行政院國家科學委員會專題研究計畫　成果報告

網路經濟與服務品質管理技術

計畫類別：個別型計畫
計畫編號：NSC93-2213-E-004-014-
執行期間：93 年 08 月 01 日至 94 年 07 月 31 日
執行單位：國立政治大學資訊科學系

計畫主持人：蔡子傑

計畫參與人員：蔡子傑,林建圻,林士發

報告類型：精簡報告
報告附件：出席國際會議研究心得報告及發表論文
處理方式：本計畫可公開查詢

中　華　民　國 94 年 10 月 28 日

行政院國家科學委員會補助專題研究計畫成果報告

※※※※※※※※※※※※※※※※※※※※※※※※※
※　　　　　　　　　　　　　　　　　　　　　　　　※
※　　　網路經濟與服務品質管理技術　　　※
※　　　　　　　　　　　　　　　　　　　　　　　　※
※※※※※※※※※※※※※※※※※※※※※※※※※

計畫類別：■個別型計畫　　□整合型計畫
計畫編號：NSC　93－2213－E－004－014－
執行期間：　93 年　08 月　01 日至　94 年　07 月　31 日

計畫主持人：　蔡子傑
共同主持人：　無

本成果報告包括以下應繳交之附件：
□赴國外出差或研習心得報告一份
□赴大陸地區出差或研習心得報告一份
■出席國際學術會議心得報告及發表之論文各一份
□國際合作研究計畫國外研究報告書一份

執行單位：國立政治大學　資訊科學系

中　華　民　國　94　年　10　月　28　日

行政院國家科學委員會專題研究計畫成果報告

網路經濟與服務品質管理技術

計畫編號：NSC 93-2213-E-004-014

執行期限：93 年 8 月 1 日至 94 年 7 月 31 日

主持人：蔡子傑　國立政治大學 資訊科學系

計畫參與人員：林建圻、林士發　國立政治大學 資訊科學系

此成果報告為論文"Pricing for Economic Efficiency in Wireless Ad Hoc Networks", submitted to 4th International Symposium on Modeling and Optimization in Mobile, Ad-hoc and Wireless Networks (WiOpt'06), Boston, Massachusetts, April 3-7, 2006. 另外計劃成果尚有一篇已發表之論文 "Economic-Oriented QoS Support on Differentiated Service Networks", in IEEE 7th International Conference on Advanced Communication Technology (ICACT 2005), Feb 21~23, 2005, Phoenix Park, Korea.Page(s):877 - 882. 礙於篇幅請參閱出席國際會議發表之論文。

一、Abstract

In wireless ad hoc networks, the collaboration is a fundamental challenge. The proposed pricing method providing incentives of packet relay, however, they did not consider fairness among multi-hop wireless flows. This paper uses economic theory to propose a pricing strategy which can provide incentives for packet forwarding in wireless ad hoc networks. Through simulation results, we show that our pricing strategy is very reasonable. In addition, economic efficiency is well established using our pricing strategy.

Keywords: multihop, ad hoc network, economic efficiency, pricing strategy

二、緣由與目的、結果與討論

1. Introduction

In a wireless ad hoc network, numerous stations are connected directly without a special access point. This mode is useful if an infrastructure of a wireless network is not formed, or can't not be formed due to some reasons [1]. In this network, a source communicate with far off destinations by using intermediate nodes as relays. However, there is no incentive for participants to relay packets for each other. Mobile users with a small computing device usually face limited resources, such as battery, CPU and memory. The forwarder incurs the real cost of battery energy expenditure and the opportunity cost of possible delay for its own data. They are likely to behave selfishly and decide to reject all relay requests, and hence paralyze the whole network [2].

Thus, the concept of introducing incentives for collaboration into the ad hoc networks is an important step. This leads us naturally to the use of pricing mechanisms which has long been an active research area in wireline networks. Example approaches such as dynamic pricing in [3] and [4], auction pricing in [5], Paris Metro Pricing in [6]. In general, a shadow price is associated with each wireline link. The network uses these prices as signals to users which reflect the traffic load on the links along their route, and users choose a transmission rate to optimize their utility. Compared with wireline networks where flows contend only at the router with other simultaneous flows through the same router, the unique characteristics of multi-hop wireless networks show that, flows also compete for shared channel bandwidth if they are within the transmission ranges of each other [7].

