A.I. Techniques for Planning Telecommunication Networks

Mario Pickavet, Chris Develder, Elise Baert, Piet Demeester
Department of Information Technology (INTEC)
Ghent University – IMEC
Sint-Pietersnieuwstraat 41, 9000 Gent (Belgium)

Abstract: *The planning of investments when building and upgrading communication networks amounts to notoriously difficult combinatorial problems. Solving these issues can not be done in a straightforward way within a reasonable calculation time, despite the ever-growing computational power of computers and the flexible off-line character of network planning. In this paper, an overview is given of the measures that can be taken to overcome these difficulties, such as introducing carefully chosen approximations in the problem formulation and the use of Artificial Intelligent techniques to come to good-quality solutions in a heuristic way. After a general overview and discussion, a practical A.I. approach will be presented, based on a philosophy of gradually increasing the level of detail. The strength of this approach will be shown for two realistic problems : the global design of a circuit-switched transport network and the assessment of the end-to-end performance in an optical packet switched network.*

Keywords: planning of communication networks, artificial intelligence, network design, Zoom-In technique, heuristics.

1. Network Planning and Design

In nowadays' telecommunication networks, the main players are the network operator realizing the existence of the network, the customers responsible for the (ever-growing) demand for services, the manufacturers providing the necessary equipment and software to build up the network and the government and regulatory institutions (see Figure 1 for a schematic overview). For more recent services, one could also add the importance of content providers and service providers in this picture.

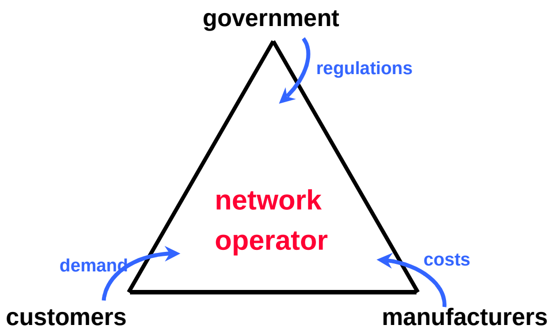

Figure 1 : Main players in telecommunications environment

The main objective of the network operator in this environment is to build up and upgrade a network in such a way that the expected net revenue (i.e. the revenue generated by the customers minus the equipment, software and operational costs of the network) is maximized. To cut down costs, it is of paramount importance for the network operator to *plan* the detailed evolution of investments over time as accurate as possible. This not only maximizes the net revenue but also creates a significant advantage over the competitors.

Planning of communication networks however involves a large number of non-trivial issues to be resolved, including the following :

- On one hand, the network costs should be minimized, e.g. by opting for a suitable technology, for cost-efficient equipment types, etc. On the other hand, the operator should strive towards an optimal network performance (avoid failures, circuit blocking or packet loss and guarantee a certain quality of service) as this will highly influence customer satisfaction and hence future revenues. These two objectives are typically antagonists, demanding a careful balance.
- A number of important input parameters for a detailed planning are not known exactly, but are merely predictions of future demand, future costs, future technology evolutions, … The uncertainty of these inputs should be taken into account in a robust planning process.
- An accurate representation of detailed network aspects, such as the traffic pattern on the individual user level and the detailed cost figures for different types of equipment, is quite hard to take fully into account in the network planning process.
- A telecommunication network typically consists of different network layers, i.e. different technologies that interwork in a client-server manner. These network layers are coupled, leading to a complex overall problem.

All these issues typically give rise to an overall network planning problem that exhibits a tremendous complexity. In practice, a frequently made simplifying assumption is to split up the network planning problem (covering a large time interval) in a number of consecutive *network design* steps (see [1] for an evaluation of the impact of this approximation). One step is shown in Figure 2, where the fixed inputs are shown on the left and the iterative design process is shown on the right. First some pre-design decisions are taken, like the choice of network architecture and technology and the assumption to consider only one time point (network design approximation of network planning). Once these initial choices have been made, the actual network design process is carried out : for given node positions, demand and possibly a fixed routing strategy, the position of the links in the network is determined, the routing of the traffic in failure-free conditions and the rerouting of the traffic in case of failures is calculated, and the network node and link capacities are dimensioned to cope with these traffic requirements. In this phase, typically some approximations are applied (e.g. simplified cost model, ignoring some details of the particular routing protocol, etc.). After the actual network design, a detailed evaluation is carried out : costs are calculated in full detail, a simulation may be needed to verify whether the actual traffic profile tallies with the approximate traffic demands and the obtained network design should be future-proof. If the evaluation turns out to be unsatisfactory, some pre-design decisions will be adjusted accordingly and a new network design will be carried out.

