Reference Transport Network Scenarios

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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 based on the following networks:

- a hypothetical German backbone network used, e.g., in [7]
- a pan-European network defined in European COST 266 project among other networks and denoted as "basic network" (BN) there [4, 5]. This network has been used, e.g., in [3].
- a US network based on a former NSF network topology [8] which has been used in many studies that have been published over the last couple of years [11]

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 the appendix.

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 on relevant topology 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 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 related to length for any node pair. Therefore, the European and the US network both have a diameter of more than 5000 km while within the German network 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 work reported in this paper has been supported by the German Ministry of Education and Research (BMBF) within the MultiTeraNet project under contract numbers 01 BP 254, 01 BP 256, and 01 BP 289. The authors are responsible for the content of this paper.

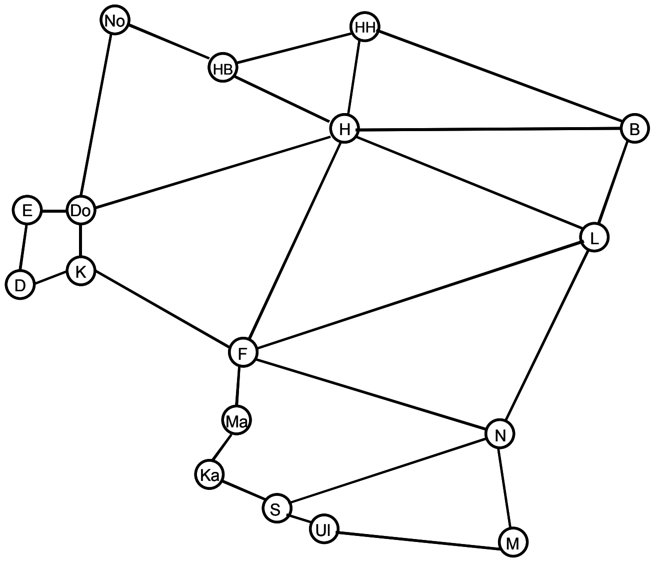

Figure 1: Germany network (17 nodes)

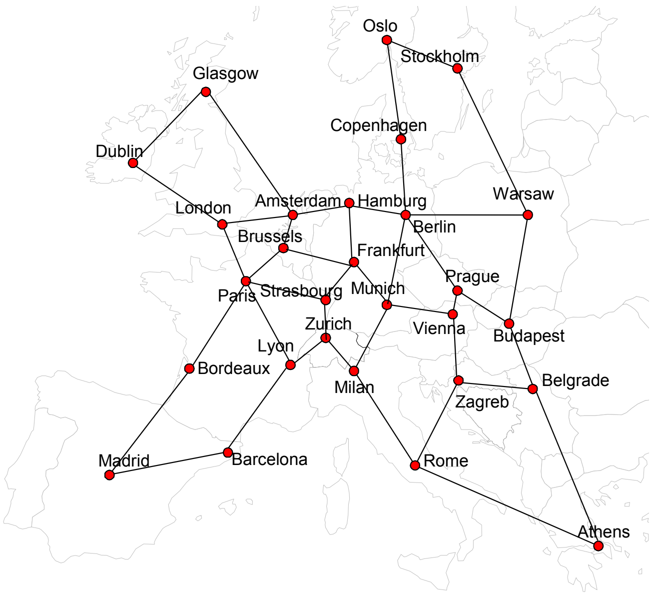

Figure 2: Pan-European network (28 nodes) [4]

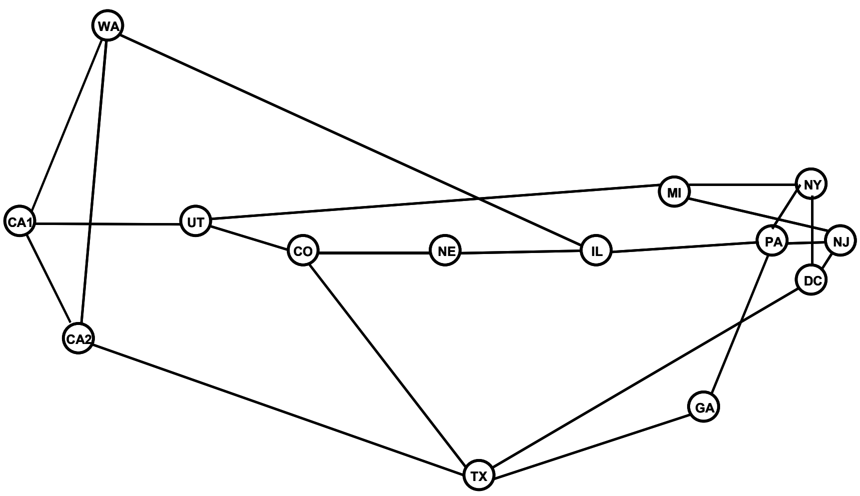

Figure 3: US network (14 nodes) [8]

	German network	European network	US network
number of nodes *n*	17	28	14
number of links *k*	26	41	21
minimum node degree	2	2	2
maximum node degree	6	5	4
average node degree	3.05882	2.92857	3
network connectivity	0.191176	0.108466	0.230769
minimum link length (km)	36	218	312
maximum link length (km)	353	1500	3408
average link length (km)	170.269	625.366	1299.05
network diameter (km)	951	5051	5316
average distance (km)	413.5	1983.06	2722.44
network diameter (hops)	6	8	3
average distance (hops)	2.69853	3.56085	2.14286

Table 1: Topological parameters

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 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 [6] which has been applied to other networks in [1, 5]. The basic idea of this approach is to separate traffic into voice, transaction data, and IP traffic and 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 the appendix. Table 2 summarises the outcome of traffic calculation describing some relevant parameters derived from the traffic matrices.

	German network	European network	US network
total traffic volume *V*	2396.2 Gbit/s	2029.4 Gbit/s	6626.7 Gbit/s
avg. traffic per node	281.9 Gbit/s	145.0 Gbit/s	946.8 Gbit/s
avg. traffic per node pair	17.6 Gbit/s	5.4 Gbit/s	72.8 Gbit/s
total traffic load *L*	6914.2 Gbit/s	6209.6 Gbit/s	12811.0 Gbit/s
average load per link	265.9 Gbit/s	151.5 Gbit/s	610.0 Gbit/s
average distance per bit	2.89	3.06	1.93

Table 2: Traffic parameters related to base year 2004

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 only carries international traffic. 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.

	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

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.

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 [2].

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).

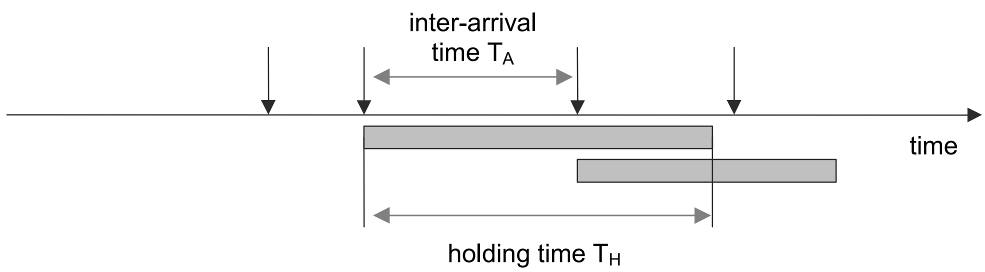

Figure 4: Modelling of dynamic traffic behaviour

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 [10]. 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 Appendix: Tables

The following tables show for each of the reference networks

- physical distance between adjacent nodes
- total inter-node traffic (in Gbit/s) for each node pair
- inter-node traffic (in Gbit/s) for each node pair, related to individual traffic types (voice, transaction data, IP)

Additionally, multiplexing of the traffic matrix into STM-16 traffic streams and resulting network dimensioning obtained with OPNET WDM Guru [9] are given as an example. The dimensioning has been performed for the unprotected and the 1+1 protected case. The dimensioning is based on a hop and physical distance shortest path calculation. For the scenario applying protection, shortest link disjoint cycles have been calculated.

4.1 German Network

The lengths of the fibre ducts in the German Network are the airline distances between the node locations multiplied by the factor 1.2, based on empirical length values in real networks.

