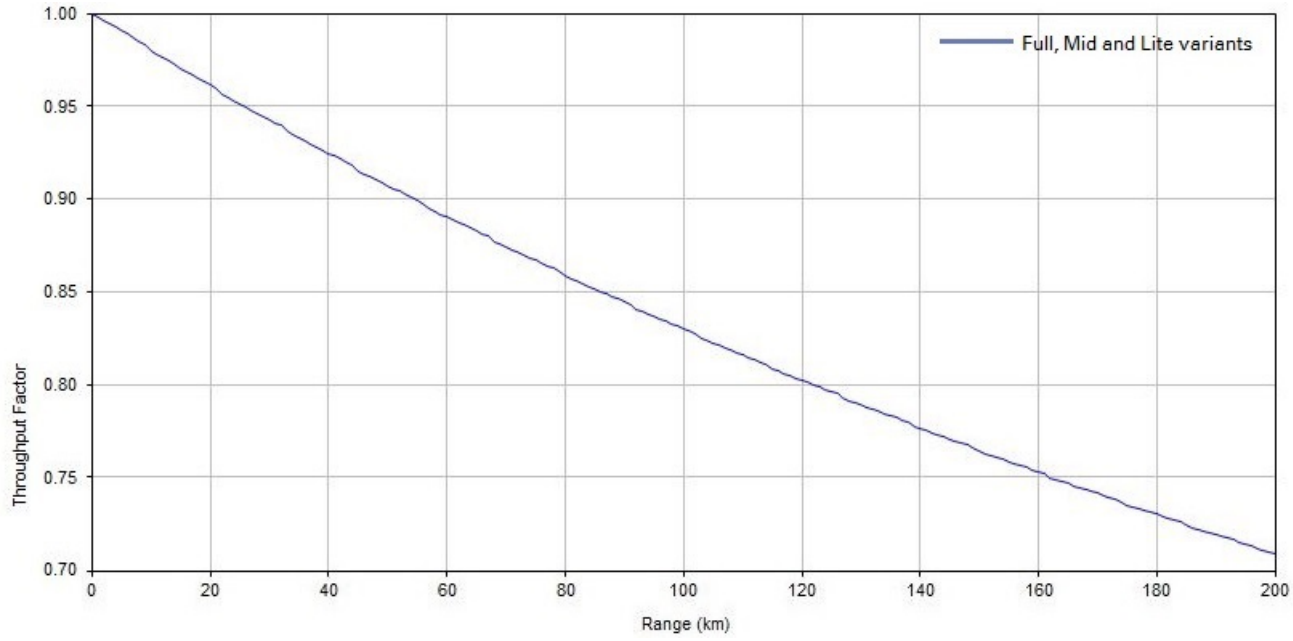


Figure 43 Range adjustment for PTP 650, symmetry 2:1, optimization IP, bandwidth 20 MHz

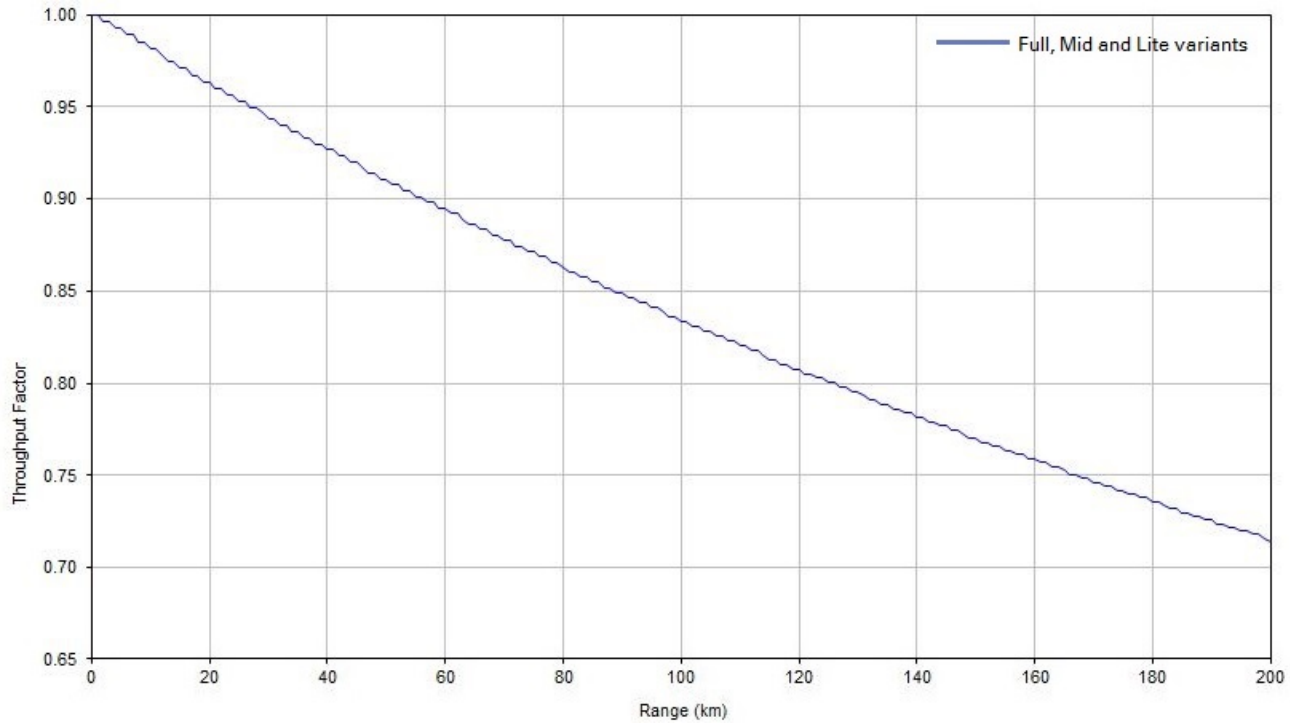


Figure 44 Range adjustment for PTP 650, symmetry 2:1, optimization IP, bandwidth 10 MHz