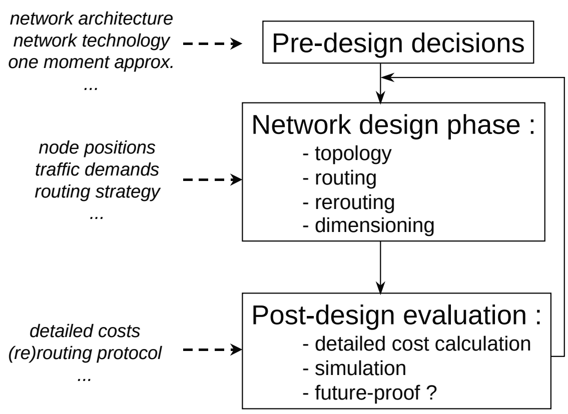

Figure 2 : Typical network planning process

2. Typical Solution Approaches

Even after several simplifying assumptions with respect to the problem description, the resulting network design problem is typically still NP-complete [2], i.e. all known exact solution approaches require a computer calculation time that grows exponentially when the characteristic dimension of the problem (e.g. number of network nodes, total network demand, …) increases. As a result, exact algorithms (e.g. based on (Integer) Linear Programming [3], [4]) usually lead to unrealistic calculation times for real-size network design problems, despite the ever-growing computational power of computers and the flexible off-line character of the network design process.

To circumvent this problem, one typically resorts to *heuristics*, i.e. Artificial Intelligent techniques that come up with sub-optimal solutions of the network design problem within a reasonable calculation time (and with reasonable computer memory requirements). These heuristic techniques can be classified according to several criteria :

- Some heuristic techniques are of a generic nature. They are applicable to a broad range of optimization problems. Of course some elements of the heuristic still have to be adapted to the properties of the specific problem, but the principle of the solution method remains the same. Other heuristic search techniques have been designed specifically for a particular optimization problem. These 'tailor-made' heuristics often outperform the generic optimization techniques, since it is possible to add a lot of intelligence and historical knowledge about a specific network design problem to the heuristic. On the other hand these specific techniques might be difficult to adapt when some elements of the optimization problem change. In practice, in most heuristics both generic and problem dependent elements are encapsulated.
- Some methods have a searching character. These will start from a particular solution (randomly chosen or historically found good) and suggest a lot of possible solutions at a high tempo (idea of trial and error). Doing so, a trajectory trough solution space is described, searching for better solutions at every step. Other methods will rather build up a solution towards a complete solution by combining small building blocks. In these constructive methods difficult decisions are made, often requiring detailed insight in the problem.
- Another aspect for classification is the stochastic character. In some heuristics a random parameter is used. By applying these algorithms several times for the same problem with the same initial state, different solutions can be found.

In the presentation, we will especially elaborate on meta-heuristics (a.o., Simulated Annealing [5], Tabu Search [6] and Genetic Algorithms [7], [8]) and how these A.I. techniques can be used to solve complex network design problems. The advantages and disadvantages of these different methods will be highlighted, and their performance will be compared with exact techniques like Integer Linear Programming. These meta-heuristics exhibit a generic nature ; hence they can be applied to a wide variety of optimization problems. However, this generality also leads to some drawbacks : for practical network design problems, the meta-heuristics often show some lack of orientation, leading to a computer program that only evolves slowly towards good solutions. To speed up these methods, the specific knowledge about the problem at hand must be exploited as much as possible.

3. Zoom-In Philosophy

To circumvent the difficulties that appear when applying meta-heuristics and exact techniques in a straightforward way to realistic network design problems, another solution method is proposed: the *Zoom-In* approach [9]. The rationale is to migrate gradually from a global, less detailed view towards a local and more detailed look, both with respect to the solution accuracy and the search effort. In the first phases of the algorithm, a rudimentary solution is constructed based on simplifying assumptions. As the algorithm proceeds, more realistic models are used and the search effort is increased to find better solutions. At the end of the algorithm, all necessary problem details are taken into account and a profound searching is carried out.

The Zoom-In concept also comes forward in the choice of the optimization methods that are applied as the algorithm proceeds. In the beginning mostly global construction heuristics are utilized, possibly enhanced with random effects to realize a more global view of the search space. The emphasis then shifts more and more towards local improvement techniques, with a more deterministic search procedure.

The Zoom-In approach aims at combining the solution quality of an approach where the problem is tackled as a whole with the calculation speed of an approach where the problem is split up in (approximately decoupled) subproblems. To this end, for each phase of the algorithm a judicious choice must be made which problem details will or will not be taken into account. These decisions are typically based on a trade-off : considering an additional aspect of the problem typically improves the solution quality but requires more calculation time (and/or memory usage).

