Dimensioning of a Transport Network Being Robust to Changes of the Traffic Pattern

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ABSTRACT

The planning and dimensioning of circuit-switched networks is investigated where the expected traffic pattern is uncertain. To model the vagueness, the static traffic matrix is replaced by a matrix with random variables for the predicted traffic. With the choice of the distribution for these variables, a scenario of different realizations may be characterized. A measure for the accuracy of the prediction is introduced. An algorithm for the dimensioning of the necessary network resources for realizations of this random process is presented and discussed. A case study for a Pan-European network is performed.

Keywords: Network planning, Uncertainty, Capacity Dimensioning

1. INTRODUCTION

Wavelength-division multiplexing (WDM) is used to an increasing extent for point-to-point connections in wide area networks to satisfy the demand for transport capacity and to cope with the tremendous demand in bandwidth. The network designer has to dimension the necessary network resources. The traditional approach assumes a traffic model and calculates from that a traffic forecast, which leads to an estimation for the expected traffic matrix and the traffic between the network nodes. This static traffic table is the starting-point for the routing of the paths of the connections and the dimensioning of the necessary network resources.

A forecast, especially in fields with high dynamics like telecommunication, is always a throw out the crystal ball. For example, Internet traffic is increasing by 300% per year [5] in the U.S. But the planning horizon extends often up to five years and it is very difficult to exactly predict traffic volume and distribution over such a long period. Therefore the predicted traffic matrix is afflicted with errors and uncertainties. The design of the network should be sufficiently robust to errors made in the forecast [3].

On the other hand, a certain flexibility of the transport network is claimed in the future. Dynamic light-paths will be established and released on demand. Therefore, it is no longer sufficient to provide a fixed number of traffic channels between two nodes in the network as reflected by a traffic matrix. Instead, the necessary number of connections between two nodes will vary with time.

The aim of this work is to cope with the vagueness in the planning process in a systematic way. The objective is to find an optimal routing for the connections, so that with minimal over-dimensioning of the installed network resources, variations from the expected traffic pattern, at least to some extend, may be tolerated. The network planner gets a tool, which permits him to balance the advantages and disadvantages between robustness to variations in demand and the installed capacity or costs in the network. For the network, a confidence interval for the realization of the supported traffic may be given.

To adapt the network to the actual traffic, it is assumed, that the cross-connects of the network nodes are re-configurable for a rerouting of the connections. The capacity of the links itself is not changed. In this work, only the capacity is investigated. Therefore full wavelength conversion functionality is supposed to be available in every network node.

The structure of the work is as following. The uncertainty description in the prediction of the traffic pattern in circuit-switched network is defined first. A model to deal with randomness in the traffic matrix is then presented. Afterwards, an algorithm for the optimization of the routing is developed, followed by an application to a case study for a Pan-European network. At the end, conclusions are drawn and further work is discussed.

2. TRAFFIC UNCERTAINTY

In [4], a technique for assessing the robustness of a circuit-switched network is proposed. The Distribution Forecast Accuracy (DFA) is being used, to characterize the deviation of the actual traffic from the predicted traffic for a already dimensioned network.

In this work, the dimensioning step of the network resources is addressed. For simplicity, in the following, a symmetric traffic pattern is assumed. Therefore, it is sufficient, to deal with a lower triangular matrix for the traffic demands. Let $\Omega = \{(i, j) \,|\, i < j;\ i, j \in [1, N]\}$ be the set of node pairs of the network with N nodes, which are labeled from $1 \ldots N$. Due to the supposed symmetry, only one direction for every node pair is investigated. The corresponding opposite connection is routed in the reverse direction of the respective path.

The work reported in this paper has been carried out in the framework of the COST 266 action, which was partly founded by the Swiss BBW (Bundesamt für Bildung und Wissenschaft).

