Soft-Decision FEC Benefits for 100G

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Introduction

Network operators face increasing capacity requirements on their optical transport networks, due to high-speed data services, 3G/4G smartphone services, and Internet video services. To accommodate these new bandwidth-hungry services, network backbone speeds are increasing from 10 Gbps to 40 Gbps and soon to 100 Gbps per wavelength. In order to efficiently utilize their networks, operators are moving to higher data rates per wavelength over existing deployed routes and WDM systems.

One of the fundamental limits in designing optical transport networks is OSNR. WDM networks must operate above their OSNR limit in order to ensure error-free operation. The OSNR limit is one of the key parameters determining how far a wavelength can travel before regeneration. Depending on whether a ROADM is designed for metro, LH, or ULH applications, 10G wavelengths can be transported 800–2000 km before regeneration is required.

At data rates above 10 Gbps, advanced modulation schemes are used to minimize the impacts of optical impairments, such as CD and PMD, as well as to ensure the optical signal fits within the 50 GHz grid window used on modern DWDM systems. The downside of these higher data rates and advanced modulation schemes is that they require substantially higher OSNR performance than at 10 Gbps. At 100 Gbps, the minimum OSNR required is +10 dB higher than for 10 Gbps wavelengths. Without some type of correction or compensation, the 100G OSNR requirements would limit 100G optical transport to extremely short distances. Fortunately, sophisticated FEC techniques are employed on 10G, 40G, and 100G signals to extend their performance and reach to much longer, more useable distances.

FEC is a method of encoding the original signal with additional error detection and correction overhead information (i.e., parity bytes), so that optical receivers can detect and correct errors that occur in the transmission path. FEC dramatically lowers the BER and extends the distances that optical signals can be transmitted without regeneration.

There are a number of FEC algorithms to choose from that vary in complexity, strength, and performance. One of the most common and standardized first-generation FECs, is Reed-Solomon (255, 239). Reed-Solomon adds slightly less than 7% overhead for the FEC bytes and provides approximately 6 dB net coding gain. In high-speed optical networks, a 6 dB gain is a very significant performance improvement—approximately quadrupling the distance between regenerators. In addition to Reed-Solomon FEC, many vendors offer stronger, second-generation FECs as a provisionable parameter on 10G and 40G optical interfaces. These UFEC/EFEC algorithms still use 7% overhead, but implement stronger, more complex encoding and decoding algorithms, which provide an additional 2–3 dB coding gain over Reed-Solomon.

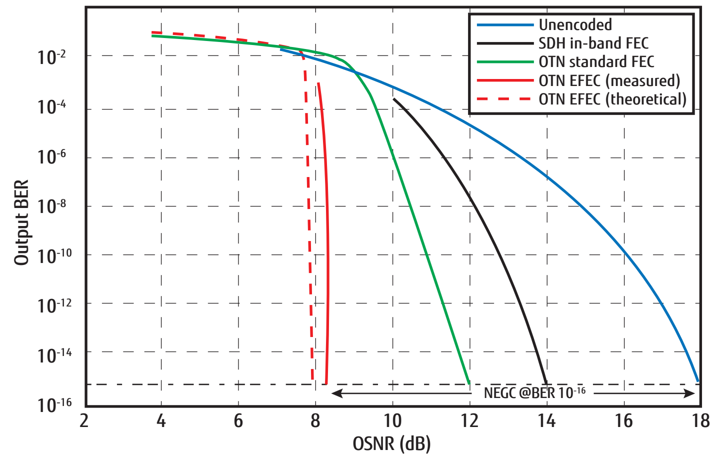

Figure 1: Comparison of Standard FEC, EFEC, Unencoded[1]

While first-generation Reed-Solomon FEC and second-generation EFEC have provided substantial performance improvements for 10G and 40G wavelengths, even stronger, more complex third-generation FEC algorithms are needed at 100G to achieve optimal performance.