An additional advantage of the Zoom-In approach is its flexibility. Depending on the available time and memory, some problem characteristics may be considered or neglected in some phases of the algorithm. For small problem instances, one will take a lot of details already into account from the beginning, typically leading to high quality results. For large problem instances however, by ignoring most problem details in the beginning, one can still end up with a satisfactory solution within a reasonable time : by taking the problem details into account in the last phases, one does not jeopardize the solution quality too much.

The practical application of this Zoom-In philosophy on realistic problem instances is illustrated in the following sections : the global design of an SDH or SONET network and the assessment of end-to-end performance in an Optical Packet Switched network.

4. Example I : Global Design of Circuit-Switched Transport Network

The first network design problem we will elaborate on is the global design of an SDH (Synchronous Digital hierarchy) VC-4 network. This problem includes :

- the design of a suitable network topology
- determining the routes of the traffic through the network
- the choice of the spare routes in case of a link failure (based on link restoration [10])
- and finally the capacity dimensioning, using a discrete capacity model with different kinds of line systems (see Figure 3).

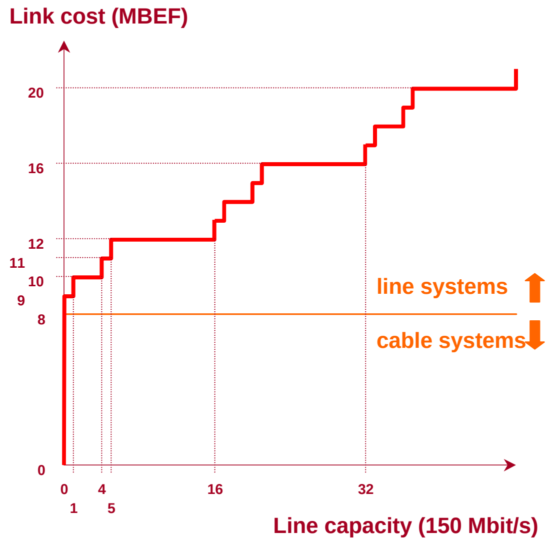

Figure 3 : Discrete capacity cost model for SDH links, including topology (cable systems) and capacity (line systems) cost

As these four subproblems are clearly interrelated, we can not solve the problems in a pure sequential way (without risking a poor overall solution quality). On the other hand, an integrated approach considering all subproblems at once would lead to a huge problem complexity and according calculation times. Therefore, a Zoom-In strategy is proposed, consisting of four main phases.

