Next-generation transport solutions for IP backbone networks – benefits of an ASTN-based multi-layer OTN network

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ABSTRACT

This paper concentrates on solutions for next-generation IP (Internet Protocol) backbone networks. This is a key issue for many network operators since IP will be the dominating network layer technology on which an ever increasing number of applications with growing bandwidth requirements will be based. Without new network solutions, this trend would lead to a strong increase in number and size of IP routers while already today's requirements make it difficult to realise large-scale IP backbone networks in a stable and cost-efficient way. This paper investigates the benefits that an appropriate transport network based on ASTN (Automatic Switched Transport Network) and OTN (Optical Transport Network) technology can bring to future IP backbone networks – providing the stable basis on which next generation IP networks can be built. Network modelling is used to show that in addition to qualitative benefits a transport network based IP backbone solution can lead to a significant reduction of network equipment cost.

Keywords: IP backbone network, ASTN/GMPLS, OTN

1. INTRODUCTION

Solutions for next-generation IP backbone networks are a key issue for many network operators since IP will be the dominating network layer technology on which an ever increasing number of applications with growing bandwidth requirements will be based. Without new network solutions, this trend would lead to a strong increase in number and size of IP routers while already today's requirements make it difficult to realise large-scale IP backbone networks in a stable and cost-efficient way. Also, those networks are increasingly leveraging on MPLS technologies (Multi-Protocol Label Switching) and thus the use of "IP network" in this paper in addition refers to combined IP/MPLS networks.

There are many benefits that an appropriate transport network technology can bring to future IP backbone networks. Some of the key aspects that will be investigated in this paper cover the following benefits:

- Transit traffic in the network can be kept in the transport domain instead of handling it on the IP layer. This aspect considers the fact that switching in the transport domain is significantly cheaper than routing on the IP layer. IP router "off-loading" not only reduces the required size and number of IP routers in each PoP (Point of Presence) thus improving scalability and stability, but it potentially also improves the quality of the IP service (by reducing latency and delay jitter issues).
- A switched transport layer offers new functionalities such as advanced restoration mechanisms or efficient bandwidth provisioning. Such a layer will incorporate new ASTN (Automatic Switched Transport Network) functionalities [9] as well as features defined in the OTN (Optical Transport Network) standards [10] and in the latest enhancements to the established transport technologies SDH (Synchronous Digital Hierarchy) and SONET (Synchronous Optical Network).
- Apart from savings in the equipment investment (Capital Expenditures, CapEx), the proposed solution also has the potential for reduction of OPEX (Operational Expenditures). While this aspect is difficult to quantify, the paper will at least contribute qualitatively to this discussion.
- Synergies between different services can be better exploited. The introduction of a transport plane into IP networks will allow the operator to carry other – potentially higher revenue – services in parallel to IP services on a common transport platform.

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The paper will first provide a network architecture description for IP over OTN networks. The development of this architecture considers the typical situation of a large-scale national IP backbone in a European country. The qualitative advantages of the proposed solution will be highlighted and based on this qualitative discussion and appropriate network modelling, several quantitative studies will be presented.

One key area for the realisation of these kinds of networks is the on-going work on ASTN-based transport network solutions, especially the development of an appropriate UNI (User Network Interface) for an efficient communication between IP router and transport network elements. Thus, this paper will also briefly mention latest research and standardisation activities in the context of this technology.

2. IP BACKBONE NETWORK ARCHITECTURE OPTIONS

In this section different approaches are presented that can be used to realise an IP backbone network:

- "IP only": IP/MPLS routers are interconnected with point-to-point links (IP-over-WDM).
- "Full transport": An SDH/SONET/OTN transport plane is introduced under the IP/MPLS layer.

The following figures show these scenarios in a schematic way by highlighting a single path through a network. For illustration purposes we selected a path from the network example in Figure 4 that will be used for network modelling studies.

In Figure 1 the so-called "IP only" scenario is represented, basically consisting of IP routers that are statically interconnected via point-to-point links (e.g. based on Wavelength Division Multiplexing, WDM). For the interconnection between IP routers and the transmission systems, several technologies can be used. Most often, these links are either based on PoS (Packet over SONET/SDH) or on Gigabit Ethernet technology. Usually, the number of interconnections of a router is limited because of port number limitations. For simplification purposes, in the scenario we assume a single IP router per location, while in reality there is usually a sub-network of routers present in every location.

