Transmission Performance of Layer-2/3 Modular Switch with *m*QAM Coherent ASIC and CFP2-ACOs over Flex-Grid OLS with 104 Channels Spaced 37.5 GHz

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Abstract: 150G 8QAM and 200G 16QAM signals, residing on a layer-2/3 modular switch card with integrated coherent optics, are sent over a fully-loaded, flexible-grid open line system with 104 co-propagating 37.5 GHz channels.
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1. Introduction

Continued growth in large-scale cloud service provider (CSP) networks, fueled by the rapid adoption of cloud services, is leading CSPs to be as efficient as possible with available bandwidth in their long-haul backbone networks. A long-term study of the traffic in Microsoft's own long-haul network [1] determined that capacity gains of over 70% could be realized by using 150G 8QAM and 200G 16QAM instead of today's 100G QPSK.

By utilizing Microsoft's long-haul open line system (OLS), which features a disaggregated photonic layer where optical transceivers are decoupled from line system common components (amplifiers, multiplexers, ROADMs), these gains can be realized with bandwidth-variable transceiver (BVT) technology. The next-generation integrated coherent optical (ICO) line card for Arista's 7500 series of layer-2/3 modular switches features BVT interfaces that allow selectable QPSK/8QAM/16QAM modulation formats and pluggable analog coherent optic (ACO) capability. This study, which may be viewed as a continuation of that in [1] and [2], pairs the line card with the flex-grid, colorless OLS to achieve 2400 km 8QAM and 1200 km 16QAM transmission over primarily NZ-DSF fiber. Relationships between OSNR penalty, number of channels, and transmission distance are presented.

2. Linecard description

The layer-2/3 modular coherent card made by Arista is depicted in Figure 1. On the line side, four embedded coherent DSP ASICs feed eight adjacent CFP2-ACO pluggable optical ports for a total line card capacity of 0.8/1.2/1.6 Tbps with QPSK/8QAM/16QAM modulation formats, respectively. The card offers 100 GbE wirespeed MACsec encryption as well as layer 2/3 switching capability with deep buffer architecture. The modular configuration of the switch enables client interfaces to be decoupled from the transport line side and provides the client to line side interface over a robust midplane. The four DSP chips are near the front panel to keep them in close proximity to the CFP2-ACO connectors. Each port can be independently configured to the desired modulation. The DSP uses a turbo-product code (TPC) based soft-decision FEC with 25% overhead and employs non-differential phase encoding. The transmit DSP's 65 FIR filter taps are optimized for precise S21 compensation, I-Q/H-V skew zeroing, and any desired pulse shaping. The output of the FIR filter passes through an 8-bit DAC and traverses the CFP2 connector to the ACO module. Pluggability of analog optics requires careful compensation of the channel