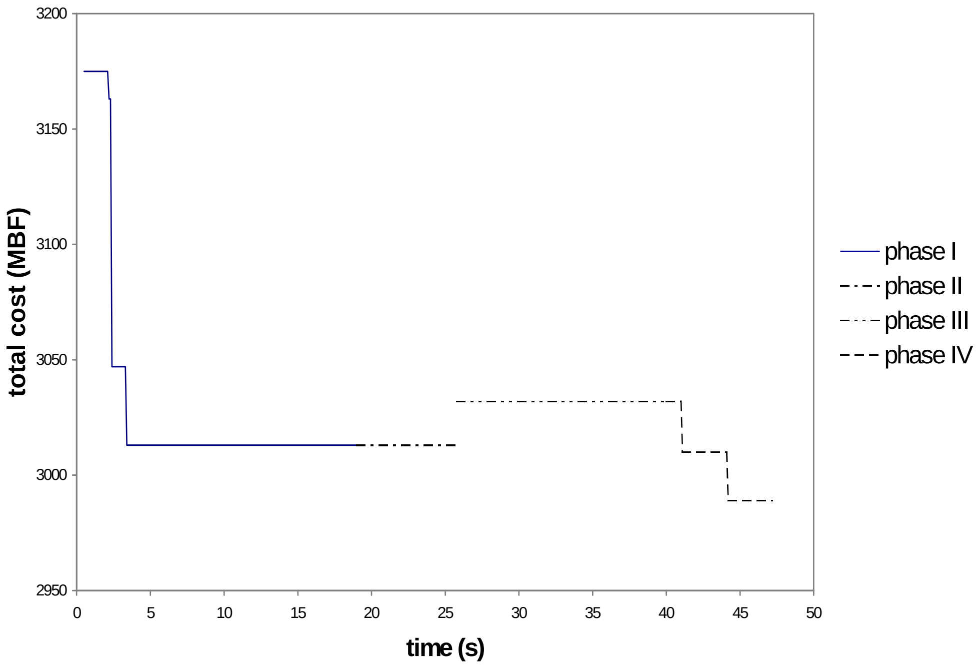

Figure 4 : Time evolution of overall network cost as algorithm proceeds

In a first phase, a basic topology is designed and the needed link capacities are estimated. The cost of the line systems is approximated by a function which is proportional to the capacity on the link. Furthermore, a simpler routing strategy is applied : a bi-routing strategy, routing all traffic twice from the source node to the destination node, once along a working path and once along a link-disjoint backup path. The algorithm in this phase is based on a Genetic Algorithm [11], enhanced with deterministic optimization routines to speed up the convergence process. In a second phase, the starting topology is locally optimized (if necessary), still based on an linear cost model and a bi-routing strategy.

From the third phase on, the accurate discrete capacity cost model (see Figure 3) is taken into account and a link-restoration based rerouting strategy is applied. Phase 3 again carries out a local improvement of the topology, while phase 4 concentrates on the optimization of the final working and link restoration routes in a fixed topology.

The time evolution of these four design phases is shown in Figure 4 for a real problem instance. In the first phase, a lot of improvement can be noticed, indicating that the Genetic Algorithm is able to construct better solutions by crossover operations. The local improvement phases 2 and 3 do not change the network design in this case[1]. Finally, in phase 4, the refinement of the routing leads to a slightly cheaper network design.

Comparison of the results of this algorithm with the results of a sophisticated ILP-technique illustrate the intrinsic power of the Zoom-In strategy (see [9]) : on the average, the Zoom-In algorithm outperforms the interrupted ILP-technique with respect to the solution quality, while consuming a comparable calculation time.

5. Example II : End-to-End Performance in OPS Network

In this second example, a future Optical Packet Switch (OPS) network is studied. This wide area network consists of a number of optical packet switches that are interconnected with Wavelength Division Multiplexing links. The

[1] The transition from an approximate capacity and routing model (phases 1 and 2) to a correct model (phases 3 and 4) leads to a small increase in the calculated network cost, as can be seen from the figure.

optical packet switch consists of an ultra-fast optical switch based on SOA technology [12]. To resolve contention if more packets are destined for a certain output fiber than there are wavelengths on this output fiber, fiber delay lines (FDLs) are used to form a recirculating buffer. This node architecture is shown in Figure 5.

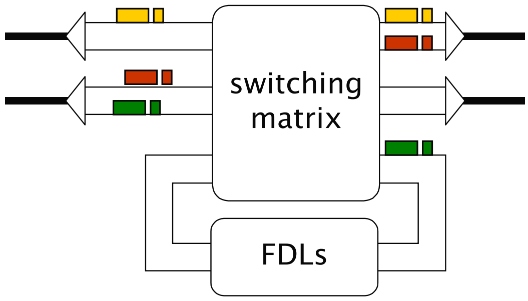

Figure 5 : Node architecture of optical packet switch

This particular node architecture, imposed by the limitations of optical RAM, raises some fundamental questions about the end-to-end performance (especially packet loss rate) of such an OPS network. To assess the influence of this node architecture on the performance, a Zoom-In strategy was chosen.

In preparation of this approach, one individual node is considered (with careful modeling of the incoming traffic, to mimic a node-in-a-network situation). A detailed node simulator was built [13], leading to numerical results for the average packet loss rate, depending on the amount of flow going through the node, on the distribution of the traffic over the different output fibers, on the nature of the traffic (e.g. Poisson-traffic, bursty traffic or self-similar traffic), etc. Based on these simulation results, a simplified node model can be created, capturing the main impact factors on the packet loss in a quantitative way.

Based on these simulation results, a first phase of the Zoom-In algorithm consists of a network-wide traffic engineering study, where the full node functionality is replaced by the simplified node model (see Figure 6 for a schematic view). In this way, global network-wide decisions can already be made about the routing and rerouting of traffic, possible admission control issues, etc… For a more accurate and refining study, the node simulator itself is used in every individual node in the second phase of the Zoom-In algorithm. This can lead to minor adaptations of the routing pattern found in the first phase.

