WHITE PAPER

Soft Decision Forward Error Correction for Coherent Super-Channels

Introduction

The goal of long haul DWDM transmission is to deliver error-free digital information at extremely high data rates and over very long distances, ideally without the need for regeneration of the signal en route.

As compared to systems that use earlier forms of Soft Decision Forward Error Correction (SD-FEC), Infinera's SD-FEC implementation allows network designers to achieve the following:

- Greater optical capacity;
- Almost double the optical reach; and
- Improved tolerance to noise or other impairments.

Why do we need Soft Decision FEC?

Achieving higher data rates and longer distances at the same time is a challenge, because by increasing data rates, the Optical Signal to Noise Ratio (OSNR) of a given system will tend to be reduced. If the increase in data rate decreases OSNR, regeneration points might be required. While these have many benefits, in some cases, such as in submarine systems, they may be impossible to add. If a submarine cable needs an increase in capacity without a multi-million dollar upgrade, then other compensation technologies need to be used to help ensure a long life for these expensive investments.

Coherent technologies such as those offered by Infinera's FlexCoherent™ Processor can help compensate digitally for OSNR degradation caused by Chromatic Dispersion, and even for record levels of Polarization Mode Dispersion. Separately from these compensation techniques, DWDM systems (including non-coherent systems) have long used Forward Error Correction (FEC) codes that allow very significant levels of error bits to be recovered to deliver an error-free digital signal. The latest enhancement for FEC is the use of a soft decision algorithm that significantly improves the Net Coding Gain, and Infinera's SD-FEC implementation is specifically designed to deliver optimum gain for a coherent super-channel based system. The two techniques (digital compensation and FEC) work in concert to increase optical reach, and lower overall costs.

What is "Q"?

In optical transmission systems, the Quality Factor, or Q, is used as a figure of merit for a given wavelength transmission budget. The higher the Q values are, the more reliable the transmission. However, a strong FEC will allow a lower "pre-FEC" Q value while still achieving error-free transmission post-FEC.

Q is used in preference to both Bit Error Rate and Optical Signal to Noise Ratio because Q takes into account the optical bandwidth of the photodetector, and the electrical bandwidth of the receiver filter. Thus, it provides a much more practical figure of merit.

Q is related to OSNR by the following formula:

$$Q_{db} = OSNR + 10 * \log_{10} \frac{B_O}{B_C}$$

Where B_O is the optical bandwidth of the photodetector, and B_C is the symbol rate bandwidth. This formula is also consistent with the pre-FEC BER.

How Does FEC Work and How Has It Evolved?

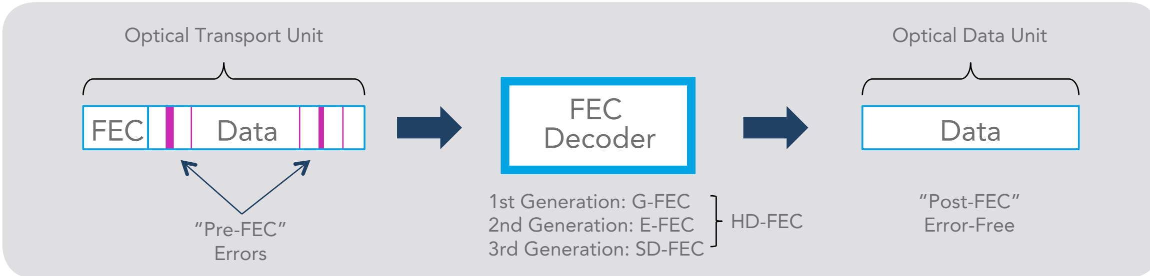

Figure 1: Schematic of Pre-FEC and Post-FEC Operation

Figure 1 shows the basic principle of Forward Error Correction in OTN systems. On the left is an OTN Optical Transport Unit (OTU) in which there are pre-FEC bit errors (shown by the red lines). The FEC field in the OTU contains overhead information that allows a FEC decoder to correct a certain level of error, producing a post-FEC, error-free Optical Data Unit (ODU) on the right hand side. Powerful electronic processing is required in the receiver to process FEC, and as the complexity of FEC algorithms has increased, the electronics has had to evolve to keep up.

