A Set of Typical Transport Network Scenarios for Network Modelling

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Abstract

This paper describes a set of typical transport network scenarios including their topology and traffic parameters. Based on an existing population model an estimation of traffic streams for 2004 is derived. Additionally, dynamic traffic characteristics as well as multi-layer model requirements like the definition of traffic mixes consisting of traffic demands with different SDH granularities are considered. As an example for using the network scenarios, results of comparative network dimensioning and simulation studies are presented for static and dynamic traffic scenarios, respectively. The network scenarios and data sets presented in this paper have been jointly developed by the partners T-Systems, Marconi, and University of Stuttgart within the MultiTeraNet research framework of the German Ministry of Education and Research (BMBF). One goal of this paper is to provide scenarios that allow in future a better comparison of results achieved by different partners.

1 Introduction

Results of network planning and performance evaluation studies carried out by different research groups are only comparable if they are based on the same or at least similar network scenarios. Therefore, this document defines three different optical transport network reference scenarios that can serve as basis for a great variety of studies in the context of photonic networks. The scenarios are based on the following networks:

- a hypothetical German backbone network used, e.g., in [11]
- a pan-European network defined in European projects COST 266 and LION among other networks and denoted as “basic network” (BN) there [8, 9]. This network has been used, e.g., in [1, 6, 7].
- a US network based on a former NSF network topology [14] which has been used in many studies that have been published over the last couple of years, e.g. [17]

The reference scenarios are defined in the following sections in terms of network and traffic parameters. Detailed information on each of the networks including cable length and traffic matrices as well as sample dimensioning results can be found in [3].

Finally, Section 4 presents several studies and results under static as well as under dynamic traffic conditions that show the impact of the different network scenarios.

2 Network Parameters

Networks are characterised by logical network topology and physical lengths of the cable ducts. Topologies of the German, European, and US networks are shown in Figure 1, Figure 2, and Figure 3, respectively. Table 1 gives an overview of relevant topology parameters.

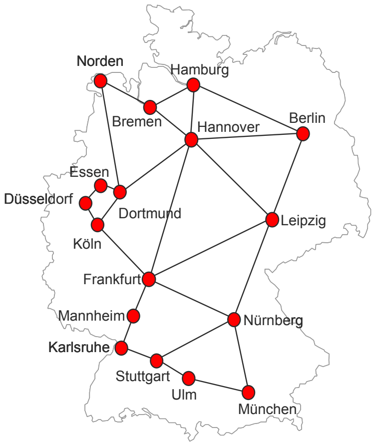

Figure 1: German network (17 nodes)

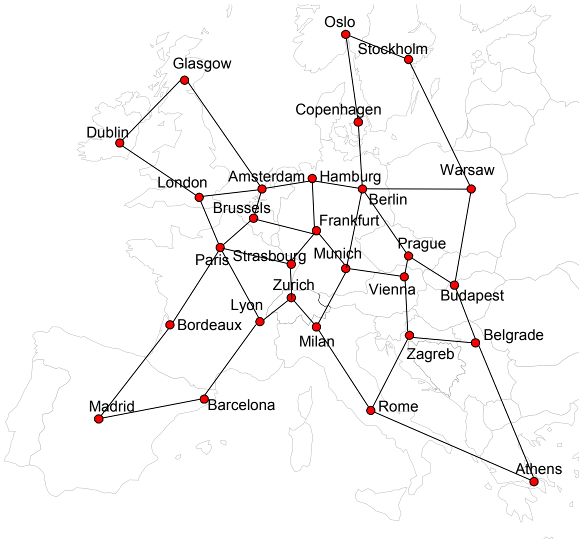

Figure 2: European network (28 nodes) [8]

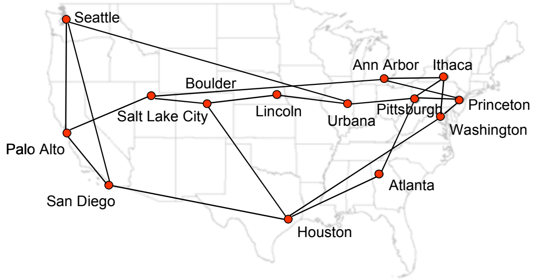

Figure 3: US network (14 nodes) [14]