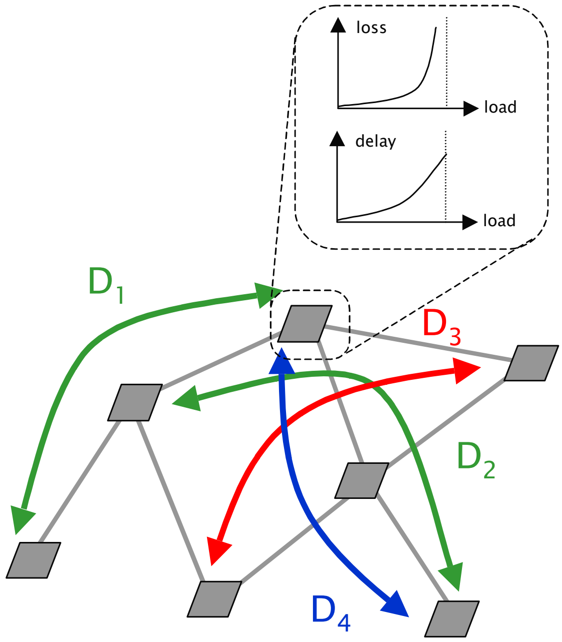

Figure 6 : Capturing the end-to-end performance in an OPS network

6. Conclusion

To reduce the huge complexity of typical network planning problems, basically two measures can be taken. First, some simplifying assumptions can be introduced, alleviating the considered problem to some extent. Secondly, by judiciously approaching the problem and by identifying the essential and less essential characteristics, one can devise an Artificial Intelligent solution strategy, which leads to a solution without jeopardizing the solution quality.

A practical heuristic approach was presented : the Zoom-In Approach. The philosophy behind this Artificial Intelligent technique is to gradually increase the level of detail, both from the problem description and the search focus point of view. This approach was applied to two realistic problems : the global design of a circuit-switched network and the assessment of end-to-end performance in an Optical Packet Switched network. Comparison with other approaches shows the intrinsic power and performance of the Zoom-In strategy.

Acknowledgements

Part of this work has been supported by the European Commission through the IST-project DAVID and by the Flemish Government through the IWT-GBOU project “Optical Networking and Node Architectures”. The second author is a Research Fellow of the Fund of Scientific Research – Flanders (F.W.O.-Vl., Belgium).

References

[1] M. Pickavet, P. Demeester, “Multi-Period Planning of Survivable WDM Networks”, European Transactions on Telecommunications, special issue on WDM Networks, vol. 11, no. 1, Jan/Feb 2000, p. 7-16.

[2] H. R. Lewis, C. L. Papadimitriou, “Elements of the Theory of Computations”, Prentice-Hall, Englewood Cliffs, NJ, 1981.

[3] G. Nemhauser, A. Rinnooy Kan, M. Todd, “Optimization”, in Handbooks in Operations Research and Management Science, vol. 1, North-Holland, Amsterdam, 1989.

[4] G. Nemhauser, L. Wolsey, “Integer and Combinatorial Optimization”, Wiley, New York, 1988.

[5] S. Kirkpatrick, C. Gelatt, M. Vecchi, “Optimization by Simulated Annealing”, Science, vol. 220, 1983, p. 671-680.

[6] F. Glover, “Future Paths for Integer Programming and Links to Artificial Intelligence”, Computers and Operations Research, vol. 5, 1986, p. 533-549.

[7] D. Goldberg, “Genetic Algorithms in Search, Optimization and Machine Learning”, Addison-Wesley, Reading, MA, 1989.

[8] Z. Michalewicz, “Genetic Algorithms + Data Structures = Evolution Programs”, Springer-Verlag, London, 1997.

[9] M. Pickavet, P. Demeester, “A Zoom-In Approach to Design SDH Mesh Restorable Networks”, Journal of Heuristics, special edition on Heuristic Approaches for Telecommunications Network Management, Planning and Expansion, vol. 6, no. 1, April 2000, p.103-126.

[10] T.-H. Wu, “Emerging Technologies for Fiber Network Survivability”, IEEE Communications Magazine, vol. 33, no. 2, 1995, p.58-74.

[11] M. Pickavet, P. Demeester, “A Genetic Algorithm for Solving the Capacitated Survivable Network Design Problem”, Proc. Fifth International Conference on Telecommunication Systems, Modeling and Analysis, Nashville (USA), 20-23 March 1997, p. 71-76.

[12] D. Chiaroni, et al., “First Demonstration of an Asynchronous Optical Packet Switching Matrix Prototype for MultiTerabitclass Routers/Switches”, 27th European Conference on Optical Communication (ECOC 2001), Amsterdam (The Netherlands), 30 September – 4 October 2001.

[13] C. Develder, M. Pickavet, P. Demeester, “Assessment of Packet Loss in an Optical Packet Router with Recirculating Buffer”, Proc. Sixth Working Conference on Optical Network Design and Modelling ONDM’2002, Turin (Italy), 4-6 February 2002.