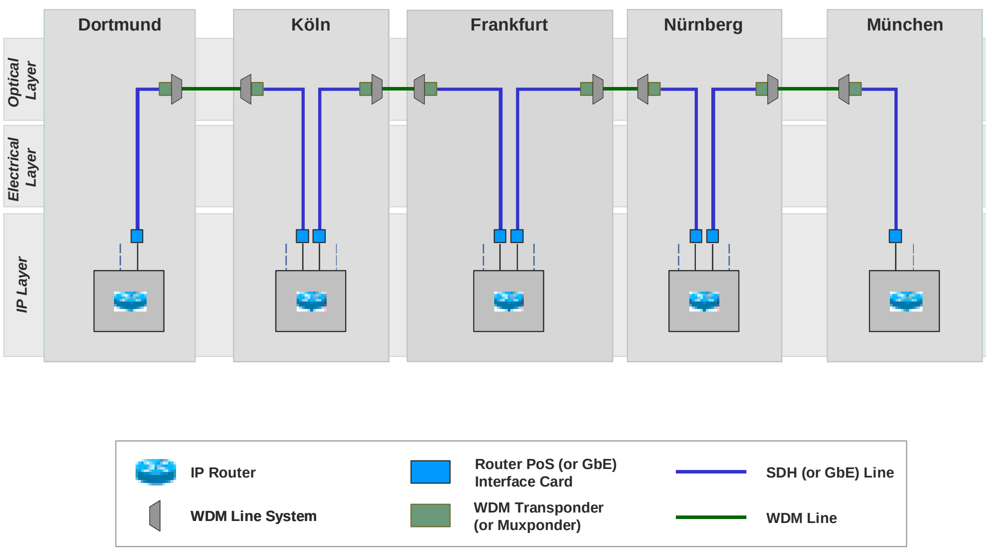

Figure 1: "IP only" scenario

In the "full transport" scenario (see Figure 2) a flexible opaque transport layer is introduced underneath the IP/MPLS layer. This layer is based on electronically switched circuits, available with technologies such as SDH, SONET, or OTN. These cross-connects are called "EXCs" (Electrical Cross-Connects) in the following. They can be interconnected with WDM systems as described above, or – as shown in the picture – these cross-connects possess so-called "coloured line cards", allowing a direct access to the WDM system without the need for "grey" interfaces. Compared to the scenario above, the full transport scenario enables setting up direct SDH/SONET/OTN connections between any IP routers thereby avoiding any transit traffic on the IP layer. Mapping of data flows into transport network connections may be done in the IP routers using channelised interfaces. However, since these interface cards are usually quite expensive we assume another alternative: to provide this function in the EXCs, thus requiring data cards that are capable of mapping the Ethernet data flow from the router into SDH Virtual Containers (VCs).

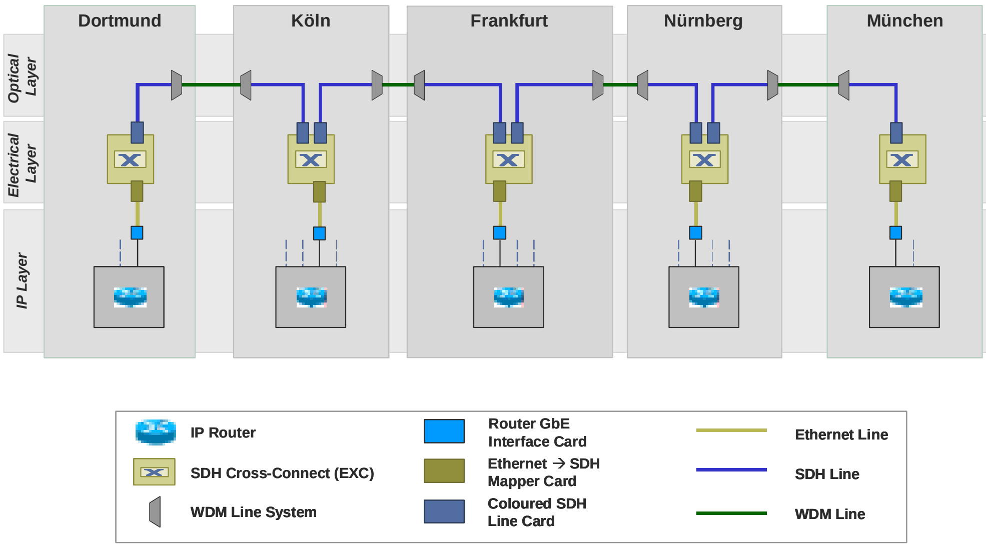

Figure 2: "Full transport" scenario (opaque network layout)