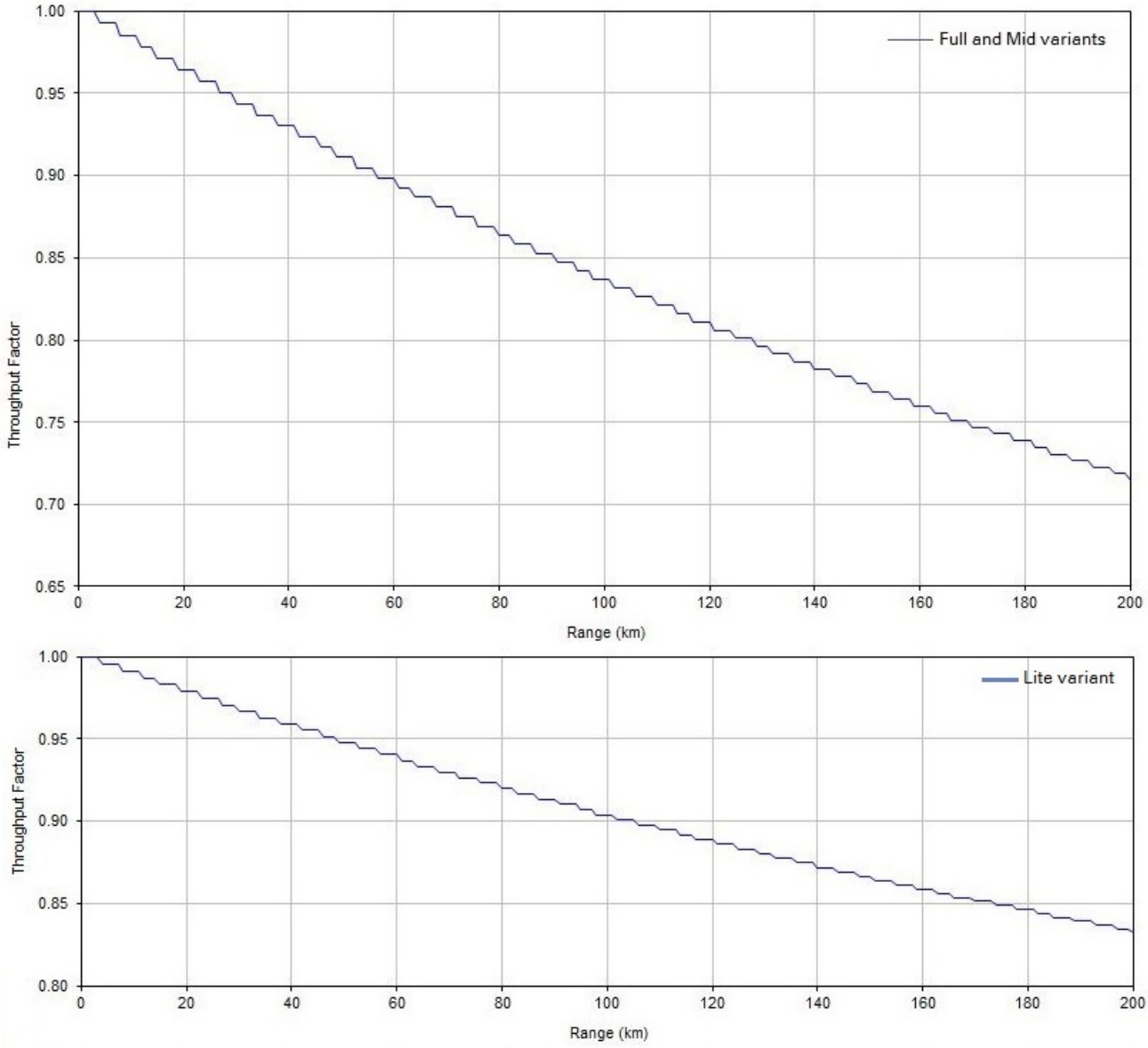


Figure 45 Range adjustment for PTP 650, symmetry 2:1, optimization TDM, bandwidth 45 MHz

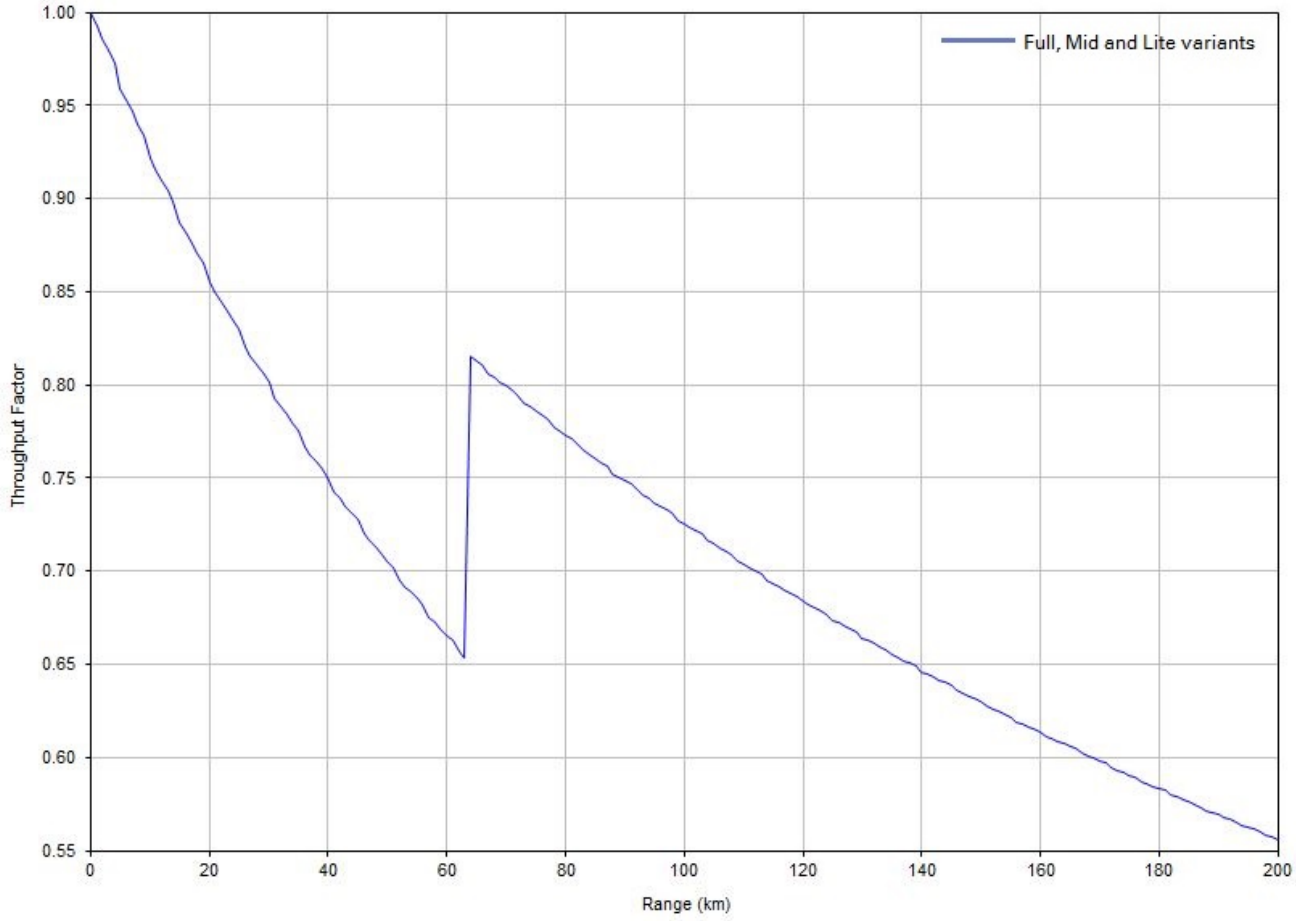


Figure 46 Range adjustment for PTP 650, symmetry 2:1, optimization TDM, bandwidth 40 MHz