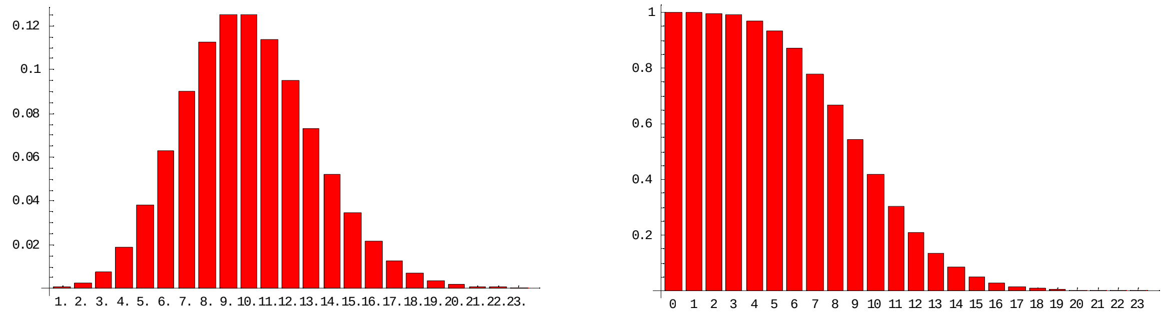


Figure 1: Poisson distribution for μ=10 (left) and corresponding probabilities for the realization of a connection (right).

To introduce uncertainty in the planning process, a random matrix replaces the originally static traffic matrix for the predicted traffic. Here, the vagueness of the future traffic is treated in such a way that the entries of the traffic matrix $T_a \sim D_a(m_a, s_a)$ are random variables with the distribution $D_a(m_a, s_a)$ for $a \in \Omega$. The expected value m_a is set equal to the predicted traffic (the former traffic matrix). In this way, an ensemble of possible realizations of different traffic patterns may be treated simultaneously.
Further, statistical independency between all traffic requests is presumed. This assumption is uncritical for two traffic requests, when neither source nor destination node are identical. For traffic with the same origin or destination, probably a certain correlation exists, e.g. when the reason for the deviation from the prediction is a change in the population that is attached to this node.
The choice for the probability distribution for the traffic matrix depends on the knowledge on the error bounds of the prediction. When there is no further information, it is a design parameter for the network planner and may be adapted for its needs. Because we are dealing with circuit-switched network (light-paths are assumed), it is natural to use a discrete distribution for the number of connections between a node pair. Here, especially the uniform, the Poisson, and the binomial distribution are relevant. For the same expectation value, the variance is highest for the uniform and lowest for the binomial distribution. Only the binomial distribution permits, for a given expectation value, to adjust the variance.
From the distribution of the traffic demand between two network nodes a, the random variable $X_a^l \in \{0,1\}$, which describes the existence of the l^{th} connection, has the distribution

$$P(X_a^l = 1) = \sum_{k=l}^{\infty} P(T_a = k); \qquad P(X_a^l = 0) = 1 - P(X_a^l = 1) \tag{1}$$

Note, that the random variables X_a^l and X_a^k for $l < k$ are not statistical independent, in contrast $P(X_a^l = 1 \mid X_a^k = 1) = 1$. As an example, in Figure 1, for a predicted traffic of 10 connections, T_a is modeled by a Poisson distribution (on the left hand side). On the right hand side, the corresponding probabilities for the occurrence of a connection are displayed.
The Poisson distribution has unlimited support and there is a small probability for even a very large number of connections to occur. Therefore, it is necessary to limit the investigated maximal number of connections for the planning process. For example, it is sufficient to take only into account all connections that happen with probability e.g. at least 10^{-3}. This procedure helps also for other distributions to speed up the computation.
The total expected traffic volume in the network is sum of the expectation values of T_a. Analog to the DFA of [4], a measure for accurateness of the prediction of the traffic is its variance. Both may be calculated due to the independence of the T_a from

$$m_{tot} = 2\sum_{a\in\Omega} m_a \qquad s_{tot}^2 = 2\sum_{a\in\Omega} s_a^2 \tag{2}$$

The better the knowledge of the future traffic pattern, the smaller s_{tot}. For a perfect prediction $s_{tot} = 0$, which corresponds to the case of a deterministic traffic matrix.