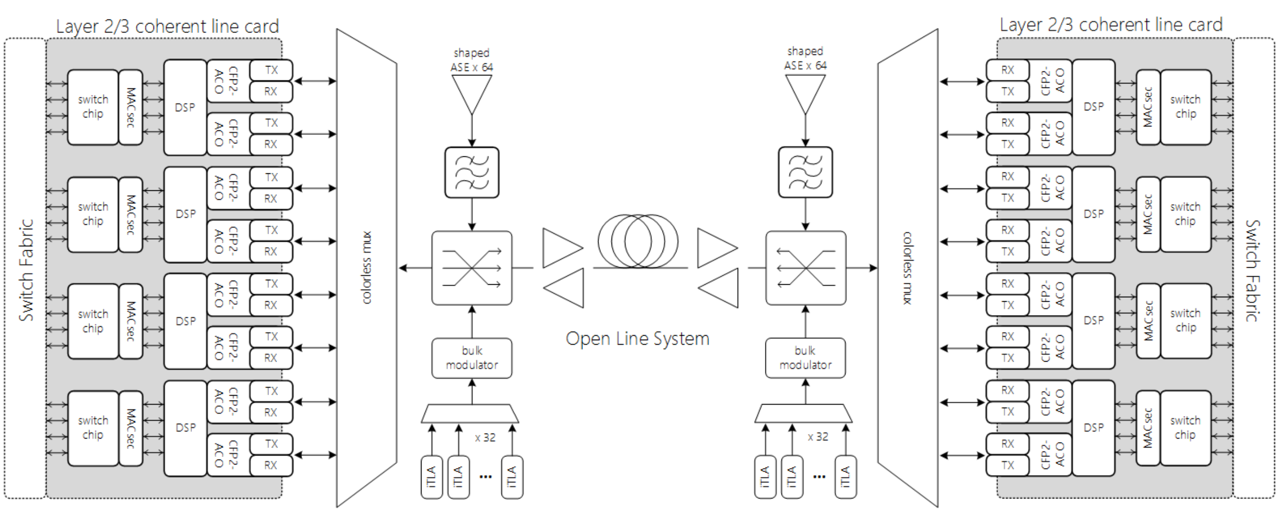

Figure 1. System configuration of coherent line card, bulk-modulated, and shaped ASE signals propagating through OLS

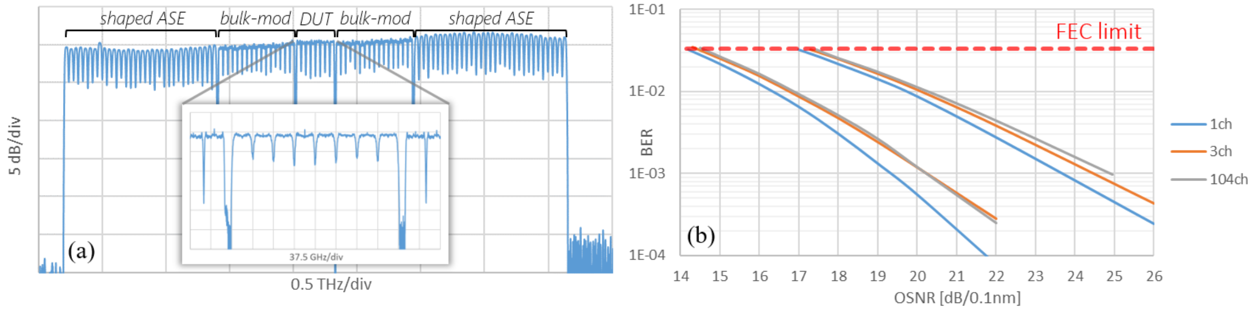

Figure 2. (a) transmitted signal spectrum, (b) 8QAM and 16QAM baseline BER vs OSNR

loss, which is the aggregate of the DAC S21, linecard circuit board traces, CFP2 connector, and the optical module's E/O response. In particular, Nyquist shaped 8QAM and 16QAM signals are sensitive to even slight deviations from ideal S21 and IQ skew compensation, so an equalization routine is automatically executed by the switch control software when the ACO module is first plugged in. The ACO modules used in this work were OIF class 2 variants and included both silicon photonic (SiP) and indium phosphide (InP) processing technologies. All interfaces support grid-less tuning with 6.25 GHz resolution and 37.5 GHz channel spacing at full line-rate.

3. System configuration

The same optical OLS and fiber testbed described in [1] and [2] were used for these measurements. The line system features a colorless, directional ROADM architecture, hybrid Raman/EDFA amplification, and able to be monitored and configured via Microsoft's SDN controller. The transmission testbed allows for 2000 km bidirectional (or 4000 km unidirectional) transmission over primarily NZ-DSF fiber. New for these measurements, the setup was augmented with 32 bulk-modulated *m*QAM channels and 64 shaped-ASE "channels" which have been optically filtered to emulate a 34 Gbaud RRC = 0.2 *m*QAM signal. These are shown in Figure 1, added at the terminal ROADM nodes. Measured performance of the devices under test (DUTs) should be conservative because 1) no specific measures were taken to time-decorrelate the bulk-modulated channels, and 2) ASE channels produce more harmful cross-phase modulation than data-modulated carriers.

Eight ports of the coherent line card were connected to an OLS colorless mux, with the module frequencies configured as eight contiguous 37.5 GHz spaced channels. These eight channels were routed to one port of the terminal ROADM mux WSS, the bulk-modulated signals to a second, and the shaped-ASE signals to a third. In total, 104 channels were independently provisioned and managed end-to-end through the OLS. The transmitted optical spectrum is shown in Figure 2. The dips observed between channel groupings are intentionally provisioned 6.25 GHz "dead-bands" which avoid the impact of WSS rolloff as adjacent channel groups are stitched together or routed for receiving at terminal ROADMs.

