Cost Model Comparison of ZR/ZR+ Modules Against Traditional WDM Transponders for 400G IP/WDM Core Networks

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Abstract *The introduction of ZR/ZR+ optics means that WDM optics can now be integrated into IP routers in a cost-effective manner without reducing IP router port density. We present a model comparing the costs of building a national network with these new modules to traditional transponders.*

Introduction

National telecom networks have typically been built using separate IP and WDM systems interconnected using grey optics modules. This architecture has been driven by the large size and power dissipation of WDM optic modules meaning that integrating the coloured optics within the IP router would decrease the port density of the router, necessitating the need for multi-chassis routers which are less efficient.

IP routers are now being manufactured utilising the QSFP-DD pluggable module cages which can support interface speeds up to 400G. The OIF have also been standardising 400ZR optics which fit into such a cage and provide tuneable WDM capabilities in a form factor that does not decrease the port density of the IP router. A further iteration of these optics called 400ZR+ gives even greater reach. These developments have the potential to allow an integrated IP over WDM networks to become a cost-effective solution.

This paper presents a technoeconomic study comparing the network capital expenditure costs of building a national core IP network with 400ZR/ZR+ optics against traditional WDM transponders.

400ZR and 400ZR+ Optical Modules

400ZR optics are being standardised by the OIF as a 400G capable QSFP-DD pluggable module. The implementation agreement has been finalised[1] with the first modules expected to be available in 2020. They are based on coherent optical technology utilising DP-16QAM modulation along with C-FEC error correction. The improvements in CMOS technology have meant that the power consumption of the digital signal processing elements have now come down to <2W per 100G[2] meaning that the overall module fits within a 15W power envelope that fits within the QSFP-DD Specification[3]. This advancement is the reason why such modules can now be directly plugged into routers without a reduction in port density.

400ZR optics can either be used directly connected or as part of a WDM system utilising filters and terminal amplifiers. When directly connected without amplifiers the reach is limited to a 11dB loss budget[1] which means a maximum 40km distance assuming a 0.275dB/km fibre loss. When terminal amplifiers are used this distance can be increased to 120km, being limited by noise. By including filters at either end of the link, multiple 400ZR signals can be multiplexed onto a single fibre pair with 100GHz (or optionally 75GHz) filter spacing.

400ZR+ optics is the name given to expected enhancements to the 400ZR specification, although these are likely to contain proprietary components meaning that modules may not be compatible between vendors. This proprietary element is likely to be based around the FEC schemes utilised. 400ZR+ optics are expected to have a reach of up to 400km in the direct point-to-point WDM systems. Due to their tighter isolation, more advanced FEC schemes and higher transmit powers, 400ZR+ modules are expected to be able to pass through ROADM structures offering the ability to be used on traditional long-haul WDM systems with appropriate filters.

Tab. 1: 400ZR/ZR+ Module and 400G WDM Transponders Summary Table

Module	Cost	R1	R2	R3
400ZR	1	25km	80km	X
400ZR+	2	X	400km	250km
Transponder	5	X	1500km	1500km

For the purposes of this paper we have assigned relative cost units and indicative reach limits for each module type and for a standard 400G long-haul WDM transponder. R1 is the reach with direct connection (no terminal amplifiers), R2 is the reach with amplification and R3 is the reach through a ROADM system. The reaches in Table 1 take account of the additional losses that would be present in telecommunications network planning rules (such as splice losses, repairs, ageing, etc.) and these reaches are used in the modelling performed within this paper.

Reference Network

The modelling in this paper was performed on a model of the BT fibre network as shown in Figure 1. It consists of 106 sites, 10 of which are classified as hubs and 3 of these are Internet peering points. Sites are connected to one of the hubs and separately to two of the Internet peering sites with diverse routing for resilience.

Each link in this network is one or more standard G.652 fibre pairs. The minimum link length is 1km and the maximum is 470km with an average of 72km. Figure 2 shows the distribution of link lengths in this network.

For the purposes for the modelling in this paper, the total peak demand from broadband traffic in 2020 is assumed to be 16.5Tbit/s. Note that additional network capacity is installed to provide resilience.

