# Comparative Assessment of Network Architectures for Transporting Packet and TDM Traffic

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***Abstract*— Advancement of communication technologies and business patterns has contributed to the increase of consumer demand and machine-to-machine network traffic. Following this, a steep downward trend in revenue per bit and a slower decay in cost per bit transported is being observed. This poses serious challenge for network operators to correctly choose the technologies and architecture for transporting both packet and legacy TDM traffic. Thus, future expansion of the network should exploit the architecture that results in the most cost-effective transport of both packet and TDM traffic, aiming to keep TCO at its lowest while ensuring traffic meets its designated SLAs. In this paper we address metro, regional and long haul networks with varying traffic patterns (both packet and TDM) looking at the fundamental problems in network scalability and point to some solutions to ensure that cost-effective network traffic scaling can continue to enable future communications services.**

***Keywords—transport networks; OTN; TDM; IP/MPLS; multi-layer optimization***

## I. INTRODUCTION

Of late a surge was noticed in video and data traffic, thus fueling exponential bandwidth growth from enterprises, broadband, and mobile data. Advanced communication technologies and change in business patterns incurs significant growth of this traffic load. As reported recently, there is an increased use and dependence of the Internet by the residential customers for a multitude of services (e.g., online gaming, video chatting, social media, online shopping), which has increased bandwidth requirements significantly. Similar trend has been noticed for the business customers segment where bandwidth consumption has increased rapidly by the financial and government organizations. As the underlying, highest capacity communications enabling infrastructure, the optical transport networks must evolve to support the increased demand of bandwidth from both residential and business sectors [1].

This data growth however adds challenges to network operators. The primary reason for the same can be designated to downward trend in revenue. Revenue growth was negatively correlated to the bandwidth growth due to the falling per-unit, per-bit cost structure [2]. Operators on one hand feel the need to converge their network to obtain an improved cost efficiency while on the other make sure that network scalability is plausible for coping with growing traffic demand. Reducing network cost is thus a strong motivation for network operators to correctly choose the technologies and architecture for transporting the traffic across the network maintaining the required Service-level Agreements (SLAs).

Here it is worth mentioning that IP is the predominant traffic in transport networks and its share is still increasing. But at the same time installed SDH/SONET infrastructure is still in use. Consequently, operators have to support, at the same time, the widely deployed TDM traffic along with the fast growing packet traffic. This provides the motivation, underlying this work, to identify the most suitable transport network architecture and associated technologies that can efficiently accommodate together large capacity of both packet-based and circuit-based traffic and also maintain or even enhance the reliability and scalability characteristics provided by traditional transport networks.

In the course of the paper, two representative network topologies were selected, aiming to cover a long-haul and a ultra-long-haul network scenario, respectively. Traffic projections combining packet and TDM traffic were generated by relating current traffic patterns with future growth estimations [3]. Following this, two architectures were considered excluding and including OTN switching, while four optimization models were exploited: Switchless Opaque, Switchless Transparent, Switchless Translucent and OTN Switching based (including both pure-OTN and packet switching enabled universal-switching). This paper is organized as follows. Section II outlines each of the architectures as mentioned above, whereas section III presents the optimization models. Section IV details the choices when selecting a particular architecture or optimization model. Following this, the network design and evaluation method is discussed in Section V. Cost comparisons between the two architectures using the four optimization models, detailed cost breakdowns, and attained savings are reported in section VI. Finally, section VII presents the concluding remarks.

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## II. NODE ARCHITECTURES

Technological advancements have seen different node architectures being proposed, each having their pros and cons. Scope of this paper concentrates mostly on two specific types: excluding an OTN switch referred to as Switchless architectures and including an OTN switch referred to as Hybrid architecture (motivated from the hybrid switching of packet and TDM traffic). Both architectures look forward to serve the internet connectivity for both fixed and mobile communities and the principle idea here is to figure out the logical extreme of each architecture to attain network simplicity and CAPEX/OPEX reduction.