In this paper, we address these unique characteristics of wireless ad hoc networks. We propose a dynamic pricing strategy to achieve the economic efficiency. Economic efficiency is well established in pricing strategies to maximize customers' net benefit, provider's surplus and social welfare.[4]

The rest of this paper is organized as follows. Section 2 present related work. In Section 3, we give some background and concepts of Economics Efficiency. In Section 4 we discuss in detail the pricing strategies which can maximize social welfare. Finally we do a simulation and demonstrate that our pricing strategy is reasonable.

2. Related Work

The primary motive in pricing for ad hoc wireless networks is to stimulate participation, that is, to ensure that mobile nodes act as routers in forwarding data. Such a pricing framework should be decentralized, due to the absence of any perceivable supporting infrastructure [8].

The *packet purse* and *packet trade* models [9] introduce the concept of a virtual currency called *nuggets*, which can be exchanged for data forwarding. In *.Packet Purse model*, the source node of a packet loads the packet with a certain number of nuggets. At every intermediate node, the packet is forwarded if there is a non-zero nugget count in the pricing header of the packet, else the packet is dropped. Each forwarding node reduces the nugget count in the packet by one, and also increases its nugget count by one. Since the hop-count to the destination is unpredictable due to the mobility, it is likely that if the source loads fewer nuggets the packet is dropped, and if it loads an excess, than either the destination acquires them or the nuggets are dropped. The packet trade model does not suffer from the problems of the packet purse model where packets can get dropped due to insufficient nugget count in the packet, resulting in a loss of nuggets for the source node. These problems are solved in the *packet trade model* by introducing a buy-and-sell transfer model. Each intermediate node at a distance k hops from the source will sell the packet to the next hop for exactly k nuggets. It can be seen that each intermediate node will get exactly one nugget for the service rendered by it.

More recently, [10] introduces pricing-and-credit based incentives in the context of multihop flow control and analyzed the system dynamics. In [11], "pay for service" incentive model has been adopted. Depending on the network communication scenario, the market models are different. In this paper, the authors focus on providing *incentive* for packet forwarding in a two-hop hotspot network. The market structure in this network depends on the number of relaying nodes（RNs）, the communication among the RNs, and the reachability of the clients to the RNs. As a result, the authors classify the network into four different scenarios and propose different pricing mechanisms for them. In Sprite [12], a secure credit and payment system is proposed for MANET, where each node saves a "receipt" when it forwards a packet, and later sends the receipts in a bulk to a central credit clearance service, such as bank, to clear the funds between the sender and the nodes. In summary, a secure payment and accounting system solves the problem of *how to pay* for packet forwarding service in MANET. In iPASS [13], which focus on *how much to pay*, an auction-based incentive scheme is used to enable cooperative packet forwarding behavior in MANET. This paper uses economic theory to propose a pricing strategy which can provide incentives for packet forwarding in wireless ad hoc networks. We solve not only the problem how much to pay, but achieve the economic efficiency. Our pricing strategy also can combine either *packet purse* or *packet trade* models easily to form a complete solution in creating incentive in a public MANET.

3. Economics Efficiency

An innovative pricing concept has come to our attentions that promise to significantly improve economic efficiency such as customers' surplus, provider's surplus and social welfare maximization. We use economic theory to analyze the relationship between demand and supply in ad hoc network to perform effective network resource allocation and meet customer's application requirements. Theorems of economics can guarantee that demand and supply control dynamically moves the system to an equilibrant point where resources are used efficiently.

A .The Customer's Problem

Utility is actually an abstract concept rather than a concrete. Utility means the aggregate sum of satisfaction or benefit a consumer gains from consuming a given amount of goods or services in an economy. Although utility usually increases as more of a good is consumed, marginal utility usually decreases with each additional increase in the consumption of a good. This decrease demonstrates the law of diminishing marginal utility.

If the customer has a utility u(x) for a quantity x of a service, and u(x) is increasing and concave. Given the price vector p, the consumer chooses to purchase the amount x=x(p) that maximizes his net benefit. Note that at x=x(p) we have $\delta u(x)/\delta x = p$.