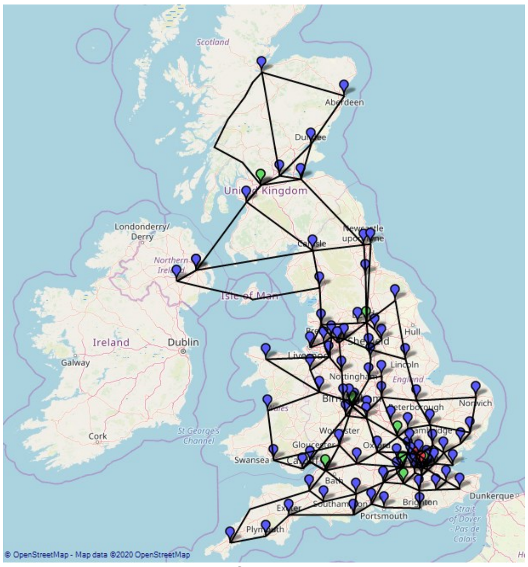

Fig. 1: Reference Network

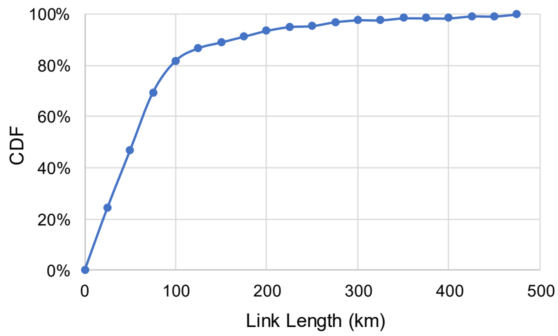

Fig. 2: Distribution of Link Lengths in the Modelled Network

Modelling Scenarios

In this technoeconomic study we have modelled four different scenarios:

Scenario A is where IP routers are connected only with 400ZR optics modules and each is given a dedicated fibre pair without amplification or filter system. Additional conversion in the electrical domain is required every 25km.

Scenario B is where IP routers are inter-connected with either 400ZR or 400ZR+ optics, depending on the link length. Terminal amplifiers are used at each end of the link along with fixed WDM filters.

Scenario C uses a ROADM network: 400ZR+ modules are used between routers where the path distance supports it and traditional 400G WDM transponders for longer paths.

Scenario D again uses a ROADM network. IP routers are connected to the WDM transponders using short reach grey optics modules for all distances.

For Scenarios A and B, traffic passes through each intermediate IP router in the path between the source and destination node with traffic being aggregated from multiple sources. For Scenarios C and D, the source and destination IP routers are directly connected across the ROADM network.

In all scenarios it is assumed that traffic grows at 30% per annum from the 2020 levels and an eight-year time frame is considered.

Modelling Approach

To perform this modelling task a bespoke multi-layer modelling tool was written in C#. The tool first takes the fibre connectivity and IP level demands and chooses which fibre links are necessary to support the IP level connectivity.

The IP traffic is then routed across the network using a pair-diverse, minimum hop routing algorithm[4] which determines two paths that are link and node diverse for each demand. By allocating the peak demand traffic over both diverse paths, a resilient network design can be obtained.

Once the demands have been routed, the total aggregate traffic on each link is determined along with the number of modules and IP router ports required. From this the cost of the network build is then calculated. The cost model includes the costs of the fibre, transceivers, incremental IP equipment (expanding existing core router with ports and cards where required and additional routers in Scenario A where required for reach reasons) and WDM/ROADM equipment, depending on the scenario. As this is a capital expenditure model, the operational costs (power, cooling, etc) are not considered.

Results and Analysis

The results of the cost modelling are shown in Figure 3 with only equipment costs in (a) and both equipment and fibre costs in (b). For each of the four scenarios, the cost projection of the network build over the eight-year time frame is shown. All curves are relative to the costs of Scenario D as this scenario is one where no ZR/ZR+ modules are used and can baseline the