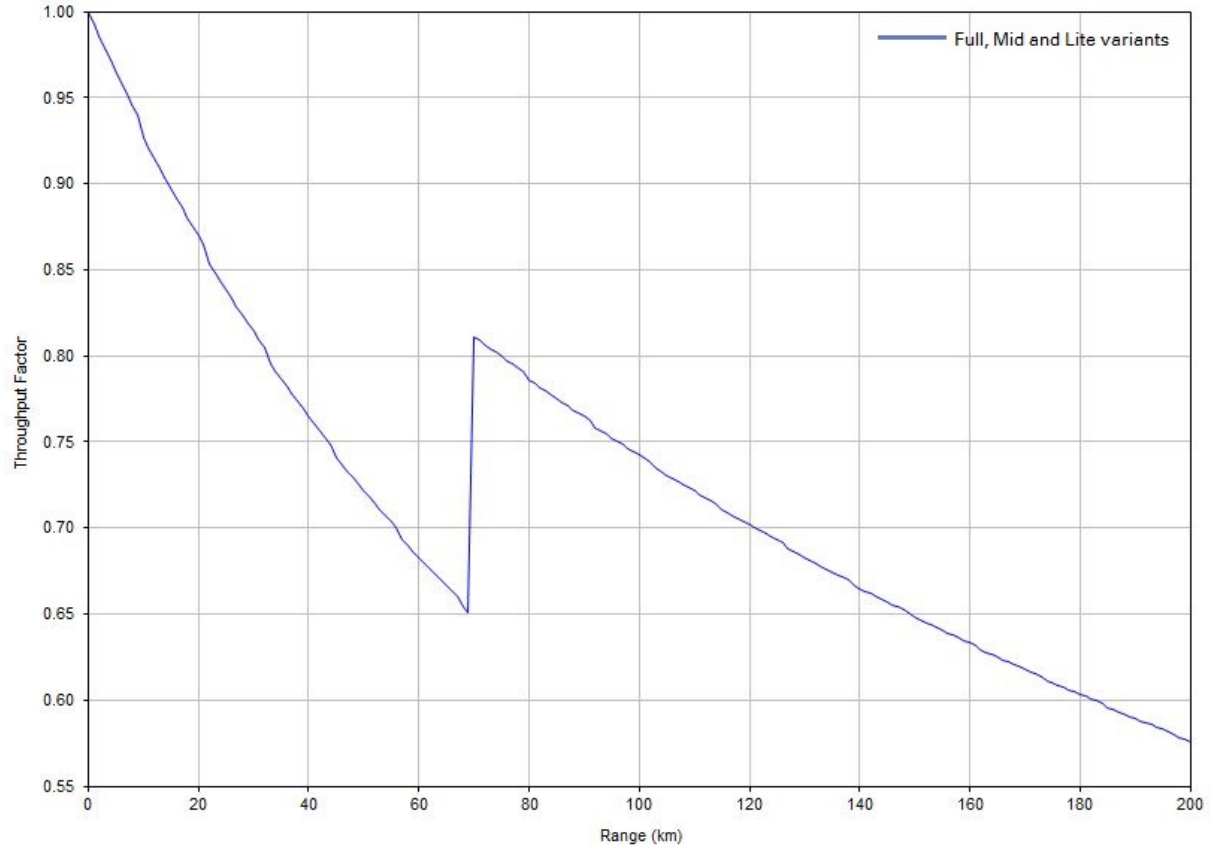


Figure 47 Range adjustment for PTP 650, symmetry 2:1, optimization TDM, bandwidth 20 MHz

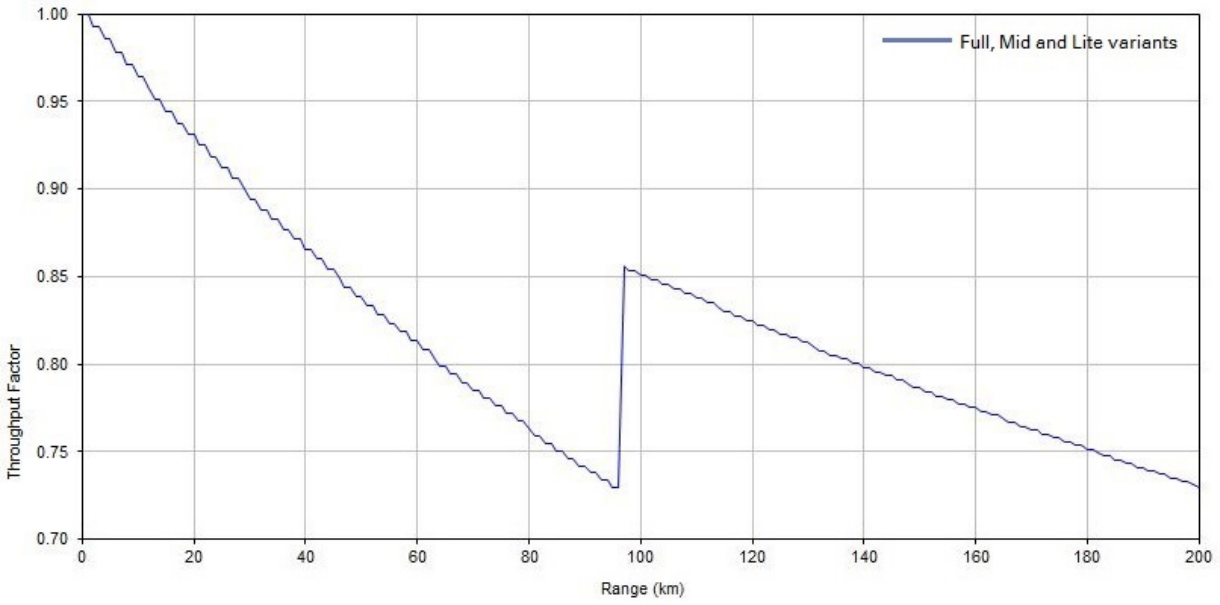


Figure 48 Range adjustment for PTP 650, symmetry 2:1, optimization TDM, bandwidth 10 MHz

