Network Economics of Optical Transport Networks with Soft Decision Forward Error Correction (SD-FEC) Technology

Anuj Malik[(1)], Marco Sosa[(1)], Onur Turkcu[(1)], Vinayak Dangui[(1)], Steve Hand[(1)], Matthew Mitchell[(1)], Serge Melle[(1)]

[(1)] Infinera, Sunnyvale, California, USA, Email: amalik@infinera.com

Abstract *This paper evaluates the impact of SD-FEC technology upon network design and economics in a long haul optical transport network. The network study shows that the SD-FEC technology not only reduces the TCO (total cost of ownership) but also simplifies the network design. A real world network model is utilized to quantify and compare results.*

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. The challenge is that, increasing data rates decreases the OSNR (Optical Signal to Noise Ratio). At data rates above 10 Gbps advanced modulation schemes are needed to compensate for optical impairments such as chromatic dispersion (CD) and polarization mode dispersion (PMD) to achieve similar reach as traditional 10Gbps systems. These advanced modulation schemes also require substantially better OSNR performance than do conventional 10Gbps transmissions. As a result, the minimum OSNR required for a 100Gbps DWDM wavelength is +10dB higher than for 10Gbps wavelengths.

Forward Error Correction (FEC) is a method of encoding a signal with additional overhead information so that optical receivers can detect and correct errors that occur in the transmission path. Without error correction or compensation, the OSNR requirements would limit 100Gbps optical transport to extremely short distances. As shown in Fig1 the impact of better FEC is to drive down OSNR for a given BER.

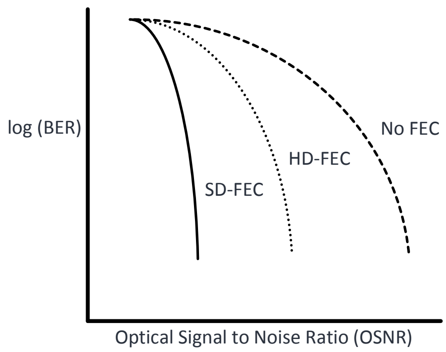

Fig. 1: FEC Evolution

In First and Second Generation HD-FEC (Hard Decision Forward Error Correction) algorithms, the FEC Decoder 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. 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 (NCG) compared to a second generation “hard decision” FEC. This can result in dramatic improvements in Q, and thus can deliver higher reach and optical performance compared to the previous technology on the same fiber. The increase in reach and performance of the system is critical for extending the life of the submarine links and for reducing the number of regenerators in long terrestrial links leading to considerable savings in CAPEX and OPEX.

While prior papers have discussed the benefits of SD-FEC for reach on a specific link [1] [2], this paper studies the network impact of SD-FEC technology and presents results that the total number of 100G line modules, regenerators, and RAMAN amplifiers are significantly reduced in a typical long haul optical transport network.

Net Coding Gain (NCG) and Overhead

The SD-FEC reach and performance improvement comes with the expense of high FEC overhead. Generally SD-FEC provides NCG of about 11dB with an overhead of 15-35%, depending on the implementation. But simply increasing the FEC overhead itself won’t increase the system’s ability to recover more bit errors. Let’s consider an example. In figure 2, on the left hand side there is an example of the Net Coding Gain for an SD-FEC with 15% overhead. On the right side 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 (or given to the payload). It is, therefore, important to get the balance right in terms of SD-FEC overhead versus overall Net Coding Gain.