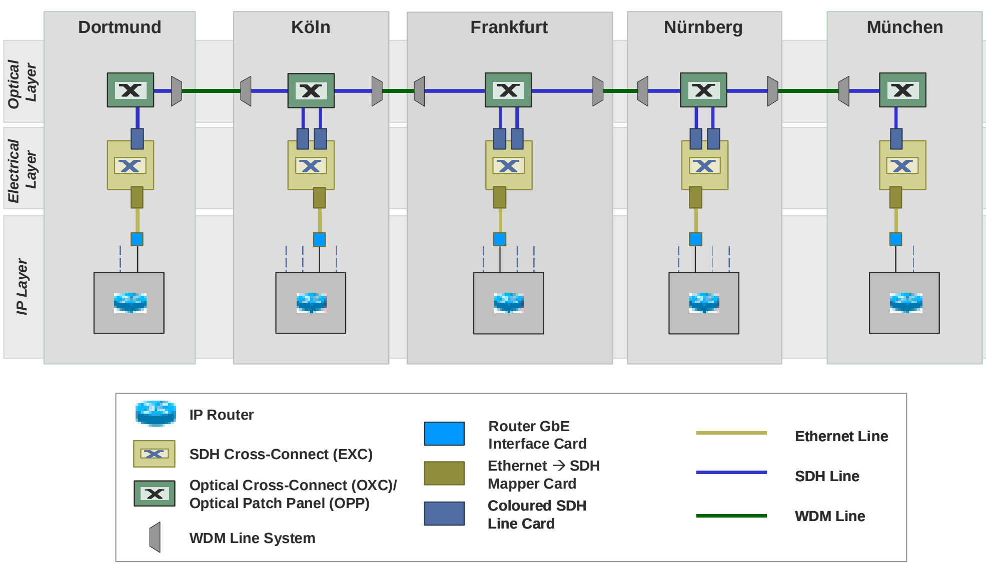

Figure 3: "Full transport" scenario (transparent network layout)

Apart from the scenario described above, the transport layer can be further enhanced by an optical plane, leading to a transparent network layout (see Figure 3). In this scenario, each node has an additional capability to transparently by-pass a wavelength channel in the optical plane, without terminating it at the EXC. However, all channels *can* be terminated if required by the traffic matrix or if beneficial for efficient grooming into wavelength channels. It has to be noted that there are different options for realising the optical cross-connect (OXC) functionality shown in Figure 3: It can be based on flexible all-optical optical switches, but could also be based on manually re-configurable optical patch panels (OPP). The latter allows a very cost-efficient realisation of traffic by-pass and can be an option if fast re-configurability is not required on the optical layer.

3. NETWORK MODELLING RESULTS

The scenarios defined in the last section have been investigated for a realistic, but hypothetical reference network, representing a German national backbone network [2]. The network scenario called "Germany 17" comprises 17 backbone node locations which are inter-connected with a meshed topology shown in Figure 4.

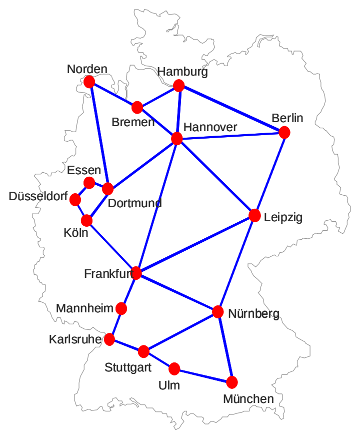

Figure 4: Topology of the "Germany 17" reference network

	Berlin	Bremen	Dortmu	Düsseld	Essen	Frankfu	Hambur	Hannov	Karlsruh	Köln	Leipzig	Mannhe	Münche	Norden	Nürnber	Stuttgar	Ulm
Berlin		0.9196	1.3268	1.4618	1.0508	4.9122	1.8778	2.0794	0.463	1.5652	3.0666	0.811	1.646	0	1.3	1.9434	1.2152
Bremen	0.9196		0.5694	0.6274	0.451	2.1546	0.806	0.8926	0.1988	0.6718	1.3162	0.3482	0.7066	0	0.558	0.8342	0.5216
Dortmu	1.3268	0.5694		0.9054	0.6508	3.0866	1.163	1.2878	0.2868	0.9694	1.899	0.5024	1.0194	0	0.805	1.2036	0.7526
Düsseld	1.4618	0.6274	0.9054		0.717	3.3928	1.2814	1.419	0.316	1.068	2.0924	0.5534	1.1232	0	0.887	1.3262	0.8292
Essen	1.0508	0.451	0.6508	0.717		2.4564	0.921	1.02	0.227	0.7676	1.504	0.3978	0.8074	0	0.6376	0.9532	0.596
Frankfu	4.9122	2.1546	3.0866	3.3928	2.4564		4.326	4.773	1.0934	3.626	6.9144	1.904	3.8076	25.2	3.0256	4.4718	2.8326
Hambur	1.8778	0.806	1.163	1.2814	0.921	4.326		1.8226	0.4058	1.372	2.6878	0.711	1.4428	0	1.1394	1.7034	1.0652
Hannov	2.0794	0.8926	1.2878	1.419	1.02	4.773	1.8226		0.4494	1.5192	2.9764	0.7872	1.5976	0	1.2618	1.8864	1.1794
Karlsruh	0.463	0.1988	0.2868	0.316	0.227	1.0934	0.4058	0.4494		0.3382	0.6626	0.1754	0.3556	0	0.281	0.42	0.2626
Köln	1.5652	0.6718	0.9694	1.068	0.7676	3.626	1.372	1.5192	0.3382		2.2404	0.5926	1.2026	0	0.9498	1.4198	0.8878
Leipzig	3.0666	1.3162	1.899	2.0924	1.504	6.9144	2.6878	2.9764	0.6626	2.2404		1.1608	2.356	0	1.8606	2.7818	1.7394
Mannhe	0.811	0.3482	0.5024	0.5534	0.3978	1.904	0.711	0.7872	0.1754	0.5926	1.1608		0.6232	0	0.4922	0.7358	0.46
Münche	1.646	0.7066	1.0194	1.1232	0.8074	3.8076	1.4428	1.5976	0.3556	1.2026	2.356	0.6232		0	0.9988	1.4932	0.9336
Norden	0	0	0	0	0	25.2	0	0	0	0	0	0	0		0	0	0
Nürnber	1.3	0.558	0.805	0.887	0.6376	3.0256	1.1394	1.2618	0.281	0.9498	1.8606	0.4922	0.9988	0		1.1792	0.7374
Stuttgar	1.9434	0.8342	1.2036	1.3262	0.9532	4.4718	1.7034	1.8864	0.42	1.4198	2.7818	0.7358	1.4932	0	1.1792		1.1024
Ulm	1.2152	0.5216	0.7526	0.8292	0.596	2.8326	1.0652	1.1794	0.2626	0.8878	1.7394	0.46	0.9336	0	0.7374	1.1024	