		Network		
		German	**European**	**US**
number of	**nodes *n***	17	28	14
	links *k*	26	41	21
node degree	**minimum**	2	2	2
	maximum	6	5	4
	average	305.882	292.857	3
network connectivity	**y**	0.191176	0.108466	0.230769
link length [km]	**minimum**	36	218	312
	maximum	353	1500	3408
	average	170.269	625.366	1299.05
network diameter	**[(km]**	951	5051	5316
	[hops]	6	8	3
average distance	**[km]**	413.5	1983.06	2722.44
	[hops]	269.853	356.085	214.286

Table 1: Topological parameters

The European network has 28 nodes and is therefore the largest network. The German network (17 nodes) and the US network (14 nodes) have about the same number of nodes (*n*) and bi-directional links (*k*). Average node degree ($2 \cdot k / n$) is approximately the same for all networks. Minimum, maximum, and average link length is significantly larger in the European network compared to the German network. The US network contains both rather short and very long links.

The link lengths together with the number of nodes determine the network diameter in km, which is defined as the longest shortest path with respect to length for any node pair. Therefore, the European and the US network both have a diameter of more than 5000 km while in the German network the diameter is below 1000 km. The same difference between the network topologies occurs concerning the average distance between node pairs on the shortest path. The length distance is mainly important in case of transparent networks with transparency restrictions caused by physical layer effects.

The distance between node pairs based on the number of hops – given as both maximum (diameter) and average value in Table 1 – is a good indicator for the amount of through traffic in network nodes (which also depends on the traffic matrix). Through traffic share is an important parameter when, e.g., comparing opaque and transparent node architectures. As the average node degree is about the same in all networks the average distance in number of hops is almost proportional to the number of nodes in the network with an offset of 1 in the average distance.

3 Traffic Parameters

3.1 Traffic Matrices

Calculation of traffic matrices follows the model proposed in [10] which has been applied to other networks in [2, 9]. The basic idea of this approach is to separate traffic into voice, so called transaction data traffic (data traffic except Internet traffic) and IP traffic to derive corresponding traffic demands from published statistical data in different ways:

$$Traffic_{voice} = K_V \cdot \frac{P_i \cdot P_j}{D_{ij}}$$

$$Traffic_{data} = K_T \cdot \frac{E_i \cdot E_j}{\sqrt{D_{ij}}}$$

$$Traffic_{IP} = K_I \cdot H_i \cdot H_j$$

This means that traffic between two cities/regions *i* and *j* depends on the population P_i and P_j (voice), the number of employees E_i and E_j (transaction data), and the number of hosts H_i and H_j (IP), respectively. Moreover, there is a strong dependence on inter-city/region distance D_{ij} in case of voice traffic while this dependence is minor or not present for transaction data and IP traffic, respectively. Constants K_V, K_T, and K_I can be determined by comparing the overall traffic with measured traffic.

This approach has been applied to the previously defined reference networks. Resulting bandwidth matrices (with values in Gbit/s) for the different traffic types have been summed up to obtain an overall traffic matrix for each scenario, which will be sufficient for most of the studies. Matrix entries represent bi-directional traffic streams. All matrices are given in [3]. Table 2 summarises the outcome of traffic calculation describing some relevant parameters derived from the traffic matrices.

Total traffic volume V is in the range between 2 to 7 Tbs. Although being the largest network regarding the number of nodes the European network has the lowest traffic volume as it does only consider the population within the city regions, while for the other two networks the entire population in the country has taken into account. Average bi-directional traffic terminated at a node is defined as $2 \cdot V / n$. It is significantly higher in the US network as compared to the other networks. This effect is even more pronounced in case of the average traffic per node pair which is defined as $2 \cdot V / (n \cdot (n-1))$. Total traffic load L given in Table 2 represents the aggregate traffic induced on all links in the network if traffic is routed along the shortest path (with relation to hop count). From that parameter the average load per link L / k and the average distance per bit L / V can be derived. The latter parameter describes the number of links that have to be traversed in average, whereby the average is related to the amount of traffic. This value is usually smaller than the average distance between nodes in number of hops given in Table 1. This is mainly due to the fact that inter-node voice and transaction data traffic depends on the distance with a bias towards small distances. Average distance per bit in the German network is an exception to that rule as it is larger than the average distance given in Table 1. The main reason is that in this network a huge proportion of the overall traffic is between two specific nodes (Frankfurt and Norden) which are the aggregation and interconnection points for international traffic, respectively.

