行政院國家科學委員會專題研究計畫　成果報告

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行政院國家科學委員會專題研究計畫成果報告
數位網路上多重目標規劃的數學模式
Mathematical Models of Pareto Optimal Path Selection on All-IP Networks

計畫編號: **NSC 92-2219-E-004-004**
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1 Abstract

We present an approach for the fair resource allocation problem and QoS routing in All-IP networks that offer multiple services to users. The objective of the optimization problem is to determine the amount of required bandwidth for each link and each class to maximize the sum of the users' utility. In this work, we focus on approaches that, while allocating bandwidth, attempt to provide a proportionally fair treatment of all the competing classes. First, we will show that an achievement function can map different criteria subject to various utility onto a normalized scale. It may be interpreted as a measure of QoS (Quality of Service) on All-IP networks. Using the bandwidth allocation model, we can find a Pareto optimal allocation of bandwidth on the network under a limited available budget. This allocation can provide the so-called proportional fairness to every class, that is, this allocation can provide the similar satisfaction to each user. Next, we present a routing scheme under consideration of the delay. Such an optimal path provides the end-to-end QoS guarantees to each user. Finally, a numerical example is given to illustrate how to solve the fair resource allocation problem and how to modify the nonlinear parts.

(Keywords : multiple-objective problems, routing, achievement function, proportional fairness, delay, Pareto optimal, ordered weighted averaging method, fair bandwidth allocation)

中文摘要

面對通訊與資訊科技的大幅進步，通訊網路正在進行一個巨大的變革，要將電信網路與數據網路整合成一個單一的*All-IP*網路以支援所有網路應用服務。欲達到整合型網路的理想，仍有許多困難尚待克服，而服務品質問題是其中最關鍵的問題之一。因為受限於封包交換網路之原有的特性，*All-IP*網路有影響服務品質的三項因素：過長的延遲時間、抖動以及封包遺失。首先，我們利用了達成度函數*(achievement function)*來處理單位的轉換，使得能夠同時考量此三項不同單位的因素。接著，本文中提出一套方法來解決*All-IP*網路上端對端*(end-to-end)*的資源配置及路徑規劃問題。在分配資源時，我們企圖提供一種成比例的公平性給各個不同等級。此公平性的精神是要使得所有網路使用者的滿足程度相當，而非各個不同等級的使用者分配到相同的資源。我們將以預算方式控制端對端品質管理，以追求使用者之整體最大滿意程度。

(關鍵字:多重目標規劃問題、達成度函數、選徑、有序的加權平均法、公平的頻寬配置、延遲、比例性公平、柏雷托最適)

2 Introduction

Packet switched networks suffer three major quality problems in offering time-sensitive services: long delay time, jitter, packet loss. The Universal Mobile Telecommunications System (UMTS) [1] has specified

表格 1: UMTS Service Classes

Traffic Classes	Examples of Applications	Sensitivity to Jitter	Sensitivity to Delay	Sensitivity to Packet Loss
Conversational	VoIP	high	high	low
Streaming	VoD	high	high	low
Interactive	WWW, Telnet	low	low	high
Background	E-mail, FTP	very low	low	high

four different traffic classes according to their quality of service (QoS) requirements for different applications as Table 1 shows. Different people have different expectations to the network QoS. There are a number of characteristics that qualify QoS, including minimizing delivery delay, minimizing delay variations, providing consistent data throughput capacity.

QoS routing concerns the selection of a path satisfying the QoS requirements of a flow. The path selected most likely is not the traditional shortest path. Depending on the specifics and the number of QoS metrics involved, computation required for path selection can become prohibitively expensive as the network size grows. The path selection process involves the knowledge of the flow's QoS requirements and characteristics and (frequently changing) information on the availability of network resources (expressed in terms of standard metrics, e.g., available bandwidth and delay). Resource allocation decisions are concerned with the allocation of limited resources so as to achieve the best system performances.