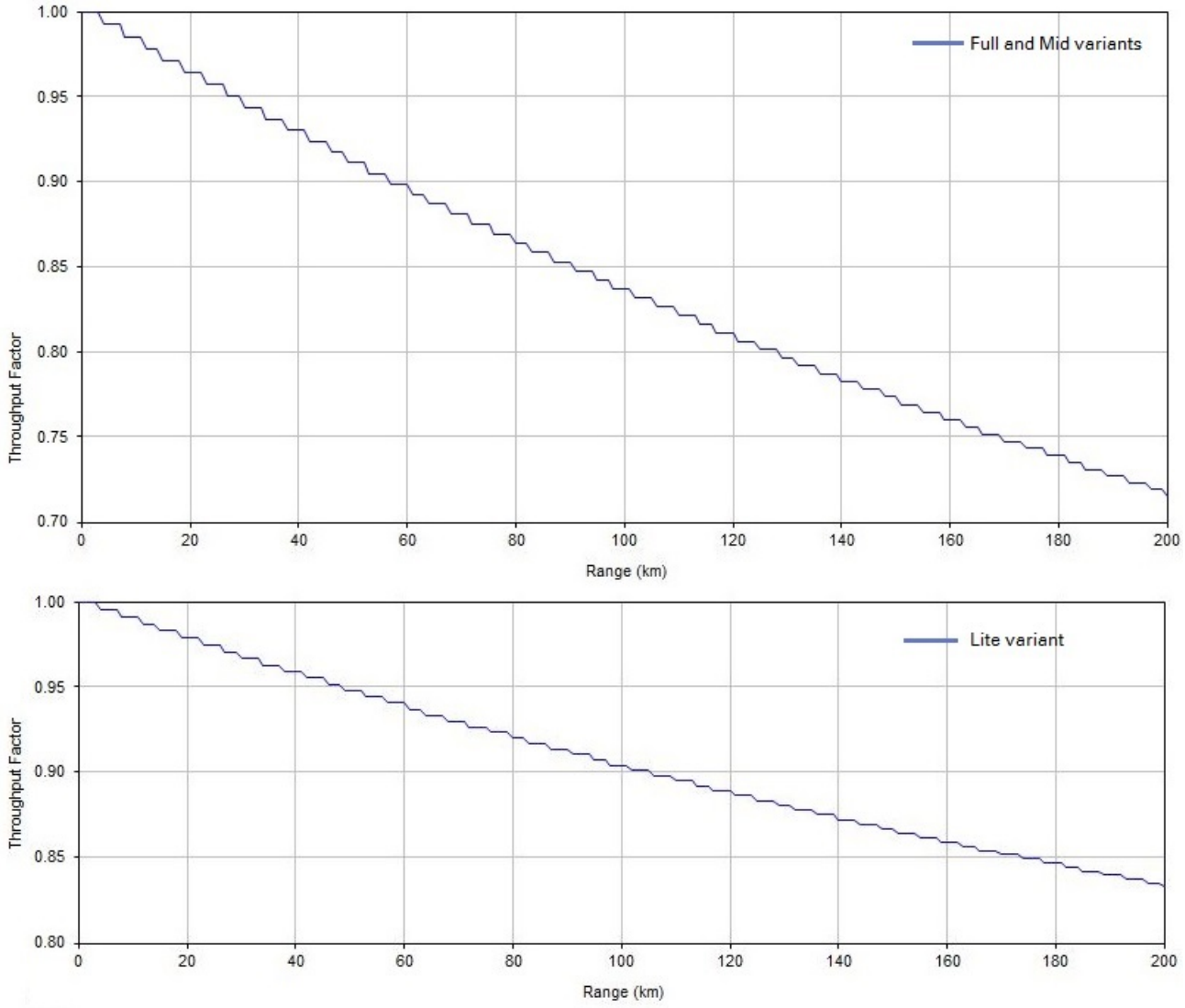


Figure 49 Range adjustment for PTP 650, adaptive, optimization IP, bandwidth 45 MHz

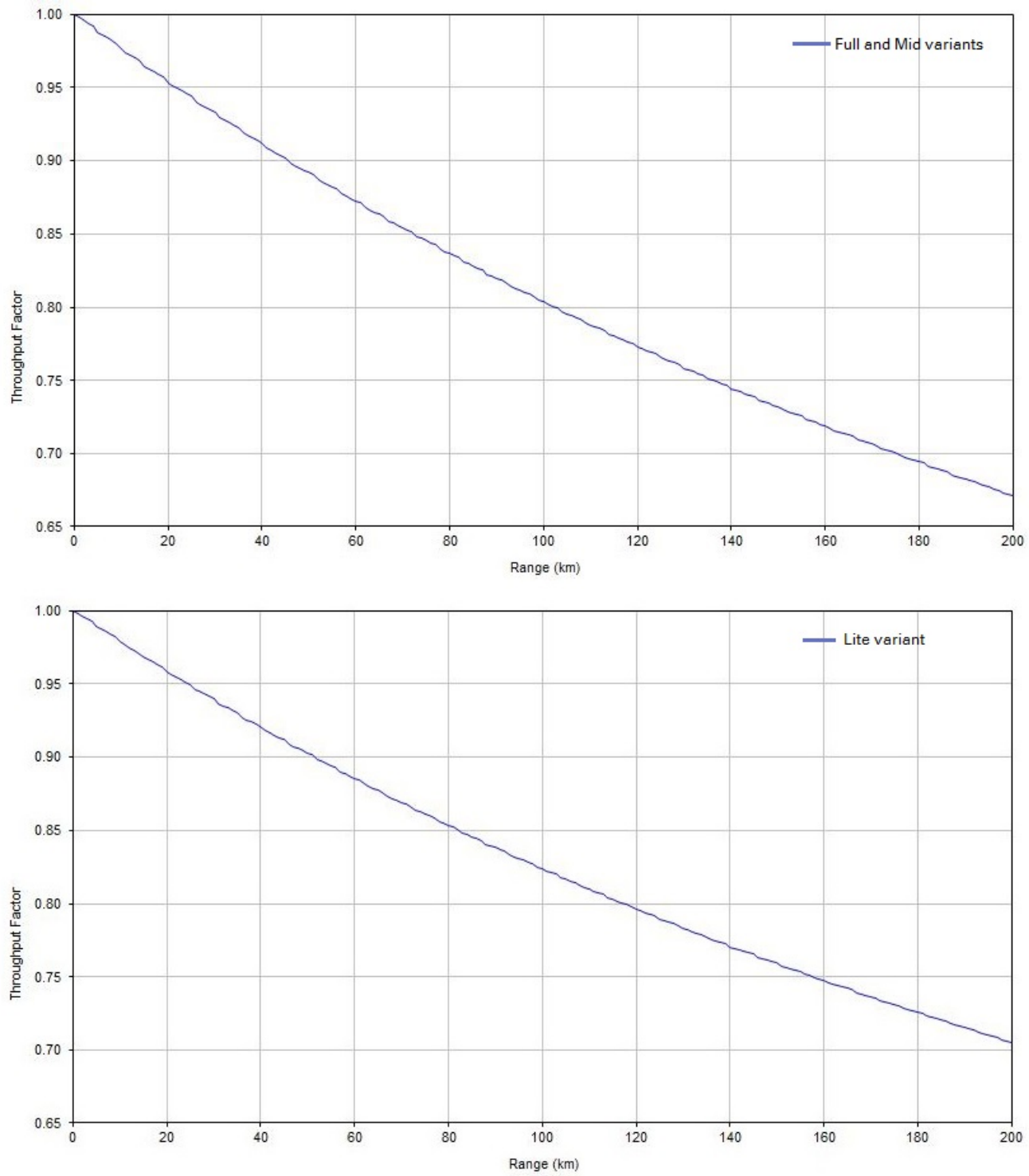


Figure 50 Range adjustment for PTP 650, adaptive, optimization IP, bandwidth 40 MHz

