Generic Analytical Model for Cost-Optimal Packet Network Design

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Abstract

A novel analytical model is developed to analyze the impact of the cost ratio of transport and switching/routing equipment, providing insights into critical parameters affecting cost-optimal network design.

Introduction

Prices for network transport services decline continuously [1], allowing information to be transported over long distances at very low cost – a prerequisite for the growth of the Internet and IP enabled services. Optical technologies are the core of this development, enabling cost efficient transport solutions and backhauling over long distances. Ultimately this development will lead to novel architectural and topologicals solutions, the design rules for which are not completely understood. Cost-optimal network design is a complex task due to the large number of boundary conditions to be considered [2]. The purpose of this paper is to investigate the trade-off between the costs of different technologies used in different network areas. The analysis is based on a generic analytical model allowing cost optimal network design on a national scale. The model is no substitute for sophisticated optimization and planning tools, e.g. based on integer linear programming or heuristics [2]. Instead the model described here provides insights into the rules of future network design on a strategic level [3], combining both technical and economic aspects. The focus is on the impact of cost ratios of different equipment types, transport equipment, and topological and architectural choices they enable.

Network Architecture and Cost Model

Network architectures typically are composed of three main structural elements: the access part, connecting the customers to the network, the aggregation network which multiplexes the traffic of individual users, and the backbone/core network providing global connectivity and reachability. Each segment consists of an optical transmission system (wavelength division multiplexing, WDM), and routing functionality located in the nodes. The model considers the price and functionality of network equipment in the three segments as (Figure 1):

- Core: Terabit routers with Ethernet interface; Longhaul WDM transport systems.
- Aggregation: A single hierarchy of switches connected to the core via metro WDM systems.
- Access: Digital subscriber line access multiplexer (DSLAM) with Ethernet interfaces, linked to an aggregation switch with an optical fibre connection.

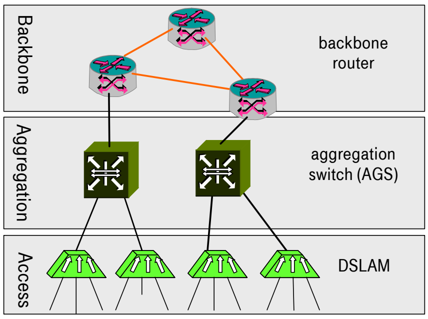

Figure 1: Segmentation of the generic network in core/backbone, aggregation, and access

The cost model comprises the cost of shelfs and terminals, which are shared costs and costs for interface cards and interfaces; the cost of nodal equipment is normalized to throughput in Gbit/s. Transmisson costs are assumed to be proportional to the distance covered, and are mainly a result of the transponders required, optical line amplifiers (OLAs), and end terminals (ETs). The model allows particularly assessing the topological trade-off between the number of backbone and aggregation nodes. Due to the high cost of equipment in the core, it would be desirable to shift functionality towards more cost-efficient aggregation nodes, even for the price of longer backhauling distances towards core nodes. However, it remains unclear which sets of parameters lead to cost optimal designs.

Model Topology and Methodology

A generic network model is used, based on the idea of using quadratic areas, hence abstracting any real geographic constraints. The number and location of DSLAMs is fixed, whilst the number core and aggregation nodes is flexible. Network traffic and hence network nodes are homogeneously distributed across the surface, and are optically interconnected to one another. To investigate the scalability of the design, each quadrat can be subdivided into more quadrats, leading to a quadratic increase in the number of nodes, e.g. from

1 to 4 to 9 etc. in the design. Each of the sub areas has one extraordinary node (i.e. y in total), which is acting as a backbone node. All other x nodes in a sub area, i.e. aggregation area, are driectly connected to a backbone node (hub), and all backbone nodes are fully meshed by optical connections (WDM based). Figure 2 shows an example for x=9 and y=4, and N = x·y = 36. At this stage, resilience has not yet been considered.