In a multi-objective decision-making situation in the absence of uncertainty we often search for Pareto optimal solutions. One scheme for dealing with multi-objective models that permits more balanced handling of the objectives is simply to combine them in a weighted sum. Multiple objective functions can be combined into a single composite one to be maximized by summing objectives with positive weights on maximizing and negative weights on minimizing. If the composite is to be minimized, weights on maximizing objectives should be negative, and those on minimizing should be positive. Signs orient all objectives in the same direction, and weights reflect their relative importance. If a single weighted-sum objective model derived from a multi-objective optimization produces an optimal solution, the solution is an Pareto-optimal solution of the multi-objective model. In this work, we use the method of weighted sums to solve our problems.

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. In our work, we will focus on the following subjects: (i)How do we transform the different criteria measurement onto a normalized scale? (ii)How do we allocate resources with proportional fairness and find a routing scheme on All-IP communication networks? (iii)How do we modify the nonlinear multiple-objective problems as solvable Mixed-Integer programming models?

3 Achievement Function

In order to transform the different measurements onto a normalized scale, we construct the achievement function μ_i for each criteria i which can be viewed as an extension of the fuzzy membership function in terms of a strictly monotonic and concave utility function as shown in Figure 1. We assume that the decision maker specifies requirements in aspiration and reservation levels by introducing desired and required values for several outcomes. Depending on the specified aspiration and reservation levels, a_i and r_i, respectively, we construct our achievement function of z_i as follows:

$$\mu_i(z_i) = \log_\alpha \frac{z_i}{r_i}, \quad \text{where } \alpha = \frac{a_i}{r_i}. \tag{1}$$

Formally, we define $\mu_i(\cdot)$ over the range $[0, \infty)$, with $\mu_i(0) = -\infty$ and $\mu_i'(0) = \infty$. Depending on the specified reference levels, this achievement function can be interpreted as a measure of the decision maker's satisfaction with the value of the i-th criteria. It is a strictly increasing function of z_i, having value 1 if $z_i = a_i$, and value 0 if $z_i = r_i$. The achievement function can map the different criteria values onto a normalized scale of the decision maker's satisfaction. Moreover, the logarithmic achievement function will be intimately associated with the concept of proportional fairness (see [6] and [8]). We will formulate the mathematical model of the fair bandwidth allocation by using the achievement function.

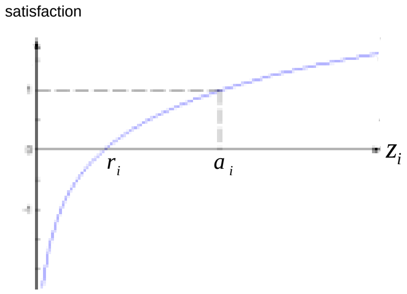

圖 1: The Graph of an Achievement Function $\mu_i(z_i)$

4 Formulation of the Bandwidth Allocation Model with Proportional Fairness

Given a network topology $G =< V, E >$, where V and E denote the set of nodes and the set of links in the network respectively. There is given a set S of m classes, i.e., $|S| = m$. We denote by S^i a set of sessions in class i. There is also given the maximal possible number K^i in each class i, that is $|S^i| = K^i$. We will get the following mathematical model (MP1):