### *A. Switchless Node Architecture (excluding OTN Switch)*

With a view of simplifying network architecture, the switchless architecture has been promoted some time ago, mainly focusing on utilization of trans/mux-ponders to map services onto DWDM interfaces (refer to Figure 1). In a mixed network that carries TDM and/or Packet traffic, when the service closely matches the WDM line rate, it is mapped using a transponder. Alternatively, when the service data rates are smaller when compared to WDM line rate, a muxponder (e.g. 10x10Gb/s or 2x40+2x10Gb/s) is used to aggregate these sub-rate demands into a WDM line.

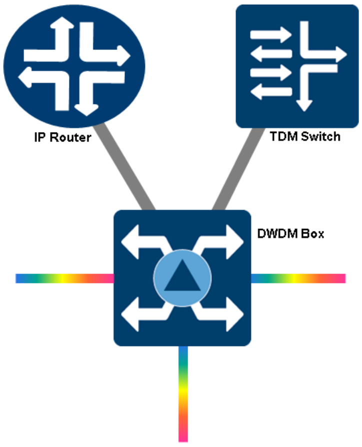

**Figure 1 – Switchless Architecture**

Though the services are aggregated at the end-points allowing end-to-end connections with optical bypass, the option of intermediate grooming still exists with minimum flexibility, resorting to manually performed interconnection of muxponder client ports. Intermediate grooming is mostly performed at sites where regeneration is required thus forcing an OEO conversion. This architecture is most efficient in cases where router up-link connections are already filled with Internet data (which can be treated as point to point traffic) and the up-link rate is the same as the DWDM wavelength rate. However, using this approach operators consistently build up two layers: Packet Layer and Transmission Layer in parallel at the same growth rate, thus resulting in scalability limitations or in missing the chance to exploit state-of-the-art technology in the transmission layer, thus resulting in worst CAPEX and OPEX. Also, when neither packet nor TDM traffic sources generate full or near-full connections a major drawback of this model is that, packet and TDM traffic cannot be groomed/aggregated into the same ODU (even though G.709 ODU frames are generated from the router or transmission equipment), thus at times flooding the network with partially filled ODU containers. This approach hinders bandwidth optimization, streamlining of network efficiency, and improvement of wavelength fill.

### *B. Hybrid Node Architecture (including OTN switch)*

To cope with the mix of packet traffic and widely deployed legacy TDM traffic, recent node architectures include an OTN switch to provide service-agnostic switching for mapping different client services into ODU frames and then switch them at that level. The main idea is to allow sub-wavelength services to be multiplexed and thus reduce the use of WDM ports. This architecture utilizes a similar trans/mux-ponder structure described in the Switchless Node Architecture with the introduction of a digital OTN switch. This node architecture could place a stand-alone OTN switch separated from the WDM box using short-reach optics or integrated with the WDM box thus reducing space and power.

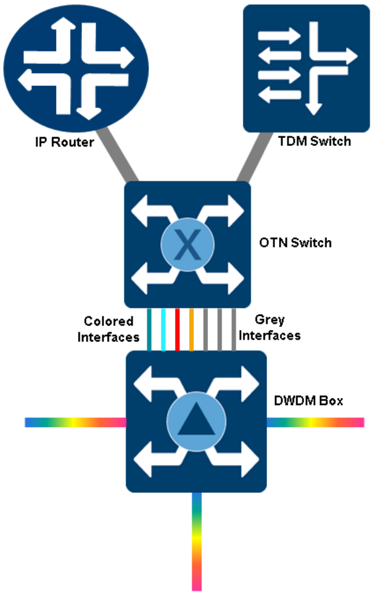

**Figure 2 – Hybrid Architecture (with OTN switch)**

Several other benefits from deploying an OTN switch include fast end-to-end service provisioning, rapid restoration, high scalability, and easy support of new/multiple traffic types. Also, sub-lambda level switching, client service level mapping, and router port offloading deserve to be mentioned.