Table 1: Traffic matrix with end-to-end traffic demands between nodes given in Gbps

The traffic matrix for this network scenario (Table 1) has been created by applying the traffic estimation model proposed in [3]. Note that the traffic matrix contains the special case of node "Norden" which is used for international traffic only (Norden is the transition point to trans-atlantic links). Total traffic volume (counting uni-directional demands) is 381 Gbps which is a reasonably realistic number for the IP traffic volume in a national backbone network of today.

Based on the topology and traffic assumptions an optimised network dimensioning has been performed for the scenarios defined in Section 2. Due to simplification reasons the following results are based on two assumptions:

- Any protection issues are not taken into account. Therefore, all numbers refer to pure working traffic load. If network resilience aspects would be considered the required amount of resources would be increased by at least a factor of two.
- A PoP is assumed to consist of a single router. In reality, most IP networks are designed in a different way: Because of redundancy requirements and because of limitations with regards to number of ports or total router throughput, most PoPs consist of a "sub-network" of IP routers. This design significantly increases the resource requirements for the IP layer. Thus it can be concluded that the consideration in this paper is somehow the "best case" scenario from an IP resource requirement point of view.

In case of the "IP only" scenario traffic demands as given in Table 1 are routed through the network on the shortest paths. For the "full transport" scenarios the given traffic matrix is mapped to a VC-4 granularity traffic matrix describing the traffic demand towards the SDH/OTN layer. These VC-4 traffic demands are routed through the network making use of optimised grooming techniques described in [1]. The optimisation algorithm aims at minimisation of the number of required transponders. In the opaque case routing affects the electrical SDH/OTN layer only while in the transparent case decisions about setting up all-optical lightpaths between certain nodes have to be made and the corresponding wavelengths have then to be assigned and routed on the optical layer.

Figure 5 and Figure 6 show the resulting capacity required for the IP routers in the network for the "IP only" and the "full transport" scenarios. Note that this capacity is identical for the two transport network scenarios (transparent and opaque). It can be seen that a transport network solution significantly reduces both the overall router capacity required in the network as well as the size of the largest routers required in the network. In the present network scenario a 41% reduction of the overall IP router size can be achieved due to the removal of transit traffic from the IP layer.

The price that has to be paid for the reduction of IP router capacity in the full transport solutions is the introduction of EXCs. The required EXC capacity for the opaque and the transparent network layout is shown in Figure 7 and Figure 8, respectively. It becomes obvious that the required EXC capacity is larger than the savings in router capacity due to the following reasons:

- Add/drop traffic has to go through both the routers and the EXCs, i.e. add/drop capacity is required on both layers.
- The gross capacity required on the SDH/OTN layer is increased by the frame overhead.
- When traffic is mapped to VC-4 connections some VC-4s might not be fully utilised. This effect is emphasised in the case of low traffic demands per node pair.
- Some extra capacity is required if traffic is not routed on the shortest path due to optimised grooming. This might be necessary to reduce the number of transponders. While in opaque networks this effect is negligible it is very significant in transparent networks.

The overall EXC capacity required for a full transport solution with opaque network layout can be approximated by the following expression that takes the first three of the above effects into account:

$$C_{EXC} = \frac{C_{IP}}{C_{IP,AD}} \cdot \max(C_{IP,AD} \cdot \frac{R_{VC4}}{R_{C4}} + n \cdot (n-1) \cdot R_{VC4}, 2 \cdot n \cdot (n-1) \cdot R_{VC4})$$

The formula uses the following parameters:

- C_{IP}: total IP router capacity in the "IP only" case
- $C_{IP,AD}$: total add/drop IP router capacity in the "IP only" case
- R_{VC4}: gross rate of a VC-4 (155.52 Mbps)
- R_{C4}: net rate of a VC-4 (149.76 Mbps)
- n: number of nodes

