Challenges for Constraint Programming in Networking

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Abstract. In this talk we present a number of problems for network design, planning and analysis and show how they can be addressed with different hybrid CP solutions. Clearly, this problem domain is of huge practical importance, but it also provides us with interesting, complex problem structures. CP directly competes with MILP and local search approaches to these problems, with best results often obtained by a combination of different solution techniques. Teams at Parc Technologies and IC-Parc have been working in this field over the last years, with a number of applications now embedded in commercial products.

1 Introduction

In recent years computer networks have become ubiquitous, they are now part of everyday life. This has caused a rapid growth in traffic volume, but has also increased our dependency on their undisturbed operation. The current move toward 'converged' networks, which combine both connection-less (Internet) and connection-based (voice, video) traffic in a single IP network environment, increases the demand for reliable but cost-effective network services. Constraint programming can help to provide software tools for various aspects of network design and operations. In this talk we show five areas where constraint techniques are already used, most often in the form of hybrid solvers, combining constraints with LP or local search methods.

2 Network Design

In its simplest form, network design consists in selecting a capacitated topology of nodes and links which can transport predicted demands between customers. Links typically can only be chosen between certain locations and from few, predefined capacity types. The objective is to minimize investment cost, while allowing enough spare capacity for robust operation. Different solution approaches were

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compared in [1], and a branch and price scheme was presented in [2]. But the design problem has many variations, for example allowing multi-cast traffic [3], while optical network design may use a very different model [4].

3 Traffic Engineering

Traditionally, IP networks relied on destination-based routing to forward packets using routing protocols like OSPF. In this approach the shortest path (wrt link weights) between source and destination is used to transport packets. This can lead to bottlenecks in the network when multiple shortest paths use the same link. Traffic engineering(TE) tries to overcome this problem by permitting explicit paths for each source and destination pair. Choosing these paths taking connectivity and capacity constraints into account allows to spread the traffic over the whole network, removing bottlenecks in utilization. There are three main models for expressing TE problems:

- *Link based models* use 0/1 integer variables to express whether a demand is routed over a link or not. The model grows cubically with the network size, which makes a direct MILP solution impractical for large networks.
- *Path based models* choose some of the possible paths for each demand and select a combination of the possible paths which satisfies the capacity constraints. This approach lends itself to a column generation method with a branch and price scheme to generate new paths on demand as used in [2].
- *Node based models* use a decision variable for each node and demand, which indicates the next-hop for the demand. This model can be expressed with traditional finite domain constraints [5].

In recent years, many different techniques have been proposed to solve these problems. Hybrid models using constraints include Lagrangian relaxation [6, 7], local probing [8, 9], probe backtracking [10] and local search hybrids [11]. A decomposition method was introduced by [12].

4 Deducing the Demand Matrix

The models for traffic engineering and network design all rely on an accurate *demand matrix*, which describes the traffic size between nodes in the network. This matrix is surprisingly difficult to obtain. In traditional, connection-based networks this data is readily available by design, but IP networks typically only collect aggregate link traffic counters. The task is complicated by the fact that counter collection may be incomplete and inconsistent. Deducing the traffic matrix from link counters is the problem of traffic estimation [13], which can be seen as a constraint problem with incomplete and incorrect data [14, 15].

5 Network Resilience

The failure of a single network element (link, router) should have minimal impact on the operation of the network. Depending on the network technology used, we can provide different solutions for improved network resilience:

- In destination-based routed networks, we can predict the utilization of the network under element failure based only on current link traffic counters. This is achieved by a combination of bounds reasoning with a linear traffic model [16].
- In MPLS networks, it is possible to automatically reroute important traffic around an element failure, a technique called *fast re-route*. Parc Technologies has provided a solution for Cisco's *TunnelBuilder Pro* to automatically find such detours. This problem is related to the traffic bypass problem described in [17].
- For traffic engineered networks, we can provide secondary paths, which are node or link disjoint from the primary paths chosen. We can use these secondaries if one of the elements on the primary path fails. Depending on the capacity constraints used, this can lead to very challenging models.

6 Bandwidth-on-Demand

Traffic engineering considers the impact of a set of demands on the current network, all demands are active at the same time. We can generalize this concept where demands have fixed start and end times, and compete for resources only if they overlap in time. This is the problem of *Bandwidth-on-Demand*, where customers can reserve network capacity for future time periods, for example a video conference between multiple sites with guaranteed throughput and quality of service. The model of [5] extends to this case, an alternative, repair-based model for this problem has been proposed in [18, 19] in the context of an ATM network.

Parc Technologies and IC-Parc have developed a Bandwidth-on-Demand (BoD) system for Schlumberger's *dexa.net*, a global MPLS network providing services in the oil-field sector. This network combines traffic engineering, multiple classes of service and rate limiting at the ingress points to guarantee delivery of BoD requests without disrupting existing traffic.

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