However, if the service data rates are the same as the data rates of the WDM wavelength channels or that only packet traffic is present, then the switchless architecture can have a CAPEX advantage over the switched one by simplifying the overall equipment from network layers L3 to L0. Also, stand-alone OTN switching may imply increased power and space consumption, challenging network operators' wallet.

## III. OPTIMIZATION MODELS

Based on the two architectures described, the following optimization models can be used. Note that these models mimic the field deployment of packet and TDM (legacy technology) traffic.

### A. *Switchless Opaque*

This model mimics a pure L3 aggregation scheme for the packet traffic, where at every hop all packet demands are processed at the core routers and the TDM traffic is processed at the TDM switch. Also, the packet traffic and TDM traffic are carried over separate wavelength channels. Every hop involves OEO conversion with in-between manual patching of connections if reconfiguration is required. In this approach, the WDM layer is purely used for wavelength multiplexing and transmission and optical bypass is not exploited, thereby avoiding the deployment of Remote Optical Add Drop Multiplexer (ROADM) nodes. All routing and resilience mechanisms reside at the packet and TDM layers. Optical interfaces are required at every node for all added, dropped and transit wavelength channels. As a result, it is also referred as Full Router Model concerning packet Traffic (refer to Figure 3).

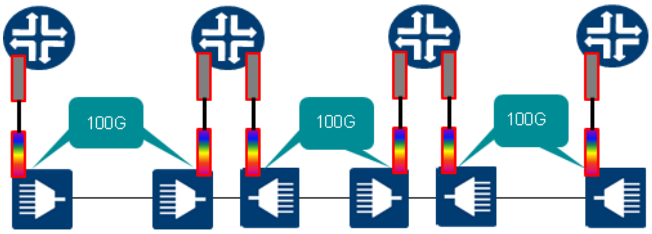

**Figure 3 – Full Router Model**

Still, this model has severe limitations. Firstly, each time, a new router port is added, the same needs to be reflected in the WDM layer. Secondly, transit traffic (mostly contributed by Internet traffic) which can be modeled as point-to-point traffic is also processed at intermediate router nodes, thus making the router bulky. Also, as packet traffic and TDM traffic are handled in separate containers, it is more likely that some wavelength channels are lightly loaded, resulting in sub-optimal utilization of WDM resources in addition to the need of large and expensive routers. Thirdly, as all traffic needs to be processed at the router, this introduces delay and decreases system throughput, particularly in networks with large node count. This model tends to be more suitable for L3 VPN traffic that results in any to any, highly meshed connectivity, where effectively most of the traffic needs to stop at every core router and not Internet traffic where traffic is destined for Internet Gateways.

### B. *Switchless Transparent*

This optimization model takes advantage of ROADM in the DWDM network and routes traffic end-to-end employing optical bypass for the transit traffic, thus helping to increase throughput without incurring additional fiber-related costs. This is also referred to as “Router offload” where any transit traffic at any intermediate core router is offloaded to the WDM layer. Still, packet and TDM traffic will be handled as separate ODU containers. The model will generate point-to-point wavelength channels between all traffic end-points and OEO conversion is restricted to signal regeneration purposes. muxponders can be used to aggregate sub-rate traffic and improve wavelength channel fill ratio. Hence, this model enables to reduce core routers from being bulky as transit traffic will not be processed by the router. The model also exploits the fact that the WDM layer has the smallest cost per bit transported.

On the downside, besides the additional CAPEX due to the introduction of ROADMs, another disadvantage of this model lies in the fact that, as only end-to-end wavelength channels will be generated, for a densely meshed traffic this will lead to wavelength congestion and often fibers can run out of capacity. Moreover, partially filled wavelengths can contribute to non-optimal use of network resources, namely line interfaces.

### C. *Switchless Translucent*

Owing to the disadvantages of the previous two models, this model was proposed to overcome the shortcomings from partially filled lambdas while maintaining the advantage of router offload (Figure 4). Basically, it exploits the advantage of intermediate grooming where wavelength channels undergo OEO conversion at transit nodes for improved filling. However, in the absence of OTN switching, this intermediate grooming capability requires either interconnecting client ports of muxponders (which can only be done manually) or utilizing the routers for that task, (with risk of having to increase their size). Due to the complexity and inflexibility of muxponder-based intermediate grooming, the latter scheme is typically preferred.

