Knowledge-based Design of Leased-Line Networks

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Abstract:

This paper presents a knowledge-based approach to the design of leased line networks. The tool OPTOLL assists in the optimization of networks by applying in a successive way a number of rules based on heuristics. The optimization so far is driven by the costs of the network, but other optimization criteria can be implemented in an easy way by modifying the knowledge base. The optimization starts with an initial configuration consisting of a primitive solution for the network: point to point lines with no routing. Starting from this the tool applies so called *Expansion* and *Contraction* operations according to heuristics like prevention of long lines or search for backbone lines. The approach is demonstrated by an example where the overall network costs are reduced considerably with respect to the primitive solution.

CR Categories and Subject Descriptors:

C.2.1 [Computer-Communication Networks]:Network Architechture and Design

General Terms: Algorithms, Design

Additional Key Words: Corporate Networks (CN), Artificial Intelligence (AI), Expert System (ES)

1. Introduction

The success of an enterprise depends on an efficient use of telecommunication facilities. With this need for telecom transmission capabilities the need for powerful network design tools grows. The University of Berne started the research project OptiNet in 1991, to develop concepts for the design of corporate networks (CN). One part of this project deals with the design of leased-line networks, described in this paper [GRE92].

The design of leased-line networks is partitioned into two levels. The upper level consists of the description of the network dataflow. The traffic matrix is described in form of a set of connections, which contain the two nodes involved and the corresponding transmisson speed. It is possible to define more than one connection between two nodes. The upper level is also called the logical level, because it characterizes the network logically. A connection can be routed over one or more leased-lines.

The lower level on the other hand is called the physical level. This level describes the physical (leased)-lines of the network provided by the telecos. A leased-line is defined between two nodes and transmits data of several connections. The costs of leased-lines are calculated out of the geographical location of the nodes and the used capacity.

The optimization problem for leased-line networks consists of the optimal routing of the connections on the leased-lines. This is a mapping problem between the connection and the lines and is known as the capacity assignment problem [BER87]. Optimal means that the costs are minimal under the given constraints. The constraints are for example a limitation of the number of leased-lines used by one connection or capacity restrictions of nodes.

2. Complexity

Given the number of nodes n and the number of connections k we can calculate the number of possible configurations. Each connection can be routed directly or over one or more nodes. The number of possible nodes is n-2. The number of routes of one connection is calculated by the following formula:

$$1 + \sum_{l=2}^{n-1} \frac{(n-2)!}{(n-l-1)!}$$

From this formula follows the hyperexponential complexity $O(n^n)$ for the number of routes of one connection. Extended to all k connections we get the complexity $O(n^{nk})$. This complexity is illustarted in Figure 1. The x-axis represents the nodes while the y-axis stands for the time. The connections are estimated by *n log n*. Supposed the computer can verify 1 Million configuration every second we get the following graph with the indicated times. For example it takes more than 4 month to evaluate all configuration for 6 nodes and 11 connections.

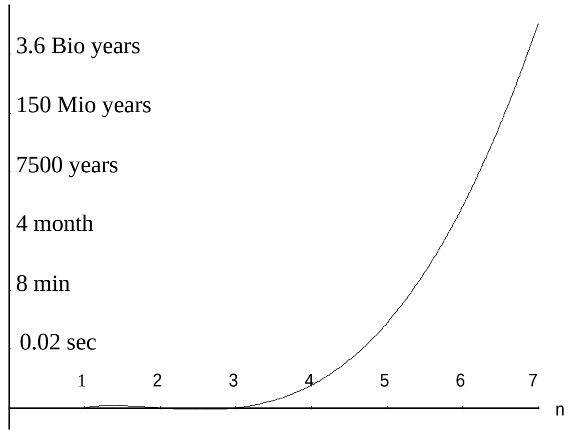

Figure 1 Complexity

These calculations show in a impressive way the infeasibility of calculating all configurations. In the next section we discuss problem solving methods.

3. Problem solving methods

One possible way to solve this optimization problem are analytical methods of the operations research, especially the Mixed Integer Programming method. With this method it is possible to get the optimal configuration through mathematical modelling with the approximation of the costs. This approach needs a big computation effort and is only feasible for small networks.

[BER87] found out that the use of Operations Research (OR) Methods for the capacity assignment problem is not practicable, because the cost function has many local minima and is very difficult to minimize. Furthermore the described formulation is unrealistic because, in practice, capacity costs are not linear and the capacity of a leased line usually must be selected from a finite number of choices. [GER90] describes similar reasons why the OR Methods are not feasible. Both recommend to use heuristics to solve this problem.