3. HEURISTICS FOR DIMENSIONING NETWORK CAPACITY

Networks are usually dimensioned with the goal to minimize an objective function, e.g. the necessary costs to realize the network. Equipment costs are hard to quantify, therefore a simple approach is to minimize the necessary transport capacity which has to be installed.
The approach here is as following. The topology is assumed to be given in advance. For every node-pair, the number of connections is modeled as described in the previous section. This yields a set of investigated connections with corresponding probabilities for their realization.

Distribution/ Confidence Level	0.9	0.95	0.99	0.995	0.999
Uniform	18	18	20	20	20
Poisson	14	15	18	19	21
Binomial (s =2)	13	13	14	15	16

Table 1: Required capacity for a predicted traffic of µ=10 and different distributions and confidence levels.

Each request is routed from the source to the destination node. This gives a distribution for the required capacity due to the carried connections on every link. For the dimensioning, the expectation value of the required capacity on that link k plus an over provisioning proportional to the variance $c_k = m_k + g \cdot s_k$ is taken. Due to the central limit theorem, the addition of several independent random variables results in a normal distribution for the required capacity on the links. A choice of $g = 1.65$ corresponds to a confidence level of 95% that is the probability, that the link is able to carry the traffic. An example for a predicted traffic of 10 connections and different distributions and confidence levels is shown in Table 1.

For simplicity reasons, protection here is neglected. Note, that for e.g. dedicated path protection, the occurrence of the working path and the protection path are perfectly correlated. This has to be taken into account, when calculating the distribution for the necessary capacity on a link.

With the optimization process the total amount of the needed capacity should be minimized. The idea is to lower the relative variance s / m by combining several statistical independent traffic sources. In that way, it might be favorable to choose a longer path in order to share a link with other connections.

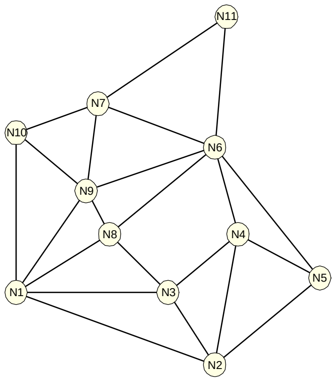
A set of possible paths for every node-pair in the network is computed, usually the k shortest paths between the two nodes. For the starting configuration, one of the candidate paths is assigned to each connection request. The network is dimensioned for this routing. The configuration is evaluated with respect to the total required capacity. By rerouting one of the paths, a variation of this configuration is derived. This neighbor configuration is accepted when it needs less capacity than the original one.

This greedy algorithm is a very simple one and may be trapped by local minima. Here, probably a meta heuristic like Simulated Annealing would perform much better.

For the deterministic static case with $s_{tot} = 0$, the best solution for the routing that minimizes the required total transport capacity is to assign the shortest path to each connection. Due to the uncertainty, the variance in the capacity results in over-provisioning on the links. By optimizing the routing, the best trade-off between longer paths and higher variances is being searched.

4. Case Study for a Pan-European Network

In the framework of the European research action COST 239, a reference scenario for a Pan-European network has been defined [1]. In Figure 2, the given fiber topology the corresponding traffic matrix is depicted. The uncertainty has been modeled with a Poisson and a uniform distribution with an expectation value as listed in Figure 2. For every node-pair, the 10 shortest paths have been calculated as candidates for the routing of a connection between the two nodes. For this study, the cases of a granularity of 2.5 Gbit/s (STM-16) and 10 Gbit/s (STM-64) per connection have been considered. Routing was always performed symmetrically. As initial configuration, the shortest path has been chosen for all connections. The results for the required total capacity in the network for different confidence levels are depicted in Table 1. For each scenario, five runs, with 100000