Traffic matrices are related to the base year 2004. From these basic traffic matrices modified demand matrices with higher or lower traffic may be derived by either linear scaling or application of different growth rates per year for individual traffic types. Examples of appropriate growth rates can be found in Table 3.

Due to the high growth rate of IP traffic (especially in the optimistic scenario) this leads to a reduced dependence on inter-city distance, i.e. traffic distribution becomes more uniform with time.

	Network		
	German	**European**	**US**
total traffic volume *V* [Gbit/s]	2396,2	2029,4	6626,7
avg. traffic per node [Gbit/s]	281,9	145	946,8
avg. traffic per node pair [Gbit/s]	17,6	5,4	72,8
total traffic load *L* [Gbit/s]	6914,2	6209,6	12811
average load per link [Gbit/s]	265,9	151,5	610
average distance per bit	2,89	3,06	1,93

Table 2: Traffic parameters related to base year 2004

	conservative	**medium**	**optimistic**
voice traffic	5%	10%	15%
transaction data traffic	15%	30%	45%
IP traffic	50%	100%	150%

Table 3: Sample traffic growth rates

3.2 Traffic Granularities

For transport network studies a definition of inter-node traffic on a bandwidth level is not sufficient as demands are usually modelled on a level of OChL (optical channel layer) or SDH (synchronous digital hierarchy)/SONET (synchronous optical network) connection requests. Especially the latter case requires traffic modelling to comprise a definition of demand granularities and corresponding split ratios as different granularities may be present in the same network. Table 4 contains several sets of granularities and split ratios that have been identified to cover a reasonably broad spectrum of relevant traffic mixes.

Split ratios in Table 4 are given as both traffic shares with relation to total traffic volume and shares with relation to the number of connections (values in brackets). The table contains coarse-granular homogenous traffic on STM-16 (VC-4-16c, 2.5 Gbit/s) and STM-64 (VC-4-64c, 10 Gbit/s) level as well as more fine-granular traffic mixes including STM-1 (VC-4) and STM-4 (VC-4-4c) demands.

Traffic Mix	STM-1	STM-4	STM-16	STM-64	Mean/ STM-1
Mix I	50% (87.9%)	20% (8.8%)	30% (3.3%)	–	**1,76**
Mix II	10% (49.2%)	30% (36.9%)	40% (12.3%)	20% (1.5%)	**4,92**
STM-16	–	–	100% (100%)	–	**16**
STM-64	–	–	–	100% (100%)	**64**

Table 4: Split ratios for different traffic mixes

The numbers of connections per node pair for each bandwidth granularity (which may be interpreted as static demands or mean values depending on the type of study) are derived from the values in the bandwidth matrix (containing values in Gbit/s) by applying the corresponding split ratios related to the number of connections (values in brackets in Table 4) and dividing by the connection rate. For simplicity reasons we take the gross connection rate including SDH frame overhead (i.e., $x \cdot 155.52$ Mbit/s for STM-x) for this calculation. Moreover, static network dimensioning often requires fixed traffic demand sets consisting of a matrix with integer numbers of connections for each granularity. In this case an appropriate rounding scheme has to be applied. A simple way is to round all non-integer values up to the next higher integer value. This, however, may lead to a significantly increased total traffic volume. Therefore, rounding schemes have been developed that are able to minimise the increase of the total sum during rounding [4].

3.3 Dynamic Traffic Characteristics

If network performance has to be evaluated (e.g., via event-driven simulation) a characterisation of dynamic traffic behaviour has to be given additionally. In this case connections are assumed to arrive and to be released in a random fashion. This requires a statistical description of the arrival and connection holding processes, e.g. by specifying random distributions of inter-arrival and holding times (Figure 4).