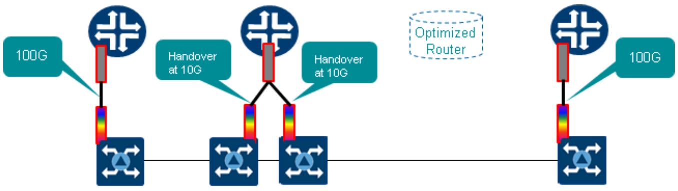

**Figure 4 – Switchless Translucent Model**

In view of the abovementioned limitations, intermediate grooming is mostly limited to a relatively coarse granularity to avoid excess manual patching and the use of cascaded muxponders. For example, in a 100G network grooming is performed for 10G data rates but lower granularity data like Gb/s is treated end-to-end. Furthermore, any change in traffic pattern results in the manual reconfiguration of the muxponder client ports thus involving onsite service staff. At the end, packet and TDM traffic are still addressed separately in different ODU containers, thus also resulting in partially filled ODUs.

### D. *OTN Grooming*

To overcome several limitations of the previously described models, an OTN switch can be introduced, allowing

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to optimize grooming at low bit rates such as 1.25Gb/s. Hence, wavelength channels can be optimally filled and router offload can also be exploited. These OTN switches implement an efficient sub-wavelength layer, which transports connections (circuits) ranging from 1.25Gb/s to the wavelength rate. For example, when provisioning a 6Gb/s service and mapping it onto an ODU2, inefficiencies can range up to 40%. The issue of packet and TDM traffic not being mapped in the same ODU can also be overcome by using a universal OTN switch which supports both packet (MPLS-TP) and SDH/SONET switching, popularly known as hybrid switching. Hybrid OTN switching becomes particularly efficient if not only the switching matrix but also traffic cards are agnostic to the traffic protocol. Higher data rates are transported directly on the WDM layer while lower data rates are transported over the OTN layer first. Protection/restoration against outages in the WDM or fiber layers can be handled via the OTN layer while failure of line ports of uplinks between edge routers and OTN switches with packet switching can be restored by 1:N port protection (e.g., Ethernet LAG). OTN switching enables traffic in transit to bypass many of the network's IP layer routers and thus reduces the amount of expensive router capacity required. It also provides efficient grooming of the optical signal on a sub-wavelength level and can multiplex packet and TDM traffic over the same wavelength channel, thus maximizing wavelength utilization and reducing the number of expensive line interfaces required [4].

However, introducing an OTN switch increases CAPEX. As a result, a careful analysis of the trade-off between this additional source of cost and the savings it may enable is paramount. For instance, in nodes with low traffic load, it may be more cost-effective to just deploy muxponders.

## IV. CHOOSING AN ARCHITECTURE AND MODEL

It is often a complicated job to take a decision on the right architecture and model that would suit a particular network, so that service providers and network operators can gain the maximum from their investment. It is worth to mention here that, there's no 'one size fits all' solution to this.

According to statistics from Cisco VNI, fixed Internet traffic is predicted to increase at a rate of 23% till 2019 and will contribute to three-fourth of all data carried over the network [5]. Hence, it will become an increasingly decisive factor for choosing a particular architecture and model. Internet traffic follows a specific pattern where it flows from different points in the network towards fixed gateways (contrary to L3 VPN traffic which needs to stop at every router following a mesh connectivity). So, offloading the Internet traffic to OTN/WDM layer could be a right choice as no L3 processing is required at transit nodes. Thus, it is key to know the traffic and its growth pattern and to design the network accordingly.

