Deployment Challenges at 40 Gbit/s and beyond in Optical Transport Networks

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Abstract: We investigate the tradeoffs that service providers face in deploying 40 Gbit/s networks due to the convergence of layers. Two predominant modulation formats used in transponders are compared with respect to the level of convergence.

OCIS codes: (060.2330) Fiber optics communications, (060.5060) Phase modulation;

1. Introduction

In the coming years, applications such as IPTV, gaming, voice and high-speed Internet will be responsible for the tremendous traffic growth on the optical transport network. Already, today's access speed is constrained by the optical transport network capacity forcing service providers to deploy networks with greater capabilities at 40 Gbit/s. Along with the advent of 100 Gbit/s Ethernet standardization by 2010 [1], the cost and upgradeability of optical transport networks become important factors when choosing network technologies. With the convergence of transport layers in progression, service providers are faced with multiple solutions supported by emerging technologies such as 40 Gbit/s DWDM transponders in high-end routers with OC-768/STM-56 interfaces [2]. Through simplified network architecture from the collapsing of layers, the network layer becomes the control of the service provider. Major changes in the software are required to unify the network controllability. Additionally, uncertainty in how well the routers will support their new functions may necessitate alteration of the optical link to maintain the required physical layer performance. On the other hand, maintaining separate layers simplifies the functions and enables the connectivity between various routers from different vendors in the network. The drawback of this approach is that the network architecture complexity will increase in the future as 100 Gbit/s Ethernet pushes its use onto the optical transport along with legacy protocols [3].

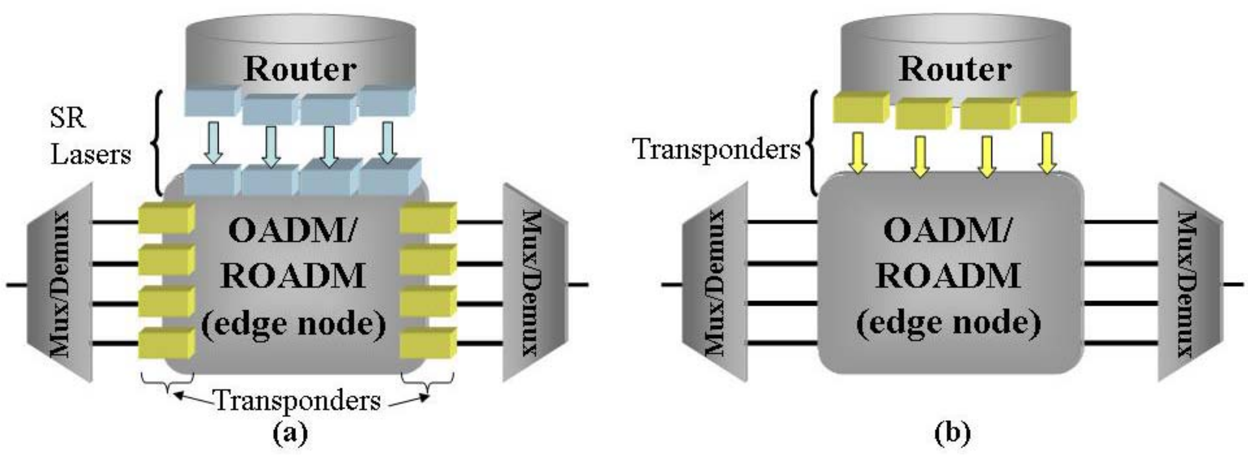

Fig. 1: Illustration of the two approaches. (a) Short reach (SR) optics used with transponders residing in the edge node within an optical add-drop module (OADM) or a reconfigurable optical add-drop module (ROADM). (b) Convergence of the transport layer with the transponders residing in the routers.

In Fig. 1, we show the two main proposed solutions available to service providers at 40 Gbit/s. One solution favors the separation of layers with the transponders residing in the high-end service edge node (Fig. 1a). The other solution integrates the transponders in the carrier routing system on the client side (Fig. 1b). In this work, we investigate the performance of two predominant modulation formats used in the two proposed solutions for 40 Gbit/s optical transport networks. The direct detection of partial differential binary phase shift keying (BPSK) modulation

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and the coherent detection of polarization multiplexing quadrature phase shift keying (PM-QPSK) modulation have attracted attention for their superior optical signal-to-noise ratio (OSNR) sensitivity and tolerance to fiber impairments [4]-[8]. The type modulation format comes with the choice of the network solution proposed by the router's vendors (Fig. 1a or 1b) and is somewhat imperceptible by the service providers. With lower cost routers relative to the edge node, transponder performance differs between the two approaches. Through simulation, we present the performance of both solutions with respect to the components' specifications.