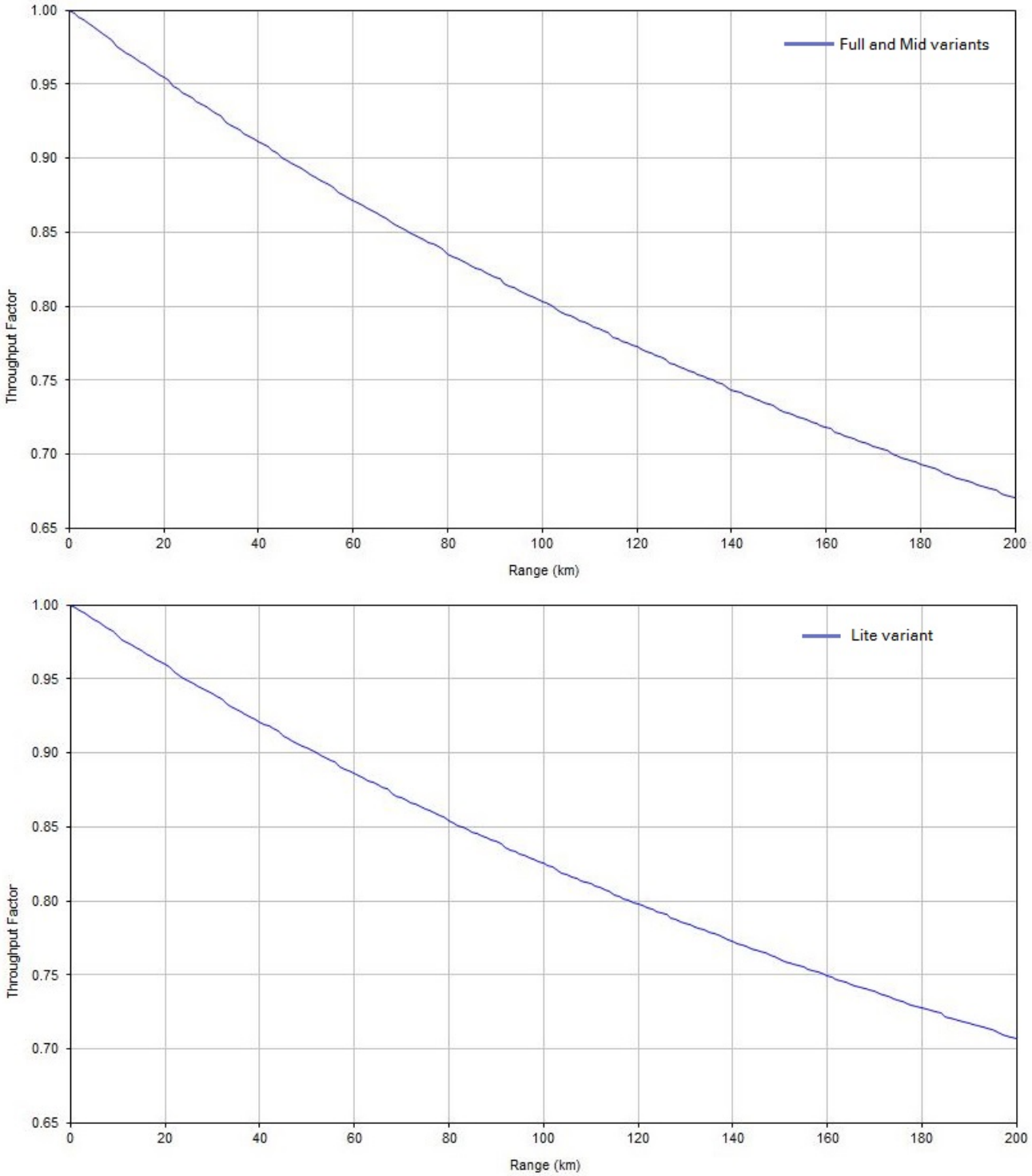


Figure 51 Range adjustment for PTP 650, adaptive, optimization IP, bandwidth 20 MHz

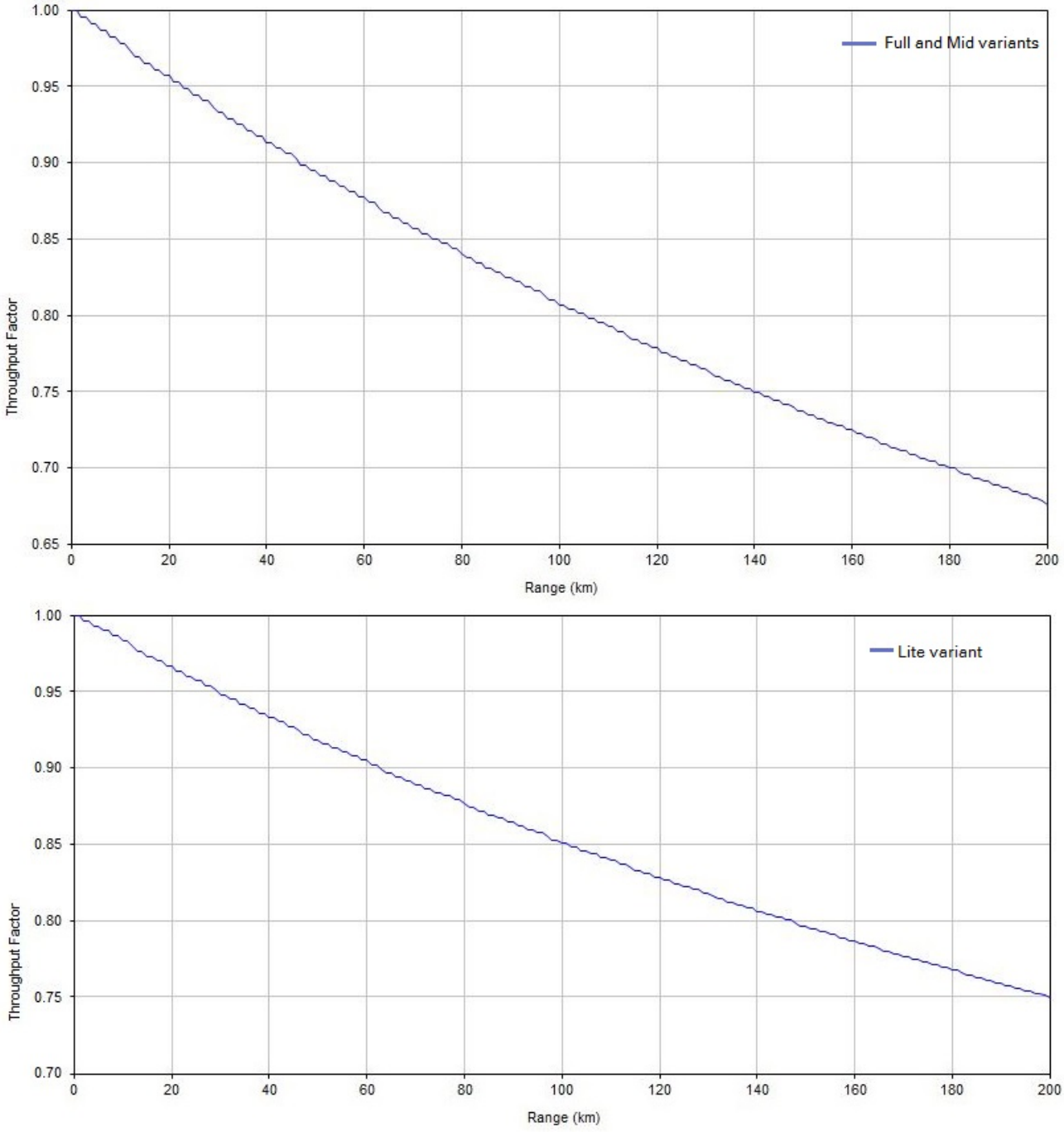
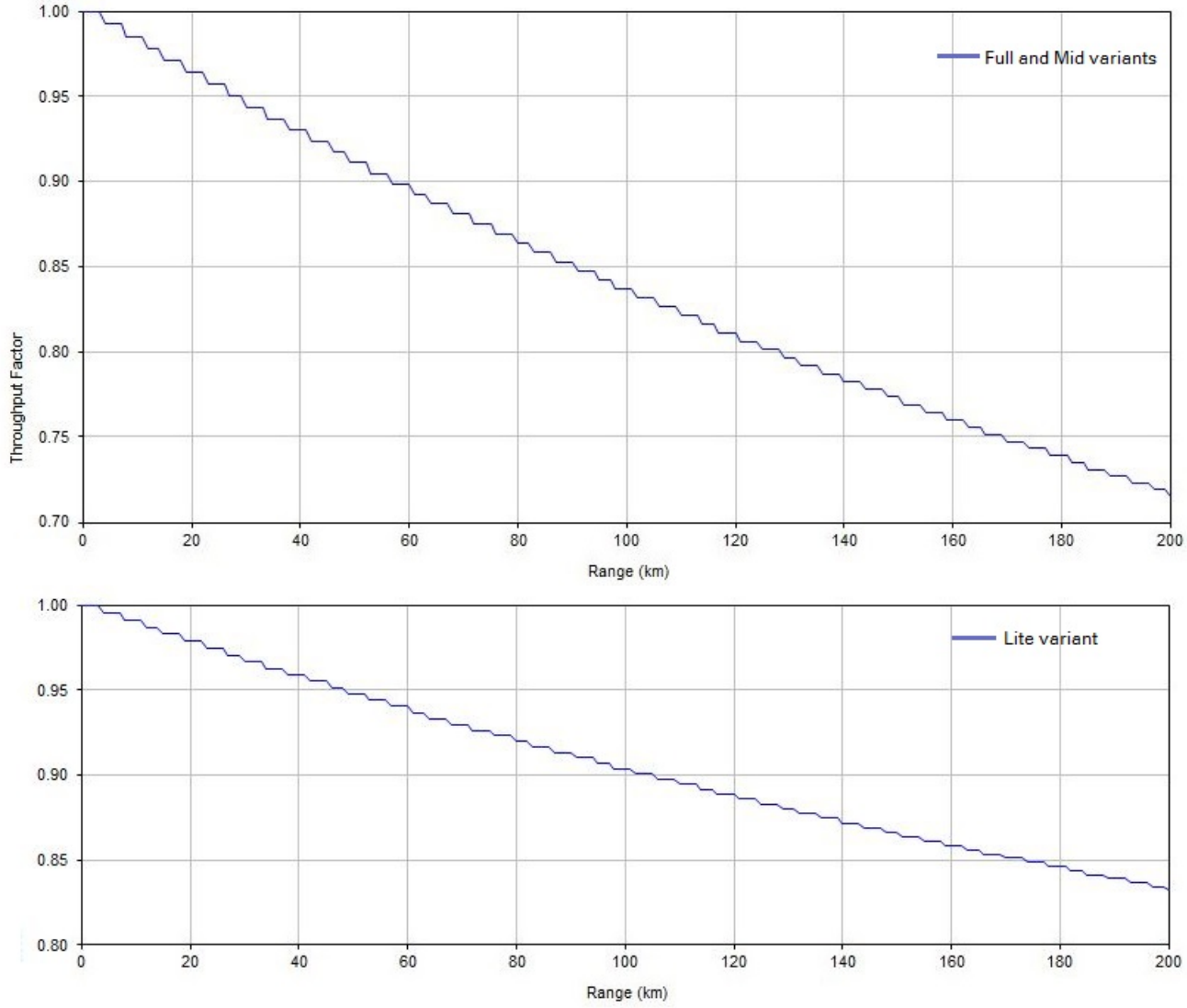