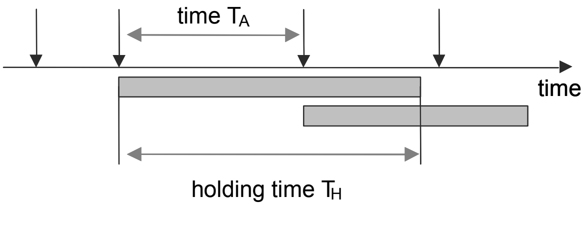

Figure 4: Modelling of dynamic traffic behaviour

In many cases it is justified to assume statistical independence of connection arrivals which generally leads to Poisson arrival process (characterised by negative-exponentially distributed inter-arrival times) in the case of a superposition of many traffic sources. A Poisson process is characterised by the following features (among others):

- Superposition of Poisson arrival processes leads again to a Poisson process.
- Random branching of a Poisson process results in a set of Poisson processes.

This leaves several options for implementation of a connection arrival generation in a network simulation. For example, assuming a Poisson arrival for the total traffic in the network with a subsequent random branching to node pairs and granularities (with branch probabilities derived from the traffic matrix and the split ratios, respectively) is equivalent to a superposition of individual Poisson streams for each node pair and demand granularity.

Concerning the holding time, also a negative-exponential distribution is used in many studies. It has been shown that the holding time distribution has minor influence in case of Poisson arrivals while the impact is significant if arrivals are non-Poisson [16]. Furthermore, it has to be considered that for given distribution types network performance is determined by the offered load which is defined as the product of mean holding time and arrival rate. The absolute value of the mean holding by itself is therefore not relevant for performance evaluation.

More enhanced models for dynamic traffic may consider correlations in the arrival process leading to bursty traffic. Bursts can be modelled as correlated events in the overall arrival process or they may occur independently of each other at a certain node or a certain node pair. Another direction to extend dynamic traffic models is to consider characteristics of different services, e.g. a fixed or variable delay between arrival of a service request and the beginning of service provisioning.

4 Network Studies

In this section, some sample network studies are presented which have been carried out for the network scenarios defined above. Moreover, the following studies based on static and dynamic traffic assumptions, respectively, show the influence of some of the characteristic parameters.

4.1 Static Traffic

In a first study, for each network a set of static SDH traffic demands is derived from the total traffic matrices for year 2004 using traffic mix I as defined in Table 4. Traffic demands are routed across the network and the required number of 10G transponders is determined. This is done for three different network architectures:

- an opaque network with all nodes being capable of intermediate grooming on VC-4 level
- a transparent network enabling optical by-passing in each node
- a network configuration consisting of hybrid nodes which have both intermediate grooming and optical by-passing capabilities

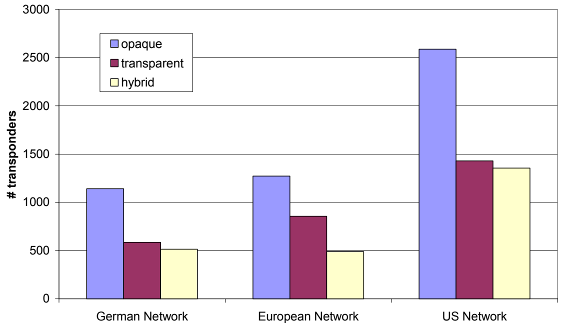

Figure 5: Required 10G transponders for year 2004 traffic matrices

The results shown in Figure 5 basically confirm the effects reported in literature, e.g. [1], like significant transponder savings by the introduction of optical by-passing and an additional reduction when using hybrid nodes. However, the amount of savings is different for each network scenario. In the European network, e.g., hybrid nodes reduce the number of transponders significantly, while they add little benefit compared to a transparent architecture in the NSF network. However, it is hard to see which network parameters are really responsible for the different behaviour.