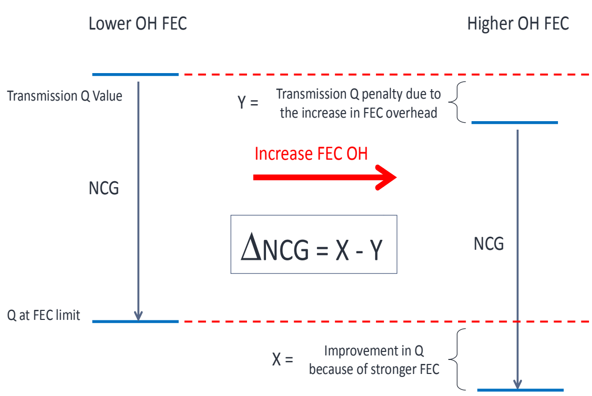

Fig. 2: NCG and Overhead

HD-FEC vs. SD-FEC

For this study, two different sets of 500G super-channel based line modules are considered with HD-FEC and SD-FEC technology.The line cards with HD-FEC technology have net coding gain of approximately 9dB with 7% of overhead and ones with SD-FEC technology have net coding gain of 11dB using 15% of overhead. The typical reach for HD-FEC line modules is 2500km and for SD-FEC modules is 3500km.

Network Model and Traffic Model

For our study on the impact of SD-FEC technology enabled line modules on various network parameters, we consider a network topology representative of a typical US data center ring network with fiber topology, nodes, and service demands approximating those of a real-world data center network.

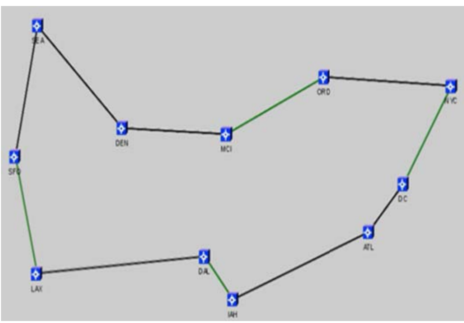

Fig. 3: Topology of nodes for the US Data Center Network

The network topology (Figure 3) comprised of 11 data centers with the average distance of 1418km and maximum distance of 3166km. The links are points to point with maximum node degree of two.

The initial service demands between the data centers was estimated using market research data on Internet traffic flows and sources (European Internet Exchange Association and www.datacentermap.com), and used to generate an initial seed bandwidth for data center traffic. The starting bandwidths were then modeled to grow at 50 percent per period (see Table 1), and used to generate a 5-period service traffic profile. Demands between each pair of nodes were assigned to a service interface on the appropriate WDM and/or switching systems, assuming 10Gb/s, 40Gb/s or 100Gb/s port interface speeds.

The total traffic at year i(Ti) is only the growth over the initial seed (3.6 Tb/s).

$$T_i = 3.6 \times (1 + 0.50)^i - 3.6$$

Table 1: Summary of traffic volume in US data center network model (Tbit/s)

	Y1	Y2	Y3	Y4	Y5
Traffic Volume (Tbit/s)	1.8	4.5	8.5	14.6	23.7

Results

i.Number of Line Modules Deployed

In the first part of the study (Fig. 4), the total number of line modules is compared over a period of five years when the network is deployed with only HD-FEC line modules against the mix of the HD-FEC and SD-FEC line modules. Initially only HD-FEC line modules are used and when link is not getting closed by HD-FEC modules, regenerator is used; in the second case SD-FEC line modules are used when the link is not getting closed by HD-FEC modules.

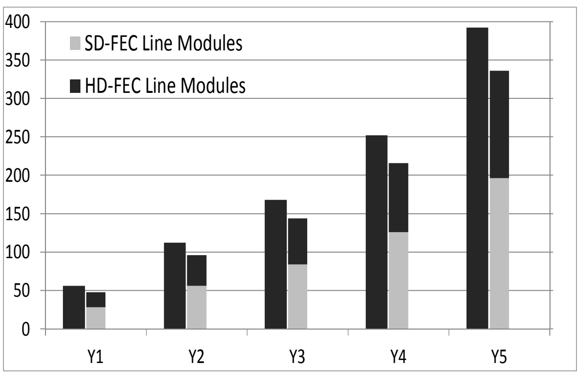

Fig. 4: Total Number of Line Modules deployed over a period of 5 years with HD-FEC vs. SD-FEC

With only HD-FEC line modules, 56 line

modules are deployed in the first year and 392 in the fifth year. With the mix of SD-FEC and HD-FEC modules, the total number of line modules deployed is reduced to 48 in first year and 336 in the fifth year (refer Fig. 4). This is about 14% reduction in total number of line modules deployed. This reduction in the total number of line modules deployed leads to significant savings in both CAPEX and OPEX. The table shows the line module breakup with HD-FEC and SD-FEC in second case when both types of line modules are used.