Typically the heuristics start with some network topology, and then successively perturb this topology by changing one or more routes of the connections at a time. They create a new configuration by applying certain rules on an old one in order to find a better solution.

Normally heuristics are applied in iterations. At the start of each iteration, there is a current best configuration and some test configurations. The heuristics derive from these configurations new ones and evaluate them to get the set of configurations for the next iteration. The iteration stops when there are no more configurations to derive.

This structure makes the problem an excellent application for expert systems.

4. Expert System Solution

The principle of the expert system approach is changing an existing configuration to a configuration, which fulfills the given requirements better. The new configuration consist of a different routing of one or more connections. The changes are selected by the rules of the expert system. A rule describes a method for changing the route of a connection. It will be applied to all connections, which seem to provide a successful change in the direction to the best configuration.

In order to make sure that every possible configuration can be derived from an initial configuration, the rules must be based on operations which are minimal and complete. Completeness means that these operations guarantee the derivation of every possible configuration from any given configuration. Minimality stands for the requirement that no operation can be taken away without violating the completeness condition.

In this optimization problem we can define two operations: *Expansion* and *Contraction* (Figure 2).

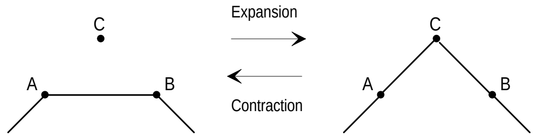

Figure 2 Basic operations

The operation *Expansion* routes a connection, which is routed directly between A and B over the additional node C, which is not yet on the route of this connection. The *Contraction* operation is the inversion of the *Expansion.* It eliminates a node C from the route of the chosen connection. It is obvious that these two operations fulfill the minimality and completeness conditions.

How to decide which one of these operations has to be applied in a given situation is the goal of heuristics that are explained in the following section.

5. Heuristics

Based on the *Expansion* and *Contraction* operations, four heuristics are defined:

- Critical Connections
- Prevention of Long Lines
- Generalized Expansion
- Backbone Lines

Critical Connections
The first and most important heuristic is based on the critical connections. The leased-lines are classified in order to determine the expensive ones. Expensive doesn't refer to the effective costs, but to the relation between the effective costs and the data transmitted. A line is expensive if the costs per used byte are high. In an expensive line the critical connections are defined as those connections, which increase the costs per used byte.

This heuristic considers critical connections as candidates for a potential expansion or contraction.

Prevention of Long Lines
Prevention of Long Lines is a heuristic that replace two long lines in a triangle with a long and a short line (Figure 3). It is only applied to expansions.

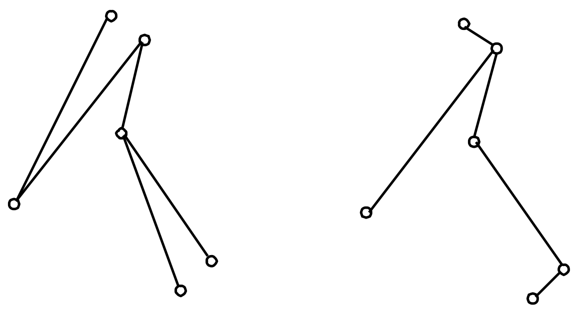

Figure 3 Prevention of Long Lines

Generalized Expansion
The Generalized Expansion is a special Expansion-heuristic. Instead of expanding a single connection, it looks at a specific line and reroutes a whole bunch of connections mapped to this line by determining the bypass with the highest free capacity. The free capacity is defined as the minimal free capacity of all its lines, whereas the free capacity of a line is defined as the difference between the size of the line and the sum of all connections mapped to it.

Figure 4 shows two bypasses of a line, one with free capacity of min(50,40,35,60) = 35 kbps, the other one with a free capacity of min(30,100) = 30 kbps. The first one would be preferred in this case.

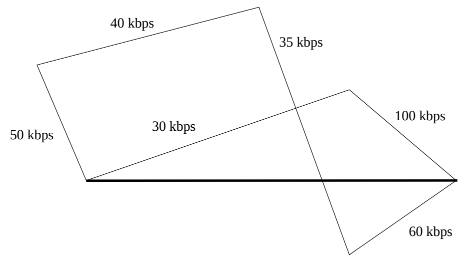

Figure 4 Generalized Expansion

Backbone Lines
The heuristic Backbone-lines tries to support backbone-lines as candidates for expansions and contractions by assigning them a bonus value (Figure 5).

