Poster ResCom: Backbone Network Design With Capacity-dependant Costs

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***Abstract*—We address the problem of designing at minimum cost a backbone network. This problem finds its motivation in the rapidly developing field of telecommunication networks and the introduction of fiber-optic technology. A novel model for backbone design is proposed in this paper. Our model is based both on original ideas and on improvements of the existing ones. It considers the Steiner node's concept, modular capacities, survivability and delay constraints. The novelty of our model is that it integrates dimensioning of the communication links and equipment costs in the early stages of the design process.**

***Index Terms*—Backbone Network Design, Capacity-dependant Model.**

I. Introduction

In a world where information technologies (IT) are becoming pervasive, communication networks appear more and more as strategic resources. Near-optimal design of these networks is a critical issue since network design greatly affects the long-term network performance and determines most of the investment cost. Since this investment cost is typically huge and the return on investement cannot be expected before years, it is crucial to ensure that it is properly minimized.

Design of Wide Area Networks (WANs) is usually partitioned into two sub-problems: the access network design and the backbone network design. In the access problem, one must determine how to connect the terminals to the access sites so that the total network cost is minimized. The backbone design problem deals with finding a backbone network, interconnecting the access nodes, with minimal total cost. This paper addresses the problem of backbone design. This problem has been widely studied and several design models have been proposed.

Some design models involve what is commonly called "Steiner Nodes" (see e.g., [3]). A Steiner node is an optional backbone node which may be use to reduce the backbone cost. The survivability constraint has also been widely considered while building the backbone network topology. The term "survivability" means the ability of the network to provide protection against links or nodes failure. This restriction is often expressed in terms of network connectivity and the most studied models in the literature deal with bi-connected topologies.

Some works such as [1] and [2] consider that the bi-connectivity restriction is insufficient to have a performant backbone network. They consider an additional constraint on path length of the backbone graph. Fortz et al. introduce in [1] a new model to the problem of network design they called *two-connected network with bounded meshes problem.* In this model the authors propose that, in an instance of the backbone design problem, every node must be on a cycle whose length is bounded by a given constant K. Constraints involving distance conditions are also considered by D. Huygens et al in [2] who introduced what they called *design of survivable networks with bounded-length paths.*

Models introduced in the works mentioned above, are capacity-independent and deal only with topological aspects, that is, they see a network as a set of nodes and links. The only costs considered are costs associated with the length of networks links. In these models, the capacity-planning problem, i.e., the dimensioning of the communication links connecting the different sites and the equipments (routers, line cards) to be settled in these sites, is separated from the design process. The rationale for the separation between topological design and equipment dimensioning is that the former incurs capacity-independent "fixed" costs which are several orders of magnitude larger than the equipment costs. These " fixed" costs typically represent the costs of digging trenches for optic fibers, site opening costs, or even equipment installation and configuration costs. As a consequence, it is frequently assumed that link costs are independent of the type of communication line that will effectively be installed and that other equipment costs (routers, communication cards) can be neglected in this first design phase. However, with the massive deployment of optic fiber in all western countries, the cost of leasing transmission lines becomes cheaper and cheaper. Equipment costs are now a significant fraction of the total cost when designing a network. There is therefore an increasing need for an integrated approach of network design problems taking into account dimensioning of the communication links and equipment costs in the early stages of the design process.

Our current work presents a novel model for backbone networks design problem. Our model integrates dimensioning of the communication links and equipment costs in the early stages of the design process; it also considers the Steiner node's concept, modular capacities and survivability and delay constraints.

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II. Our Model Description

We present in this section the optimization problem that models the backbone network design. We use the following notations and assumptions.

- Let A be the set of access routers installed in the access sites,
- Let W be the set of intermediate transit nodes (Steiner nodes). Steiner nodes represent backbone routers. They could be installed either in the access sites or in the backbone sites.
- Let T be the number of link/port models and r_t be the bandwidth of the link/port model $t = 1, ..., T$.
- Let F be the set of possible connections (u, v) between nodes $u, v \in A \cup W$.

The backbone design problem can be stated as follows. How to interconnect the access routers of A with a minimal cost such that at least one path between each pair of access routers exists, even after a single link or node failure; the number of hops of this path must be less than or equal to a given threshold value K. Since statistical studies have revealed that the probability of dealing with two simultaneous failures is very low, we assume in our model that two failures cannot occur simultaneously.

The set Φ of feasible solutions contains the graphs $G = (V, E)$ such that:

- $A \subset V \subset A \cup W$,
- $E \subset F$,
- All access routers of A are in the same biconnected component of G.
- $\max_{x \in V \cup E}[d_{u,v}(G), d_{u,v}(G_x)] \le K$.

where G_x, $x \in V \cup E$, is the graph obtained by removing the element x from the graph G (x could be either a link or a vertex), $d_{u,v}(G)$ denotes the length of the shortest paths in G between the access routers $u, v \in A$, and $K > 0$ is a given integer.

The total cost of the backbone network induced by G is given by,

$$\Gamma(G) = \sum_{e \in E} f(t(y_e), d_e) \; + \; \sum_{v \in V} \mu^*([p_v^t]_{t \in T}) \qquad (1)$$

In this equation, $f(t(y_e), d_e)$ is the cost of link $e \in E$, d_e denotes the length of link e, y_e is the traffic flow on link e and $t(y_e)$ is the link model required on link e to support the traffic y_e. The value of y_e is calculated as follows,

$$y_e = \max[y_e(G), \max_{x \in V \cup E} y_e(G_x)] \qquad (2)$$

where $y_e(G)$ is the traffic flow on link e in the backbone network induced by the graph G. We assume that the traffic is routed along shortest paths, splitting flows at nodes where several outgoing links are on shortest paths to the destination.

In equation (1), $\mu^*([p_v^t]_{t \in T})$ expresses the cost of node $v \in V$. This cost is equal to the cost of equipments (routers and cards) to be settled at that node. In this expression, p_v^t is the number of cards of type t required on node $v \in V$ to connect to other nodes. Furthermore, μ^* is a function which returns the optimal cost of equipments to be settled at node $v \in V$. μ^* input is a vector of the form $p_v = [p_v^1, ..., p_v^T]$; such a vector is called a card configuration. The function μ^* can efficiently be calculated before-hand using a dynamic-programming algorithm (see [4]).

The backbone design problem can be written as

Minimize $\Gamma(G)$

With $G = (E, V) \in \Phi$ and

$$\Gamma(G) = \sum_{e \in E} f(t(y_e), d_e) + \sum_{v \in V} \mu^*([p_v^t]_{t \in T}) \qquad (3)$$

Subject to :

$$r_{t(y_e)} \ge y_e \quad \forall e \in E$$

III. Conclusion

The main goal of this paper was to introduce a comprehensive backbone design model. The model is new in the sense that it integrates dimensioning of the communication links and equipment costs in the early stages of the design process. It is comprehensive in the sense that it includes real operational constraints. There is still some work to be done on this problem. Different heuristic approaches could be used to put in practice our model. Furthermore, as is always the case with novel design models such as that we introduce in this paper, there is the nagging question of the usefullness of over model overs those introduced in the literature.

References

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