The traffic matrices are calculated for the basis year 2001 with the following constants (see section 3.1):

$$K_V = 0{,}000646$$
$$K_T = 0{,}00978$$
$$K_I = 0{,}0002695$$

Starting with the basis year 2001, the traffic volume for the year 2004 was estimated by using the following growth rates which are derived from forecasts of federal statistics offices and broadcast corporations:

$$Voice : 15\%$$
$$Data : 30\%$$
$$IP : 100\%$$

Physical Distances																	
	B	HB	Do	D	E	F	HH	H	Ka	K	L	Ma	M	No	N	S	Ul
B																	
HB																	
Do																	
D																	
E			37	36													
F																	
HH	306	114															
H	298	120	208			316	157										
Ka																	
K			88	41		182											
L	174					353		258									
Ma						85			64								
M																	
No		144	278														
N						224					275		179				
S									74						187		
Ul													143			86	
Fibre Length [km]																	

Table 5: German network physical distance matrix

2004: voice traffic estimation [Gbit/s]																	
	B	HB	Do	D	E	F	HH	H	Ka	K	L	Ma	M	No	N	S	Ul
B		0.788	0.852	0.828	0.626	2.338	1.974	2.248	0.238	0.886	5.67	0.456	0.884	0	0.932	1.028	0.634
HB	0.788		0.78	0.676	0.556	1.304	2.276	2.394	0.118	0.668	1.132	0.234	0.326	0	0.34	0.468	0.266
Do	0.852	0.78		4.258	5.628	3.34	1.094	1.996	0.27	3.56	1.49	0.57	0.576	0	0.628	0.984	0.516
D	0.828	0.676	4.258		6.408	3.676	1.012	1.654	0.314	8.42	1.44	0.652	0.624	0	0.656	1.108	0.572
E	0.626	0.556	5.628	6.408		2.622	0.798	1.278	0.212	3.61	1.082	0.442	0.442	0	0.47	0.764	0.4
F	2.338	1.304	3.34	3.676	2.622		2.198	3.496	1.53	4.434	4.51	4.426	2.35	9.358	2.898	5.234	2.458
HH	1.974	2.276	1.094	1.012	0.798	2.198		3.73	0.21	1.028	2.436	0.41	0.632	0	0.66	0.854	0.498
H	2.248	2.394	1.996	1.654	1.278	3.496	3.73		0.312	1.664	3.712	0.63	0.874	0	0.988	1.266	0.714
Ka	0.238	0.118	0.27	0.314	0.212	1.53	0.21	0.312		0.384	0.464	0.888	0.38	0	0.376	1.816	0.522
K	0.886	0.668	3.56	8.42	3.61	4.434	1.028	1.664	0.384		1.578	0.82	0.712	0	0.758	1.322	0.67
L	5.67	1.132	1.49	1.44	1.082	4.51	2.436	3.712	0.464	1.578		0.902	1.756	0	2.178	2.044	1.264
Ma	0.456	0.234	0.57	0.652	0.442	4.426	0.41	0.63	0.888	0.82	0.902		0.622	0	0.706	2.122	0.762
M	0.884	0.326	0.576	0.624	0.442	2.35	0.632	0.874	0.38	0.712	1.756	0.622		0	1.798	2.13	2.104
No	0	0	0	0	0	9.358	0	0	0	0	0	0	0		0	0	0
N	0.932	0.34	0.628	0.656	0.47	2.898	0.66	0.988	0.376	0.758	2.178	0.706	1.798	0		2.028	1.402
S	1.028	0.468	0.984	1.108	0.764	5.234	0.854	1.266	1.816	1.322	2.044	2.122	2.13	0	2.028		4.104
Ul	0.634	0.266	0.516	0.572	0.4	2.458	0.498	0.714	0.522	0.67	1.264	0.762	2.104	0	1.402	4.104	
Demand [Gbit/s]																	

Table 6: German network voice traffic matrix

2004: data traffic estimation [Gbit/s]																	
	B	HB	Do	D	E	F	HH	H	Ka	K	L	Ma	M	No	N	S	Ul
B		1.554	1.732	2.036	1.364	6.38	4.086	4.024	0.594	2.166	7.254	1.034	2.386	0	1.882	2.454	1.42
HB	1.554		0.972	1.08	0.754	2.84	2.572	2.436	0.246	1.104	1.902	0.434	0.85	0	0.668	0.972	0.54
Do	1.732	0.972		2.904	2.57	4.708	1.912	2.384	0.398	2.73	2.338	0.728	1.21	0	0.972	1.51	0.806
D	2.036	1.08	2.904		3.27	5.824	2.192	2.588	0.51	5.006	2.74	0.928	1.502	0	1.184	1.91	1.01
E	1.364	0.754	2.57	3.27		3.82	1.498	1.752	0.324	2.524	1.828	0.588	0.974	0	0.772	1.222	0.65
F	6.38	2.84	4.708	5.824	3.82		6.036	6.998	2.024	6.542	8.95	4.194	5.346	27.122	4.544	7.412	3.836
HH	4.086	2.572	1.912	2.192	1.498	6.036		5.05	0.544	2.272	4.63	0.956	1.966	0	1.542	2.18	1.224
H	4.024	2.436	2.384	2.588	1.752	6.998	5.05		0.612	2.668	5.278	1.096	2.136	0	1.742	2.448	1.354
Ka	0.594	0.246	0.398	0.51	0.324	2.024	0.544	0.612		0.582	0.846	0.59	0.64	0	0.488	1.33	0.526
K	2.166	1.104	2.73	5.006	2.524	6.542	2.272	2.668	0.582		2.95	1.07	1.65	0	1.31	2.146	1.124
L	7.254	1.902	2.338	2.74	1.828	8.95	4.63	5.278	0.846	2.95		1.488	3.434	0	2.938	3.532	2.046
Ma	1.034	0.434	0.728	0.928	0.588	4.194	0.956	1.096	0.59	1.07	1.488		1.028	0	0.842	1.812	0.8
M	2.386	0.85	1.21	1.502	0.974	5.346	1.966	2.136	0.64	1.65	3.434	1.028		0	2.224	3.006	2.2
No	0	0	0	0	0	27.122	0	0	0	0	0	0	0		0	0	0
N	1.882	0.668	0.972	1.184	0.772	4.544	1.542	1.742	0.488	1.31	2.938	0.842	2.224	0		2.252	1.38
S	2.454	0.972	1.51	1.91	1.222	7.412	2.18	2.448	1.33	2.146	3.532	1.812	3.006	0	2.252		2.93
Ul	1.42	0.54	0.806	1.01	0.65	3.836	1.224	1.354	0.526	1.124	2.046	0.8	2.2	0	1.38	2.93	
Demand [Gbit/s]																	

Table 7: German network transaction data traffic matrix

2004: IP traffic estimation [Gbit/s]																	
	B	HB	Do	D	E	F	HH	H	Ka	K	L	Ma	M	No	N	S	Ul
B		9.196	13.268	14.618	10.508	49.122	18.778	20.794	4.63	15.652	30.666	8.11	16.46	0	13	19.434	12.152
HB	9.196		5.694	6.274	4.51	21.546	8.06	8.926	1.988	6.718	13.162	3.482	7.066	0	5.58	8.342	5.216
Do	13.268	5.694		9.054	6.508	30.866	11.63	12.878	2.868	9.694	18.99	5.024	10.194	0	8.05	12.036	7.526
D	14.618	6.274	9.054		7.17	33.928	12.814	14.19	3.16	10.68	20.924	5.534	11.232	0	8.87	13.262	8.292
E	10.508	4.51	6.508	7.17		24.564	9.21	10.2	2.27	7.676	15.04	3.978	8.074	0	6.376	9.532	5.96
F	49.122	21.546	30.866	33.928	24.564		43.26	47.73	10.934	36.26	69.144	19.04	38.076	252	30.256	44.718	28.326
HH	18.778	8.06	11.63	12.814	9.21	43.26		18.226	4.058	13.72	26.878	7.11	14.428	0	11.394	17.034	10.652
H	20.794	8.926	12.878	14.19	10.2	47.73	18.226		4.494	15.192	29.764	7.872	15.976	0	12.618	18.864	11.794
Ka	4.63	1.988	2.868	3.16	2.27	10.934	4.058	4.494		3.382	6.626	1.754	3.556	0	2.81	4.2	2.626
K	15.652	6.718	9.694	10.68	7.676	36.26	13.72	15.192	3.382		22.404	5.926	12.026	0	9.498	14.198	8.878
L	30.666	13.162	18.99	20.924	15.04	69.144	26.878	29.764	6.626	22.404		11.608	23.56	0	18.606	27.818	17.394
Ma	8.11	3.482	5.024	5.534	3.978	19.04	7.11	7.872	1.754	5.926	11.608		6.232	0	4.922	7.358	4.6
M	16.46	7.066	10.194	11.232	8.074	38.076	14.428	15.976	3.556	12.026	23.56	6.232		0	9.988	14.932	9.336
No	0	0	0	0	0	252	0	0	0	0	0	0	0		0	0	0
N	13	5.58	8.05	8.87	6.376	30.256	11.394	12.618	2.81	9.498	18.606	4.922	9.988	0		11.792	7.374
S	19.434	8.342	12.036	13.262	9.532	44.718	17.034	18.864	4.2	14.198	27.818	7.358	14.932	0	11.792		11.024
Ul	12.152	5.216	7.526	8.292	5.96	28.326	10.652	11.794	2.626	8.878	17.394	4.6	9.336	0	7.374	11.024	
Demand [Gbit/s]																	