2. Optical Transmission Configuration

To migrate to higher channel data rates, the modulation format must tolerate the impairments experienced on the current transmission system which has been built for 10 Gbit/s as well as the filtering effect of a cascade of ROADMs for 50 GHz channel spacing. With a reduced bit interval from 100 ps to 25 ps, chromatic dispersion (CD) and polarization mode dispersion (PMD) further affect the optical signal in the physical layer while higher OSNR are required. The direct detection of BPSK offers superior OSNR sensitivity using a balanced detector. Consequently, BPSK has been a predominant format for 40 Gbit/s transmission links. Other more complex modulation can be used such as QPSK which encodes 2 bits per symbol instead of 1 bit per symbol as with BPSK. In fact by coding two orthogonal polarization states through polarization multiplexing (PM), 4 bits per symbol can be encoded in PM-QPSK reducing the symbol rate to 10 Gbaud. Direct detection of QPSK is quite complex and costly to justify its use at 40 Gbit/s. Alternatively, coherent detection offers greater performance in terms of OSNR sensitivity and powerful post data processing capabilities to compensate for fiber impairments. The complexity and cost of coherent PM-QPSK modulation format can be justified for the transponders in the high-end edge node of the optical transport network (Fig. 1a) while BPSK modulation format is proved to be more suitable in the convergence option with transponders located in the routers (Fig. 1b). However, the question remains as to the justification of PM-QPSK in terms of performance relative to BPSK due to its design complexity and speed requirement of the analog-to-digital converters (ADC) and digital signal processors (DSP).

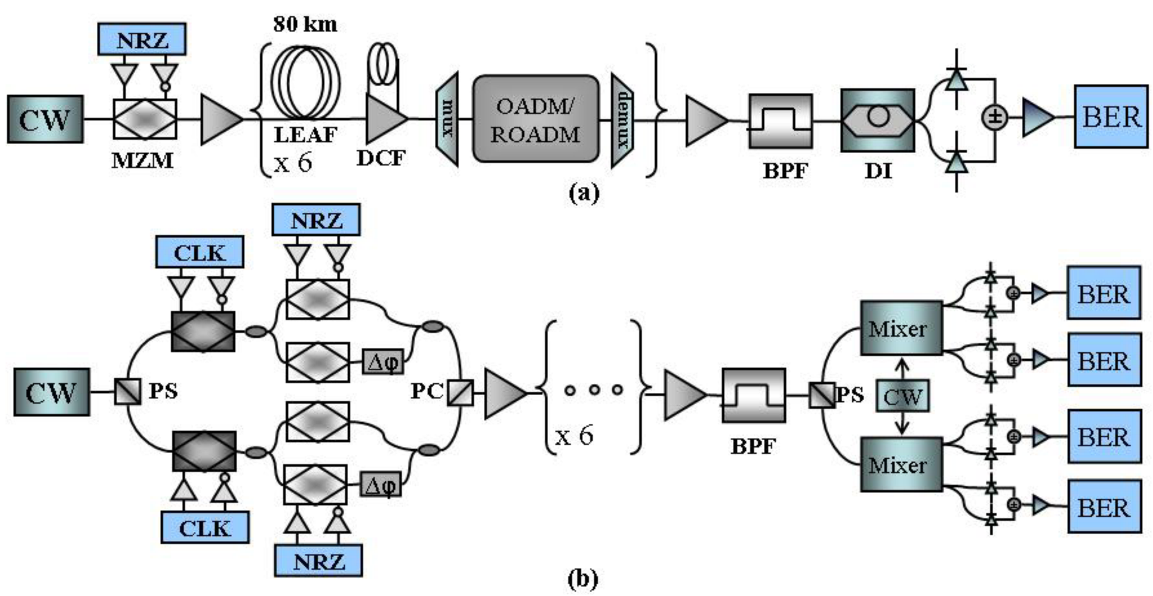

Fig. 2: Schematic of the optical link for (a) BPSK and (b) PM-QPSK modulation formats.

