行政院國家科學委員會專題研究計畫　成果報告

隨機數位網路上最佳路徑選擇之研究(I)

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行政院國家科學委員會專題研究計畫成果報告
隨機數位網路上最佳路徑選擇之研究(I)
Optimal Path Selection on Stochastic Networks

計畫編號：NSC 94-2213-E-004-003
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Abstract. We propose a precomputation-based scheme which offers a Pareto optimal solution to the network optimization problem. This scheme is performed by means of a two-phase procedure. The first phase precomputes paths for a wide range of possible constraints, while the second phase just needs to select a adequate path through a simple procedure. That is, the first phase prepares a database which enables to identify a suitable path upon each connection request through the second phase. We propose a bandwidth allocation model with nonlinear utility functions. The objective of the problem is to provide a proportionally fair treatment of all the competing classes. We also study fairness in allocating bandwidth for modern communication networks.

Keywords: Bandwidth Allocation, QoS Routing,

1 Introduction

We consider the operational processes involved in the efficient set-up and usage of a network. The three main components of these processes are designing which links to develop to meet certain connectivity requirements, determining how much capacity to put on the links to serve all traffic demands, and choosing which paths to use for the various traffic streams to meet demand without violating capacity restrictions on links.

In this report, we focus on the precomputation perspective of QoS routing [8]. We deal with the problem of dimensioning bandwidth for elastic data applications in packet-switched communication networks, which can be considered as a multiple-objective optimization model. We focus on allocating resources with proportional fairness and finding a routing scheme on All-IP communication networks. We present an approach for the fair resource allocation problem and QoS routing in All-IP networks that offer multiple services to users. The basic function of QoS routing [2] is to select a path that is likely to be able to meet the QoS requirements. Users' satisfaction is summarized by means of their achievement functions, and each user is allowed to request more than one type of service. The objective of the optimization problem is to determine the amount of required bandwidth for each class to maximize the sum of the users' satisfaction.

2 Bandwidth Allocation Policies

Consider a directed network topology $G = (V, E)$, where V and E denote the set of nodes and the set of links in the network respectively. There are m (different) QoS classes in this network. Given the maximal possible capacity U_e of each link $e \in E$. Suppose, for each link e, the cost consists of delay d_e and the purchasing cost κ_e of bandwidth. In this network, there are m different classes which have their own QoS requirement. In each class i, every connection is allocated the same bandwidth θ_i and has the same QoS requirement. Suppose each connection is delivered between the same source o and destination d in this (core) network. Under a limited available budget B, we want to allocate the bandwidth in order to provide each class with maximal possible QoS.

Kelly et al. [3] advocated proportional fairness characterized by $\log(\theta_i)$. This log utility function is strictly concave. The proportional fair bandwidth allocation is determined by the following objective function:

$$\text{Maximize} \qquad \sum_{i\in I} K_i \log(K_i\theta_i). \tag{1}$$

Determining the maximizer of (1) can be done explicitly for simple networks.

In [6], an allocation policy called minimum potential delay is proposed with utility functions (2). The minimal potential delay allocation is characterized as the following objective function:

$$\text{Maximize} \qquad \sum_{i\in I} -\frac{K_i}{\theta_i}. \tag{2}$$

For any given number α ($\alpha > 0$, $\alpha \neq 1$), the class of (w, α)- proportionally fair bandwidth allocation [7] is characterized as the following objective function:

$$\text{Maximize} \qquad \sum_{i\in I} w_i K_i^{\alpha} \frac{(K_i\theta_i)^{1-\alpha}}{1-\alpha}, \tag{3}$$

where w_i, $i \in I$, are fixed parameters.

3 A Precomputation Scheme for Network Optimization

First, we transform the different measurements onto a normalized scale by using the concept of achievement functions [4]. Depending on the specified aspiration and reservation levels, a_i and r_i, respectively, we construct our achievement function of θ_i as follows [5]:

$$f_i(\theta_i) = \log_{\alpha_i} \frac{\theta_i}{r_i}, \quad \text{where } \alpha_i = \frac{a_i}{r_i}. \tag{4}$$

When using the achievement function (4) interpreted as a measure of QoS on All-IP networks, we can formulate the mathematical model of the fair bandwidth allocation.

$$\text{Max} \qquad \sum_{i=1}^{m} w_i f_i(\theta_i) \tag{5}$$

$$\text{s. t.} \qquad \sum_{e\in E}\sum_{i=1}^{m}\sum_{j=1}^{K_i} \kappa_e A_{i,j}(e) \le B \tag{6}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{K_i} A_{i,j}(e) \le U_e \tag{7}$$

$$A_{i,j}(e) - M\cdot\chi_{i,j}(e) \le 0 \tag{8}$$

$$\theta_i - A_{i,j}(e) \le M(1-\chi_{i,j}(e)) \tag{9}$$

$$A_{i,j}(e) - \theta_i \le M(1-\chi_{i,j}(e)) \tag{10}$$

$$\theta_i \ge b_i \tag{11}$$

$$\sum_{e\in E_o} A_{i,j}(e) = \theta_i \tag{12}$$

$$\sum_{e\in E_\nu^{in}} A_{i,j}(e) = \sum_{e\in E_\nu^{out}} A_{i,j}(e) \tag{13}$$

$$\sum_{e\in E_d} A_{i,j}(e) = \theta_i \tag{14}$$

$$A_{i,j}(e) \ge 0 \tag{15}$$

$$\theta_i \ge 0 \tag{16}$$

$$\chi_{i,j}(e) = 0 \text{ or } 1 \tag{17}$$

where $w_i \in (0,1)$ is given for each class i and $\sum_{i=1}^{m} w_i = 1$.

