Deployment of 40 Gb/s systems: Technical and cost issues

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Abstract: First we discuss market opportunities for 40 Gb/s systems. Next we discuss practical requirements that 40 Gb/s systems must meet to become commercially deployed. Finally, we discuss the trade-off between the achievable transmission distance and the complexity/cost of transponders and line systems.

Introduction

Increasing the data rates by a factor of four has historically reduced the cost for the transmission of a unit bandwidth by approximately 40%. As the next natural increase in data rate, 40 Gb/s has been the focus of extensively investigation in research and development labs around the world for several years [1-9]. However, despite the obvious potentials, 40 Gb/s systems have not yet been commercially deployed, in part because 40 Gb/s is associated with a number of misconceptions, e.g., that 40 Gb/s technology is not mature and that the transmission distance is severely limited by fiber dispersion.

In this paper we address the practical requirements that 40 Gb/s systems must meet to become commercially deployed. We show that seamless migration to 40 Gb/s per channel is possible with correctly designed line cards. Moreover, we discuss the technologies needed to implement different modulation formats, and the corresponding trade-off between complexity/cost of line cards and the achievable fiber transmission distance.

Market opportunities

The deployment of 40 Gb/s is expected to follow a path similar to when 10 Gb/s was initially introduced 7 years ago. At that time, 10 Gb/s systems were primarily deployed to provide a capacity boost of new systems, and later to support 10 Gb/s interfaces on high-end routers. As the number of installed 10 Gb/s systems increased, the benefit of high volume made 10 Gb/s systems very cost effective, further increasing the deployment rate and eventually providing carriers with the 40% cost savings.

Though the main long-term driver for deployment of 40 Gb/s systems is the lower cost per managed bit per km, a main near term driver for deployment of 40 Gb/s transport system is the need to support 40 Gb/s services. High-end routers with OC-768/STM-256 interfaces are on the horizon prompting many carriers and service providers to prepare their backbone network to 40 Gb/s data rates. This is because native 40 Gb/s services can more efficiently be transported by a 40 Gb/s line rate rather than using a costly and complicated inverse-multiplexing transport scheme that is also difficult to maintain and manage. Moreover, by adding 40 Gb/s data rates on the last wavelengths in an installed 10 Gb/s system provides a cost effective means to upgrade capacity constrained 10 Gb/s systems, thereby offering carriers and service providers the opportunity to postpone an expensive new network installation.

40 Gb/s over existing 10 Gb/s system

A key to successful and seamless migration to 40 Gb/s line rates is the ability to utilize the existing transmission infrastructure. For example, it is very important that 40 Gb/s systems can use the same type of transmission fibers, optical amplifiers and dispersion compensating fibers as currently deployed 10 Gb/s systems. However, to overlay 40 Gb/s on an existing 10 Gb/s line system as shown in Fig. 1, requires thorough interoperability assessments between the 10 Gb/s line system and the added 40 Gb/s channels. For example,

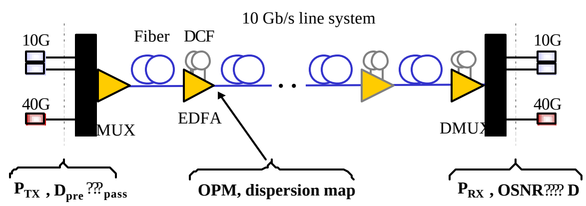

Fig. 1 40 Gb/s overlay on 10 Gb/s line system. P_{TX}: transmitter power, D_{pre}: dispersion pre-compensation, $?_{pass}$: pass-band of MUX/DMUX, OPM: optical performance monitoring, P_{RX}: received power, ?D: dispersion tolerance.

adding 40 Gb/s channels to an existing l0G line system requires the 40 Gb/s receivers to have an OSNR sensitivity, a dispersion tolerance and a power dynamic range similar to the 10 Gb/s line cards. In the same way, the 40 Gb/s transmitter must provide an output power similar to the 10 Gb/s signals and the 40 Gb/s modulation format must be transmittable through typical 10 Gb/s optical mux/demux without significant filtering penalty. To meet the above requirements, the 40 Gb/s line cards must for example include powerful forward error correction to improve the OSNR sensitivity and adaptive dispersion compensators (ADC's) to widen the otherwise tight dispersion tolerance of 40 Gb/s. Commercially available ADC's typically provide a tuning range of >400 ps/nm, enabling 40 Gb/s receivers to have practically the same dispersion tolerance after transmission as 10 Gb/s receivers.

