CAPEX Savings Enabled by Point-to-Multipoint Coherent Pluggable Optics Using Digital Subcarrier Multiplexing in Metro Aggregation Networks

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Abstract Acknowledging the predominantly hubbed traffic profile in the metro, we apply digital subcarrier multiplexing techniques to 400Gb/s coherent pluggable optics, enabling a point-to-multipoint architecture which shows TCO savings of 76% over a five-year period compared to a traditional architecture based on ROADMs and point-to-point transponder

Introduction

Communication Service Providers (CSPs) build the infrastructures that allow users to connect to the Internet through wireless, access, metro and core optical networks. While basic service speeds per subscriber keep increasing, the revenue, typically, does not. CSPs consequently react by increasing the network capacity within a fixed annual CAPEX budget, a solution that is not sustainable over long periods, driving the need for new architectures to further accelerate the reduction in cost per transported bit.

In core networks, with large point-to-point (P2P) traffic flows, advanced coherent transponders continue to drive down the cost per bit. The usage of high capacity coherent transponders, however, does not efficiently apply to aggregation networks where the traffic flow at the edge is inherently smaller than at the core. The consequence is that CSPs are both forced to compromise on the appropriate transponder capacity and required to accurately estimate the future traffic needs of the network which is often difficult to predict.

In this study, we explore the impact of using emerging point-to-multipoint (P2MP) DWDM coherent optics, enabling a paradigm shift in the way aggregation networks are designed. The P2MP optics are packaged in standard transceiver form factors amenable to insertion in layer 3 (L3) equipment. We have modelled the total cost of ownership (TCO) savings over five years of traffic growth – across a nationwide footprint of metro area networks (MAN) with current traffic demands and assumed average Compound Annual Growth Rate (CAGR) of 30%. We have compared the costs against a reference architecture using a separate L0/L1 network, where traffic is carried by traditional P2P transponders.

Both scenarios use the same L3 architecture and network topology with protection provided within the IP layer via diverse optical paths. For the reference architecture, P2P transponders with breakout cables are used to interconnect 400GbE router ports to 100GbE transponder ports. The P2MP transceivers can manage this connectivity directly. 400GbE router ports are utilized in all hub sites from day one, while intermediate node ports all start with single 100GbE ports. As traffic grows, routers in intermediate nodes can be upgraded to use 400GbE on a per-site basis.

Digital Subcarrier Coherent 400G DWDM Pluggable Technology

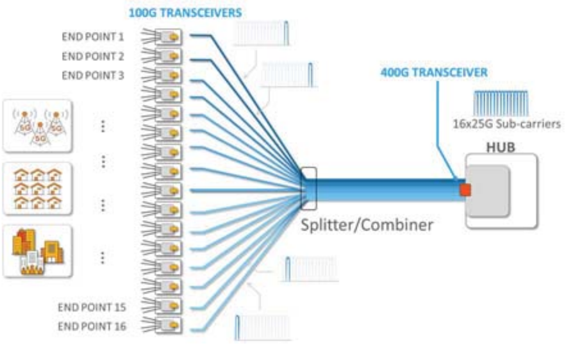

Fig. 1. Nyquist digital subcarriers enable point-to-multipoint transmission.

P2MP optical transmission is realized by installing 400GbE transceivers directly into hub site L3 hardware and leveraging DSP algorithms to generate Nyquist digital subcarriers at a lower data rate[1]-[3]. Each subcarrier can be used independently to directly connect to low-speed and high-speed optical transceivers in intermediate nodes. The hub transceiver in Fig. 1 broadcasts 16 Nyquist digital subcarriers to all end points, where lower-capacity transceivers tune into their allocated frequencies to receive their dedicated Nyquist subcarriers. Each end point transceiver uses its incoming Nyquist subcarrier's frequency as reference for its transmitter, allowing Nyquist subcarriers from all end points to be multiplexed into the hub site transceiver without collision. This directly enables novel L1 network architectures with fewer aggregation devices [1][2]

Management and control of the P2MP transceivers is enabled via an external controller enabling power, alarm and configuration management to be partitioned from the L3 environment.