We can think of u(x) as the amount of money customer is willing to pay in pursuit of products and px means the money customer actually pays. The expression that is maximized is called the customer's net benefit or consumer surplus. It presents the net benefit the consumer obtains as the utility of x minus the amount paid for x.

$$CS = \sum_{i=1}^{N} [u_i(x^i) - p^i x^i] \qquad (1)$$

B .The Supplier's Problem

Profit, or producer surplus, is the difference between the revenue that is obtained form selling these services, say r(y), and the cost of production, say c(y), Denote $y=(y_1,\ldots,y_k)$ the vector of quantities of these services. We know that r(y) exactly equals the money customer actually pays. An independent firm having marvelous profit seeks to solve the problem of maximizing the profit.

$$PS = \sum_{i=1}^{k} [r(y_i) - c(y_i)] \qquad (2)$$

An important simplification of the problem takes place in the case of linear prices, when $r(y)=p^T y$ for some price vector p. Then the profit is imply a function of p, say PS(p), as is also the optimizing y, say y(p). Here y(p) is called the supply function, since it gives the quantities of the various services that the supplier will produce if the prices at which they can be sold is p.

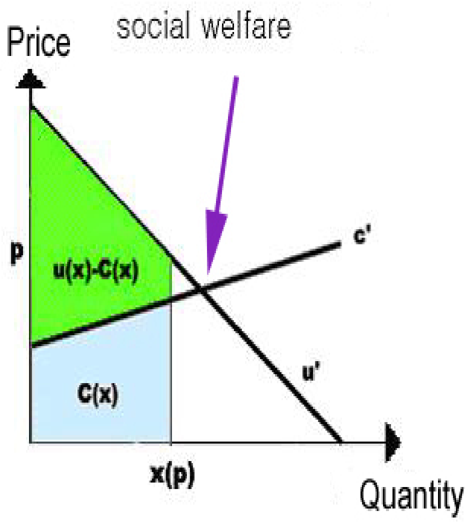


Fig.3. Social Welfare

C .Welfare Maximization

Social welfare (social surplus) is defined as the sum of all consumer and producer surpluses. We speak interchangeably of the goals of social welfare maximization, social surplus maximization, or economic efficiency. The key idea is that, under certain assumptions about concavity and convexity of utility and cost functions. Social welfare should be maximized by setting an appropriate price and allowing producers and consumers to choose their optimal level of production and consumption. This has the great advantage of maximizing social welfare in decentralized way. Suppliers and consumers see these prices and then optimally choose their level of production and demand. They do this on the basis of information they know. A supplier sets his level of production knowing only his own cost function. The Fig.3 shows that a simple illustration of the social welfare maximization problem for a single good. The maximum is achieved at the point where the customer's aggregate demand curve u' intersects the marginal cost curve c'.

$$S = CS + PS = \sum_{i=1}^{N} u_i(x^i) - c(x) \qquad (3)$$

We have the remarkable result that the social planner can maximize social surplus by setting an appropriate price vector p, In practice, it can be easier for him to control the dual variable p, rather than to control the primal variable $x_1,\ldots, x_n$. This price control both production and consumption. Among this price vector, the consumers maximize their surpluses and producer maximizes his profit. Moreover, prices equal the supplier's marginal cost and each consumer's marginal utility at the solution point, we call that price marginal cost prices. Through social welfare in economics, we design a hybrid pricing method to accomplish commercially efficient resource allocations in ad hoc network.

4. Pricing Strategy

To introduce our pricing strategies, we have several main parts to stress. We will introduce utility functions for customers and cost function for provider to construct our pricing models. Our mechanism changes the price for personal customers in reaction to instantaneous network congestion conditions.

A. Utility Function

Utility function is strictly increasing and strictly concave, so we define utility function like below.

$$u(x_i) = x_i^a - D, \quad 0 < a < 1 \qquad (4)$$

where x_i is the bandwidth allocate to user i, D means average delay personally. We assume the average delay time is 0.06 second. We take the exponent as 0.6 (a = 0.6), we would proof our pricing strategies feasible in economics. In this case, we can generate utility functions of users is $U= x^{0.6}-0.006$.