The answer to the question whether or not to introduce OTN switching is based on several criteria. For instance, the deployment of OTN switching is a straightforward choice, if the line rates are greater than the client rates, if there is dynamic traffic in the network which requires easy network reconfiguration, if there is legacy traffic alongside currently growing packet traffic in the network, if each truck roll to reconfigure a network is much costlier than a remote configuration, or if fast configuration along with protection/restoration are required. Keeping the Router Uplink Data rate the same as the OTN client (e.g 10G) port gives benefits such as "pay as you grow" to the operators instead of matching to the DWDM line rate (e.g. 100G).

Adding MPLS-TP capabilities to the OTN switching layer can provide further improvement to the overall CAPEX savings as it shifts from a physical router port per router destination (router adjacency) to a logical port per destination (VLAN or LSP) concept thereby reducing the amount of physical ports needed on the router side and transport side, as well as improving the utilization of used ports and wavelengths. Also, QoS behavior of IP/MPLS can be maintained when using MPLS-TP.

Importantly, in some network scenarios, the requirements do not define in advance which architecture/model has to be deployed. In these cases, an in depth analysis of the network properties and traffic pattern should be performed in order to identify which architecture/model will first and foremost result in minimum CAPEX (eventually also considering OPEX).

## V. NETWORK DESIGN AND EVALUATION

In the following, the different architectures/models are compared via a detailed case study. The network topologies considered are two long distance optical transport networks inspired in networks operated by Telecom Italia/TIM. One is the Italian national backbone, which has 44 nodes and 71 fiber links (mainly G.655, with some G.652 and G.653 fiber types) and has already been used in other studies [6]–[8]. It meets the needs of circuits at a national level, mainly for IP router interconnection and for connectivity of big clients. With its shortest paths under 2200 km and backup paths (disjoint from the shortest one) under 2600 km, it can be classified as a long-haul network. The other network is the Telecom Italia/TIM Sparkle Pan-European backbone [9], a geographically expanding network that currently covers Central, Southern and Eastern Europe with 49 nodes and 72 fiber links (mainly G.652 fiber type). It has been utilized in network studies [8] and [10] and classifies as an ultra-long-haul network (shortest paths under 5500 km and backup paths under 7000km). Both backbone networks are depicted in Figure 5 and more detailed information is available in a FP7 IDEALIST project deliverable [11] and in [12].

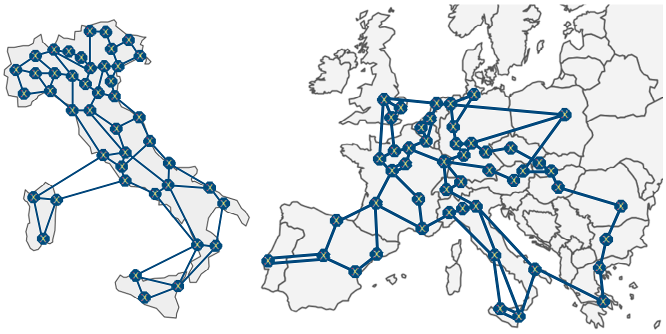
(a) National backbone (b) European Backbone

**Figure 5 –Telecom Italia reference network topologies**

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With respect to the client rates to be serviced by the networks during their entire lifecycle, the following data rates are considered: 10G, 40G and 100G for the Italian National Backbone and 1.25G, 2.5G, 10G for the European Backbone. The traffic comprises both Internet Packet traffic and SONET/SDH TDM traffic. Two traffic periods are considered where at the starting phase, both packet and TDM traffic are dominant. However, in the next phase, extrapolated to be at the end of four years from the current period, Internet Packet traffic has grown almost 100% with 25% growth each year. But TDM traffic has kept the same volume. The total traffic for the two periods under analysis and the partitioning of bandwidth among different client rates is described for the Italian national backbone (IT) and the European backbone network (EU) and depicted in Table I.

