Topological Design of Mesh Communication Networks Using Multiobjective Genetic Optimisation

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Abstract. Designing an optimal communication network is a complex, multi-constraint and multi-criterion optimisation problem. Previous work in this field has optimized a single objective or a combination of multiple values into a single scalar value. In this work, we use the multiobjective genetic optimisation technique along with the convergence to obtain a Pareto front – a set of solutions, which are nondominated with respect to a set of constraints and non-inferior to each other – for the network design problem.

1 Introduction

Computer and telecommunication network topology design is affected by various factors like network cost, average packet delay, network throughput, reliability of the network and the maximum link capacities. Typically, a network design targets reduction in cost and network delays and increasing the throughput. However, reliability and the maximum possible traffic in a link are the additional requirements to be satisfied. Thus, network design requires simultaneous optimisation of conflicting factors, subject to various constraints. For example, reducing the packet delay could mean an increase in the link capacities, which will result in an increase in the network cost. Similarly, network reliability means that failure of one node should not disrupt the entire network. A spanning tree network connecting all the nodes, with no additional links, achieves minimal cost but fails to meet the required reliability constraint. Exploring the whole solution space for such a design problem is NP-complete, and heuristics have to be relied upon to solve practical problems.

Conventional solutions to this problem have been based on rigorous mathematical programming, queuing and network flow concepts [2]. Alternately, heuristic techniques like the Branch X-Change (BXC) method, the Concave Branch Elimination (CBE) method and the Cut Saturation method have also been used. However, some of these heuristic solutions have their own limitations. For example, the BXC method is computationally expensive, and the CBE method does not provide for insertion of new links. Previous work in the filed of network design using genetic algorithms, has optimised only single, *ad hoc* objectives and the eventual solutions have been strongly influenced by the linear coefficients used to combine the different (sub-) objectives into a single scalar fitness value. For example, Dengiz *et al.* [1] attempted maximising reliability of a network given a cost constraint and vice versa. Ko *et al* [3] decomposed the problem of network design into three optimisation processes – for topology, routing and capacity – and applied the genetic algorithm technique to each for minimising the total connection cost. Such approaches yield a single optimal solution.

2 Multiobjective Genetic Optimisation for Network Design

However, *simultaneous* optimisation of multiple (*conflicting*) objectives and constraint satisfaction are very much two aspects of the same problem. In fact, most of the problems in engineering and related areas require the simultaneous optimisation of a number of, possibly competing, objectives. The multiobjective optimisation approach uses the notion of Pareto optimality in which an optimal *set* of solutions prescribes a surface – the Pareto front – in the vector space of the objectives. Key to Pareto optimality is the concept of *domination*, and the multiobjective optimisation yields a range of *non-dominated* solutions lying on the Pareto front.

Another issue in multiobjective optimisation is of *convergence*. Solutions are non-dominated *relative* to the population sample not its universe; just because a solution dominates all others in the current population does not imply that it lies on the (desired) Pareto front. It is completely normal for solutions which are non-dominated at some stage in the computation to become dominated by a superior solution at some later stage. Many researchers have observed that they were in no position to appreciate, for stubborn problem, whether their obtained set was indeed a true optimal solution. Kumar & Rockett [4, 5] have proposed rank-histograms for assessing the convergence, the approach we used in this work.

Pareto Converging Genetic Algorithm (PCGA) [5] naturally performs good sampling of the solution space and ensures population advancement towards the Pareto-front. PCGA has been tested on some benchmark analytical problems as well as on complex real problems. The added advantages of PCGA strategy are that the algorithm does not need *a priori* knowledge of the objective space and ensures the population advancement towards convergence.

In this work, the network design methodology is based on well-known problem formulation for packet switched networks [2]. The aim is to decide the optimal set of links connecting the given nodes and the capacities of these links such that both the cost and the average packet delay are minimised. This algorithm ensures that the network is bi-connected and hence reliable and also that each link can sustain the traffic flow along it under peak load conditions. The technique also provides an optimal routing scheme based on a modification to the Single Source Shortest Path (SSSP) algorithm. The All Source Shortest Path (ASSP) can not be used as it would generate a routing scheme based on a spanning tree. This would mean that a number of links in the network would have no traffic through them and some links get too over burdened. Since link flows depend on the routing pattern, an adaptive routing strategy wherein if a link is already allocated to a certain route its delay is increased, is used.

3 Implementation and Results

We are currently working on simulation using Pareto Converging Genetic Algorithms [5]. Each chromosome in the population encodes (i) a possible topology for the network, including the link-capacities, details of the link types and the interface components, and (ii) a routing vector that gives the path between every pair of nodes for the topology represented by this individual. Selection is done through Pareto-ranking [4]. Individuals are ranked based on the objective functions for cost and time delay, while also considering the reliability and flow constraints.

We are unable to include the detailed results due to limitation on number of pages; the results shall be presented and analysed during the workshop.

4 Discussion and Conclusions

The outcome of the simulator is that we have a set of (near) optimal network topologies that are non-inferior with respect to each other. A network designer having a range for network cost and packet delay in mind can examine several topologies simultaneously and choose one based on his requirements and other engineering considerations. These topologies are reliable in case of single node failure and it is guaranteed that the maximum packet load on any link will not exceed the link capacity. Additionally, a routing scheme is developed for each of the networks.

Thus, in this paper, we have provided a framework for topological design of mesh communication networks using multiobjective genetic algorithms. We are currently testing the simulator with different sets of inputs and tuning the genetic algorithm parameters for getting the (near-) optimal sets of solutions with minimal computational efforts. We shall then analyse the solutions so obtained with those obtained with conventional approaches. The simulation can also be extended to develop an enhanced scheme for routing.

References

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