Figure 52 Range adjustment for PTP 650, adaptive, optimization IP, bandwidth 10 MHz



Chapter 4: Legal and regulatory information

This chapter provides end user license agreements and regulatory notifications.

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- Cambium Networks end user license agreement on page 4-2 contains the Cambium and third party license agreements for the PTP 650 Series products.
- Compliance with safety standards on page 4-23 lists the safety specifications against which the PTP 650 has been tested and certified. It also describes how to keep RF exposure within safe limits.
- Compliance with radio regulations on page 4-27 describes how the PTP 650 complies with the radio regulations that are in force in various countries, and contains notifications made to regulatory bodies for the PTP 650.

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D3 JS library

Compliance with safety standards

This section lists the safety specifications against which the PTP 650 has been tested and certified. It also describes how to keep RF exposure within safe limits.

Electrical safety compliance

The PTP 650 hardware has been tested for compliance to the electrical safety specifications listed in Table 60.

Table 60 PTP 650 safety compliance specifications

Region	Standard
USA	UL 60950-1, 2nd Edition; UL60950-22
Canada	CAN/CSA C22.2 No.60950-1-07, 2nd Edition; CAN/CSA C22.2 No.60950-22-07
EU	EN 60950-1:2006 + Amendment 12:2011, EN 60950-22
International	CB certified to IEC 60950-1: 2005 (modified); IEC 60950-22: 2005 (modified)

Electromagnetic compatibility (EMC) compliance

The PTP 650 complies with European EMC Specification EN301 489-1 with testing carried out to the detailed requirements of EN301 489-4.

Note

For EN 61000-4-2: 1995 to 2009 Electro Static Discharge (ESD), Class 2, 8 kV air, 4 kV contact discharge, the PTP 650 has been tested to ensure immunity to 15 kV air and 8 kV contact.

Table 61 lists the EMC specification type approvals that have been granted for PTP 650 products.

Table 61 EMC emissions compliance

Region	Specification (Type Approvals)
Europe	ETSI EN301 489-4

Human exposure to radio frequency energy

Relevant standards (USA and EC) applicable when working with RF equipment are:

- ANSI IEEE C95.1-1991, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.
- Council recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) (1999/519/EC) and respective national regulations.
- *Directive 2004/40/EC of the European Parliament and of the Council of 29 April 2004* on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (18th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC).
- US FCC limits for the general population. See the FCC web site at http://www.fcc.gov, and the policies, guidelines, and requirements in Part 1 of Title 47 of the Code of Federal Regulations, as well as the guidelines and suggestions for evaluating compliance in FCC OET Bulletin 65.
- Health Canada limits for the general population. See the Health Canada web site at http://www.hc-sc.gc.ca/ewh-semt/pubs/radiation/99ehd-dhm237/limits-limites_e.html and Safety Code 6.
- EN 50383:2002 to 2010 Basic standard for the calculation and measurement of electromagnetic field strength and SAR related to human exposure from radio base stations and fixed terminal stations for wireless telecommunication systems (110 MHz - 40 GHz).
- BS EN 50385:2002 Product standard to demonstrate the compliances of radio base stations and fixed terminal stations for wireless telecommunication systems with the basic restrictions or the reference levels related to human exposure to radio frequency electromagnetic fields (110 MHz – 40 GHz) – general public.
- ICNIRP (International Commission on Non-Ionizing Radiation Protection) guidelines for the general public. See the ICNIRP web site at http://www.icnirp.de/ and Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields.

Power density exposure limit

Install the radios for the PTP 650 family of PTP wireless solutions so as to provide and maintain the minimum separation distances from all persons.

The applicable power density exposure limit for RF energy in the 4.9, 5.4 and 5.8 GHz frequency bands is **10 W/m²**. For more information, see Human exposure to radio frequency energy on page 4-24.

Calculation of power density

The following calculation is based on the ANSI IEEE C95.1-1991 method, as that provides a worst case analysis. Details of the assessment to EN50383:2002 can be provided, if required.

Peak power density in the far field of a radio frequency point source is calculated as follows:

$$S = \frac{P.G}{4\pi d^2}$$

Where:	Is:
S	power density in W/m^2
P	maximum average transmit power capability of the radio, in W
G	total Tx gain as a factor, converted from dB
d	distance from point source, in m

Rearranging terms to solve for distance yields:

$$d = \sqrt{\frac{P.G}{4\pi.S}}$$

Calculated distances and power compliance margins

Table 62 shows calculated minimum separation distances, recommended distances and resulting margins for each frequency band and antenna combination. These are conservative distances that include compliance margins. At these and greater separation distances, the power density from the RF field is below generally accepted limits for the general population.