$$
\begin{array}{ll}
\text{Maximize} & \displaystyle\sum_{i=1}^{m} w_i \psi_i \\
\text{Subject to} & \displaystyle\sum_{e \in E} \kappa_e x_e = B \\
& \displaystyle\sum_i \sum_j \chi_j^i(e) \theta_j^i = x_e, \ \forall e \in E \\
& \displaystyle\sum_i (K^i \cdot c^i + \pi^i) = B \\
& \theta_j^i \geq b^i, \ \forall j \in S^i, \ \text{for } i = 1, \ldots, m \\
& x_e \leq U_e, \ \forall e \in E \\
& \displaystyle\psi_i = i t_i - \sum_{k=1}^{m} d_{ki}, \ \forall i = 1, \ldots, m \\
& t_i - d_{ki} \leq f_k(\mathbf{x}), \ \forall i, \ k = 1, \ldots, m \\
& d_{ki} \geq 0, \ \forall i, \ k = 1, \ldots, m \\
& \displaystyle\theta_j^i \cdot \sum_e \kappa_e \chi_j^i(e) = c^i, \ \forall j \in S^i, \ \text{for } i = 1, \ldots, m \\
& \theta_1^i = \theta_2^i = \cdots = \theta_{K^i}^i, \ \forall i = 1, \ldots, m \\
& x_e \geq 0, \ \forall e \in E \\
& \theta_j^i \geq 0, \ \forall j \in S^i, \ \text{for } i = 1, \ldots, m \\
& \chi_j^i(e) = 0 \text{ or } 1, \ \forall e \in E, \\
& t_i \text{ unrestricted}, \ \forall i = 1, \ldots, m,
\end{array}
$$

where $w_m = \nu_m$, $w_i = \nu_i - \nu_{i+1}$ for $i = 1, \ldots, m-1$, $\nu_i \in (0, 1)$ is given for each i, and $\sum_{i=1}^{m} \nu_i = 1$. The individual function ψ_i is the first i sum of the ordered multiple objective functions ψ_i in the allocation pattern $\mathbf{x} = \{x_e \mid e \in E\}$ and the bandwidth θ^i allocated to class i. Here, we let K^i in (MP1) be a fixed number for the discussion under deterministic assumption of feasibility of (MP1). In general, K^i may be random which is beyond scope of the thesis.

5 Modifications of Nonlinear Parts

We rewrite (MP1) as the following model (MP2).

$$
\begin{array}{ll}
\text{Maximize} & \displaystyle\sum_{i=1}^{m} i w_i t_i - \sum_{i=1}^{m} \sum_{k=1}^{m} w_i d_{ki} \\
\text{subject to} & \displaystyle\sum_{e \in E} \kappa_e x_e = B \\
& \displaystyle\sum_i \sum_j A_j^i(e) = x_e, \ \forall e \in E \\
& \displaystyle\sum_i (K^i \cdot c^i + \pi^i) = B \\
& x_e \leq U_e, \ \forall e \in E \\
& d_{ki} \geq 0, \ \forall i, \ k = 1, \ldots, m \\
& -A_j^i(e) + b^i \leq M \cdot \chi_j^i(e), \ \forall e \in E, \\
& \forall j \in S^i, \ \text{for } i = 1, \ldots, m \\
& -A_j^i(e) \leq M \cdot (1 - \chi_j^i(e)), \\
& \forall e \in E, \ \forall j \in S^i, \ \text{for } i = 1, \ldots, m
\end{array}
$$

$$\begin{array}{l}
\sum_{e} \kappa_e A_j^i(e) = c^i,\ \forall j \in S^i,\ \text{for } i = 1,\ldots,m \\
t_i - d_{ki} \le z_1^i \hat{f}_i(0) + z_2^i \hat{f}_i(b_{i,1}) + z_3^i \hat{f}_i(1) \\
+z_4^i \hat{f}_i(b_{i,2}) + z_5^i \hat{f}_i(b_{i,3}) - z_6^i \hat{f}_i(10) - z_7^i \hat{f}_i(b_{i,4}) \\
-z_8^i \hat{f}_i(M_i),\ \forall i,\ k = 1,\ldots,m \\
\theta^i = z_2^i b_{i,1} + z_3^i + z_4^i b_{i,2} + z_5^i b_{i,3} + 10 z_6^i + z_7^i b_{i,4} \\
+z_8^i M_i,\ \text{for } i = 1,\ldots,m \\
z_1^i \le y_1^i,\ \text{for } i = 1,\ldots,m \\
z_k^i \le y_{k-1}^i + y_k^i,\ \forall k = 2,\ldots,7,\ i = 1,\ldots,m \\
z_8^i \le y_7^i,\ \text{for } i = 1,\ldots,m \\
\sum_{k=1}^{8} z_k^i = 1,\ \text{for } i = 1,\ldots,m \\
\sum_{k=1}^{7} y_k^i = 1,\ \text{for } i = 1,\ldots,m \\
y_k^i = 0 \text{ or } 1, \forall k = 1,2,\ldots,7,\ i = 1,\ldots,m \\
z_k^i \ge 0, \forall k = 1,2,\ldots,8,\ i = 1,\ldots,m \\
x_e \ge 0,\ \forall e \in E \\
\chi_j^i(e) = 0 \text{ or } 1,\ \forall e \in E,\ \forall j \in S^i, \\
\text{for } i = 1,\ldots,m \\
A_j^i(e) \ge 0,\ \forall e \in E,\ \forall j \in S^i,\ \text{for } i = 1,\ldots,m \\
t_i \text{ unrestricted}, \forall i = 1,\ldots,m,
\end{array}$$