The 40 Gb/s signals might need dispersion pre-compensation to convert a deployed 10 Gb/s dispersion map into an optimum dispersion map for the 40 Gb/s signals. This is illustrated in Fig. 2, which shows the calculated transmission penalty after 8x100 km of SSMF as function of pre-compensation and the inline dispersion compensation ratio. As seen, to convert a typical deployed 10 Gb/s dispersion map with a 95% inline compensation ratio and no pre-compensation into an optimum 40 Gb/s dispersion map, -500 ps/nm of pre-compensation (30% of 100 km SSMF) is needed for the 40 Gb/s signals.

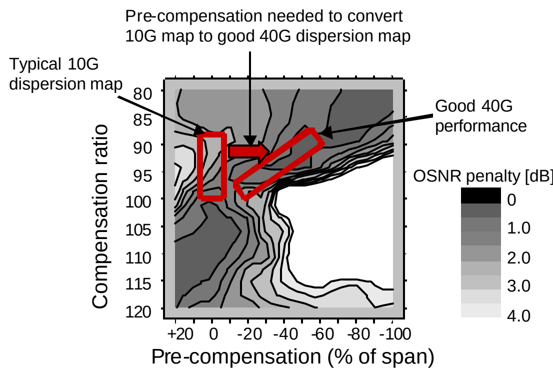

Fig. 2 OSNR penalty for DWDM 40 Gb/s CS-RZ over 8x100 km SSMF as function of pre and inline compensation

For seamless interoperability, any already installed optical performance monitoring (OPM) systems must also be able to handle the 40 Gb/s signals. Moreover, deployment of 40 Gb/s systems should not require extra training of carrier personal or any advanced pre-characterization of the fiber plant, and it should use simple and common turn-up and installation procedures.

Trade-off between complexity of TX/RX and transmission distance

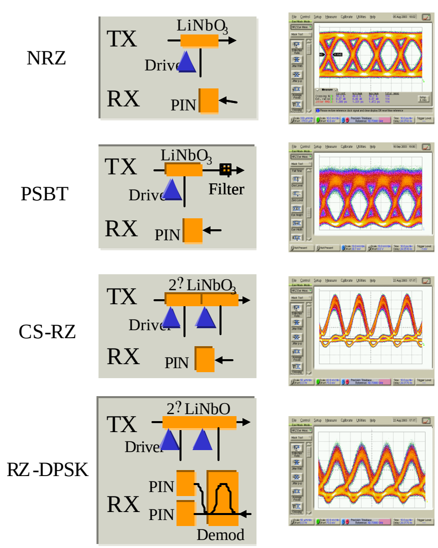

Fig. 3 Schematics of key building blocks for different modulation formats, and the corresponding measured 40 Gb/s eye-diagrams.

Besides the ability to utilize the existing infrastructure, low cost 40 Gb/s line cards is a key to deployment of 40 Gb/s systems. The cost of 40 Gb/s line cards is primarily determined by the electronics and optics operating at the serial line rate, i.e., electrical Mux and CDR/Demux, electrical driver, optical modulator(s), PIN, and adaptive dispersion compensator (ADC). Today, all these key modules are available from several suppliers in a mature form that allow volume manufacturing and thus the promise for low cost. The only key building block not readily available is 40 Gb/s FEC devices, forcing many line card suppliers to currently implement the FEC functions at the 10 Gb/s level. The main consequence is additional chips and hence added cost.