FEC evolution is generally regarded as having three distinct generations:

- **First generation:** A Generic-FEC (G-FEC) that is defined in ITU-T G.709, and can be configured to allow interoperability between DWDM vendors. However, G-FEC delivers only around 6dB of Net Coding Gain (NCG) with a 6.69% overhead. G-FEC uses hard decision decoding.

- **Second generation:** An Enhanced FEC (E-FEC), the algorithms for which are listed in ITU-T G.975.1 but which are typically based on iterative decoding techniques. There is no expectation of interoperability between multi-vendor E-FEC systems; but they deliver between 8dB and 9.5dB of NCG with overhead between 6.69% and 10%, depending on the implementation. E-FEC uses hard decision decoding. G-FEC and E-FEC can be used with both non-coherent and coherent transmission systems. Note that second generation, E-FEC implementations for submarine networks typically have overhead as high as 25%.

IIn January 2012 Telstra Global and Infinera conducted a field trial of Infinera's super-channel SD-FEC implementation on a 4,200 kilometer submarine cable between California and Hawaii. Not only was the test a resounding success, but Infinera was able to demonstrate an enhanced-capacity polarization-multiplexed binary phase-shift keying (PM-BPSK) modulation technique that boosted spectral efficiency by 50 percent compared to traditional PM-BPSK modulation. This is a standard feature of the FlexCoherent chipset.

- **Third generation FEC** uses soft decision decoding (SD-FEC), and is enabled by advances in electronic signal processing for coherent systems at 100Gb/s and beyond. SD-FEC is capable of delivering a NCG of 11 dB or more with an overhead of 15-35%, depending on the implementation.

Hard Decision Versus Soft Decision Algorithms

In First and Second Generation FEC algorithms, the FEC Decoder shown in Figure 1 would detect bit errors using a binary decision—anything above the hard decision threshold is interpreted as a 1, and anything below is interpreted as a 0. The primary difference between G-FEC and E-FEC is simply that in E-FEC implementations an iterative decision can be made, with little or no impact on latency, by taking advantage of higher speed electronics in the FEC Decoder.

With SD-FEC, the Decoder uses additional overhead bits in the FEC field to provide a "soft," or more granular, indication that not only produces a 1 or 0 as the output, but also a confidence level in the decision. By combining the confidence level with the additional recovery bits in the FEC overhead, the SD-FEC algorithm can deliver about 2dB increase in Net Coding Gain compared to a second generation "hard decision" E-FEC. This can result in dramatic improvements in Q, and thus can deliver almost twice the reach compared to the previous technology on that cable. This is extremely advantageous in terms of both CapEx and OpEx for the service provider, and in particular is key to extending the commercial life of submarine cables in the face of exponential increase in demand.

Net Coding Gain and the Impact of Higher Overhead FEC

In the explanation above, the overhead of the SD-FEC field was quoted at between 15% and 35%; but why is there such a variation in overhead for different implementations? In simple terms, by increasing the FEC overhead, it is possible to recover more bit errors and improve the Q value for a given transmission budget. However this is not the whole story.