Soft-Decision FEC

At 100G rates, leading optical suppliers are implementing third-generation FEC capabilities to extend performance and overall optical distances even further. These third-generation FECs are based on even more powerful encoding and decoding algorithms, iterative coding, and something referred to as "soft-decision" FEC. In a hard-decision FEC implementation the decoding block makes a firm decision based upon the incoming signal, and provides a single bit of information (1 or 0) to the FEC decoder. A signal is received and compared to a threshold; anything above the threshold is a "1" and anything below the threshold is a "0."

A soft-decision decoder uses additional data bits to provide a finer, more granular indication of the incoming signal. In other words, the decoder not only determines whether the incoming signal is a "1" or a "0" based on the threshold, but also provides a "confidence" factor in the decision. This provides an indication of how far the signal is from the threshold crossing. These additional "confidence" or "probability" bits are used by the soft-decision FEC decoder, along with the stronger, more complex third-generation FEC coding algorithms, to provide 1–2 dB of additional net coding gain. In practice, a 3-bit confidence estimation normally provides most of the theoretically achievable performance improvement. While 1–2 dB coding gain doesn't sound like much, it can translate into 20–40% improvement in overall achievable distances, which is a very substantial improvement at 100G.

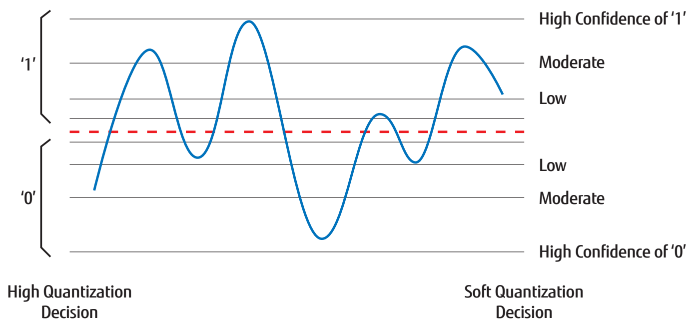

Figure 2: Finer Granularity Soft-Decision Thresholds

One trade-off with these more advanced, third-generation FECs is they require ~20% overhead for the FEC bytes, compared to first- and second-generation FECs, which only require ~7% overhead. The higher 20% FEC overhead translates to slightly higher optical data rates, which are already operating at the edges of currently available technology at 100G.

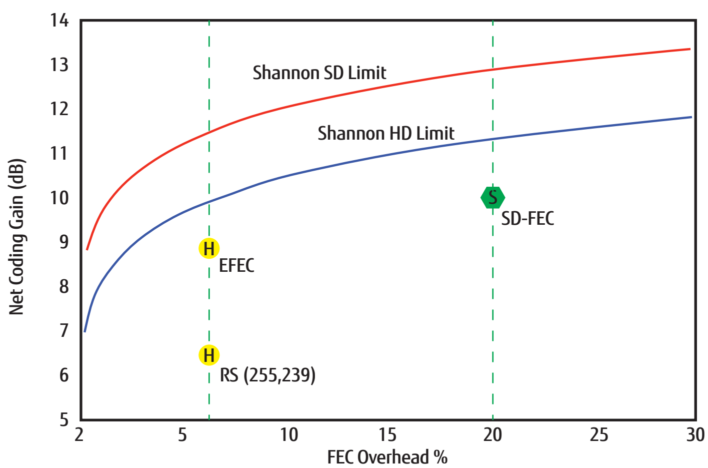

Figure 3: Net Coding Gain vs Overhead[2]

Implementing 100G Soft-Decision FEC

While the mathematics behind soft-decision FEC algorithms have been known for many years, and utilized in the wireless industry, it is only recently that SD-FEC has gained interest for use on high-speed optical signals. Until recently, numerous technology and ASIC limitations prevented implementation of third-generation concatenated and SD-FEC. In other words, semiconductor chips weren't fast enough, didn't have enough processing power or memory, and consumed too much power to implement soft-decision FEC algorithms for 100G optical signals. A key example is the high-speed ADCs used inside a 100G receiver. These devices operate at an incredible 56 gigasample per second (Gsa/s) and are just starting to become generally available in 2011. However, SD-FEC requires the use of even higher speed ADCs, operating at 63 Gsa/s to implement the SD-FEC processing, along with an equally fast and powerful SD-FEC chip. Component limitations prevented the implementation of SD-FEC for 100G optical signals—until now.