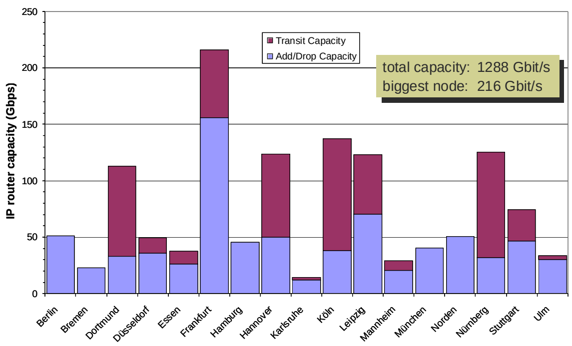

Figure 5: Required router sizes in "IP only" scenario

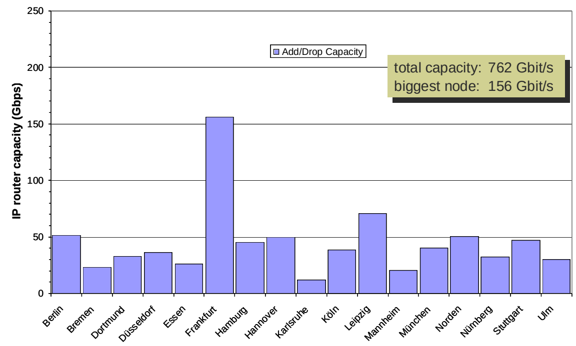

Figure 6: Required router sizes in "full transport" scenario

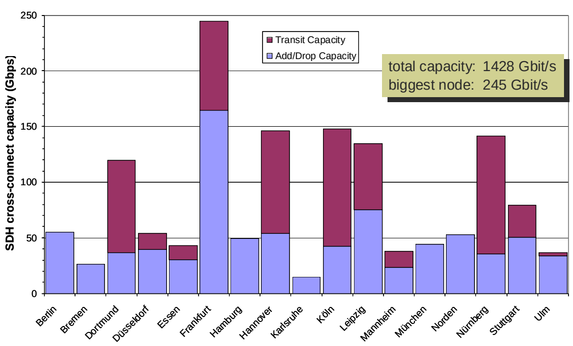

Figure 7: Required EXC sizes in opaque "full transport" scenario

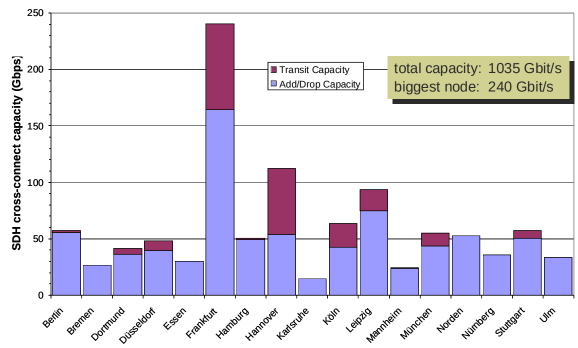

Figure 8: Required EXC sizes in transparent "full transport" scenario

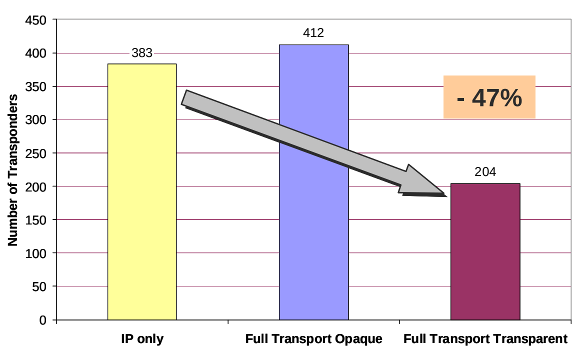

Figure 9: Number of required transponders in case of 2.5 Gbps transponder line rate

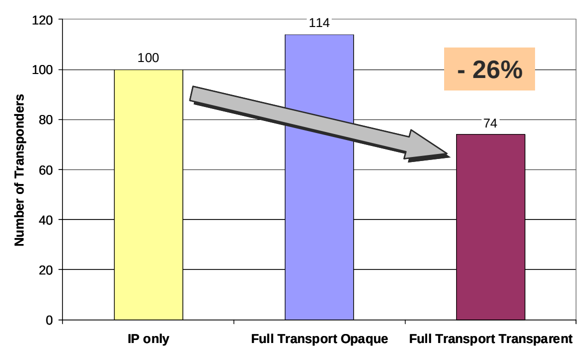

Figure 10: Number of required transponders in case of 10 Gbps transponder line rate

In our example this leads to a total EXC capacity of around 1.4 Tbps in the opaque case, which is approximately 2.7 times the savings in IP router capacity. The EXC capacity in the transparent case is significantly lower as there the transit traffic can be mostly routed on the optical layer. Therefore, the required EXC capacity is mainly determined by the add/drop traffic. However, there is still some transit traffic in the SDH/OTN layer due to the optimised grooming effect mentioned above.