Table 8: German network IP traffic matrix

2004: total traffic estimation [Gbit/s]																	
	B	HB	Do	D	E	F	HH	H	Ka	K	L	Ma	M	No	N	S	Ul
B		11.536	15.85	17.48	12.496	57.834	24.836	27.066	5.46	18.702	43.588	9.6	19.728	0	15.812	22.916	14.204
HB	11.536		7.446	8.028	5.818	25.688	12.906	13.752	2.35	8.488	16.192	4.148	8.24	0	6.586	9.778	6.02
Do	15.85	7.446		16.214	14.704	38.91	14.636	17.258	3.532	15.982	22.816	6.318	11.978	0	9.648	14.528	8.846
D	17.48	8.028	16.214		16.844	43.424	16.014	18.43	3.982	24.104	25.102	7.112	13.354	0	10.708	16.278	9.874
E	12.496	5.818	14.704	16.844		31.004	11.504	13.228	2.804	13.81	17.95	5.006	9.488	0	7.616	11.514	7.008
F	57.834	25.688	38.91	43.424	31.004		51.492	58.224	14.484	47.234	82.6	27.656	45.768	288.48	37.692	57.36	34.614
HH	24.836	12.906	14.636	16.014	11.504	51.492		27.004	4.81	17.018	33.942	8.472	17.022	0	13.594	20.066	12.372
H	27.066	13.752	17.258	18.43	13.228	58.224	27.004		5.414	19.522	38.752	9.596	18.986	0	15.344	22.574	13.86
Ka	5.46	2.35	3.532	3.982	2.804	14.484	4.81	5.414		4.346	7.934	3.228	4.574	0	3.67	7.344	3.672
K	18.702	8.488	15.982	24.104	13.81	47.234	17.018	19.522	4.346		26.928	7.814	14.386	0	11.564	17.666	10.67
L	43.588	16.192	22.816	25.102	17.95	82.6	33.942	38.752	7.934	26.928		13.998	28.748	0	23.722	33.392	20.702
Ma	9.6	4.148	6.318	7.112	5.006	27.656	8.472	9.596	3.228	7.814	13.998		7.88	0	6.468	11.288	6.16
M	19.728	8.24	11.978	13.354	9.488	45.768	17.022	18.986	4.574	14.386	28.748	7.88		0	14.008	20.066	13.638
No	0	0	0	0	0	288.48	0	0	0	0	0	0	0		0	0	0
N	15.812	6.586	9.648	10.708	7.616	37.692	13.594	15.344	3.67	11.564	23.722	6.468	14.008	0		16.07	10.154
S	22.916	9.778	14.528	16.278	11.514	57.36	20.066	22.574	7.344	17.666	33.392	11.288	20.066	0	16.07		18.056
Ul	14.204	6.02	8.846	9.874	7.008	34.614	12.372	13.86	3.672	10.67	20.702	6.16	13.638	0	10.154	18.056	
Demand [Gbit/s]																	

Table 9: German network total traffic matrix

2004: total traffic estimation [STM-16 equivalents]																	
	B	HB	Do	D	E	F	HH	H	Ka	K	L	Ma	M	No	N	S	Ul
B		5	7	8	6	24	10	11	3	8	18	4	8	0	7	10	6
HB	5		3	4	3	11	6	6	1	4	7	2	4	0	3	4	3
Do	7	3		7	6	16	6	7	2	7	10	3	5	0	4	6	4
D	8	4	7		7	18	7	8	2	10	11	3	6	0	5	7	4
E	6	3	6	7		13	5	6	2	6	8	3	4	0	4	5	3
F	24	11	16	18	13		21	24	6	19	34	12	19	116	16	24	14
HH	10	6	6	7	5	21		11	2	7	14	4	7	0	6	9	5
H	11	6	7	8	6	24	11		3	8	16	4	8	0	7	10	6
Ka	3	1	2	2	2	6	2	3		2	4	2	2	0	2	3	2
K	8	4	7	10	6	19	7	8	2		11	4	6	0	5	8	5
L	18	7	10	11	8	34	14	16	4	11		6	12	0	10	14	9
Ma	4	2	3	3	3	12	4	4	2	4	6		4	0	3	5	3
M	8	4	5	6	4	19	7	8	2	6	12	4		0	6	9	6
No	0	0	0	0	0	116	0	0	0	0	0	0	0		0	0	0
N	7	3	4	5	4	16	6	7	2	5	10	3	6	0		7	5
S	10	4	6	7	5	24	9	10	3	8	14	5	9	0	7		8
Ul	6	3	4	4	3	14	5	6	2	5	9	3	6	0	5	8	
Demand [STM-16 equivalents]																	

Table 10: German network STM-16 traffic demand matrix

STM-16 Dimensioning: unprotected / 1+1 protected																	
	B	HB	Do	D	E	F	HH	H	Ka	K	L	Ma	M	No	N	S	Ul
B							10	45			80						
HB							6	60						0			
Do					68			115		190				116			
D					81					106							
E			188	188													
F								72		306	97	79			161		
HH	90	77						104									
H	151	207	301			421	143				127						
Ka												37				17	
K			333	188		397											
L	211					243		287							148		
Ma						228			228								
M															89		17
No		166	166														
N						307					333		190			170	
S									228						330		88
Ul													190			190	
STM-16 Dimensioning (1+1 protected)																	

STM-16 Dimensioning (unprotected)

Table 11: German network STM-16 network dimensioning

4.2 European Network

The topology and traffic parameters for the European Network are all based on publications of the department of Information Technology, University of Ghent [4].

Physical Distances

	Amsterdam	Athens	Barcelona	Belgrade	Berlin	Bordeaux	Brussels	Budapest	Copenhagen	Dublin	Frankfurt	Glasgow	Hamburg	London	Lyon	Madrid	Milan	Munich	Oslo	Paris	Prague	Rome	Stockholm	Strasbourg	Vienna	Warsaw	Zagreb	Zurich
Amsterdam																												
Athens																												
Barcelona																												
Belgrade		1209																										
Berlin																												
Bordeaux																												
Brussels	259																											
Budapest				474																								
Copenhagen					540																							
Dublin																												
Frankfurt							474																					
Glasgow	1067									462																		
Hamburg	552				381						592																	
London	540									690																		
Lyon			796																									
Madrid			760			834																						
Milan																												
Munich					757						456						522											
Oslo									722																			
Paris						747	393							514	594													
Prague					420			668																				
Rome		1500															720											
Stockholm																			623									
Strasbourg											271									600								
Vienna																		534			376							
Warsaw					775			819															1213					
Zagreb				551																		783			400			
Zurich															507		327							218				

Fibre Length [km]

Table 12: European network physical distance matrix

2004: voice traffic estimation [Gbit/s]