B. Cost Function

The cost function we want to find are concerned with the effects of congestion and pricing that take congestion into account. Because users share a common network resource such as bandwidth, we model cost function by supposing that user i has a net benefit that depends on the amount service demanded by other users.

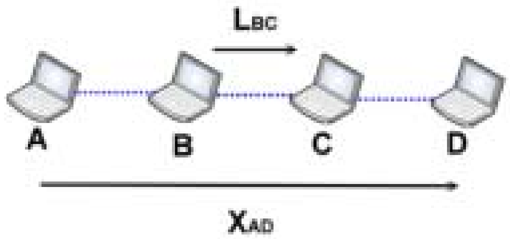
$$C(x_i) = \frac{x_i}{1-y} \qquad (5)$$

where $y=\Sigma_i x_i / k$, and k is the resource capacity of the system. In multi-hop wireless ad hoc networks, flows that traverse the same geographical vicinity contend for the same wireless channel capacity. So k will change with time whether the ad hoc network topology or the number of users is different.

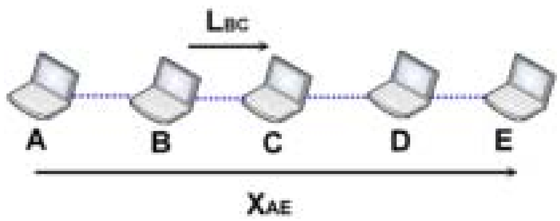
The definition of the load $y=\Sigma_i x_i / k$ is natural for a single link network in which xi is an average flow and k is the bandwidth of the link. In the principle, congestion measures, such as delay and packet loss, can be directly determined given the statistics of the traffic and service discipline of the link. Our cost function is powerful and useful for more general situations, in which we desire to price dynamic parameters of the contract and yearn to find the rules to avoid the occurrence of congestion. Here, D(y)xi is a congestion cost.

5. Simulation Results

Here we conduct simulations to evaluate our pricing strategies. We perform our simulations using QualNet simulator. In our simulation, the channel capacity of wireless networks are 11Mbps. We proceed to show a detailed comparison between the two types of networks using chain topologies, on which the flows with different characters of hops are sharing the resources. As shown in Fig. 4(A) and (B), L_{BC} means the loading of traffic from node B to node C. X_{AD} is the equilibrium bandwidth between node A and node D, X_{AD} is the equilibrium bandwidth between node A and node E.



(A)3-hop chain topology



(B)4-hop chain topology

Fig.4. Simulation topology

Figure.4. shows the simulation results. It is obviously that node A should pay more money to transmit data when the route is across more hops. As L_{BC} increasing from 0% to 80%, the total bandwidth between node A and node D (and E) will drop dramatically because of the location dependent characteristics. The variable k in function (5) decreases results in price increases. The more hops cross, the price will increase more dramatically. It is very reasonable because the price should shared by all intermediate nodes. Using our pricing strategy, every node has incentive to forward packets for each other. We have presented a simple but effective approach to stimulate forwarding incentives in ad hoc network. We will still investigate and incorporate routing support for wireless multihop networks in future.

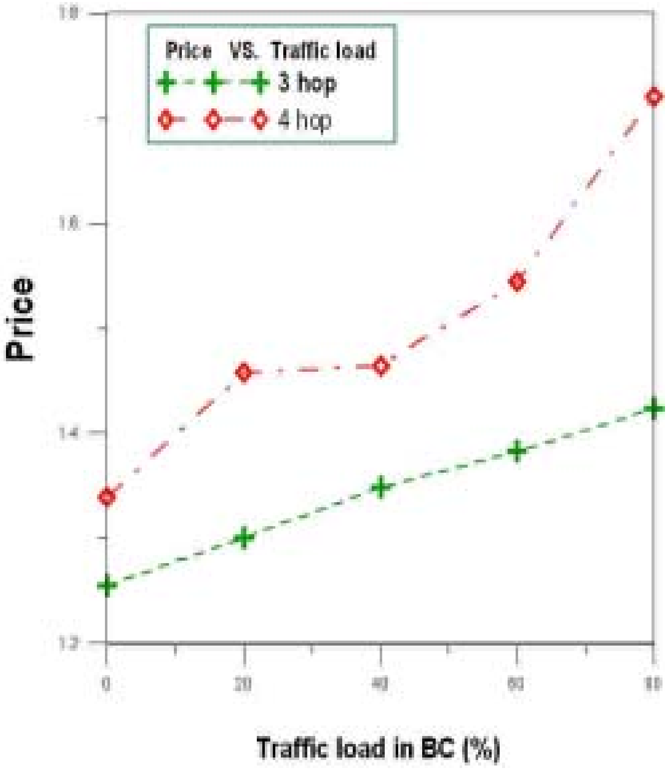


Fig.5. Equilibrium Price

References

[1] Stallings, W, *Data and Computer Communications*, Six Edition, Prentice Hall, 2000