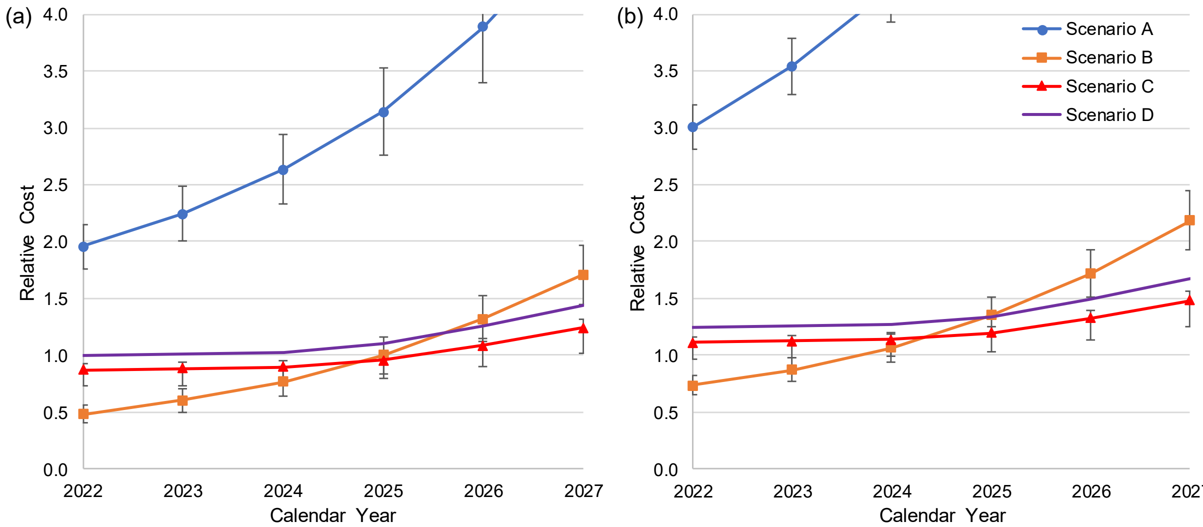

Fig. 3: Modelling results (a) equipment only and (b) equipment and fibre costs. All costs relative to Scenario D equipment only.

other scenarios. Error bars show the impact of a ±30% cost of ZR/ZR+ modules and +0% and −30% on WDM transponders to reflect the cost of these decreasing as the market evolves.

Scenario A is clearly a higher cost solution than the other three scenarios, due to the number of ZR modules and additional routers required to cover the short reach of unamplified ZR optics. As Figure 2 shows, only 24% of the links in the modelled network are less than 25km, this means that 76% links will need additional routers to regenerate the signals. Significant additional fibre costs are seen due to no fixed filters being used to multiplex signals.

Scenarios C and D track each other closely as they are both based on an underlying ROADM network topology. Scenario C is always a lower cost as it uses ZR+ optics where the path length allows.

While Scenarios A and B show increasing costs from the start, Scenarios C and D only start growing in cost from 2024. This is because traffic between any site and its associated hub and peering points remains under 400Gbit/s until that time. As sites are directly connected via a ROADM network in Scenarios C and D, this means that links remain underutilised until traffic grows enough to fill a 400Gbit/s link which then triggers the addition of a new transponder pair. For Scenarios A and B, this underutilisation means that traffic aggregates efficiently as it traverses each IP router from source to destination but requires additional ZR/ZR+ modules each year to deliver the traffic growth.

Comparing Scenarios B and C, Scenario B starts off as a lower cost and then ends with a higher cost compared to Scenario C with a crossover between years 2023 and 2025. This is again due to the underutilisation of the 400G links in the early years meaning the aggregation of traffic is utilising spare capacity in the network. However, as the traffic grows, a point is reached where the yearly incremental traffic growth between two sites approaches 400Gbit/s. While this additional growth can be delivered using a single transponder pair in Scenario C, Scenario B requires additional ZR+ module pairs for each hop in the end-to-end path. If there are more than three hops, then the cost of ZR+ outweighs the cost of a traditional WDM transponder and this results in the cost of Scenario B growing at a faster rate than C.

Conclusions

The results show that the emerging ZR/ZR+ modules can be used to support 400G links in IP/WDM core networks in several different ways. They can be used to interconnect IP routers hop-by-hop either with or without filters and amplifiers, although without, the limited reach of ZR and additional fibre increases costs significantly. ZR+ modules can also be used within a ROADM network alongside standard WDM transponders. We have compared the costs of different options and we expect that ZR/ZR+ will almost certainly feature in future core networks. In both scenarios which use ZR/ZR+ modules there are significant cost savings to be made by avoiding the use of transponders. The price points and the ability to collapse IP and WDM technologies into one device without losing router system density is now available for the first time.

Acknowledgements

The authors would like to thank Cisco, Ciena and Nokia for helpful discussions.

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