Summary

Network operators are under tremendous pressure to expand network capacity to order to meet the ever-increasing demand for high-speed data services, especially Internet video services. As backbone speeds increase from 10G per wavelength to 100G per wavelength, the OSNR requirements increase by +10 dB. Without some type of compensation or correction, 100G optical distances would be very limited and uneconomical. First- and second-generation FEC algorithms have been used at both 10G and 40G to lower the BER and improve overall distances. Soft-decision FEC is a third-generation encoding algorithm that enables longer distances and fewer regenerations on 100G optical networks. Up until recently, semiconductor and component technology did not exist to allow implementation of SD-FEC on high speed, 100G optical signals. As of 2011, Fujitsu is leading the optical industry by introducing SD-FEC on the newest generation of 100G optical modules.

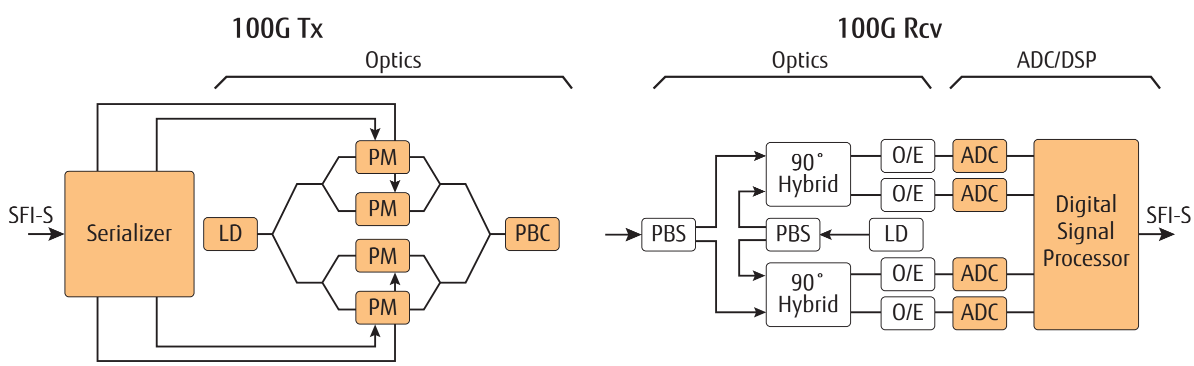

Figure 4: Generic 100G Tx and Rcv Implementation

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References

1) ITU, "Optical Transport Networks (OTN) Tutorial," page 14, March 2005.

2) ECOC2009, "FPGA based Prototyping of Next Generation Forward Error Correction," T. Mizuochi, Mitsubishi Electric Corporation, slide 21, September 22, 2009.

Acronyms	
ADC	Analog to Digital Converter
ASIC	Application Specific Integrated Circuit
BER	Bit Error Ratio
CD	Chromatic Dispersion
DSP	Digital Signal Processor
DWDM	Dense Wavelength Division Multiplexing
FEC	Forward Error Correction
ILA	Inline Amplifier
LH/ULH	Long Haul/Ultra-Long Haul
OSNR	Optical Signal Noise Ratio
PMD	Polarization Mode Dispersion
ROADM	Reconfigurable Optical Add Drop Multiplexer
SD-FEC	Soft-Decision Forward Error Correction
UFEC/EFEC	Ultra Forward Error Correction/ Enhanced Forward Error Correction
WDM	Wavelength Division Multiplexing

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