Fig. 2 shows the optical link with the transmitters and receivers for both modulation formats. For BPSK format, a dual-drive Mach-Zehnder modulator (MZM) is fed with a pseudo-random bit sequence at 40 Gbit/s. The MZM is biased at null transmission with $\pm V_\pi$ amplitude on both arms. For PM-QPSK, the DFB laser (CW) emitting at 1552 nm is split using a polarization splitter (PS) into two QPSK structures. Each structure consists of a pulse carver followed by two parallel MZMs with a relative optical phase of $\pi/2$ ($\Delta\varphi$). The two polarization states are combined using a polarization combiner (PC). The optical link consists of a loop representing the network comprised of 80-km spans of LEAF fiber with an average dispersion of 4 ps/nm/km at 1550 nm. An erbium-doped fiber amplifier is used followed by dispersion compensation fiber with an average dispersion of -85 ps/nm/km. A 50 GHz Gaussian filter representing the effect of a ROADM for 50 GHz channel spacing is inserted in the loop. An optical bandpass filter follows at the output of the loop. The receiver for the BPSK consists of a delay interferometer (DI) with a balanced detector. For the coherent detection of PM-QPSK, the optical signal is separated into its two polarization states. A mixer consisting of a 90 degree optical hybrid using the DFB laser as a reference converts the phase information into amplitude onto four balanced detectors. In this work, post-processing is not included and the BER and eye diagram is observed with respect to the laser linewidth.

3. Results

The 40 Gbit/s BPSK modulation format has a wider spectrum profile compared to QPSK (Fig. 3a and 4a). No pulse carving is used in the case of BPSK to keep the spectral energy compacted. Even so, the NRZ-BPSK spectrum profile is wider than the 50 GHz filters in ROADMs (Fig. 3b) and signal energy is lost due to the filtering. Recently, it has been demonstrated that the performance is improved by slightly increasing the free spectral range (FSR) of the DI [6][7]. Essentially, the improvement is achieved by using a delay less than one-bit between the two arms of the DI. This modulation format is referred as partial BPSK. In Fig. 3c, we can see a clear open eye diagram as an effect of the modified DI.

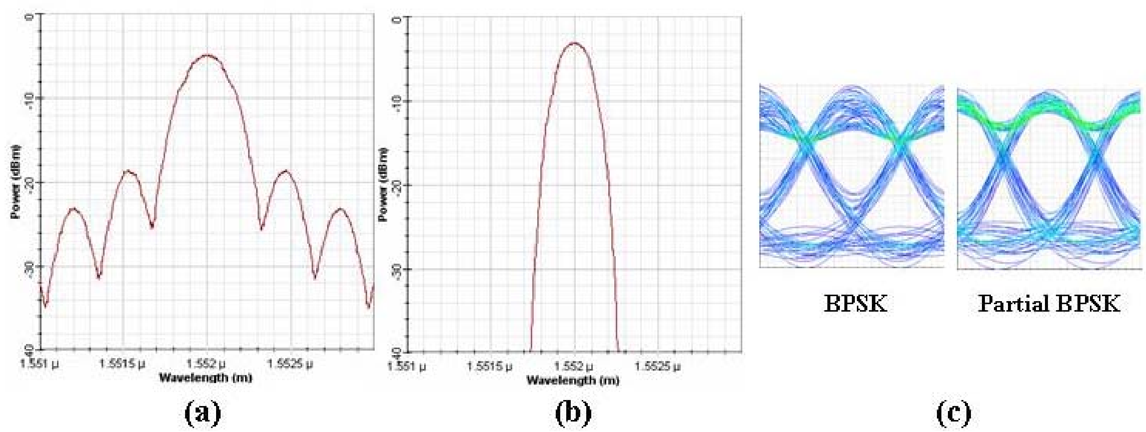

Fig. 3: Simulation results of 40 Gbit/s BPSK modulation format. (a) Spectrum of the launch signal, (b) Spectrum after 6 ROADMs with (c) corresponding eye diagram at 40 Gbit/s.