**Table I – Client rate distribution in TI (I) and EU (E) networks for the first (P1) and second (P2) periods**

| Period | Traffic (Tb/s) | | 1,25G % Share | | 2,5G % Share | | 10G % Share | | 40G % Share | | 100G % Share | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | E | I | E | I | E | I | E | I | E | I | E |
| P1 | 13 | 18 | 24 | 27 | 0 | 22 | 11 | 32 | 9 | 0 | 56 | 19 |
| P2 | 19 | 28 | 22 | 29 | 0 | 14 | 20 | 22 | 7 | 0 | 51 | 35 |

The multi-layer optimization framework described in [13] is utilized to perform traffic grooming, optical channel routing and wavelength assignment tasks, which are key to minimize the number of expensive line interfaces. It is assumed that all lightpaths use QPSK modulation format, resulting in a data rate of 100 Gb/s, and that every network link can support 96 wavelength channels.

## VI. RESULTS AND DISCUSSION

The multi-layer optimization framework is tailored to dimension the network using architectures and optimization approaches mentioned in Section II and Section III, respectively. We have analyzed both networks from Telecom Italia (National and International) with two traffic loads and five different optimization models, i.e. pure L3 processing of packet traffic (switchless opaque), e2e aggregation of packet traffic (switchless transparent), translucent architecture with muxponder-based aggregation (switchless translucent), hybrid OTN grooming, and hybrid OTN (MPLS.TP) grooming.

Figure 6 shows the number of line-side ports required in the TI Backbone topology for both periods and considering every architecture and optimization model. From the results, it is evident that pure L3 switching of packet traffic (i.e., even transit traffic passes through the Router) and where TDM traffic is also processed at every hop, leads to the highest requirements of 100G line ports (colored transponders).

Following an e2e aggregation and using ROADMs, there is a 5% improvement in port count in the first period. This is mostly due to the fact that the traffic distribution is not fully meshed and the traffic data rate closely matches the line data rate and thus containers carrying the traffic are filled. A further reduction of 40% in 100G line ports could be achieved by enforcing intermediate grooming but using muxponders. As the cross-connections are manually patched, the grooming is performed on 10G pipes but not on lower granularity traffic like Gigabit Ethernet. Bringing in an OTN switch further reduces the transponder port count by 6% compared to muxponder-based grooming as grooming can be performed at finer granularity.

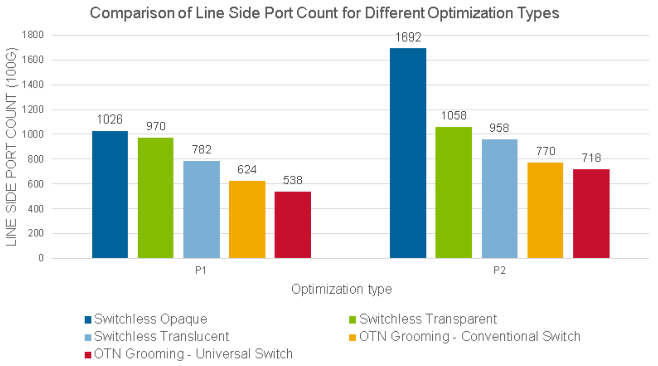

**Figure 6 – Telecom Italia National Backbone**

OTN switching benefits from the fact that both Packet and TDM Traffic can be groomed in the same ODU container. But a port needs to be engaged per direction and there can be inefficiency in grooming as a 6 Gbit/s Packet traffic could be mapped to a 10 Gbit/s port. This is overcome by MPLS-TP switching leading to further reduced line side port count. When considering the second period with increased traffic load, it is also seen that pure L3 processing performs even worse, when compared to the remaining solutions.

Analyzing the results for Telecom Italia International topology, depicted in Fig. 7, a similar outcome is observed which further strengthens the argument.