We have the budget constraint (6) due to the limited budget on network planning. The constraint (7) says that the aggregate bandwidth of all connections at any link does not exceed the capacity. Constraints (9), (10), and (11) show that every connection in the same class uses the same bandwidth and has the same bandwidth requirement. Constraints (12), (13), and (14) express the node conservation relations indicating that flow in equals flow out for every connection j in class i. Although $A_{i,j}(e)$ are continuous variables, constraints (12)-(14) are standard flow conservation constraints with the help of constraints (8)-(10). Continuous decision variables and binary variables must be nonnegative in constraints (15)-(17). From the optimization of this precomputation scheme (the first phase), we have the pareto optimal bandwidth allocation and a routing database. Next, using the output of the first phase, we will formulate a routing scheme with end-to-end QoS guarantees (the second phase).

4 Model Solutions

Using the mathematical model, given a limited available budget B, we can get the optimal solutions $A^*_{i,j}(e)$ and θ^*_i which represent the optimal bandwidth allocation for each link e and for each connection of class i. We find the bandwidths $K_i\theta^*_i$ allocated to each class i. Moreover, we also attain the maximal bandwidth $R_{i,e}$ which the link e can offer for class i. That is,

$$R_{i,e} = \sum_{j=1}^{K_i} A^*_{i,j}(e). \tag{18}$$

Bandwidth are allocated along less expensive paths that connect the origin o and the destination d. After the optimization of the above precomputation scheme, we can obtain the optimal path p from the source o to the destination d. The optimal path p may not be unique. Let P denote the set of all optimal paths, the routing database, obtained from the execution of the first phase. That is, $P = \{p | p \text{ is the optimal path from } o \text{ to } d\}$. The set P includes the inexpensive routes from the source to the destination on the network.

If, for each class i, the bandwidth allocated to each optimal path p is $\theta_{i,p} \geq 0$, then

$$\sum_{p\in P} \theta_{i,p} = K_i\theta^*_i \tag{19}$$

and

$$0 \leq \sum_{i=1}^{m} \theta_{i,p} \leq \min_{e\in p} U_e. \tag{20}$$

A link e is called bottleneck link if the right equality holds in (20).

5 A Routing Scheme with End-to-End QoS Guarantees

From the optimization in the first phase, we have a network $G = (V, E')$, where V is the original set of nodes and E' is the subset of links used for each end-to-end path $p \in P$. In each class i, a connection should be routed through some path p between the source and destination nodes. We shall denote by $n(p)$ the number of links of a path p. When a connection of class i is routed over a path p with a bandwidth θ^*_i, the following end-to-end delay $D(p)$ applies [1]:

$$D(p) = \frac{n(p)\cdot\sigma_i}{\theta^*_i} + \sum_{e\in p} d_e. \tag{21}$$

A path p between o and d is feasible, for a connection of class i, if $D(p) \leq D_i$. A connection of class i is feasible if it has a feasible path.

For a path p, we denote by A_p the residual bandwidth of its bottleneck link, that is,

$$A_p = \min_{e\in p}(R_{i,e} - \theta^*_i). \tag{22}$$

The problem is to find an optimal path p that maximizes A_p from the routing database P (obtained by the first phase.) This routing scheme distributes the connection among the paths so as to avoid overloaded links.

For each class i, we give the following scheme (the second phase) of the routing with End-to-End QoS guarantees.

$$\begin{array}{ll} \text{maximize} & A_p \\ \text{subject to} & A_p \leq R_{i,e} - \theta^*_i, \ \ \forall e \in p \\ & D(p) \leq D_i \\ & p \in P. \end{array} \tag{23}$$

The optimization goals of this scheme is to enhance the performance of IP traffic while utilizing the bandwidth on All-IP networks economically. This QoS routing is to make more efficient use of bandwidth on the network.

6 Conclusions

We present an approach for the fair bandwidth allocation and QoS routing in All-IP networks. Our approach is performed by means of a two-phase procedure. The first phase is executed in advance and its purpose is to precompute solutions as a database for later usage. The second phase selects one of the solutions (precomputed at the first phase) by performing a few additional computations. The purpose of the second phase is to promptly provide an adequate solution when connections arrive. Users' utility functions are summarized by means of achievement functions. Using the bandwidth allocation model, we can find a Pareto optimal allocation of bandwidth on the network under a limited available budget, and this allocation can provide the so-called proportional fairness to every class. That is, this allocation can provide the similar satisfaction to each user in all classes.

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