Packet Optical Networks and Forward Error Correction (FEC)

Packet optical networks and links depend on three key technology concepts:

- Optical networking with dense wavelength-division multiplexing (DWDM).
- Tunable wavelengths and coherent communications using higher-order modulation.
- Forward error correction (FEC).

Forward Error Correction

Different FEC types are needed because with increased DWDM bit-carrying capacity comes increased risk. A failed or marginally-operating link can affect many other bit streams that flow on the same physical link unless some method to compensate for these losses, like FEC, is used.

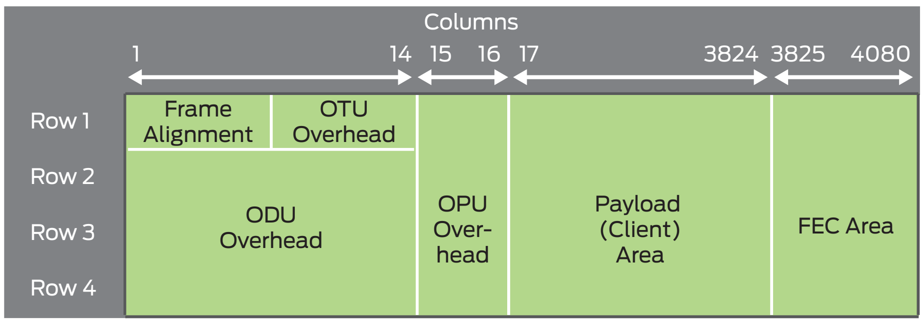
The main standard for packet optical networks is G.709, which defines a standard Optical Transport Network (OTN). There are other closely related standards, such as G.707 and G.975, and RFC 6363 defines how FEC types can be used with a stream of IP packets, whether or not packet optical network technologies are being used.

The G.709 OTN standards allow digital wrappers to operate at tunable wavelengths. The common Optical Transport Unit (OTU) levels of the OTN digital hierarchy are:

G.709 OTN Level	Line Rate	Contents
OTU1	2.666 Gbps	OC-48/STM-16 (2.488 Gbps)
OTU2	10.709 Gbps	OC-192/STM-64 or WAN PHY for 10GBase-W Ethernet
OTU2e	11.09 Gbps	10G LAN Ethernet from switch/router at 10.3 Gbps (G.Sup43)
OTU2f	11.32 Gbps	10 Fibre Channel
OTU3	43.018 Gbps	OC-768/STM-256 or 40G Ethernet
OTU3e2	44.58 Gbps	Up to four OTU2e signals
OTU4	112 Gbps	100 Gbps Ethernet

FEC Area (Frame Structure)

OTN uses Reed Solomon (RS) (255, 239) FEC code built right into the OTN frame outside of the payload area in a special section called the FEC area. This is considered out-band FEC instead of in-band because it is outside of the payload, but still inside the OTN frame. Each 255 byte block contains 16 FEC bytes generated from 239 data bytes. As the code designation indicates, OTN can correct up to 8 bytes of errors in a block and detect up to 16 bytes of errors in a block. More sophisticated interleaving can improve this correction rate (at the cost of more processing and buffering delay). The overall structure of the OTN frame is shown here:



Juniper Networks line cards can detect and correct up to 1 in every 70 bits in error, or up to 1.9 billion error corrections per second, all in real-time and without resending any information. That kind of error rate without packet loss is what makes FEC so attractive. There are three FEC options for 10G interfaces:

Common Name of FEC Method	Formal Name	Organization (Originator)
gfec ("RS(255,239)" or "G709 FEC")	ITU G.709 Annex A	ITU G.975
efec ("Enhanced FEC")	ITU G.975.1 Clause I.4	AMCC (APM)
ufec ("Ultra FEC")	ITU G.975.1 Clause I.7	Cortina/Inphi

These three methods are for Juniper Networks' DWDM and OTN hardware, but most other vendors support them, although interoperability is not always a given. Because gfec/efec/ufec are so common, they are sometimes called the *tri-FEC methods*.

100G FEC Types

Recently more powerful and intelligent FEC methods called soft-decision (SD) FEC types have been developed to distinguish them from their hard-decision predecessors. Both perform the same basic tasks (error correction and signal gain) but SD-FEC types are better at the task.

In other words, SD-FEC types can correct more errors and tolerate more noise on a link over greater distances than HD-FEC types can. Here are the FEC parameters that can be used on Juniper Networks' 100G Ethernet interfaces by common name, formal name, and FEC type.

Common Name of FEC Method	Formal Name	FEC Type
gfec ("RS(255,239)" or "G709 FEC")	ITU G.709 Annex A	Hard decision
hg-fec ("High-gain FEC", "staircase")	NA (proprietary)	Hard decision
sd-fec-ldpc	NA (Juniper-specific)	Soft decision
sd-fec-tpc	NA (Juniper-specific)	Soft decision

Junos® OS FEC Configuration on a 100G Link

Once you've configured sd-fec-ldpc on a 100G link, how do you know that the FEC method is doing its job? All routers and related devices have ways to examine the operation of the interface, and for Juniper Networks you can use the Junos `show interfaces … extensive` command. Here's an example of FEC performance output:

```
<...>
OTN FEC statistics:
    Corrected Errors                        13032402
    Uncorrected Words                              0
    Corrected Error Ratio (3 sec average) 3.42e-05
<...>
```

What do these number statistics mean?

FEC Performance Parameter	Definition	Notes
Corrected errors	Number of bits received that had errors but were corrected	Count of corrected errors (should be viewed along with uncorrected words)
Uncorrected words (UCW)	Number of code words received that could not be corrected	A non-zero UCW count equals packet loss
Corrected Error Ratio	Number of corrected bits divided by number of bits received	An estimate of the bit error rate (BER) on the link. A good overall measure of link health.

DID YOU KNOW?

Even low-power lasers used in packet optical systems can damage your eyes. The eye focuses all of the energy on the retina: wear protection when required!

Power is lost even as the light enters the packet optical fiber. This is called injection loss.

Kinking a packet optical fiber can permanently damage it. File cabinet corners and rolling office chairs are real hazards.

Submarine packet optical cables are often attacked by sharks. Cables have been retrieved with shark teeth embedded in them.

For additional technical resources, please visit: www.juniper.net/documentation/

https://www.juniper.net/us/en/products-services/packet-optical/

https://www.juniper.net/assets/kr/kr/local/pdf/solutionbriefs/3510589-en.pdf

https://www.juniper.net/techpubs/en_US/release-independent/nce/information-products/pathway-pages/nce/nce-158-pkt-opt-ptx-configuring.pdf

Poster concept: Walter Goralski

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