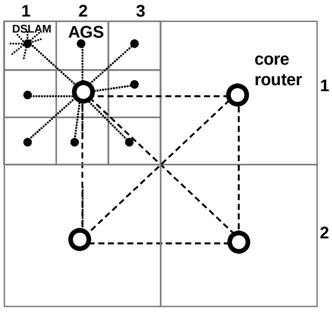

Figure 2: Example of Generic Network Structure with y = 4 core nodes, and x = 9 AGS per core node

Numerical results and analysis

The model was used to evaluate the contributions of the nodal and the transport cost to the total investment for a generic network described in the section above. The analytical nature of the model allows the investigation of a large number of parameters with respect to their impact on optimal network design. Two technically relevant examples related to a German national network are selected to demonstrate the versatility of the models and the technical problems addressed.

The model input for the examples discussed here is as follows: A surface area of approx. 357,000 km^2, no. of DSLAMs 300,000, and total user generated traffic in the network 10 Tbps. An established investment cost model was used to define equipment and transmission cost [2], reflecting realistic price relationships.

Figure 3 shows the total invest as a function of the number of core nodes as well as the number of aggregation nodes connected to each core node. A large area of parameters for the aggregation and core nodes – the total number of nodes ranges from 1 to 40,000. Three major conclusions can be drawn: 1) The results show that there is not a single set of parameters which leads to a minimum, but many. Hence optimal network design with respect to the number of core and aggregation nodes may take a variety of forms: using the values provided here, it would be possible to obtain a cost optimal result for a total of 7,500 backbone and aggregation nodes

2) Figure 3 also shows that an ever smaller number of core routers – in the extreme only a single one remaining for the entire country – does not lead to an investment cost minimum.

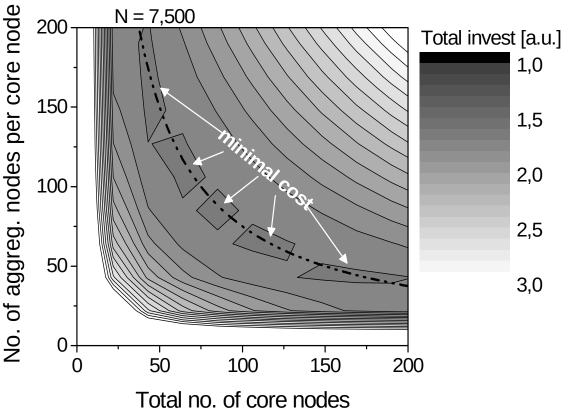

Figure 3: Total cost as a function of the no. of core nodes and the no. of aggregation nodes per core node. The dotted line shows the trajectory for a constant number of core and aggregation nodes with N = 7,500, as well as the areas of minimal cost

3) Keeping the total number of core and aggregation nodes constant is a common strategy in optimizing networks. The results derived from the model show that investment cost for a constant number of nodes follows a trajectory – a line of only small cost variations. It would be much better – yet for operators more difficult – strategy to allow for a variable number of locations to reach a true cost optimum.

Conclusions

A generic analytical model was developed to investigate the impact that different technologies and their relative costs have on future network architectures and designs. The results of the numerical example demonstrate that for realistic parameter sets there does not necessarily exist a single optimal solution; rather, a number of mutually interchangeable solutions for the combination of aggregation and core nodes can be found. The total cost is robust with respect to the distribution of core and aggregation nodes, provided that their total number remains constant. Minimizing the investment cost would require the number of aggregation and core locations to be treated flexibly, rather than being kept constant.

References

1. A. M. Odlyzko, "The evolution of price discrimination in transportation and its implications for the Internet," Review Network Econom., vol. 3, no. 3, Sept. 2004, pp. 323-346
2. R. Huelsermann etal.:, "Cost Modeling and Evaluation of Capital Expenditures in Optical Multilayer Networks," submitted for publication to OSA J. Optical Networking (JON)
3. K. Ward, "Network Infrastructure Economics," IBTE, issue 31, 4/99