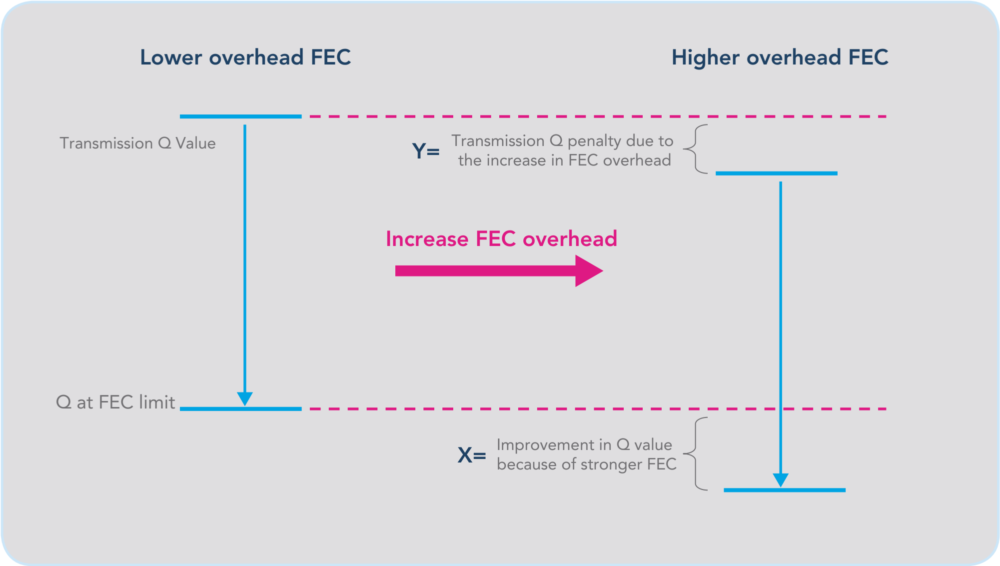

Figure 2: Understanding Net Coding Gain

On the left hand side of Figure 2 there is an example of the Net Coding Gain for an SD-FEC with 15% overhead. On the right is a 35% overhead FEC, and the increase in Q is shown as the parameter, X. However, the increased overhead had to be transmitted over the fiber, and there is therefore an associated Q penalty, shown as the parameter Y.

The relative Net Coding Gain by using the higher overhead FEC is, therefore, given by X–Y. In general, there is a diminishing return for higher overhead SD-FEC, and bandwidth used by this higher overhead may be better used by other compensation techniques. It is, therefore, important to get the balance right in terms of SD-FEC overhead versus overall Net Coding Gain.

Summary

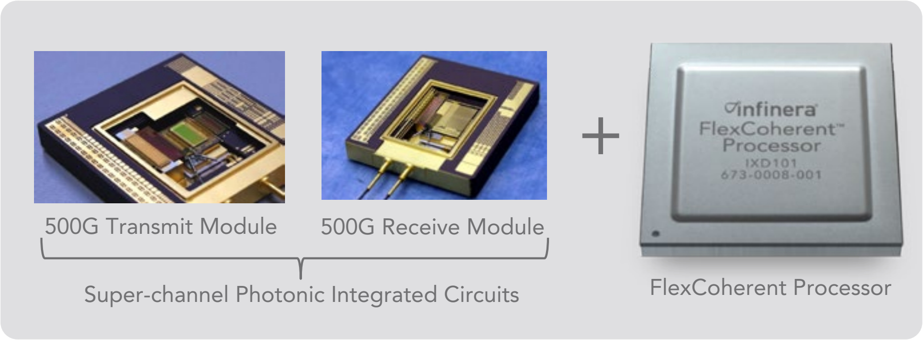

Figure 3: Infinera's Integrated Photonic and Electronic Line Card Architecture

- **SD-FEC combined** with the power of coherent compensation techniques can now deliver a significant increase in optical reach for optical transmission systems at 100 Gb/s and, which can be extremely beneficial for hard-to-upgrade submarine cables as well as long terrestrial links.

- **Infinera has developed an SD-FEC capability** that has been integrated into our third generation FlexCoherent™ Processor chip.

- **The Infinera implementation** is engineered to optimize coherent super-channel operation, and is matched to the outstanding performance and integration levels offered by Infinera's unique Photonic Integrated Circuit capabilities. A discussion of Infinera's industry leading PMD performance can be found in this white paper."

- **The end result** allows service providers to potentially enjoy significant additional optical capacity or significant additional optical reach on existing fiber routes compared to systems that use a hard decision FEC or less capable implementations of SD-FEC. For more information on Infinera's coherent detection and SD-FEC capabilities, please visit http://www.infinera.com/go/Coherent_SD-FEC/index.php.

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