4. Results and discussion

Since measurements with QPSK were previously reported in [2] and the majority of the Microsoft long-haul backbone can be serviced by higher order modulation [1], study of QPSK was omitted and the focus was 8QAM / 16QAM performance. First, BER versus OSNR was baselined for 8QAM and 16QAM in single channel configuration, with adjacent 37.5 GHz neighbors, and with all 104 37.5 GHz-spaced channels incident upon the receiver (however, those outside the 8-channel DUT band were blocked by the egress WSS), shown in Figure 2b. Observed back to back OSNR sensitivities for 8QAM and 16QAM were 14.2 and 16.9 dB, respectively. About 0.3–0.4 dB penalty is observed when adding immediate 37.5 GHz, where the bandwidth of the receiver/TIA chain allows enough of the neighboring signals beating with the target channel local oscillator (LO) to pass through the analog

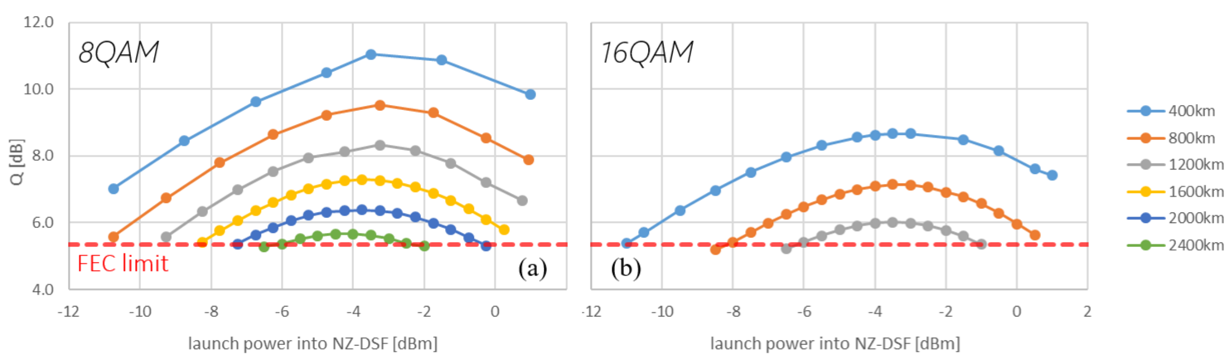

Figure 3. Launch power optimization for (a) 8QAM, (b) 16QAM (average of all 8 DUT channels)

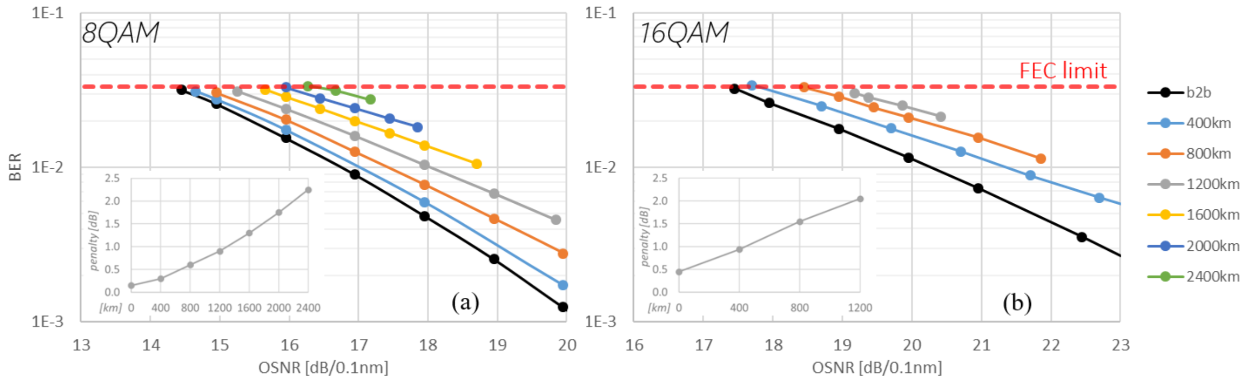

Figure 4. BER vs OSNR at full-fill optimal launch power for (a) 8QAM, (b) 16QAM (average of all 8 DUT channels)

interface and contribute to the random noise at the DSP ADC. Addition of channels outside of the immediate 37.5 GHz neighbors yields no further impact, as theory would predict.