The achievable transmission distance depends on the applied modulation format. The modulation formats that provide the best transmission distance are generally also the most complex to realize, and therefore the most costly to implement. For example, it has been shown by several research groups [1-3] that the RZ-DPSK format offers a 3 dB improvement in OSNR sensitivity in comparison to the CS-RZ format, which in turn offers a 1-2 dB improvement in sensitivity compared to the simple NRZ format. Moreover, RZ-DPSK permits a 1 dB higher launch power for the same non-linear transmission penalty. Figure 3 shows schematically the key building blocks for the different formats including measured eye-diagrams. The figure also includes the PSBT format, which has a very narrow spectral width but also a relative poor sensitivity. The improved performance of RZ-DPSK corresponds to a 60% increase in transmission distance relative to CS-RZ, and a doubling of the reach compared to NRZ. However, the RZ-DPSK format requires two $LiNbO_3$ modulators (one for DPSK modulation and a one for RZ modulation) and a balanced receiver in addition to an optical demodulator that is needed to convert the phase modulation into intensity modulation. Obviously, the cost of a line card based on RZ-DPSK is higher than one based on the simpler NRZ format, but due to the increase in distance RZ-DPSK can provide a lower cost per bit per km. Near-term, however, 40 Gb/s long-haul systems is likely to be implemented with the simpler NRZ and CS-RZ formats, which support cost effective transmission up to at least 1000 km of fiber as discussed below.

PMD is frequently stated as prohibitive for 40 Gb/s transmission. The fact is that most deployed fiber will support 40 Gb/s transmission up to 1000 km without PMD compensation [10]. Moreover, multi-channel PMD compensators are emerging, enabling 40 Gb/s transport on old, high PMD fiber as well.

Transmission examples

Besides the modulation format, the achievable transmission distance for 40 Gb/s DWDM systems depends on fiber type and the amplification scheme (EDFA, EDFA/Raman or all-Raman). SSMF and NZDSF support very similar transmission distance, whereas systems using distributed Raman amplification support a 50% longer distance by using newer fiber types like dispersion-managed fiber [11]. Figure 4 below illustrates the difference in transmission reach between an advanced future system and a conventional system using existing fiber, DCF and optical amplifiers as used today at 10 Gb/s: the left figure shows transmission of 40 channels over 10,000 km of UltraWave fiber using All-Raman and the advanced RZ-DPSK format [2], whereas the right figure demonstrates transmission of 40 DWDM channels over 1,700 km of SSMF using the simpler CS-RZ format, conventional EDFAs only and a typical 10 Gb/s dispersion map. The above transmission demonstrations were carried out with very little margin. Practical systems will need at least 6 dB of margin, reducing the achievable transmission distance by a factor of two. Still, using conventional EDFAs and DCFs and a relative simple modulation format like CS-RZ, transmission over 800 km of SSMF is achievable with a robust margin.

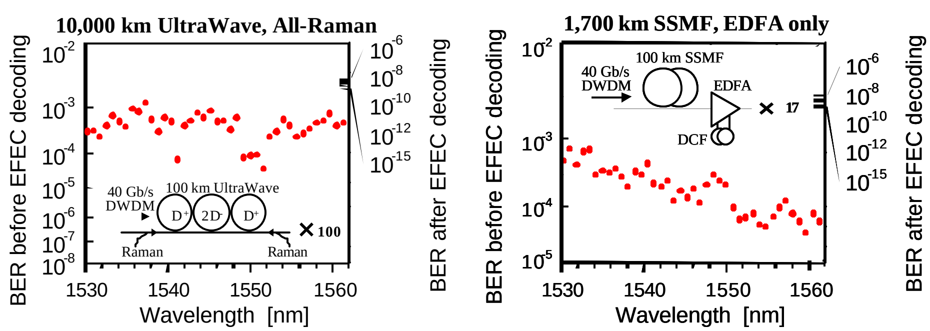

Fig. 4 Transmission performance after 10,000 km UltraWave (left) and 1700 km SSMF (right).

Summary

40 Gb/s is the next natural data rate to become commercially deployed. The drivers are the needs to transport 40 Gb/s services, and the desire to reduce network costs through lower transport cost and fewer wavelengths to manage. A cost effective implementation of 40 Gb/s line cards is obviously essential. 40 Gb/s can also effectively be used to upgrade capacity constrained 10 Gb/s systems, thus postponing an expensive new installation. Since 40 Gb/s channels can be overlaid on existing 10 Gb/s line systems, the transition to 40 Gb/s data rates will be a seamless and natural evolution from today's 10 Gb/s systems.

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