	Amsterdam	Athens	Barcelona	Belgrade	Berlin	Bordeaux	Brussels	Budapest	Copenhagen	Dublin	Frankfurt	Glasgow	Hamburg	London	Lyon	Madrid	Milan	Munich	Oslo	Paris	Prague	Rome	Stockholm	Strasbourg	Vienna	Warsaw	Zagreb	Zurich
Amsterdam		0.131	0.426	0.200	0.953	0.425	1.573	0.232	0.228	0.136	1.515	1.110	1.493	2.193	0.535	0.357	0.924	0.824	0.130	0.920	0.383	0.589	0.209	0.845	0.232	0.933	0.107	0.315
Athens	0.131		0.187	0.233	0.203	0.121	0.087	0.158	0.044	0.024	0.203	0.183	0.180	0.219	0.147	0.148	0.347	0.244	0.030	0.125	0.118	0.483	0.065	0.150	0.112	0.424	0.072	0.079
Barcelona	0.426	0.187		0.229	0.455	1.093	0.317	0.221	0.100	0.087	0.624	0.585	0.462	0.859	0.921	1.294	1.308	0.647	0.069	0.586	0.249	1.103	0.128	0.535	0.199	0.679	0.119	0.286
Belgrade	0.200	0.233	0.229		0.365	0.158	0.132	0.561	0.071	0.032	0.343	0.247	0.297	0.310	0.213	0.173	0.569	0.471	0.044	0.181	0.244	0.700	0.096	0.248	0.293	0.820	0.210	0.133
Berlin	0.953	0.203	0.455	0.365		0.382	0.540	0.500	0.512	0.101	1.671	0.848	2.796	1.092	0.520	0.365	1.170	1.406	0.183	0.579	1.255	0.832	0.374	0.860	0.536	2.549	0.196	0.373
Bordeaux	0.425	0.121	1.093	0.158	0.382		0.331	0.161	0.087	0.093	0.561	0.584	0.412	0.987	0.840	0.879	0.922	0.510	0.060	0.731	0.199	0.639	0.107	0.480	0.149	0.530	0.083	0.236
Brussels	1.573	0.087	0.317	0.132	0.540	0.331		0.151	0.119	0.085	1.111	0.634	0.717	1.561	0.443	0.257	0.702	0.584	0.070	0.960	0.242	0.416	0.117	0.718	0.152	0.562	0.073	0.251
Budapest	0.232	0.158	0.221	0.561	0.500	0.161	0.151		0.088	0.034	0.423	0.268	0.371	0.340	0.223	0.167	0.605	0.609	0.050	0.198	0.383	0.589	0.112	0.291	0.624	1.172	0.244	0.153
Copenhagen	0.228	0.044	0.100	0.071	0.512	0.087	0.119	0.088		0.028	0.272	0.252	0.632	0.276	0.107	0.085	0.220	0.218	0.083	0.128	0.143	0.166	0.152	0.154	0.083	0.509	0.035	0.067
Dublin	0.136	0.024	0.087	0.032	0.101	0.093	0.085	0.034	0.028		0.122	0.621	0.124	0.416	0.082	0.088	0.131	0.097	0.023	0.123	0.045	0.098	0.035	0.086	0.031	0.135	0.016	0.038
Frankfurt	1.515	0.203	0.624	0.343	1.671	0.561	1.111	0.423	0.272	0.122		0.951	1.798	1.595	0.902	0.472	1.908	2.335	0.139	1.064	0.854	1.027	0.256	2.811	0.468	1.477	0.207	0.824
Glasgow	1.110	0.183	0.585	0.247	0.848	0.584	0.634	0.268	0.252	0.621	0.951		1.074	2.650	0.566	0.571	0.953	0.741	0.222	0.816	0.361	0.720	0.317	0.637	0.246	1.123	0.120	0.278
Hamburg	1.493	0.180	0.462	0.297	2.796	0.412	0.717	0.371	0.632	0.124	1.798	1.074		1.407	0.538	0.382	1.094	1.159	0.216	0.681	0.716	0.752	0.375	0.885	0.377	1.756	0.156	0.359
London	2.193	0.219	0.859	0.310	1.092	0.987	1.561	0.340	0.276	0.416	1.595	2.650	1.407		0.989	0.777	1.477	1.109	0.191	2.132	0.487	0.986	0.304	1.120	0.325	1.305	0.161	0.460
Lyon	0.535	0.147	0.921	0.213	0.520	0.840	0.443	0.223	0.107	0.082	0.902	0.566	0.538	0.989		0.536	2.087	0.882	0.068	0.919	0.292	0.943	0.124	0.941	0.219	0.684	0.124	0.527
Madrid	0.357	0.148	1.294	0.173	0.365	0.879	0.257	0.167	0.085	0.088	0.472	0.571	0.382	0.777	0.536		0.798	0.460	0.062	0.464	0.190	0.694	0.113	0.381	0.149	0.553	0.085	0.192
Milan	0.924	0.347	1.308	0.569	1.170	0.922	0.702	0.605	0.220	0.131	1.908	0.953	1.094	1.477	2.087	0.798		2.831	0.132	1.104	0.755	2.852	0.255	1.948	0.620	1.597	0.391	1.585
Munich	0.824	0.244	0.647	0.471	1.406	0.510	0.584	0.609	0.218	0.097	2.335	0.741	1.159	1.109	0.882	0.460	2.831		0.117	0.742	1.168	1.411	0.231	1.782	0.786	1.622	0.354	1.036
Oslo	0.130	0.030	0.069	0.044	0.183	0.060	0.070	0.050	0.083	0.023	0.139	0.222	0.216	0.191	0.068	0.062	0.132	0.117		0.082	0.068	0.106	0.158	0.086	0.045	0.268	0.020	0.038
Paris	0.920	0.125	0.586	0.181	0.579	0.731	0.960	0.198	0.128	0.123	1.064	0.816	0.681	2.132	0.919	0.464	1.104	0.742	0.082		0.285	0.637	0.141	0.911	0.194	0.690	0.099	0.364
Prague	0.383	0.118	0.249	0.244	1.255	0.199	0.242	0.383	0.143	0.045	0.854	0.361	0.716	0.487	0.292	0.190	0.755	1.168	0.068	0.285		0.528	0.143	0.493	0.552	1.261	0.153	0.235
Rome	0.589	0.483	1.103	0.700	0.832	0.639	0.416	0.589	0.166	0.098	1.027	0.720	0.752	0.986	0.943	0.694	2.852	1.411	0.106	0.637	0.528		0.213	0.849	0.507	1.388	0.400	0.504
Stockholm	0.209	0.065	0.128	0.096	0.374	0.107	0.117	0.112	0.152	0.035	0.256	0.317	0.375	0.304	0.124	0.113	0.255	0.231	0.158	0.141	0.143	0.213		0.159	0.096	0.697	0.043	0.073
Strasbourg	0.845	0.150	0.535	0.248	0.860	0.480	0.718	0.291	0.154	0.086	2.811	0.637	0.885	1.120	0.941	0.381	1.948	1.782	0.086	0.911	0.493	0.849	0.159		0.315	0.924	0.155	1.225
Vienna	0.232	0.112	0.199	0.293	0.536	0.149	0.152	0.624	0.083	0.031	0.468	0.246	0.377	0.325	0.219	0.149	0.620	0.786	0.045	0.194	0.552	0.507	0.096	0.315		0.933	0.222	0.166
Warsaw	0.933	0.424	0.679	0.820	2.549	0.530	0.562	1.172	0.509	0.135	1.477	1.123	1.756	1.305	0.684	0.553	1.597	1.622	0.268	0.690	1.261	1.388	0.697	0.924	0.933		0.348	0.443
Zagreb	0.107	0.072	0.119	0.210	0.196	0.083	0.073	0.244	0.035	0.016	0.207	0.120	0.156	0.161	0.124	0.085	0.391	0.354	0.020	0.099	0.153	0.400	0.043	0.155	0.222	0.348		0.088
Zurich	0.315	0.079	0.286	0.133	0.373	0.236	0.251	0.153	0.067	0.038	0.824	0.278	0.359	0.460	0.527	0.192	1.585	1.036	0.038	0.364	0.235	0.504	0.073	1.225	0.166	0.443	0.088	

Demand [Gbit/s]

Table 13: European network voice traffic matrix

2004: data traffic estimation [Gbit/s]

	Amsterdam	Athens	Barcelona	Belgrade	Berlin	Bordeaux	Brussels	Budapest	Copenhagen	Dublin	Frankfurt	Glasgow	Hamburg	London	Lyon	Madrid	Milan	Munich	Oslo	Paris	Prague	Rome	Stockholm	Strasbourg	Vienna	Warsaw	Zagreb	Zurich
Amsterdam		1.164	2.874	0.530	5.281	2.622	4.116	1.556	1.425	0.829	6.659	6.835	6.610	9.609	2.940	2.629	5.104	4.911	0.988	3.857	2.460	4.074	1.655	3.697	1.491	6.506	0.779	1.959
Athens	1.164		1.408	0.424	1.801	1.036	0.715	0.949	0.464	0.257	1.803	2.052	1.700	2.248	1.140	1.253	2.313	1.977	0.353	1.051	1.009	2.731	0.683	1.153	0.768	3.244	0.471	0.727
Barcelona	2.874	1.408		0.574	3.688	4.251	1.868	1.533	0.955	0.669	4.322	5.017	3.720	6.083	3.903	5.061	6.141	4.399	0.727	3.112	2.006	5.641	1.311	2.973	1.398	5.612	0.828	1.885
Belgrade	0.530	0.424	0.574		0.891	0.436	0.325	0.659	0.217	0.109	0.864	0.879	0.803	0.984	0.506	0.498	1.092	1.012	0.157	0.466	0.535	1.211	0.307	0.546	0.457	1.663	0.297	0.347
Berlin	5.281	1.801	3.688	0.891		3.090	2.997	2.835	2.651	0.887	8.690	7.425	11.24	8.427	3.604	3.304	7.141	7.973	1.457	3.803	5.532	6.022	2.755	4.635	2.817	13.37	1.308	2.648
Bordeaux	2.622	1.036	4.251	0.436	3.090		1.746	1.195	0.811	0.631	3.744	4.583	3.209	5.957	3.405	3.812	4.712	3.569	0.620	3.177	1.637	3.923	1.094	2.575	1.105	4.533	0.632	1.565
Brussels	4.116	0.715	1.868	0.325	2.997	1.746		0.945	0.774	0.494	4.300	3.895	3.454	6.114	2.018	1.682	3.356	3.118	0.547	2.971	1.475	2.583	0.936	2.569	0.909	3.809	0.483	1.319
Budapest	1.556	0.949	1.533	0.659	2.835	1.195	0.945		0.656	0.307	2.608	2.493	2.444	2.807	1.410	1.335	3.062	3.131	0.456	1.326	1.823	3.023	0.899	1.608	1.814	5.407	0.872	1.011
Copenhagen	1.425	0.464	0.955	0.217	2.651	0.811	0.774	0.656		0.257	1.933	2.234	2.946	2.335	0.901	0.881	1.706	1.729	0.541	0.986	1.029	1.484	0.968	1.081	0.612	3.292	0.303	0.618
Dublin	0.829	0.257	0.669	0.109	0.887	0.631	0.494	0.307	0.257		0.977	2.638	0.982	2.159	0.594	0.675	0.991	0.868	0.213	0.726	0.435	0.858	0.350	0.607	0.282	1.278	0.154	0.350
Frankfurt	6.659	1.803	4.322	0.864	8.690	3.744	4.300	2.608	1.933	0.977		7.863	9.014	10.18	4.748	3.758	9.118	10.27	1.273	5.156	4.564	6.688	2.277	8.379	2.634	10.18	1.346	3.935
Glasgow	6.835	2.052	5.017	0.879	7.425	4.583	3.895	2.493	2.234	2.638	7.863		8.357	15.75	4.510	4.959	7.729	6.942	1.928	5.416	3.558	6.720	3.041	4.784	2.289	10.64	1.229	2.742
Hamburg	6.610	1.700	3.720	0.803	11.24	3.209	3.454	2.444	2.946	0.982	9.014	8.357		9.565	3.665	3.379	6.905	7.238	1.584	4.125	4.179	5.725	2.758	4.702	2.365	11.09	1.169	2.598
London	9.609	2.248	6.083	0.984	8.427	5.957	6.114	2.807	2.335	2.159	10.18	15.75	9.565		5.962	5.783	9.622	8.491	1.786	8.755	4.135	7.862	2.980	6.345	2.633	11.47	1.422	3.527
Lyon	2.940	1.140	3.903	0.506	3.604	3.405	2.018	1.410	0.901	0.594	4.748	4.510	3.665	5.962		2.978	7.089	4.693	0.659	3.562	1.983	4.765	1.180	3.605	1.338	5.146	0.774	2.341
Madrid	2.629	1.253	5.061	0.498	3.304	3.812	1.682	1.335	0.881	0.675	3.758	4.959	3.379	5.783	2.978		4.797	3.708	0.689	2.769	1.753	4.474	1.229	2.509	1.207	5.064	0.700	1.544
Milan	5.104	2.313	6.141	1.092	7.141	4.712	3.356	3.062	1.706	0.991	9.118	7.729	6.905	9.622	7.089	4.797		11.11	1.218	5.155	4.213	10.95	2.234	6.850	2.976	10.39	1.814	5.358
Munich	4.911	1.977	4.399	1.012	7.973	3.569	3.118	3.131	1.729	0.868	10.27	6.942	7.238	8.491	4.693	3.708	11.11		1.166	4.306	5.336	7.840	2.164	6.672	3.412	10.66	1.760	4.412
Oslo	0.988	0.353	0.727	0.157	1.457	0.620	0.547	0.456	0.541	0.213	1.273	1.928	1.584	1.786	0.659	0.689	1.218	1.166		0.725	0.653	1.091	0.908	0.744	0.413	2.199	0.213	0.431
Paris	3.857	1.051	3.112	0.466	3.803	3.177	2.971	1.326	0.986	0.726	5.156	5.416	4.125	8.755	3.562	2.769	5.155	4.306	0.725		1.959	3.916	1.257	3.546	1.260	5.171	0.693	1.945
Prague	2.460	1.009	2.006	0.535	5.532	1.637	1.475	1.823	1.029	0.435	4.564	3.558	4.179	4.135	1.983	1.753	4.213	5.336	0.653	1.959		3.524	1.249	2.577	2.102	6.905	0.848	1.543
Rome	4.074	2.731	5.641	1.211	6.022	3.923	2.583	3.023	1.484	0.858	6.688	6.720	5.725	7.862	4.765	4.474	10.95	7.840	1.091	3.916	3.524		2.042	4.522	2.691	9.684	1.835	3.021
Stockholm	1.655	0.683	1.311	0.307	2.755	1.094	0.936	0.899	0.968	0.350	2.277	3.041	2.758	2.980	1.180	1.229	2.234	2.164	0.908	1.257	1.249	2.042		1.335	0.801	4.681	0.409	0.783
Strasbourg	3.697	1.153	2.973	0.546	4.635	2.575	2.569	1.608	1.081	0.607	8.379	4.784	4.702	6.345	3.605	2.509	6.850	6.672	0.744	3.546	2.577	4.522	1.335		1.607	5.984	0.865	3.567
Vienna	1.491	0.768	1.398	0.457	2.817	1.105	0.909	1.814	0.612	0.282	2.634	2.289	2.365	2.633	1.338	1.207	2.976	3.412	0.413	1.260	2.102	2.691	0.801	1.607		4.631	0.798	1.012
Warsaw	6.506	3.244	5.612	1.663	13.37	4.533	3.809	5.407	3.292	1.278	10.18	10.64	11.09	11.47	5.146	5.064	10.39	10.66	2.199	5.171	6.905	9.684	4.681	5.984	4.631		2.172	3.595
Zagreb	0.779	0.471	0.828	0.297	1.308	0.632	0.483	0.872	0.303	0.154	1.346	1.229	1.169	1.422	0.774	0.700	1.814	1.760	0.213	0.693	0.848	1.835	0.409	0.865	0.798	2.172		0.567
Zurich	1.959	0.727	1.885	0.347	2.648	1.565	1.319	1.011	0.618	0.350	3.935	2.742	2.598	3.527	2.341	1.544	5.358	4.412	0.431	1.945	1.543	3.021	0.783	3.567	1.012	3.595	0.567	