Using P2MP optics allows hub sites to leverage higher-rate ports while smaller intermediate nodes may use lower-rate ports, minimizing the cost per bit transported in all node types. In the reference P2P architecture, port rates at each end of the link per definition must match. With P2MP transceivers, the optimal rate port can be chosen, independent of its neighbouring sites. This transformation of allowing high and low speed ports to co-exist and communicate directly to each other enables operators to upgrade sites independently as capacity and economics for that individual site dictate while simultaneously enabling efficient utilization at each site.

Further savings are realized by using pluggable optics, saving on the costs of deploying separate transponders, transponder chassis, and back-to-back grey optics.

Method and Use Case

The reference network considered in this conceptual analysis consists of 226 chains connecting 880 intermediate nodes and is representative of a wide range of metro networks across a national geography[4]. At each end of the chain there is a hub node where traffic is aggregated onto the wider core network and all traffic from intermediate sites is sent to both hub sites for resilience. All traffic is hub-and-spoke in nature, with no traffic directly between intermediate nodes.

The average distance between an intermediate node and the hub sites is 44 km with a maximum distance of 284 km. The span length average is 16 km with a maximum of 100 km. The number of intermediate nodes on a chain varies between 1 and 9 with an average chain length of 3.9.

Year 0 traffic capacity is provided for each intermediate node rounded up to the nearest 25 Gb/s. For each intermediate node, its full capacity is assigned to both hubs at the end of the chains for resilience. To provide sensitivity analysis of the proposed solutions, a Monte-Carlo simulation of traffic growth was performed consisting of 30 runs over 5 years. This assumes a growth rate following a normal distribution with an average growth of 30% per annum and a standard deviation of 30% to allow sites to grow at different rates. Every intermediate node grows its traffic independently in each run and each of the years modelled.

Point-to-Multipoint Architecture

The proposed P2MP architecture is built on a filterless line system [2], featuring enough add/drop ports to last through the whole modeled time period. P2MP pluggable optics with 100GbE and 400GbE interfaces based on 25 Gb/s subcarriers have been used, allowing a 400GbE pluggable optic installed in a hub site to simultaneously communicate with up to 16 intermediate nodes.

The 25 Gb/s Nyquist subcarriers are assumed for transmission employing polarization multiplexing (PM)-16QAM modulation formats with a 4 GBd symbol rate. Any reach penalty, imposed by the constraints on space, power and cooling due to the form factor, is not significant in this study as all chains are shorter than 300 km and have at most 9 intermediate nodes. All services on all 226 chains in the reference network can be transported without intermediate signal regeneration. The aggregation point is displayed in Fig. 1.

Traffic from intermediate nodes is simply provisioned towards each hub site in 25G increments based upon that year’s demand requirement.

Traffic in the hub sites is terminated on 400GbE P2MP pluggable optics. As more Nyquist digital subcarriers are required in aggregate, more pluggable optics are added to meet the demand.

Baseline Architecture

The baseline network uses a standard Reconfigurable Optical Add/Drop Multiplexer (ROADM) L0 architecture[4], with single-stage EDFAs and colorless mux & demux structures. L1 is implemented with transponders housed in separate transponder chassis, connecting to L3 with back-to-back grey optics. A ROADM architecture was chosen to mirror the dynamic bandwidth allocation capability present in the broadcast architecture mentioned above.

The optimal transponder data rate was found by considering network traffic demands, normalized cost per bit, and operational simplicity. Whereas cost per bit goes down as transponders become more complex, a lower-rate transponder can provide better economics if the total traffic in a site is small.

A data rate of 100 Gb/s per P2P transponder for the baseline scenario provided the best network economics – as traffic is quite modest in the traffic model; the use of higher data rates results in excess lineside capacity being deployed both in hub sides and intermediate nodes.