Fiber launch power optimization was then performed for the fully-loaded system at multiple distances (Figure 3, which shows the average performance over all eight DUT channels). For both 8QAM and 16QAM, optimal launch power was approximately -3.5 dBm/channel into NZ-DSF spans (SSMF spans were nominally 3 dB higher) and was independent of distance propagated. This result is consistent with findings in [2], where optimal power was about 0.5 dB higher, but with only seven channels present. Detailed BER vs OSNR curves are in Figure 4 over transmission distance at optimal launch power. The inset shows the OSNR penalty at FEC threshold versus distance. For 8QAM, there is 2.3 dB of penalty after 2400 km of propagation, with nearly 1 dB of system OSNR margin remaining. Likewise, 16QAM transmission is achieved for up to 1200km, with 2.1 dB of OSNR penalty and 1.5 dB of system OSNR margin left.

Growth of OSNR penalty versus number of channels propagated was of particular interest, since most work to date represents this primarily in terms of nonlinear interference noise power or maximum transmission distance [3]. To that end, 16QAM propagation with 1, 3, 8, and 104 contiguous 37.5 GHz-spaced channels was performed at multiple distances, with launch powers optimized for each configuration. Figure 5 shows this both as a function of number of channels and of distance. The OSNR penalty appears to track logarithmically with number of channels, regardless of distance, which is consistent with the numerical simulation results in [4]. When slicing the results by number of channels as a function of distance, from 400 km to 1200 km the OSNR penalty appears to grow roughly linearly, regardless of channel count. The initial offset at 0 km of the 3-, 8-, and 104-channel cases from the single-channel case is a result of the neighboring 37.5 GHz channel beating with the DUT LO, as described earlier.

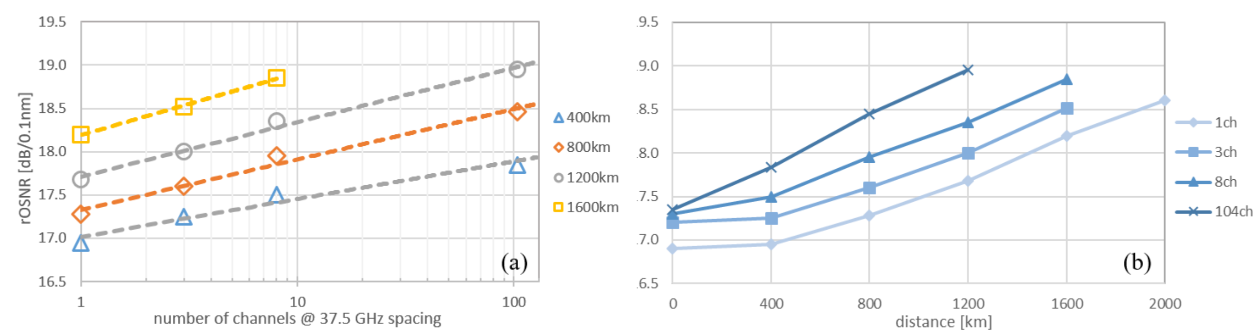

Figure 5. 16QAM required OSNR versus (a) number of channels and (b) distance

5. Conclusions

Transmission performance of 150G 8QAM and 200G 16QAM from a layer-2/3 modular switch over a fully-filled, flexible-grid OLS has been studied. Excellent back-to-back OSNR sensitivity of 14.2 dB for 8QAM and 16.9 dB for 16QAM was observed. Propagation through 2400 km at 8QAM and 1200 km at 16QAM NZ-DSF was achieved over the OLS operating at 37.5 GHz channel spacing with 1–1.5 dB of OSNR margin remaining. These results are well in line with state of the art ([5],[6]) and further prove that performance tradeoffs need not made to run a line system in an open fashion, or to use transceivers with pluggable analog optical front-ends.

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