Demand [Gbit/s]

Table 14: European network transaction data traffic matrix

2004: IP traffic estimation [Gbit/s]

	Amsterdam	Athens	Barcelona	Belgrade	Berlin	Bordeaux	Brussels	Budapest	Copenhagen	Dublin	Frankfurt	Glasgow	Hamburg	London	Lyon	Madrid	Milan	Munich	Oslo	Paris	Prague	Rome	Stockholm	Strasbourg	Vienna	Warsaw	Zagreb	Zurich
Amsterdam		0.851	2.292	0.327	4.256	1.833	1.768	0.458	1.048	0.655	4.256	10.80	4.256	10.80	1.833	2.292	3.601	4.256	1.440	1.833	1.440	3.601	2.946	1.833	1.768	3.208	0.196	2.226
Athens	0.851		0.438	0.063	0.814	0.350	0.338	0.088	0.200	0.125	0.814	2.065	0.814	2.065	0.350	0.438	0.688	0.814	0.275	0.350	0.275	0.688	0.563	0.350	0.338	0.613	0.038	0.426
Barcelona	2.292	0.438		0.168	2.190	0.944	0.910	0.236	0.539	0.337	2.190	5.560	2.190	5.560	0.944	1.179	1.853	2.190	0.741	0.944	0.741	1.853	1.516	0.944	0.910	1.651	0.101	1.146
Belgrade	0.327	0.063	0.168		0.313	0.135	0.130	0.034	0.077	0.048	0.313	0.794	0.313	0.794	0.135	0.168	0.265	0.313	0.106	0.135	0.106	0.265	0.217	0.135	0.130	0.236	0.014	0.164
Berlin	4.256	0.814	2.190	0.313		1.752	1.690	0.438	1.001	0.626	4.068	10.33	4.07	10.33	1.752	2.190	3.442	4.068	1.377	1.752	1.377	3.442	2.816	1.752	1.690	3.07	0.188	2.128
Bordeaux	1.833	0.350	0.944	0.135	1.752		0.728	0.189	0.431	0.270	1.752	4.448	1.752	4.448	0.755	0.944	1.483	1.752	0.593	0.755	0.593	1.483	1.213	0.755	0.728	1.321	0.081	0.917
Brussels	1.768	0.338	0.910	0.130	1.690	0.728		0.182	0.416	0.260	1.690	4.289	1.690	4.289	0.728	0.910	1.430	1.690	0.572	0.728	0.572	1.430	1.170	0.728	0.702	1.274	0.078	0.884
Budapest	0.458	0.088	0.236	0.034	0.438	0.189	0.182		0.108	0.067	0.438	1.112	0.438	1.112	0.189	0.236	0.371	0.438	0.148	0.189	0.148	0.371	0.303	0.189	0.182	0.330	0.020	0.229
Copenhagen	1.048	0.200	0.539	0.077	1.001	0.431	0.416	0.108		0.154	1.001	2.542	1.001	2.542	0.431	0.539	0.847	1.001	0.339	0.431	0.339	0.847	0.693	0.431	0.416	0.755	0.046	0.524
Dublin	0.655	0.125	0.337	0.048	0.626	0.270	0.260	0.067	0.154		0.626	1.589	0.626	1.589	0.270	0.337	0.530	0.626	0.212	0.270	0.212	0.530	0.433	0.270	0.260	0.472	0.029	0.327
Frankfurt	4.256	0.814	2.190	0.313	4.068	1.752	1.690	0.438	1.001	0.626		10.33	4.068	10.33	1.752	2.190	3.442	4.07	1.377	1.752	1.377	3.442	2.816	1.752	1.690	3.07	0.188	2.128
Glasgow	10.80	2.065	5.560	0.794	10.33	4.448	4.289	1.112	2.542	1.589	10.33		10.33	26.21	4.448	5.560	8.738	10.33	3.495	4.448	3.495	8.738	7.149	4.448	4.289	7.78	0.477	5.401
Hamburg	4.256	0.814	2.190	0.313	4.07	1.752	1.690	0.438	1.001	0.626	4.068	10.33		10.33	1.752	2.190	3.442	4.068	1.377	1.752	1.377	3.442	2.816	1.752	1.690	3.07	0.188	2.128
London	10.80	2.065	5.560	0.794	10.33	4.448	4.289	1.112	2.542	1.589	10.33	26.21	10.33		4.448	5.560	8.738	10.33	3.495	4.448	3.495	8.738	7.149	4.448	4.289	7.78	0.477	5.401
Lyon	1.833	0.350	0.944	0.135	1.752	0.755	0.728	0.189	0.431	0.270	1.752	4.448	1.752	4.448		0.944	1.483	1.752	0.593	0.755	0.593	1.483	1.213	0.755	0.728	1.321	0.081	0.917
Madrid	2.292	0.438	1.179	0.168	2.190	0.944	0.910	0.236	0.539	0.337	2.190	5.560	2.190	5.560	0.944		1.853	2.190	0.741	0.944	0.741	1.853	1.516	0.944	0.910	1.651	0.101	1.146
Milan	3.601	0.688	1.853	0.265	3.442	1.483	1.430	0.371	0.847	0.530	3.442	8.738	3.442	8.738	1.483	1.853		3.44	1.165	1.483	1.165	2.91	2.383	1.483	1.430	2.59	0.159	1.800
Munich	4.256	0.814	2.190	0.313	4.068	1.752	1.690	0.438	1.001	0.626	4.07	10.33	4.068	10.33	1.752	2.190	3.44		1.377	1.752	1.377	3.442	2.816	1.752	1.690	3.07	0.188	2.128
Oslo	1.440	0.275	0.741	0.106	1.377	0.593	0.572	0.148	0.339	0.212	1.377	3.495	1.377	3.495	0.593	0.741	1.165	1.377		0.593	0.466	1.165	0.953	0.593	0.572	1.038	0.064	0.720
Paris	1.833	0.350	0.944	0.135	1.752	0.755	0.728	0.189	0.431	0.270	1.752	4.448	1.752	4.448	0.755	0.944	1.483	1.752	0.593		0.593	1.483	1.213	0.755	0.728	1.321	0.081	0.917
Prague	1.440	0.275	0.741	0.106	1.377	0.593	0.572	0.148	0.339	0.212	1.377	3.495	1.377	3.495	0.593	0.741	1.165	1.377	0.466	0.593		1.165	0.953	0.593	0.572	1.038	0.064	0.720
Rome	3.601	0.688	1.853	0.265	3.442	1.483	1.430	0.371	0.847	0.530	3.442	8.738	3.442	8.738	1.483	1.853	2.91	3.442	1.165	1.483	1.165		2.383	1.483	1.430	2.595	0.159	1.800
Stockholm	2.946	0.563	1.516	0.217	2.816	1.213	1.170	0.303	0.693	0.433	2.816	7.149	2.816	7.149	1.213	1.516	2.383	2.816	0.953	1.213	0.953	2.383		1.213	1.170	2.123	0.130	1.473
Strasbourg	1.833	0.350	0.944	0.135	1.752	0.755	0.728	0.189	0.431	0.270	1.752	4.448	1.752	4.448	0.755	0.944	1.483	1.752	0.593	0.755	0.593	1.483	1.213		0.728	1.321	0.081	0.917
Vienna	1.768	0.338	0.910	0.130	1.690	0.728	0.702	0.182	0.416	0.260	1.690	4.289	1.690	4.289	0.728	0.910	1.430	1.690	0.572	0.728	0.572	1.430	1.170	0.728		1.274	0.078	0.884
Warsaw	3.208	0.613	1.651	0.236	3.07	1.321	1.274	0.330	0.755	0.472	3.07	7.78	3.07	7.78	1.321	1.651	2.59	3.07	1.038	1.321	1.038	2.595	2.123	1.321	1.274		0.142	1.604
Zagreb	0.196	0.038	0.101	0.014	0.188	0.081	0.078	0.020	0.046	0.029	0.188	0.477	0.188	0.477	0.081	0.101	0.159	0.188	0.064	0.081	0.064	0.159	0.130	0.081	0.078	0.142		0.098
Zurich	2.226	0.426	1.146	0.164	2.128	0.917	0.884	0.229	0.524	0.327	2.128	5.401	2.128	5.401	0.917	1.146	1.800	2.128	0.720	0.917	0.720	1.800	1.473	0.917	0.884	1.604	0.098	