where $w_m = \nu_m$, $w_i = \nu_i - \nu_{i+1}$ for $i = 1,\ldots,m-1$, $\nu_i \in (0,1)$ is given for each i, and $\sum_{i=1}^{m} \nu_i = 1$.

6 Conclusions

In this work, we present an approach for the fair resource allocation problem and QoS routing in All-IP networks that offer multiple services to users. Users' utility functions are summarized by means of achievement functions. First, we find that the achievement function can map different criteria onto a normalized scale. The achievement function also can work in the Ordered Weighted Averaging method. Moreover, it may be interpreted as a measure of QoS on All-IP networks. Using the bandwidth allocation model, we can find a Pareto optimal allocation $\mathbf{x}^*$ of bandwidth on the network under a limited available budget, and this allocation can provide the so-called proportional fairness to every class i. That is, this allocation can provide the similar satisfaction to each user in all classes. We also find the bandwidth allocated to each class i. Moreover, we obtain the maximal rate, which the link can offer to each class. Next, we present a routing scheme under considering the delay. This scheme aims at seeking a path for which the residual maximal rate (i.e., after establishing the new connection) of its bottleneck link is maximal. This optimal path provides the End-to-End QoS guarantees to each user.

參考書目

[1] "Enabling UMTS/Third Generation Services and Applications", *UMTS Forun Report* No.11, Oct., 2000.

[2] A. W. Berger, and Y. Kogan, "Dimensioning Bandwidth for Elastic Traffic in High-Speed Data Networks", *IEEE/ACM Transactions on Networking*, Vol. 8, No. 5, Oct. 2000.

[3] J. Gozdecki, A. Jajszczyk, and R. Stankiewicz, "Quality of Service Terminology in IP Networks", *IEEE Communications Magazine*, no. 3, pp. 153-159, Mar. 2003.

[4] P. V. Hentenryck, *ILOG OPL Studio 3.5: The Optimization Language*, Massachusetts Institute of Technology, April 2001.

[5] Y. N. Lien, H. C. Jang, T. C. Tsai, and H. Luh, "BBQ: A QoS Management Infrastructure for All-IP Networks", *Communications of Institute of Information and Computing Machinery: Mobile Communications and Wireless Networks*, Vol.7, No. 1, pp. 89-115, Mar. 2004.

[6] W. Ogryczak, T. Śliwiński and A. Wierzbicki, "Fair Resource Allocation Schemes and Network Dimensioning Problems", *Journal of Telecommunications and Information Technology*, pp. 34-42, 3/2003.

[7] A. Orda, "Routing with End-to-End QoS Guarantees in Broadband Networks", *IEEE/ACM Transactions on Networking*, Vol. 7, No. 3, June 1999.

[8] M. Pióro, G. Malicskó, and G. Fodor, "Optimal Link Capacity Dimensioning in Proportionally Fair Networks", *NETWORKING 2002*, LNCS 2345, pp.277-288, 2002.