[2] Kai Chen, Klara Nahrstedt, “iPass: an Incentive Compatible Auction Scheme to Enable Packet Forwarding Service in MANET”, in *Proc. of 24th IEEE International Conference on Distributed Computing Systems (ICDCS 2004)*, Tokyo, Japan, March, 2004.

[3] Tianshu Li, Youssef Iraqi, and Raouf Boutaba, “Pricing and admission control for QoS-enabled Internet”, Computer Networks: The International Journal of Computer and Telecommunications Networking, v.46 n.1, p.87-110, 16 September 2004.

[4] Tzu-Chieh Tsai, and Shih-Fa Lin, "Economic-Oriented QoS Support on Differentiated Service Networks", IEEE 7th International Conference on Advanced Communication Technology (ICACT 2005), Feb 21~23, 2005, Phoenix Park, Korea.

[5] Weilai Yang, Henry Owen, Douglas M. Blough, and Yongpei Guant, “An Auction Pricing Strategy for Differentiated Service Networks”, Globecom 2003, San Francisco, December 2003.

[6] A. Odlyzko, “Paris Metro Pricing for the Internet”, ACM Conference on Electronic Commerce, 1998.

[7] Yuan Xue, Baochun Li, and Klara Nahrstedt,” Price-based Resource Allocation in Wireless Ad hoc Networks”, in *Proc. of Eleventh International Workshop on Quality of Service (IWQoS 2003)*, Monterey, California, June, 2003.

[8] C. Siva Ram Murthy, B.S. Manoj ,”Ad Hoc

Wireless Networks: Architectures and protocols”, Prentice Hall, May 2004
[9] L. Buttyan and J. P. Hubaux, “Enforcing Service Availability in Mobile Ad Hoc WANs,” ACM MOBIHOC 2000, pp. 87-96, August 2000.
[10] J. Crowcroft, R. Gibbens, F. Kelly, and S. Östring, “Modeling incentives for collaboration in mobile ad hoc networks,” in *Performance Evaluation*, vol. 57, 2004, pp. 427–439.
[11] Kai Chen, Zhenyu Yang, Christian Wagener, Klara Nahrstedt, “Market Models and Pricing Mechanisms in a Multihop Wireless Hotspot Network”, ACM MobiQuitous Conference 2005.
[12] S. Zhong, J. Chen, and Y. Yang. Sprite: A simple, cheatproof, credit-based system for mobile ad hoc networks. In *Proc. 22nd Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2003)*, San Francisco, California, USA, March-April 2003.
[13] Kai Chen, Klara Nahrstedt, iPass: an Incentive Compatible Auction Scheme to Enable Packet Forwarding Service in MANET, in *Proc. of 24th IEEE International Conference on Distributed Computing Systems (ICDCS 2004)*, Tokyo, Japan, March, 2004.

三、計畫成果自評

本計畫為蔡子傑教授在研究網路服務品質方面的先導研究。利用經濟理論的量價關係，提出完善的定價策略以達成所謂的 social welfare。這兼顧到網路資源提供者(ISP)追求最大盈收與顧客追求最大滿足取得平衡。我們在定價策略與顧客的滿意度方面，曾與本校經濟系王國樑教授等請益過。我們認為未來的網路服務是分級的，分級收費也是必然的，如何達到一個合理的網路定價與服務品質保證是網路經濟行為這個跨領域研究的重要的議題。
另外近年來,ad hoc network 與 mesh network 大受關注,要成為商業用途,定價策略就顯德相當重要,除以 ISP 自行定價外,兼顧到使用者意願與社會最大利益的定價策略更顯公平合理。這就是這篇報告最大的貢獻之一。