Demand [Gbit/s]

Table 15: European network IP traffic matrix

2004: Total traffic estimation [Gbit/s]

	Amsterdam	Athens	Barcelona	Belgrade	Berlin	Bordeaux	Brussels	Budapest	Copenhagen	Dublin	Frankfurt	Glasgow	Hamburg	London	Lyon	Madrid	Milan	Munich	Oslo	Paris	Prague	Rome	Stockholm	Strasbourg	Vienna	Warsaw	Zagreb	Zurich
Amsterdam		2.146	5.591	1.057	10.49	4.881	7.457	2.247	2.701	1.620	12.43	18.75	12.36	22.60	5.308	5.277	9.628	9.991	2.558	6.611	4.283	8.264	4.810	6.376	3.491	10.65	1.082	4.501
Athens	2.146		2.033	0.719	2.818	1.508	1.139	1.195	0.709	0.407	2.819	4.300	2.694	4.533	1.638	1.839	3.349	3.035	0.659	1.526	1.403	3.903	1.311	1.653	1.218	4.281	0.580	1.231
Barcelona	5.591	2.033		0.971	6.333	6.288	3.095	1.990	1.595	1.093	7.136	11.16	6.372	12.50	5.768	7.535	9.302	7.236	1.538	4.642	2.997	8.598	2.955	4.451	2.507	7.942	1.048	3.316
Belgrade	1.057	0.719	0.971		1.569	0.728	0.586	1.253	0.365	0.189	1.520	1.921	1.413	2.088	0.854	0.839	1.926	1.795	0.306	0.781	0.885	2.175	0.620	0.928	0.880	2.720	0.522	0.644
Berlin	10.49	2.818	6.333	1.569		5.225	5.226	3.773	4.164	1.614	14.43	18.60	18.11	19.84	5.877	5.859	11.75	13.45	3.017	6.135	8.163	10.30	5.946	7.247	5.043	18.99	1.691	5.148
Bordeaux	4.881	1.508	6.288	0.728	5.225		2.805	1.544	1.330	0.994	6.057	9.615	5.373	11.39	4.999	5.634	7.117	5.831	1.273	4.663	2.429	6.044	2.414	3.810	1.981	6.384	0.796	2.717
Brussels	7.457	1.139	3.095	0.586	5.226	2.805		1.278	1.309	0.839	7.101	8.818	5.860	11.96	3.189	2.848	5.488	5.392	1.189	4.659	2.289	4.428	2.223	4.015	1.763	5.645	0.634	2.454
Budapest	2.247	1.195	1.990	1.253	3.773	1.544	1.278		0.851	0.409	3.468	3.874	3.253	4.260	1.822	1.739	4.038	4.178	0.654	1.712	2.354	3.983	1.314	2.087	2.619	6.909	1.136	1.393
Copenhagen	2.701	0.709	1.595	0.365	4.164	1.330	1.309	0.851		0.439	3.207	5.028	4.580	5.153	1.439	1.505	2.773	2.948	0.963	1.546	1.510	2.498	1.814	1.666	1.111	4.555	0.384	1.209
Dublin	1.620	0.407	1.093	0.189	1.614	0.994	0.839	0.409	0.439		1.725	4.847	1.731	4.163	0.946	1.100	1.652	1.590	0.448	1.119	0.692	1.485	0.818	0.963	0.574	1.886	0.198	0.715
Frankfurt	12.43	2.819	7.136	1.520	14.43	6.057	7.101	3.468	3.207	1.725		19.14	14.88	22.10	7.403	6.421	14.47	16.68	2.789	7.973	6.795	11.16	5.348	12.94	4.792	14.72	1.741	6.887
Glasgow	18.75	4.300	11.16	1.921	18.60	9.615	8.818	3.874	5.028	4.847	19.14		19.76	44.61	9.524	11.09	17.42	18.01	5.646	10.68	7.413	16.18	10.51	9.869	6.824	19.55	1.826	8.422
Hamburg	12.36	2.694	6.372	1.413	18.11	5.373	5.860	3.253	4.580	1.731	14.88	19.76		21.30	5.955	5.951	11.44	12.47	3.177	6.559	6.272	9.920	5.949	7.340	4.432	15.92	1.513	5.085
London	22.60	4.533	12.50	2.088	19.84	11.39	11.96	4.260	5.153	4.163	22.10	44.61	21.30		11.40	12.12	19.84	19.93	5.472	15.33	8.117	17.59	10.43	11.91	7.247	20.56	2.060	9.389
Lyon	5.308	1.638	5.768	0.854	5.877	4.999	3.189	1.822	1.439	0.946	7.403	9.524	5.955	11.40		4.458	10.66	7.327	1.320	5.236	2.868	7.190	2.518	5.301	2.285	7.151	0.979	3.785
Madrid	5.277	1.839	7.535	0.839	5.859	5.634	2.848	1.739	1.505	1.100	6.421	11.09	5.951	12.12	4.458		7.449	6.358	1.493	4.176	2.685	7.022	2.858	3.833	2.266	7.268	0.885	2.882
Milan	9.628	3.349	9.302	1.926	11.75	7.117	5.488	4.038	2.773	1.652	14.47	17.42	11.44	19.84	10.66	7.449		17.38	2.515	7.742	6.133	16.71	4.872	10.28	5.026	14.58	2.364	8.744
Munich	9.991	3.035	7.236	1.795	13.45	5.831	5.392	4.178	2.948	1.590	16.68	18.01	12.47	19.93	7.327	6.358	17.38		2.660	6.800	7.880	12.69	5.211	10.21	5.888	15.35	2.302	7.576
Oslo	2.558	0.659	1.538	0.306	3.017	1.273	1.189	0.654	0.963	0.448	2.789	5.646	3.177	5.472	1.320	1.493	2.515	2.660		1.400	1.187	2.362	2.020	1.423	1.030	3.505	0.297	1.190
Paris	6.611	1.526	4.642	0.781	6.135	4.663	4.659	1.712	1.546	1.119	7.973	10.68	6.559	15.33	5.236	4.176	7.742	6.800	1.400		2.837	6.035	2.611	5.212	2.181	7.182	0.873	3.226
Prague	4.283	1.403	2.997	0.885	8.163	2.429	2.289	2.354	1.510	0.692	6.795	7.413	6.272	8.117	2.868	2.685	6.133	7.880	1.187	2.837		5.217	2.345	3.662	3.226	9.204	1.064	2.497
Rome	8.264	3.903	8.598	2.175	10.30	6.044	4.428	3.983	2.498	1.485	11.16	16.18	9.920	17.59	7.190	7.022	16.71	12.69	2.362	6.035	5.217		4.638	6.853	4.628	13.67	2.393	5.326
Stockholm	4.810	1.311	2.955	0.620	5.946	2.414	2.223	1.314	1.814	0.818	5.348	10.51	5.949	10.43	2.518	2.858	4.872	5.211	2.020	2.611	2.345	4.638		2.707	2.067	7.501	0.581	2.328
Strasbourg	6.376	1.653	4.451	0.928	7.247	3.810	4.015	2.087	1.666	0.963	12.94	9.869	7.340	11.91	5.301	3.833	10.28	10.21	1.423	5.212	3.662	6.853	2.707		2.650	8.229	1.101	5.709
Vienna	3.491	1.218	2.507	0.880	5.043	1.981	1.763	2.619	1.111	0.574	4.792	6.824	4.432	7.247	2.285	2.266	5.026	5.888	1.030	2.181	3.226	4.628	2.067	2.650		6.838	1.098	2.062
Warsaw	10.65	4.281	7.942	2.720	18.99	6.384	5.645	6.909	4.555	1.886	14.72	19.55	15.92	20.56	7.151	7.268	14.58	15.35	3.505	7.182	9.204	13.67	7.501	8.229	6.838		2.662	5.642
Zagreb	1.082	0.580	1.048	0.522	1.691	0.796	0.634	1.136	0.384	0.198	1.741	1.826	1.513	2.060	0.979	0.885	2.364	2.302	0.297	0.873	1.064	2.393	0.581	1.101	1.098	2.662		0.754
Zurich	4.501	1.231	3.316	0.644	5.148	2.717	2.454	1.393	1.209	0.715	6.887	8.422	5.085	9.389	3.785	2.882	8.744	7.576	1.190	3.226	2.497	5.326	2.328	5.709	2.062	5.642	0.754	