	0	1	2	3	4	5	6	7	8	9	10
0 Paris	X	12.5	15	2.5	5	27.5	12.5	2.5	17.5	25	2.5
1 Milan	12.5	X	15	2.5	7.5	22.5	5	2.5	5	7.5	2.5
2 Zurich	15	15	X	2.5	7.5	27.5	7.5	2.5	7.5	7.5	2.5
3 Prague	2.5	2.5	2.5	X	2.5	5	2.5	2.5	2.5	2.5	2.5
4 Vienna	5	7.5	7.5	2.5	X	22.5	2.5	2.5	2.5	5	2.5
5 Berlin	27.5	22.5	27.5	5	22.5	X	20	5	15	20	7.5
6 Amsterdam	12.5	5	7.5	2.5	2.5	20	X	2.5	10	12.5	2.5
7 Luxembourg	2.5	2.5	2.5	2.5	2.5	5	2.5	X	2.5	2.5	2.5
8 Brussels	15	5	15	2.5	2.5	15	10	2.5	X	10	2.5
9 London	25	7.5	7.5	2.5	5	20	12.5	2.5	10	X	2.5
10 Copenhagen	2.5	2.5	2.5	2.5	2.5	7.5	2.5	2.5	2.5	2.5	X

Figure 2: Network topology of COST 239 Pan-European network (left) and corresponding traffic matrix in GBit/s (right).

Confidence Level	**0.9**		**0.95**		**0.99**		**0.995**		**0.999**	
Distribution	**S**	**O**	**S**	**O**	**S**	**O**	**S**	**O**	**S**	**O**
Granularity 2.5 Gbit/s per channel (deterministic: 540)										
Poisson	730	692	784	732	890	808	924	834	984	874
Uniform	816	758	878	806	964	882	988	910	1026	950
Granularity 10 Gbit/s per channel (deterministic: 244)										
Poisson	364	344	398	370	440	412	454	422	466	440
Uniform	368	344	406	374	480	440	506	454	542	480

Table 2: Total required capacity for the case study of the COST 239 Pan-European Network (S=Start Configuration with shortest path, O=After 100000 optimization steps).

optimization steps each, have been performed. From these runs, the best result has been taken. For comparison purposes, the required capacity for the deterministic case, where the connections are assigned according to the traffic matrix, has also been listed.

Due to the uncertainty of the traffic pattern, a substantial over-provision of the capacity in the network is necessary. With increasing confidence level, this raises, e.g. for a confidence level of 0.999, approximately to twice the capacity of the deterministic case. The higher relative variance of the uniform distribution results in a much higher required capacity for the same confidence level. On the other hand, this procedure allows designing the robustness of the network systematically and replaces the traditional design approach, to scale every demand by a constant factor.

With the very simple optimization procedure, capacity savings of 5% to 10% may be achieved. The reductions are greater for the uniform case. This is due to the higher variance of this distribution. In general, the connections, which occur with high probability, are assigned the shortest path, whereas the less likely ones take a longer path to share capacity with other connections.

This design approach tends to bundle the traffic and leads to “unbalanced” networks. Some links will carry a lot of traffic whereas periphery links are less used. This might cause problems for protection and restoration.

4.1 CONCLUSIONS AND OUTLOOK

A statistical description of the traffic matrix in a circuit-switched network is developed. This probabilistic traffic pattern is being used to find systematically an optimal routing and to dimension the network resources, so that the network is robust to deviations of the actual traffic pattern to the predicted one. For that purpose, an algorithm, which minimizes the needed additional network capacity, is developed. A case study for the Pan-European transport network of the COST action 239 has been performed.

Protection and wavelength allocation should be incorporated in the algorithm. Probably statistic correlation between the connection requests in a traffic matrix is present. Therefore, this should be included when the distribution for the capacity is calculated.

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