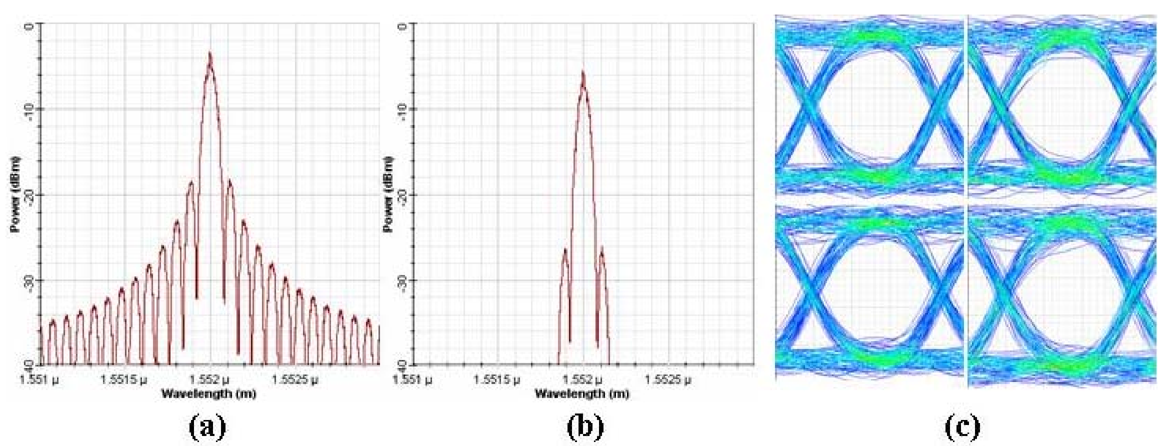

Fig. 4: Simulation results of 40 Gbit/s PM-QPSK modulation formats. (a) Spectrum of the launch signal, (b) Spectrum after 6 ROADMs with (c) corresponding four eye diagrams at 10 Gbit/s.

Next, the linewidth of a DFB laser is an important parameter in phase modulation. Linewidth broadening due to fiber nonlinearities in long-haul coherent optical fiber system occurs due to the Kerr effect and through amplifications processes. Hence, the laser design must be optimized for a narrow linewidth, an important requirement in coherent detection [8]. Additionally, large linewidth translates into timing jitter and reduces the eye diagram width. In Fig. 5, we show the bit-error-rate (BER) with respect to the linewidth of the laser for both direct detection of partial BPSK and coherent detection of PM-QPSK. Although PM-QPSK benefits from a narrow spectrum profile by encoding 4 symbols per bits (Fig. 4a), the linewidth requirement of the DFB laser is more stringent compared to BPSK. Hence, PM-QPSK necessitates narrow DFB lasers in their transponders and monitoring of linewidth broadening within the optical transport link.

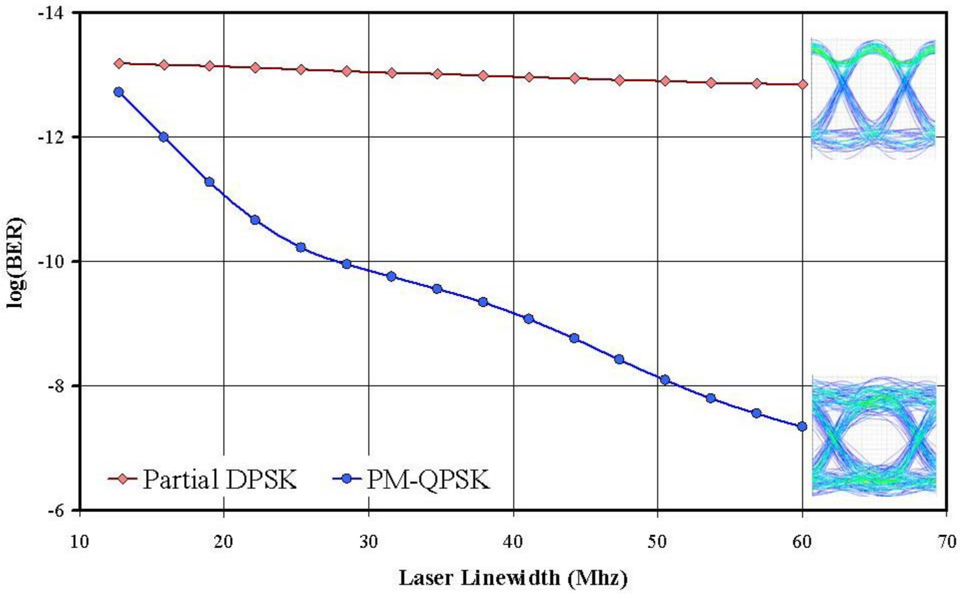

Fig. 5: Linewidth tolerance of coherent PM-QPSK and direct detection of partial BPSK with eye diagrams for a laser linewidth of 60 MHz.

4. Conclusions

With increasing traffic growth on the optical transport network, the advent of 100 Gbit/s Ethernet by 2010 and the convergence of layers, service providers are faced with different approaches in deploying 40 Gbit/s capabilities. DWDM transponders in advanced interfaces can reside either in the router or in the edge node. Correspondingly, specific modulation formats are favored with each solution. Through simulation, we show the tradeoffs between the predominant modulation formats, direct detection of partial BPSK and coherent detection of PM-QPSK. Simulation results show that although coherent PM-QPSK offers tremendous possibilities through post data processing, it has a more stringent requirement on the laser linewidth. The laser linewidth for BPSK is more relaxed; however the spectral profile requires a modification in the delay interferometer to compensate for the fiber impairments. Hence, service providers must carefully weigh those tradeoffs with other factors such as cost and upgradeability to 100 Gbit/s capability.

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