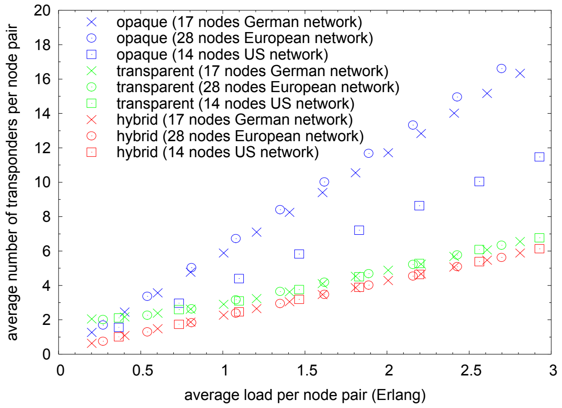

Figure 6: Required 10G transponders for variably scaled traffic matrices

In order to identify the influence of parameters like topological characteristics, traffic parameters, and line rate on the transponder count a different presentation is chosen in Figure 6. For each network the given traffic matrix for year 2004 is scaled with different factors. Traffic volume is then divided by the number of node pairs and by the line rate (10 Gbit/s in this case). The resulting average load per node pair (measured in Erlang) is used as parameter on the x axis. On the y axis the total number of required transponders divided by the number of node pairs is drawn.

In this presentation it can be easily observed that the number of transponders required in average for each node pair increases linearly with the average load per node pair (in the transparent case this is only true for an average load greater than one). For a network architecture with all-optical or hybrid nodes the slope of the curves is the same for each network scenario. The relative reduction of required resources by using hybrid nodes instead of transparent ones becomes rather small for an increasing load per node pair. A quantitative description for this effect has been given in [7].

In the opaque case the slope of the increase of the average transponder count per node pair in Figure 6 is different for each network scenario. This points to a dependence on topological parameters. A closer look to the results reveals that the slope is proportional to the “average distance per bit” as given in Table 2.

An analytical approximation for the dependencies for all three types of network architecture has been derived in [5].

4.2 Dynamic Traffic

In this study, we first show that it is essential to consider different traffic granularity mixed for a comprehensive evaluation of SDH/WDM multi layer networks. Also, we present results which stress that network topology can have a significant impact on overall performance. The network model assumed here is based on multi layer nodes that can switch traffic in the optical as well as in the electronic domain. The electronic and optical switching matrices are connected by a pool of tuneable transponders.

Two principle schemes are applied for routing and traffic grooming in the network :

- PreferSDH: preferably routes the new connection request using established single or multi hop light paths, i.e. exploring the SDH domain, before establishing a new light path.
- PreferOpt: preferably uses or establish a (new) direct light path before using the residual capacity of existing light paths and SDH switching capabilities.

In the following, the European network is used as specified above. The number of transponders is calculated by applying the dimensioning scheme ErlangB, (see [12]) whereas for simplification the number of fibers interconnecting nodes is assumed to be no limiting factor.

In Figure 7, the SDH network blocking probability is depicted versus the overprovisioning factor for traffic mix I and II (Table 4). Obviously, the increase of the number of transponders leads to a lower blocking probability. Further, it can be seen that the traffic with a granularity distribution according to mix I (the mix without requests of wavelength capacity) gets a much lower blocking probability than the traffic according to mix II independent on the routing scheme. From a teletraffic theory point of view this can be explained by modelling the transponder pool as a bundle of servers in an Erlang loss model. An equivalent bundle size for the model can be obtained by dividing the capacity of the transponder pool by the average/typical granularity of a certain traffic mix. Note that mix I is much more fine granular than mix II and does not contain any full wavelength requests. Thus, according to the economies of scale, the greater equivalent bundle size for mix I yields a lower blocking probability compared to mix II.

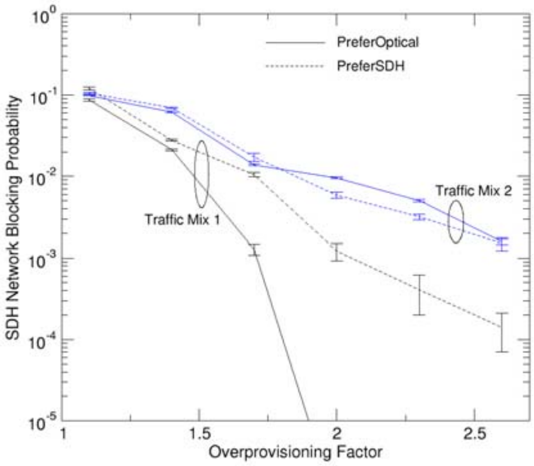

Figure 7: Impact of Traffic Mix

A further study deals with the influence of the network topology on the performance of a routing scheme. Here, we demonstrate the need for different network scenarios for ensuring the validity of statements.