Demand [Gbit/s]

Table 16: European network total traffic matrix

2004: Total traffic estimation [STM-16 equivalents]

	Amsterdam	Athens	Barcelona	Belgrade	Berlin	Bordeaux	Brussels	Budapest	Copenhagen	Dublin	Frankfurt	Glasgow	Hamburg	London	Lyon	Madrid	Milan	Munich	Oslo	Paris	Prague	Rome	Stockholm	Strasbourg	Vienna	Warsaw	Zagreb	Zurich
Amsterdam		1	3	1	5	2	3	1	2	1	5	8	5	10	3	3	4	5	2	3	2	4	2	3	2	5	1	2
Athens	1		1	1	2	1	1	1	1	1	2	2	2	2	1	1	2	2	1	1	1	2	1	1	1	2	1	1
Barcelona	3	1		1	3	3	2	1	1	1	3	5	3	6	3	4	4	3	1	2	2	4	2	2	2	4	1	2
Belgrade	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1
Berlin	5	2	3	1		3	3	2	2	1	6	8	8	8	3	3	5	6	2	3	4	5	3	3	3	8	1	3
Bordeaux	2	1	3	1	3		2	1	1	1	3	4	3	5	3	3	3	3	1	2	1	3	1	2	1	3	1	2
Brussels	3	1	2	1	3	2		1	1	1	3	4	3	5	2	2	3	3	1	2	1	2	1	2	1	3	1	1
Budapest	1	1	1	1	2	1	1		1	1	2	2	2	2	1	1	2	2	1	1	1	2	1	1	2	3	1	1
Copenhagen	2	1	1	1	2	1	1	1		1	2	3	2	3	1	1	2	2	1	1	1	2	1	1	1	2	1	1
Dublin	1	1	1	1	1	1	1	1	1		1	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Frankfurt	5	2	3	1	6	3	3	2	2	1		8	6	9	3	3	6	7	2	4	3	5	3	6	2	6	1	3
Glasgow	8	2	5	1	8	4	4	2	3	2	8		8	18	4	5	8	8	3	5	3	7	5	4	3	8	1	4
Hamburg	5	2	3	1	8	3	3	2	2	1	6	8		9	3	3	5	6	2	3	3	4	3	3	2	7	1	3
London	10	2	6	1	8	5	5	2	3	2	9	18	9		5	5	8	9	3	7	4	8	5	5	3	9	1	4
Lyon	3	1	3	1	3	3	2	1	1	1	3	4	3	5		2	5	3	1	3	2	3	2	3	1	3	1	2
Madrid	3	1	4	1	3	3	2	1	1	1	3	5	3	5	2		3	3	1	2	2	3	2	2	1	3	1	2
Milan	4	2	4	1	5	3	3	2	2	1	6	8	5	8	5	3		7	2	4	3	7	2	5	3	6	1	4
Munich	5	2	3	1	6	3	3	2	2	1	7	8	6	9	3	3	7		2	3	4	6	3	5	3	7	1	4
Oslo	2	1	1	1	2	1	1	1	1	1	2	3	2	3	1	1	2	2		1	1	1	1	1	1	2	1	1
Paris	3	1	2	1	3	2	2	1	1	1	4	5	3	7	3	2	4	3	1		2	3	2	3	1	3	1	2
Prague	2	1	2	1	4	1	1	1	1	1	3	3	3	4	2	2	3	4	1	2		3	1	2	2	4	1	2
Rome	4	2	4	1	5	3	2	2	2	1	5	7	4	8	3	3	7	6	1	3	3		2	3	2	6	1	3
Stockholm	2	1	2	1	3	1	1	1	1	1	3	5	3	5	2	2	2	3	1	2	1	2		2	1	4	1	1
Strasbourg	3	1	2	1	3	2	2	1	1	1	6	4	3	5	3	2	5	5	1	3	2	3	2		2	4	1	3
Vienna	2	1	2	1	3	1	1	2	1	1	2	3	2	3	1	1	3	3	1	1	2	2	1	2		3	1	1
Warsaw	5	2	4	2	8	3	3	3	2	1	6	8	7	9	3	3	6	7	2	3	4	6	4	4	3		2	3
Zagreb	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2		1
Zurich	2	1	2	1	3	2	1	1	1	1	3	4	3	4	2	2	4	4	1	2	2	3	1	3	1	3	1	

Demand [STM-16 equivalents]

Table 17: European network STM-16 traffic demand matrix

STM-16 Dimensioning: unprotected / 1+1 protected

	Amsterdam	Athens	Barcelona	Belgrade	Berlin	Bordeaux	Brussels	Budapest	Copenhagen	Dublin	Frankfurt	Glasgow	Hamburg	London	Lyon	Madrid	Milan	Munich	Oslo	Paris	Prague	Rome	Stockholm	Strasbourg	Vienna	Warsaw	Zagreb	Zurich
Amsterdam							182					98	182	96														
Athens				17																		19						
Barcelona															75	20												
Belgrade		49						41																			30	
Berlin									68				210					75			75					134		
Bordeaux																49				96								
Brussels	391										139									96								
Budapest				81																	45					24		
Copenhagen					128														33									
Dublin												43		68														
Frankfurt							398						63					143						66				
Glasgow	168									168																		
Hamburg	279				334						173																	
London	254									168										88								
Lyon			181																	40								90
Madrid			181			181																						
Milan																		152				101						139
Munich					274						417						255								71			
Oslo									128														7					
Paris						181	337							234	139									58				
Prague					156			153																	51			
Rome		49															172										27	
Stockholm																			128							57		
Strasbourg											226									155								87
Vienna																		286			209						29	
Warsaw					224			148															128					
Zagreb				90																		147			161			
Zurich															190		269							243				

STM-16 Dimensioning (unprotected)

STM-16 Dimensioning (1+1 protected)

Table 18: European network STM-16 network dimensioning

4.3 US Network

To estimate real fibre duct lengths in the US Network, the formula "airline distance multiplied by 1.2" was applied, as used for the German network.

The constants for the traffic matrices are:

$$K_V = 0{,}014123$$
$$K_T = 0{,}0017126$$
$$K_I = 0{,}00000178$$

for the basis year 1999.

To estimate traffic volumes for the year 2004, we used the same traffic growth rates as in [6]:

$$Voice: 8\%$$
$$Data: 34\%$$
$$IP: 100\%$$

Physical Distances

	CA1	CA2	CO	DC	GA	IL	MI	NE	NJ	NY	PA	TX	UT	WA
CA1														
CA2	834													
CO														
DC														
GA														
IL														
MI														
NE			870			864								
NJ				312			942							
NY				468			720							
PA					1008	846			540	438				
TX		2520	1746	2364	1350									
UT	1152		684				2820							
WA	1338	2056				3408								

Fibre Length [km]

Table 19: US network physical distance matrix

2004: voice traffic estimation [Gbit/s]														
	CA1	CA2	CO	DC	GA	IL	MI	NE	NJ	NY	PA	TX	UT	WA
CA1		20.676	3.25	2.862	6.686	4.67	3.566	1.968	1.262	4.432	3.51	7.374	5.786	5.964
CA2	20.676		5.34	4.39	10.614	7.154	5.41	3.054	1.91	6.69	5.322	12.69	8.622	6.068
CO	3.25	5.34		3.05	7.37	5.836	3.992	3.566	1.25	4.324	3.47	10.202	5.788	2.45
DC	2.862	4.39	3.05		34.062	19.612	23.608	3.968	39.164	92.636	142.94	12.98	2.716	2.42
GA	6.686	10.614	7.37	34.062		42.694	35.82	9.882	13.304	43.832	38.038	43.876	6.304	5.336
IL	4.67	7.154	5.836	19.612	42.694		45.12	11.338	8.174	27.836	23.142	23.71	4.796	4.054
MI	3.566	5.41	3.992	23.608	35.82	45.12		6.294	10.466	35.364	29.574	16.384	3.48	3.124
NE	1.968	3.054	3.566	3.968	9.882	11.338	6.294		1.626	5.622	4.57	10.53	2.352	1.668
NJ	1.262	1.91	1.25	39.164	13.304	8.174	10.466	1.626		139.08	229.63	5.328	1.152	1.09
NY	4.432	6.69	4.324	92.636	43.832	27.836	35.364	5.622	139.08		243.2	18.2	4.026	3.842
PA	3.51	5.322	3.47	142.94	38.038	23.142	29.574	4.57	229.63	243.2		14.96	3.204	3.02
TX	7.374	12.69	10.202	12.98	43.876	23.71	16.384	10.53	5.328	18.2	14.96		7.624	5.278
UT	5.786	8.622	5.788	2.716	6.304	4.796	3.48	2.352	1.152	4.026	3.204	7.624		4.018
WA	5.964	6.068	2.45	2.42	5.336	4.054	3.124	1.668	1.09	3.842	3.02	5.278	4.018	
Demand [Gbit/s]														