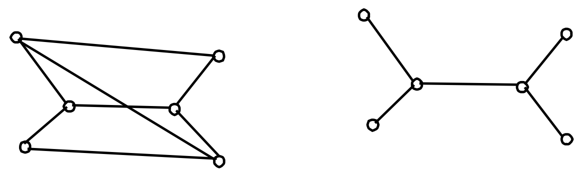

Figure 5 Backbone Lines

The advantage of the heuristic Backbone-lines is to map in a single step more than one connection on a special backbone-line.

6. Implementation

The preceding heuristics have been implemented using the expert system shell SMECI [ILO92]. SMECI is an object-oriented shell based on LeLisp. The name of the implementation is OPTOLL (Optimization Tool for Leased-Lines).

OPTOLL is based on the Swiss tariff structure. The costs structure can easily be adapted to other geographical locations. The results of this implementation are presented using the following example.

Figure 6 shows the inital configuration. The connections are directly mapped to single lines with the same terminating nodes. The thickness of the lines represents the capacity of the lines. The costs of this configuration are SFr. 42’232.- per month. The costs contain only the fees for renting the lines.

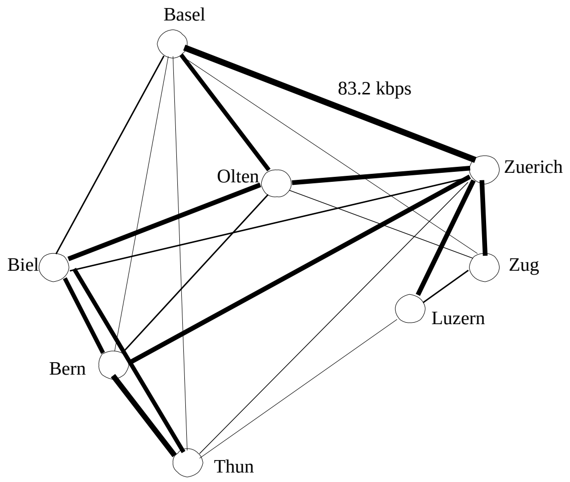

Figure 6 Initial Configuration

The best configuration of this example is shown in Figure 7. It costs SFr. 28’343.- per month. This is a reduction of 33% in comparison with the cost of the initial configuration.

7. Conclusions

OPTOLL is a knowledge based network design tool for leased-lines. A new approach using heuristics based on two operations, namely Expansion and Contraction, has been chosen.

A number of heuristics have been implemented so far: critical connections, prevetion of long lines, generalized expansion and backbone-lines. Other heuristics may become feasible as the requirements for the network

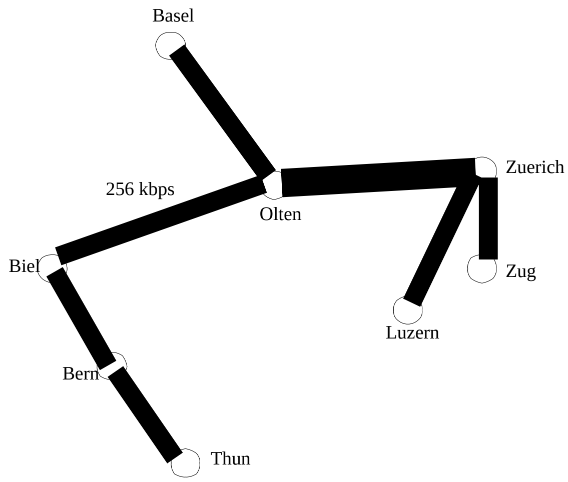

Figure 7 Best Configuration

change, for example the requirement for the existence of backup lines. These can be introduced in an easy way without changing the principles of the tool.

References

[BER87] Bertsekas D., Gallager R.
Data Networks
Prentice-Hall International, 1987

[GER90] Gersht A., Weihmayer R.
Joint Optimization of Data Network Design and Facility Selection
IEEE Journal on Selected Areas in Communications
Vol. 8, No. 9, December 1990

[GRE92] Greulich A.
An Expert System Approach to the Design of Leased Lines Networks
Institut für Informatik und angewandte Mathematik
Master these, Universität Bern, 1992

[ILO92] ILOG SA.
SMECI Reference Manual 1.65
ILOG SA, August 1992