Figure 9 and Figure 10 show another aspect of the different network solutions: The number of transponders required to realise the network strongly depends on the scenario. The results show that an opaque transport network solution increases the number of transponders compared to the "IP only" scenario (while reducing the router size as shown above). However, the transparent scenario allows a strong decrease of transponder requirements thanks to the possibility of transparently by-passing electrical transport nodes and routers. As expected, for the given traffic volume the relative differences are smaller for the 10 Gbps scenario due to the coarser granularity, but on the other hand the price for a 10Gbps transponder is higher than for a 2.5 Gbps one.

The network dimensioning results are summarised in Table 2. The table also includes the number of OXC/OPP ports required in the case of a transparent network layout.

10G Transponders					
Scenario	**Transp. Arch.**	**Router Size (Gbps)**	**EXC Size (Gbps)**	**# OXC Ports**	**# Transponders**
IP Only	N/A	1287.95	0	0	100
Full Transport	opaque	762.18	1427.67	0	114
	transparent	762.18	1035.45	220	74

2.5G Transponders					
Scenario	**Transp. Arch.**	**Router Size (Gbps)**	**EXC Size (Gbps)**	**# OXC Ports**	**# Transponders**
IP Only	N/A	1287.95	0	0	383
Full Transport	opaque	762.18	1409.01	0	412
	transparent	762.18	904.82	662	204

Table 2: Required resources for various scenarios

4. COST ANALYSIS

In order to get an overall comparison of the different IP backbone solutions a cost analysis has been made based on a simplified cost model. This model does not consider the absolute prices for the involved equipment, but rather relies on cost relations for the key components such as transponder cost, IP router cost, electrical and optical switch cost. Different cost factors describing relative cost per Gbps are assumed for the above-mentioned key components. This implies that we assume a somehow linear model for the price increase with increasing capacity requirement (while in reality this relation usually follows a step-wise function) thus meaning that specific equipment details are not considered in this model. However, the main advantage of such a simplified model is that it allows to easily investigate the influence of varying cost factors.

Figure 11 shows the resulting total cost of the network normalised to EXC cost per Gbps. The network cost is drawn over the ratio of IP router cost per Gbps and EXC cost per Gbps. As additional parameters, the values for OXC cost per Gbps and transponder cost per Gbps are needed (also normalised to EXC cost per Gbps). In the left figure these values are fixed to 0.5 and 1.0 respectively, and in the right figure to 0.2 and 1.5 respectively. That means in the right figure bigger cost differences among transport network equipment are assumed, which seems to be the more realistic cost scenario. In Figure 12 the resulting relative cost savings than can be achieved by the "full transport" scenarios with relation to the "IP only" network cost are depicted.

From the figure it can be seen that the full transport network solutions already start to be cheaper if the IP router cost per Gbps is more than two to three times the EXC cost per Gbps. Considering that this cost ratio for current technologies is more in the range of 5 to 10 or more, this means that CapEx savings in the order of 10% to 25% or more can be shown for our scenario with a transport network based IP backbone solution (Figure 12). Depending on the transport equipment cost ratios either the opaque or the transparent layout of the "full transport" scenario is more cost-effective. It has to be noted, however, that the detailed values for this kind of study strongly depend on many parameters, such as network topology, traffic matrix and geographical distribution. The general trend however could be proven in several studies for different realistic network scenarios.

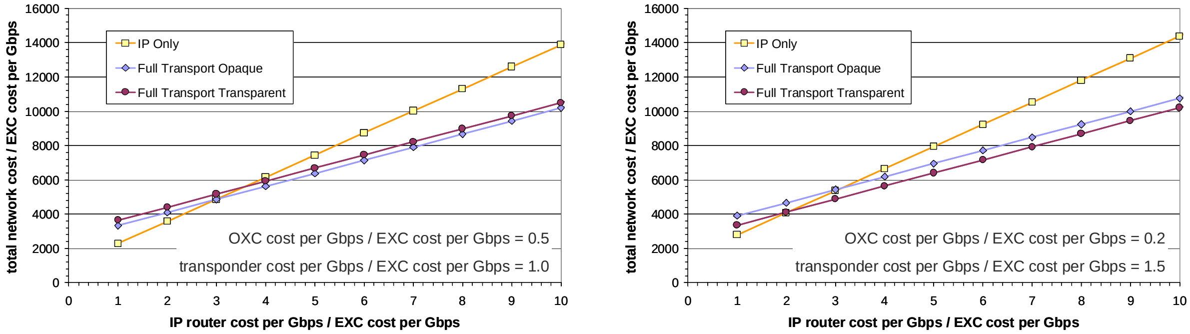

Figure 11: Simplified cost analysis for two different settings regarding ratios of OXC/EXC/transponder cost per Gbps