For what concerns costs, we employed the normalized model proposed in[5], with the additional components listed in Tab. 1. The transport chassis is used to house both L0 and L1 equipment.

Results

We assess the benefit of the novel proposed architecture by evaluating different metrics. The first is the total network capacity deployed at year 0 and how it grew over time. We studied the utilization of the deployed capacity, defined as the total amount of terminated traffic, which is a fraction of the actual line side capacity.

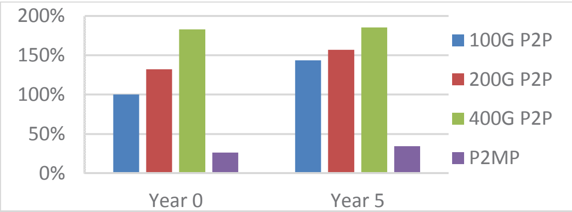

Fig. 2 Normalized cumulative CAPEX for different P2P transponder data rates compared to P2MP transceivers.

It is clear from the capacity utilization that the penalty associated with higher rate P2P transponders does not apply to the P2MP scenario – we are able to use the higher rate 400GbE transceivers at the hub sites with lower cost per bit without deploying excess lineside capacity. This will reduce the needs for statistical multiplexing at L2 and L3, providing significant cost savings outside the scope of this analysis.

Next, CAPEX costs were assigned to the scenarios using the normalized cost model described above. We compared Year 0 and Year 5 costs for different P2P transponder rates, and the results are displayed in Fig. 2. For the considered network and under the traffic conditions, going to higher rate transponders does not reduce total costs even after 5 years of traffic growth.

L0 costs were in line with previous findings, demonstrating how filterless line systems can be equally flexible but far more cost efficient than ROADM architectures, as long as the impact on total fiber capacity is acceptable[6]. Costly WSS components are removed and express losses are reduced.[5]

Product	Cost
Single-stage EDFA, variable gain	0.36
1x4 colorless mux/demux	0.10
1x8 colorless mux/demux	0.15
Transport chassis (400 Gb/s)	1.00
100GbE P2MP pluggable optic	1.50
400GbE P2MP pluggable optic	3.00

Tab. 1 Additions to normalized cost model introduced in[5].

CAPEX for the filterless line system was 62% lower than for the baseline ROADM line system, while simultaneously enabling greater flexibility in bandwidth usage across the sites.

Looking more closely at how the total CAPEX evolves over time (see Tab. 2) the use of a filterless line system and P2MP pluggable optics deliver large and consistent CAPEX savings through the whole time period.

The savings are enormous, but not surprising when considering the aggregation of traffic into fewer and larger hub site transceivers with significantly lower cost per bit combined with the elimination of transponders, ROADMs, and transport chassis.

Year	Baseline 100GbE P2P	P2MP	Delta
0	27885	7353	-74%
5	40029	9582	-76%

Tab. 2 Cumulative L0/L1 normalized CAPEX over time, measured in cost units from[5].

It is worth noting that using higher rate pluggable optics reduces recurring space and power costs and also the frequency and scope of site visits. The proposed P2MP architecture also enables a level of disaggregation that allows any node to be independently upgraded in the future without impacting other sites in the network, which could have significant impacts on future network upgrade costs and scope as compared to the current operating mode of carriers.

Conclusions

CSPs building MANs with modest traffic demands per access site should exercise caution when choosing which type of transponders to deploy – a lower cost per bit may not produce the best network TCO.

We have shown that emerging point-to-multipoint DWDM optics can produce significant CAPEX savings in the transport layer by allowing operators to optimize the choice of optical transceiver capacity on a per site basis.

Further, we have shown that pluggable optics provide savings in MANs with links of up to 300 km with 9 intermediate nodes.

This work could be expanded to include the effects on L2 and L3 equipment and to add the impact on OPEX to the model.

Acknowledgements

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