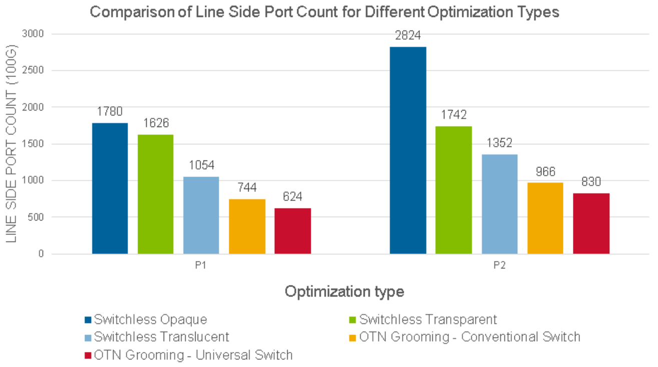

**Figure 7 – Telecom Italia International Network**

The usage of ROADM for e2e grooming proves to be efficient compared to pure L3 processing (switchless opaque). Also, the inefficiency of L3 processing increases as the traffic increases due to the fact that majority of transit traffic can be processed at the DWDM layer below which in the other case had to be processed at L3 or electrical layer, as applicable. This trend is visible in both the networks. Employing

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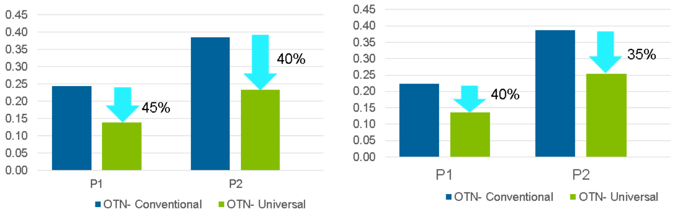
muxponders for intermediate grooming further results in saving of line interfaces, though we can see later that this is not the most efficient one. Deployment of an OTN switching layer results in a better wavelength utilization due to the fact that grooming is supported for lower granularity traffic and also that packet and TDM traffic are carried inside the same ODU container. Finally, integrated MPLS-TP switching leads to a further line port count reduction as a maximum utilization of the ODU containers is achieved due to integrated packet aggregation. On average, 80% savings in terms of transponder line port count are achieved by employing OTN switching compared to L3 Opaque processing and further 8-10% line port savings are achieved by introducing MPLS-TP switching.

However, the real advantage of bringing in the universal OTN switch (with packet functionality) is not merely dependent on the savings in terms of line interface count but the CAPEX savings. For TI National network, CAPEX savings were observed in the order of 42% between pure OTN switch and the universal OTN switch, while it was around 37% for the TI European Backbone Network. These savings are due to savings in router ports and dense packing of packet traffic. In pure OTN switch, one router port is engaged per direction of traffic while in the universal hybrid switch, the same traffic can be packed together and handed off from the router port while the packet switching is thereafter performed in the switch itself. Packet traffic can thus be packed more densely discarding the chance of nearly empty containers flooding the network.



(a) National backbone (b) European Backbone

**Figure 8 – CAPEX savings comparison**

It is evident that optical bypass does provide savings in terms of line-side port count though there is clearly a significant dependence on the traffic matrix and network topology. If L3 processing or e2e grooming is performed, the colored line interface may be positioned either at the router or at the muxponder. Similarly, for OTN switching, colored line interfaces may be positioned either at the OTN switch or at the DWDM equipment. Optical bypass combined with intermediate grooming may still be competitive compared to pure L3 processing, following the rule of thumb that it is more cost-effective to switch traffic at the lowest possible layer. Trend shows increasing use of OTN within the carrier's environment due to the increased demand for higher bandwidth where OTN offers efficient traffic grooming and optimal granularity. OTN's flexibility and the combination with MPLS-TP switching for packet traffic makes it the main client transport mechanism today, especially up to 100G.

## VII. CONCLUSIONS

This paper has overviewed the available architectures and optimization models for designing and implementing state-of-the-art transport networks. A case study, using two reference networks and realistic assumptions for their traffic patterns, has shown that there are considerable cost savings by employing optical bypass. However, the answer to the question whether it is better to use muxponder-based grooming or to deploy OTN switches, depends on the topology, traffic matrix, and growth pattern. It is also clear from the results that MPLS-TP switching can add further savings by enabling better aggregation when lower granularity client demands are present. Moreover, major CAPEX savings can be achieved by employing the universal switching platform when compared to a pure OTN switch.

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