We use again the multi layer model described above, but now the dimensioning schemes of [12] are applied to both links and transponders. We keep the total number of fibers constant whereas the number of transponders is scaled from 0 to a maximum that is defined by the maximum traffic that can be carried by the network. The links are dimensioned such that in both networks the routing scheme PreferSDH can reach a blocking probability of approx. 10^{-3}. Instead of using the routing scheme PreferOpt, the routing scheme PureOptical is applied (see [13]) that only uses or establishes a (new) direct light path and does not use the residual capacity of existing light paths on alternate routes in the electrical layer.

In Figure 8 and Figure 9, the SDH network blocking probability versus the fraction of transponders installed for two different scenarios is shown. The upper graph depicts the results for the German network, the lower one that for the European network. The behaviour can be best explained by looking at the two sections separately [13]. In the right part, the fraction of transponders is large and the network dimensioning limits the performance. In the left part, the fraction of transponders is low and the transponder shortage dominates the blocking of connections. Further, it can be seen that in the German network the routing scheme PureOptical outperforms PreferSDH by more than one order of magnitude. However, in the European network, the situation is inverted as PreferSDH outperforms PureOptical by half an order of magnitude.

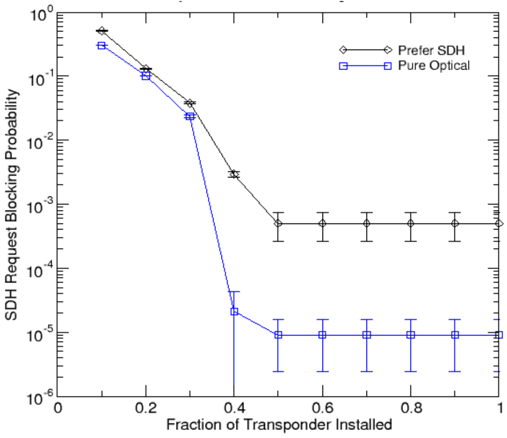

Figure 8: Performance Evaluation of German Network

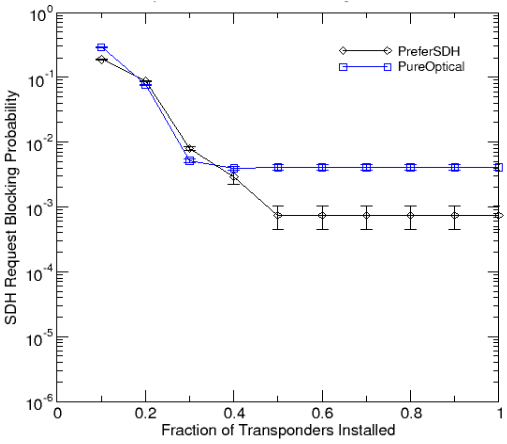

Figure 9: Performance Evaluation of European Network

5 Conclusions

This paper describes a set of typical transport networks scenarios, including their topology and traffic characteristics. The scenarios are an appropriate basis for network planning and simulation studies. Assumptions about traffic matrix, traffic mix, and growth rates are derived from real data sets. This ensures the relevance of case studies based on these scenarios.

As examples we have presented several case studies based on the proposed network scenario. In a first case study static network dimensioning for different optical network architectures has been investigated. Effects like the reduction of transponder count by the introduction of optical by-passing have been confirmed for all three network scenarios. Moreover, it has been shown to what extent the amount of transponder savings depends on topological and on traffic parameters.

Furthermore, case studies under dynamic traffic conditions have been presented. They show that for comprehensive performance evaluation in multi-layer networks a single topology and traffic mix are insufficient. Instead, a representative set of network scenarios, traffic mixes and traffic growth rates as described in this document should be used.

6 Acknowledgement

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