Table 20: US network voice traffic matrix

2004: data traffic estimation [Gbit/s]														
	CA1	CA2	CO	DC	GA	IL	MI	NE	NJ	NY	PA	TX	UT	WA
CA1		11.014	3.276	4.474	8.498	5.898	4.604	2.462	2.074	7.242	4.96	7.712	3.934	4.642
CA2	11.014		5.038	6.644	12.84	8.758	6.802	3.68	3.06	10.672	7.328	12.134	5.76	5.618
CO	3.276	5.038		4.16	8.038	5.942	4.388	2.986	1.86	6.444	4.444	8.172	3.546	2.682
DC	4.474	6.644	4.16		25.132	15.842	15.524	4.582	15.146	43.386	41.486	13.408	3.534	3.876
GA	8.498	12.84	8.038	25.132		29.052	23.766	8.988	10.972	37.092	26.598	30.636	6.69	7.154
IL	5.898	8.758	5.942	15.842	29.052		22.158	7.998	7.144	24.556	17.236	18.71	4.848	5.178
MI	4.604	6.802	4.388	15.524	23.766	22.158		5.322	7.22	24.718	17.4	13.89	3.688	4.06
NE	2.462	3.68	2.986	4.582	8.988	7.998	5.322		2.05	7.096	4.924	8.018	2.182	2.136
NJ	2.074	3.06	1.86	15.146	10.972	7.144	7.22	2.05		37.134	36.73	6	1.606	1.818
NY	7.242	10.672	6.444	43.386	37.092	24.556	24.718	7.096	37.134		70.402	20.654	5.594	6.352
PA	4.96	7.328	4.444	41.486	26.598	17.236	17.4	4.924	36.73	70.402		14.416	3.842	4.336
TX	7.712	12.134	8.172	13.408	30.636	18.71	13.89	8.018	6	20.654	14.416		6.358	6.148
UT	3.934	5.76	3.546	3.534	6.69	4.848	3.688	2.182	1.606	5.594	3.842	6.358		3.09
WA	4.642	5.618	2.682	3.876	7.154	5.178	4.06	2.136	1.818	6.352	4.336	6.148	3.09	
Demand [Gbit/s]														

Table 21: US network transaction data traffic matrix

2004: IP traffic estimation [Gbit/s]														
	CA1	CA2	CO	DC	GA	IL	MI	NE	NJ	NY	PA	TX	UT	WA
CA1		31.67	13.618	31.354	63.34	38.32	32.936	12.422	14.188	50.34	39.112	48.296	15.328	17.862
CA2	31.67		19.594	45.112	91.136	55.136	47.39	17.874	20.414	72.43	56.276	69.49	22.054	25.7
CO	13.618	19.594		19.398	39.188	23.71	20.378	7.686	8.778	31.146	24.198	29.882	9.484	11.052
DC	31.354	45.112	19.398		90.224	54.586	46.916	17.696	20.21	71.706	55.714	68.796	21.834	25.444
GA	63.34	91.136	39.188	90.224		110.27	94.78	35.748	40.828	144.86	112.55	138.98	44.11	51.4
IL	38.32	55.136	23.71	54.586	110.27		57.342	21.628	24.702	87.64	68.094	84.084	26.686	31.098
MI	32.936	47.39	20.378	46.916	94.78	57.342		18.59	21.232	75.328	58.528	72.27	22.938	26.728
NE	12.422	17.874	7.686	17.696	35.748	21.628	18.59		8.008	28.41	22.074	27.258	8.652	10.08
NJ	14.188	20.414	8.778	20.21	40.828	24.702	21.232	8.008		32.448	25.212	31.132	9.88	11.514
NY	50.34	72.43	31.146	71.706	144.86	87.64	75.328	28.41	32.448		89.452	110.46	35.056	40.85
PA	39.112	56.276	24.198	55.714	112.55	68.094	58.528	22.074	25.212	89.452		85.822	27.238	31.74
TX	48.296	69.49	29.882	68.796	138.98	84.084	72.27	27.258	31.132	110.46	85.822		33.634	39.194
UT	15.328	22.054	9.484	21.834	44.11	26.686	22.938	8.652	9.88	35.056	27.238	33.634		12.438
WA	17.862	25.7	11.052	25.444	51.4	31.098	26.728	10.08	11.514	40.85	31.74	39.194	12.438	
Demand [Gbit/s]														

Table 22: US network IP traffic matrix

2004: Total traffic estimation [Gbit/s]														
	CA1	CA2	CO	DC	GA	IL	MI	NE	NJ	NY	PA	TX	UT	WA
CA1		63.35	20.144	38.69	78.524	48.888	41.108	16.854	17.524	62.014	47.582	63.382	25.05	28.47
CA2	63.35		29.97	56.146	114.59	71.048	59.604	24.608	25.384	89.792	68.926	94.314	36.436	37.386
CO	20.144	29.97		26.608	54.596	35.486	28.758	14.24	11.888	41.914	32.112	48.256	18.816	16.182
DC	38.69	56.146	26.608		149.42	90.04	86.05	26.244	74.522	207.73	240.14	95.184	28.084	31.74
GA	78.524	114.59	54.596	149.42		182.02	154.37	54.618	65.106	225.79	177.19	213.5	57.104	63.89
IL	48.888	71.048	35.486	90.04	182.02		124.62	40.962	40.02	140.03	108.47	126.5	36.33	40.33
MI	41.108	59.604	28.758	86.05	154.37	124.62		30.204	38.918	135.41	105.5	102.54	30.104	33.912
NE	16.854	24.608	14.24	26.244	54.618	40.962	30.204		11.682	41.13	31.568	45.806	13.186	13.884
NJ	17.524	25.384	11.888	74.522	65.106	40.02	38.918	11.682		208.66	291.57	42.46	12.638	14.422
NY	62.014	89.792	41.914	207.73	225.79	140.03	135.41	41.13	208.66		403.05	149.31	44.676	51.046
PA	47.582	68.926	32.112	240.14	177.19	108.47	105.5	31.568	291.57	403.05		115.2	34.284	39.096
TX	63.382	94.314	48.256	95.184	213.5	126.5	102.54	45.806	42.46	149.31	115.2		47.616	50.62
UT	25.05	36.436	18.816	28.084	57.104	36.33	30.104	13.186	12.638	44.676	34.284	47.616		19.546
WA	28.47	37.386	16.182	31.74	63.89	40.33	33.912	13.884	14.422	51.046	39.096	50.62	19.546	
Demand [Gbit/s]														

Table 23: US network total traffic matrix

2004: Total traffic estimation [STM-16 equivalents]														
	CA1	CA2	CO	DC	GA	IL	MI	NE	NJ	NY	PA	TX	UT	WA
CA1		26	9	20	16	32	17	7	8	25	20	26	11	12
CA2	26		13	29	23	47	24	10	11	37	28	38	15	16
CO	9	13		15	11	22	12	6	5	17	13	20	8	7
DC	20	29	15		37	74	51	17	17	57	44	51	15	17
GA	16	23	11	37		61	35	11	30	84	97	39	12	13
IL	32	47	22	74	61		63	22	27	91	72	86	23	26
MI	17	24	12	51	35	63		13	16	55	43	42	13	14
NE	7	10	6	17	11	22	13		5	17	13	19	6	6
NJ	8	11	5	17	30	27	16	5		84	118	18	6	6
NY	25	37	17	57	84	91	55	17	84		162	61	18	21
PA	20	28	13	44	97	72	43	13	118	162		47	14	16
TX	26	38	20	51	39	86	42	19	18	61	47		20	21
UT	11	15	8	15	12	23	13	6	6	18	14	20		8
WA	12	16	7	17	13	26	14	6	6	21	16	21	8	
Demand [STM-16 equivalents]														

Table 24: US network STM-16 traffic demand matrix

STM-16 Dimensioning: unprotected / 1+1 protected															
	CA1	CA2	CO	DC	GA	IL	MI	NE	NJ	NY	PA	TX	UT	WA	STM-16 Dimensioning (unprotected)
CA1		139											145	81	
CA2	365											315		79	
CO								115				154	137		
DC									282	355		348			
GA											501	397			
IL								123			490			161	
MI									30	375			193		
NE			614			614									
NJ				1207			248				307				
NY				1058			709				519				
PA					1062	812			1057	1105					
TX		501	716	903	1062										
UT	489		578				533								
WA	296	244				390									
STM-16 Dimensioning (1+1 protected)															

Table 25: US network STM-16 network dimensioning

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