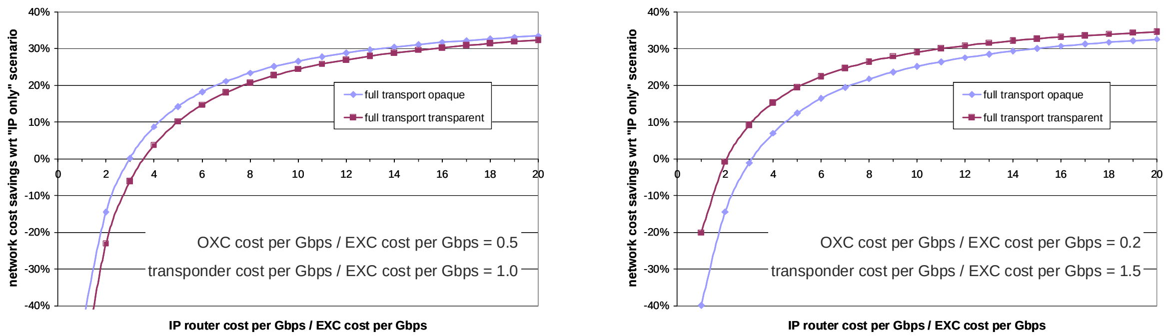

Figure 12: Cost savings by "full transport" solutions compared to "IP only" for two different settings regarding ratios of OXC/EXC/transponder cost per Gbps

5. ELABORATION ON FURTHER KEY ISSUES FOR IP BACKBONE SOLUTIONS

In the last sections it has been shown that an IP backbone solution that is based on a transport network layer is attractive from a CAPEX point of view. In this section we highlight some qualitative benefits such a solution. These qualitative benefits can be mainly derived from the features available with new transport technologies ASTN and OTN.

5.1. ASTN-based Control Plane Solutions for Transport Networks

There is currently a lot of work done in the area of distributed control plane solutions for transport networks. These solutions are discussed and developed in various standardisation bodies and industry fora, with key activities going on in the ITU-T, the IETF and the OIF (Optical Internetworking Forum). In addition to standardisation activities, there are also several big research projects working (amongst other topics) on progress of control plane technology. Within the 6th research activities framework of the European Commission, control plane topics are covered by integrated projects NOBEL (Next-generation Optical networks for Broadband European Leadership) and MUPPET (MUlti-Partner EuroPEan Test beds for research networking). NOBEL [7] is focussing on end-to-end broadband solutions for residential and business customers, while MUPPET [8] concentrates on the next generation of research networks and especially elaborating on control plane based, flexible multi-domain transport solutions supporting very demanding research applications such as grid computing, storage networking, and high quality video transmission.

ITU-T standard G.807 [9] created a framework called ASTN which when combined with new transport equipment can automate a whole host of functions that used to be carried out manually, or by the management system. This has been achieved by adding a considerable amount of computing power into the transport equipment that runs complex software modules, which perform sophisticated network operations. The result is a control plane function, which essentially automates the set-up and changes of circuits as well as the information management in the network.

The introduction of an automatic control plane in the transport network opens up a number of potential applications. Distributed functions allow fast execution of bandwidth saving restoration schemes. These schemes are not necessarily new but their past NMS (Network Management System) implementations were slower and might limit their use. New flexibility in transport service provisioning may, thus, be introduced. Automatic functions to discover pieces of equipment and their links are also a benefit of an automatic control plane. Fully automatic circuit provisioning also makes it possible to expose service request directly to client networks. With the help of a distributed signalling protocol, it is possible to reduce the restoration time to a few hundred milliseconds. The introduction of a control plane technology allows different realisation approaches for distributed restoration mechanisms, such as "pre-planned" or "on-the-fly" restoration mechanisms. These mechanisms allow fast reaction times on failures, while at the same time they efficiently use the network resources and – thanks to the capability to handle multiple-failure scenarios – even increase network availability.

Interoperability is a strong requirement for and strength of ASTN. It provides interoperability with client networks, via UNI (User-Network Interface). Several ASTN networks may combine to provide service on a broader network. They may be deployed on different regions, provided by different manufacturers or even owned by different operators. In this scenario, an ASTN requires interoperability with peer ASTN networks, via E-NNI (External Network-Network Interface). Finally, an ASTN must inevitably coexist with non-ASTN pieces of network. This may happen because of either legacy equipment already in the network or for TMN managed functionality requested by an operator, as TMN complements ASTN in providing specialised service characteristics. Since interoperability is a key issue, a lot of effort is made to ensure appropriate development of the relevant standards. Very recently, the OIF organised a big "interoperability" test, which was also presented publicly [4]. For the first time, a world-wide, distributed control plane interoperability test was done, including 7 carriers' test beds (based in three continents) with equipment from 15 different vendors.