Explanation of terms used in Table 62:

Tx burst – maximum average transmit power in burst (Watt)

P – maximum average transmit power capability of the radio including cable loss (Watt)

G – total transmit gain as a factor, converted from dB

S – power density (W/m^2)

d – minimum distance from point source (meters)

R – recommended distances (meters)

C – compliance factor

Table 62 Power compliance margins

Band	Antenna	Tx burst (W)	P (W)	G	S (W/m^2)	d (m)
4.9 GHz	Integrated (23.0 dBi)	0.25	0.2	200	10	0.56
	Parabolic 6 ft (36.0 dBi)	0.2	0.16	2818	10	1.89
	Sectorized (17.0 dBi)	0.25	0.2	35.5	10	0.24
	Omni (13.0 dBi)	0.25	0.2	14	10	0.15
5.4 GHz	Integrated (23.0 dBi)	0.005	0.004	200	10	0.08
	Parabolic 4 ft (34.9 dBi)	0.0005	0.0004	2188	10	0.08
	Sectorized (17.0 dBi)	0.008	0.006	35.5	10	0.04
	Omni (13.0 dBi)	0.025	0.02	14	10	0.05
5.8 GHz	Integrated (23.0 dBi)	0.646	0.513	200	10	0.9
	Parabolic 6 ft (38.1 dBi)	0.646	0.513	4571	10	4.32
	Sectorized (17.0 dBi)	0.1	0.08	35.5	10	0.15
	Omni (13.0 dBi)	0.25	0.2	14	10	0.15

Note

Gain of antenna in dBi = 10*log(G).

The regulations require that the power used for the calculations is the maximum power in the transmit burst subject to allowance for source-based time-averaging.

At 5.4 GHz and EU 5.8 GHz, the products are generally limited to a fixed EIRP which can be achieved with the Integrated Antenna. The calculations above assume that the maximum EIRP allowed by the regulations is being transmitted.

Note

If there are no EIRP limits in the country of deployment, use the distance calculations for FCC 5.8 GHz for all frequency bands.

At FCC 5.8 GHz, for antennas between 0.6m (2ft) and 1.8m (6ft), alter the distance proportionally to the antenna gain.

Compliance with radio regulations

This section describes how the PTP 650 complies with the radio regulations that are in force in various countries.

Caution

Where necessary, the end user is responsible for obtaining any National licenses required to operate this product and these must be obtained before using the product in any particular country. Contact the appropriate national administrations for details of the conditions of use for the bands in question and any exceptions that might apply.

Caution

Changes or modifications not expressly approved by Cambium Networks could void the user's authority to operate the system.

Caution

For the connectorized version of the product and in order to reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the Effective Isotropically Radiated Power (EIRP) is not more than that permitted for successful communication.

Type approvals

The system has been tested against various local technical regulations and found to comply. The frequency band in which the system operates is "license exempt" and the system is allowed to be used provided it does not cause interference. The licensing authority does not guarantee protection against interference from other products and installations. Table 63, Table 64 and Table 65 list the radio specification type approvals that have been granted for PTP 650 products.

Table 63 Radio certifications (4.9 GHz)

Region	Regulatory approvals
USA	FCC 47 CFR Part 90
Canada	IC RSS-211, Issue 4
Europe	Europe EN302 625; V1.1.1 Broadband Disaster Relief (BBDR)

Table 64 Radio certifications (5.4 GHz)

Region	Regulatory approvals
USA	FCC 47 CFR Part 15 E
Canada	IC RSS-210 Issue 8, Annex 9 (or latest)
Europe	ETSI EN301 893 v1.6.1

Table 65 Radio certifications (5.8 GHz)

Region	Regulatory approvals
USA	FCC 47 CFR Part 15 C
Canada	IC RSS-210 Issue 8, Annex 8 (or latest)
Denmark	Radio Interface 00 007
Eire	ComReg 02/71R4
Germany	Order No 47/2007
Iceland	ETSI EN302 502 v1.2.1
Finland	ETSI EN302 502 v1.2.1
Greece	ETSI EN302 502 v1.2.1
Liechtenstein	ETSI EN302 502 v1.2.1
Norway	REG 2009-06-02 no. 580
Portugal	ETSI EN302 502 v1.2.1
Serbia	ETSI EN302 502 v1.2.1
Spain	CNAF 2010
Switzerland	ETSI EN302 502 v1.2.1
UK	UK IR 2007

FCC/IC compliance

The PTP 650 complies with the regulations that are in force in the USA and Canada.

Caution

If this equipment does cause interference to radio or television reception, refer to Radio and television interference on page 8-10 for corrective actions.

FCC/IC product labels

FCC IDs and Industry Canada Certification Numbers are reproduced on the product labels (Figure 53 and Figure 54).

Figure 53 FCC and IC certifications on integrated ODU product label

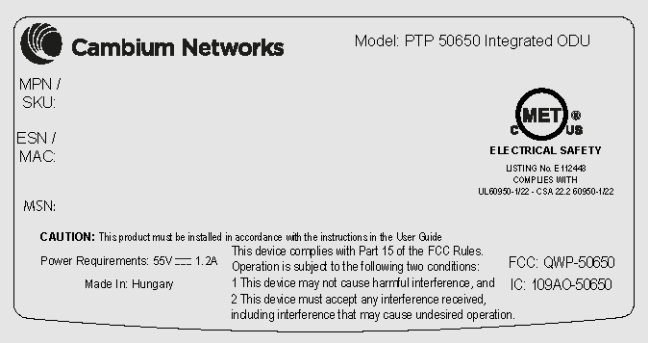
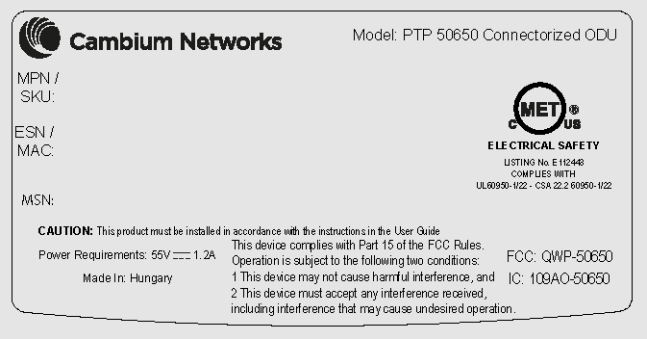


Figure 54 FCC and IC certifications on connectorized ODU product label



4.9 GHz FCC and IC notification

The system has been approved under FCC Part 90 and Industry Canada RSS-111 for Public Safety Agency usage. The installer or operator is responsible for obtaining the appropriate site licenses before installing or using the system.

5.4 GHz FCC and IC notification

This device complies with part 15E of the US FCC Rules and Regulations and with Industry Canada RSS-210 Annex 9. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) This device must accept any interference received, including interference that may cause undesired operation. In Canada, users should be cautioned to take note that high power radars are allocated as primary users (meaning they have priority) of 5250 – 5350 MHz and 5470 – 5725 MHz and these radars could cause interference and/or damage to license-exempt local area networks (LELAN).

For the connectorized version of the product and in order to reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (EIRP) is not more than that permitted by the regulations. The transmitted power must be reduced to achieve this requirement.

5.8 GHz FCC notification

This device complies with part 15C of the US FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) This device must accept any interference received, including interference that may cause undesired operation.

5.8 GHz IC notification

RSS-GEN issue 3 (7.1.3) Licence-Exempt Radio Apparatus:

> This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.
>
> *Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes : (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.*

In Canada, high power radars are allocated as primary users (meaning they have priority) of the 5650 – 5850 MHz spectrum. These radars could cause interference or damage to license-exempt local area network (LE-LAN) devices.