Table 2: Line Module breakup with mix of HD-FEC and SD-FEC lines modules

	Y1	Y2	Y3	Y4	Y5
HD-FEC	20	40	60	90	120
SD-FEC	28	56	84	126	196
Total	48	96	144	216	226

ii. Number of Regenerators

In the second part of the study (Fig. 5), the total numbers of regeneration sites are compared with only HD-FEC and mix of HD-FEC and SD-FEC line modules. Due to higher reach SD-FEC line modules can close longer routes and hence the average number of regeneration sites with SD-FEC line modules is reduced to 1 from 3 with HD-FEC. This is about 66% reduction in regeneration sites leading to both CAPEX and as well big OPEX savings.

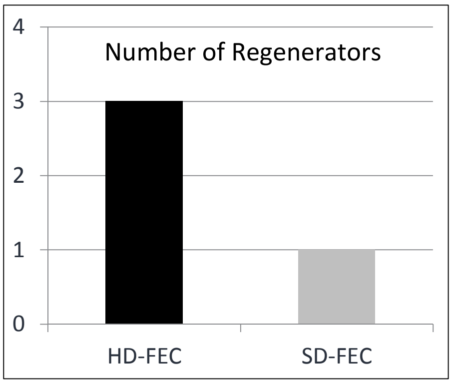

Fig. 5: Average number of regenerators deployed with HD-FEC vs. SD-FEC

iii. Line System Deployed

In the third part of the study (Fig. 6), the optimized line system designs with only HD-FEC line modules and mix of HD-FEC and SD-FEC line modules is considered. In both cases, the two different types of the line amplifiers (EDFA vs. hybrid EDFA-RAMAN) deployed. As the optical performance of the SD-FEC line modules is better than that of HD-FEC modules, fewer hybrid (EDFA+RAMAN) amplifiers are required when using mix of SD-FEC and HD-FEC line modules while minimizing regeneration leading to considerable CAPEX savings. With SD-FEC line cards, the ratio of hybrid amplifiers to the total amplifiers is reduced from 42% to 26% leading to considerable CAPEX savings. Also, a line system design with less RAMAN amplifiers simplifies deployment and is suitable for more fiber installations in the network as there can be operational issues with RAMAN amplifiers if there are splices in the fiber or if the network is prone to more fiber cuts.

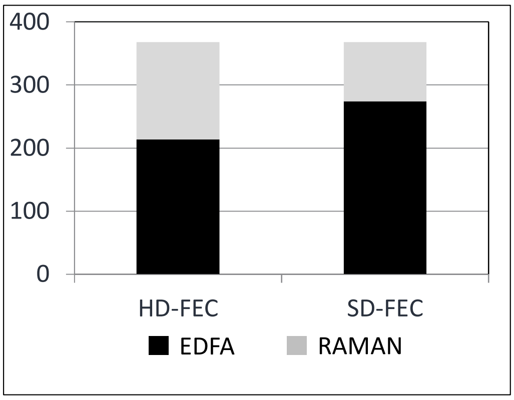

Fig. 6: Types of line amplifiers deployed with HD-FEC vs. SD-FEC

Conclusions

Clearly, SD-FEC offers better optical performance and longer reach than the previous technology, HD-FEC. Our network study shows that SD-FEC technology in real world networks can significantly decrease the number of DWDM line cards and regenerators resulting in CAPEX and OPEX savings that dramatically reduce TCO (total cost of ownership). In addition, our study further shows that SD-FEC isn't just about reach; it also simplifies the line system design and leads to a decrease in the number of RAMAN amplifiers deployed causing further savings in CAPEX.

References

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