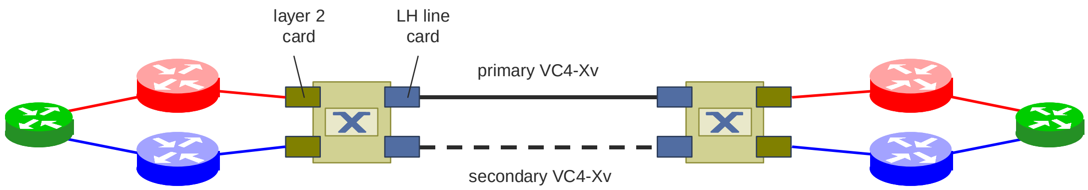

Figure 13: Network resilience aspects in IP backbones

For the usage of ASTN in an IP backbone scenario more than basic protocol interoperability is required. ASTN restoration mechanisms have to be combined with network resilience concepts applied in the IP layer (Figure 13). The latter will still be required to protect the network against IP router failures. This is usually done by connecting IP routers collecting the traffic dedicated to certain services to two backbone routers in each PoP. While this provides robustness in the network, recovery from failures is often slow. Therefore it can be useful to handle all failures that occur in the transport part of the network (including link failures) via the ASTN mechanisms to enable fast recovery at least for these types of failures [2]. There are still many open issues for such multi-layer network resilience and related protocol functionality including questions about OAM. It has, however, been shown in [6] that major concerns about a huge increase of control traffic due to increased meshing on the IP layer are not justified.

5.2. OTN Transport Technology

OTN is based on the G.709 standard [10], which provides a means of delivering a "managed" wavelength service and to extend existing standards towards higher line rates. This includes both directly mapped client signals such as IP / Ethernet and composite SDH signals that are mapped, switched, and transported throughout the OTN network without the need to process or manipulate any portion of the "customer" signal. This allows SDH multiplex section protection switching schemes for instance to pass transparently through the OTN network while still providing the same level of visibility and functionality to the carrier with which it is accustomed.

Transport over a WDM system is anyhow required in many cases and the G.709 Optical Transport Unit (OTU) already includes Forward Error Correction (FEC) allowing for significantly higher noise, attenuation, and other WDM impairments. The G.709 standard also supports a number of other common SONET / SDH functions like multiplexing (Figure 14) as well as protection switching, performance monitoring, fault isolation, voice & data user channels, etc. Therefore, OTN can be considered as a consequent next step that solves many technical issues present in DWDM and SDH networks up to now. However, it does not necessarily replace SDH as each has a unique function that compliments the other (Figure 15).

OTN is also excellently suited for IP backbone solutions due to the efficient mapping of packets into reliable circuits; operational benefits thanks to enhanced OAM functionality and performance improvement. In addition it allows for "synergetic use" of transport plane for multiple services. This means that for example Ethernet client services are attached to the same OTN cross-connect that carries the IP backbone traffic.

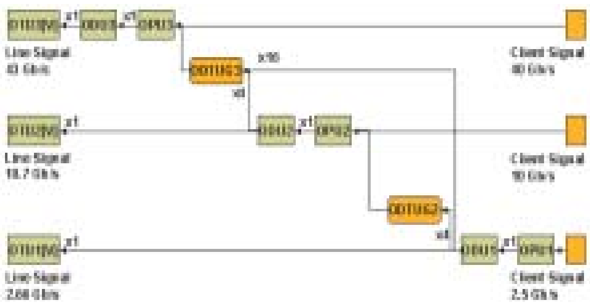

Figure 14: ITU-T G.709 multiplexing structure

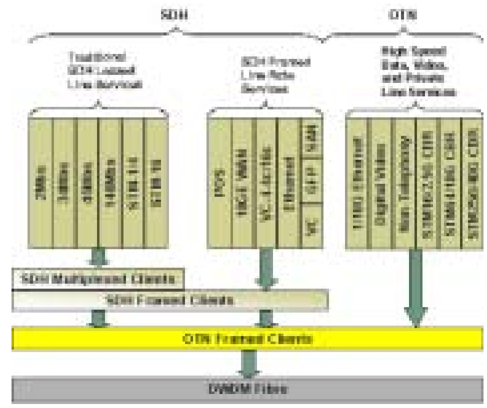

Figure 15 : SDH & OTN Service Examples

6. CONCLUSIONS

This paper has been describing several aspects of solutions for next generation IP backbone networks – an area of high importance because of increasing traffic volume and cost pressure for network operators around the world. The paper elaborated on a promising approach based on the introduction of a flexible and powerful transport network layer underneath the IP/MPLS layer. The paper discussed several fundamental network architecture options, specifically an approach based on statically interconnected IP routers, and an approach based on a flexible transport layer with two variants: with and without optical by-passing capability on the optical layer. Then a reference network scenario was presented, describing in detail a realistic topology and traffic matrix for a big IP backbone network.

Based on studies performed on that reference scenario, the different network architecture options have been analysed in detail. Several effects, such as the reduction of router size, the reduction of number of transponders, and the required transport layer resources have been derived quantitatively. In addition, a cost model was also presented. This model allows for the determination of the most beneficial solution based on a variety of cost parameters influencing the problem, such as IP router cost, transponder cost, and cost of transport cross-connects.

Finally the paper has been completed by a qualitative discussion of further aspects of high importance for future IP backbone networks, specifically the role and advantages of ASTN control plane technology and OTN transport technology. These technologies are based on latest achievements in standardisation and are currently being further developed. In summary, the necessary mechanisms to build efficient IP backbone networks, also capable of cost-efficiently handling future traffic demands, are already available or under development. Applying an optimised combination of these technologies will offer network operators an excellent solution to base their IP networks on a stable and future proof basis.

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