5.4 GHz band edge channel power reduction

Equivalent isotropic radiated power (EIRP) is restricted in edge channels when the PTP 650 is operated the 5.4 GHz band with the USA or Canada country license. The amount of EIRP reduction has been determined during regulatory testing and cannot be changed by professional installers or end users. Units intended for the USA and Canada market are locked for use in the USA or Canada and cannot be operated under the regulations for other regulatory domains.

The PTP 650 takes into account the antenna gain and cable loss configured by the professional installer in the web-based interface to limit the EIRP to ensure regulatory compliance. No additional action is required by the installer to reduce transmitter power in band edge channels.

The maximum EIRP in band edge channels for the USA and Canada 5.4 GHz band is listed in Table 66.

Table 66 Edge channel power reduction in regulatory bands 12 and 13

Channel Bandwidth	Channel Frequency	Maximum EIRP
5 MHz	Below 5476.0 MHz	24 dBm
	Above 5720.0 MHz	24 dBm
10 MHz	Below 5478.0 MHz	27 dBm
	Above 5715.0 MHz	25 dBm
15 MHz	Below 5480.0 MHz	29 dBm
	Above 5709.0 MHz	26 dBm
20 MHz	Below 5482.0 MHz	30 dBm
	Above 5704.0 MHz	23 dBm
30 MHz	Below 5492.0 MHz	27 dBm
	Above 5694.0 MHz	25 dBm
40 MHz	Below 5500.0 MHz	28 dBm
	Above 5691.0 MHz	24 dBm
45 MHz	Below 5508.0 MHz	24 dBm
	Above 5686.0 MHz	22 dBm

5.8 GHz band edge channel power reduction

Transmitter power is restricted in edge channels when the PTP 650 is operated the 5.8 GHz band with the USA or Canada country license. The amount of transmitter power reduction has been determined during regulatory testing and cannot be changed by professional installers or end users. Units intended for the USA and Canada market are locked for use in the USA or Canada and cannot be operated under the regulations for other regulatory domains.

The maximum transmitter power in band edge channels for the FCC 5.8 GHz band is listed in Table 67.

Table 67 Edge channel power reduction in regulatory band 1

Channel Bandwidth	Channel Frequency	Maximum conducted power
5 MHz	Below 5733.0 MHz	24 dBm
	Above 5838.0 MHz	24 dBm
10 MHz	Below 5737.0 MHz	25 dBm
	Above 5837.0 MHz	25 dBm
15 MHz	Below 5740.0 MHz	25 dBm
	Above 5835.0 MHz	25 dBm
20 MHz	Below 5742.0 MHz	25 dBm
	Above 5832.0 MHz	25 dBm
30 MHz	Below 5752.0 MHz	25 dBm
	Above 5822.0 MHz	25 dBm
40 MHz	Below 5765.0 MHz	25 dBm
	Above 5810.0 MHz	25 dBm
45 MHz	Below 5778.0 MHz	23 dBm
	Above 5795.0 MHz	22 dBm

Selection of antennas

For guidance on the selection of dedicated external antennas refer to Choosing external antennas on page 3-25.

For a list of antennas submitted to the FCC and IC for use with the PTP 650 refer to FCC and IC approved antennas on page 2-14.

Note

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (EIRP) is not more than that necessary for successful communication.

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante.

European Union compliance

The PTP 650 complies with the regulations that are in force in the European Union.

Warning

This is a Class A product. In a domestic environment this product may cause radio interference, in which case the user may be required to take adequate measures.

If this equipment does cause interference to radio or television reception, refer to Radio and television interference on page 8-10 for corrective actions.

EU product labels

The European R&TTE directive 1999/5/EC Certification Number is reproduced on the product labels (Figure 55 and Figure 56).

Figure 55 European Union certification on integrated product label

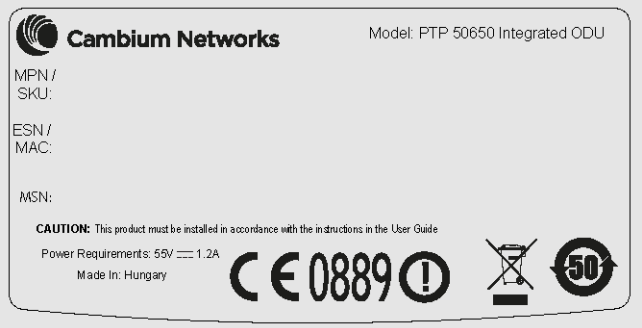
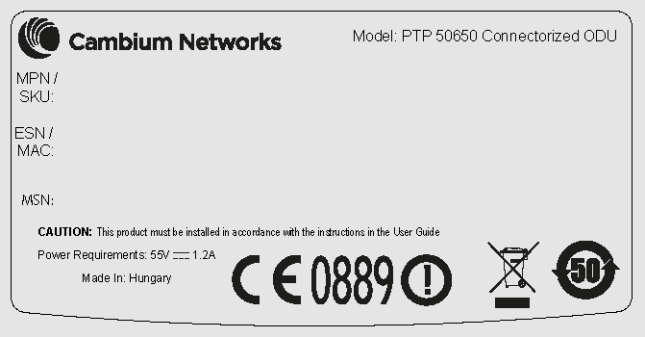


Figure 56 European Union certification on connectorized product label



5.4 GHz European Union notification

The PTP 650 product is a two-way radio transceiver suitable for use in Broadband Wireless Access System (WAS), Radio Local Area Network (RLAN), or Fixed Wireless Access (FWA) systems. It is a Class 1 device and uses operating frequencies that are harmonized throughout the EU member states. The operator is responsible for obtaining any national licenses required to operate this product and these must be obtained before using the product in any particular country.

Hereby, Cambium Networks declares that the PTP 650 product complies with the essential requirements and other relevant provisions of Directive 1999/5/EC. The declaration of conformity may be consulted at the support website (see Contacting Cambium Networks on page 1).

5.8 GHz European Union notification

The PTP 650 is a Class 2 device as it operates on frequencies that are not harmonized across the EU. Currently the product may only be operated in the countries listed in Table 65. However, the regulatory situation in Europe is changing and the radio spectrum may become available in other countries in future. See www.ero.dk for further information. The operator is responsible for obtaining any national licenses required to operate this product and these must be obtained before using the product in any particular country.

Caution

This equipment operates as a secondary application, so it has no rights against harmful interference, even if generated by similar equipment, and must not cause harmful interference on systems operating as primary applications.

Hereby, Cambium Networks declares that the PTP 650 product complies with the essential requirements and other relevant provisions of Directive 1999/5/EC. The declaration of conformity may be consulted at the support website (see Contacting Cambium Networks on page 1).

5.8 GHz operation in the UK

The PTP 650 connectorized product has been notified for operation in the UK, and when operated in accordance with instructions for use it is compliant with UK Interface Requirement IR2007. For UK use, installations must conform to the requirements of IR2007 in terms of EIRP spectral density against elevation profile above the local horizon in order to protect Fixed Satellite Services. The frequency range 5795-5815 MHz is assigned to Road Transport & Traffic Telematics (RTTT) in the U.K. and shall not be used by FWA systems in order to protect RTTT devices. UK Interface Requirement IR2007 specifies that radiolocation services shall be protected by a Dynamic Frequency Selection (DFS) mechanism to prevent co-channel operation in the presence of radar signals.