Optimizing Fast Handover for Mobile IPv6 with Dynamic Price

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***Abstract*— Fast Handover for Mobile IPv6 (FMIPv6) reduces the handover latency and packet loss during handover procedure by using tunneling and buffering mechanisms. However, when the arrival rate of fast handover sessions is high, the request for buffer and tunneling bandwidth may cause network congestion and performance degradation. Some fast handover sessions have to be dropped, hence the service quality and user's satisfaction degree is decreased. In our paper, an extension to FMIPv6 is proposed to avoid the congestion and service degradation, in which dynamic pricing strategy is applied.**

I. Introduction

With the rapidly deployment of wireless networks, supporting the mobility of the mobile device among different networks has become an important issue. Mobile IPv6 [1] is such a mobility management protocol that enables a Mobile Node (MN) to maintain its connectivity to the Internet while moving from one Access Router (AR) to another. This process is referred to as handover. During handover, there is a period during which the MN is unable to send or receive packets because of link switching delay and IP protocol operations. The handover latency and packet loss resulting from standard Mobile IPv6 procedures, namely movement detection, new Care of Address (CoA) configuration, and Binding Update, are often unacceptable to real-time traffic such as Voice over IP. Reducing the handover latency could be beneficial to non-realtime and throughput-sensitive applications as well. Many mechanisms have been proposed to optimize the handover process with regard to reducing packet loss and handover delay. Fast Handover for Mobile IPv6 (FMIPv6) [2] is such an important mechanism being standardized by IETF and has been applied into 802.11 [3] and 802.16e networks.

FMIPv6 reduces the handover latency involved during the MN's BU procedure by providing a bi-directional tunnel between the old and new networks while the BU procedures are performed [4]. In addition, FMIPv6 minimizes the packet loss by buffering the received packets during Layer-2 handover latency. However, these approaches introduce additional performance overhead on network and those access routers during fast handover. Each fast handover session would consume additional bandwidth and cache capacity. When lots of fast handover requests arrive on the access router and network, it may cause handover congestion. For example, if the cache is full or no more bandwidth can be allocated for the use of fast handover, then any further fast handover would be dropped by the access routers. Certainly it will decrease the service quality and lower user's satisfaction degree. Hence it's necessary to find a solution to avoid or reduce fast handover congestion.

Until now, the problem avoiding congestion of fast handover has not been considered and solved by any known literature. In past, some mechanisms have been proposed to reduce the network congestion by admission control [5] [6]. However, fast handover is not considered by these mechanisms. On the other hand, in the past years, dynamic pricing has been used into congestion control and admission control. For example, in [7], Li et al. proposed to integrate dynamic pricing with call admission control to avoid congestion and improve the global performance. However, they only consider the case of circuit-based call, not of IP networks. In [8], the authors propose an integrated pricing and call admission control scheme where the price is adjusted dynamically based on the current network conditions in order to alleviate the problem of congestion in Internet. The access router could monitor the network's load and charge the use according to a pre-defined function in which the real-time load is the main parameter. On the other hand, the user's behavior upon price change is modeled as a probability function where the probability of the user accepting a certain price for a certain service is a function of current price versus the normal price. When the price is high, fewer users would accept the price and while price is low, more users will tend to accept the price. The authors proved that an equilibrium price can be found to optimize the network resource and the price is stable in this model. However, in this model the user's reaction only depends on the current price which is per bandwidth unit. In reality, the user's reaction always depends on the cost which is the product of current price and the user's bandwidth. So this model can't be applied onto our scenario since during the handover the bandwidth and buffer consumed by each user are different. In this paper, we propose an extension of FMIPv6 and adopt a market model to avoid the possible congestion and improve the performance of FMIPv6.

The rest of the paper is organized as follows. Section II briefly introduces FMIPv6. Section III gives an overview of the basic idea of our mechanism. In Section IV, the modified

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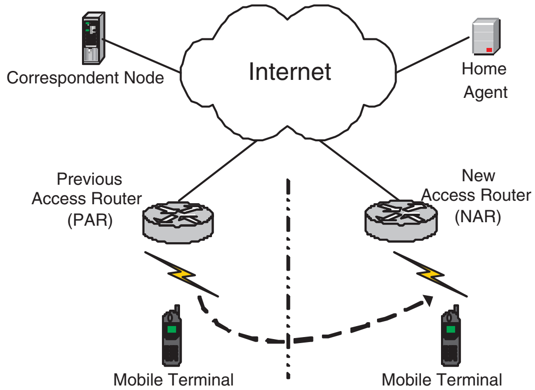

Fig. 1. FMIPv6 Components.

FMIPv6 procedure is described. Section V introduces the proposed economic market model and the numerical results are presented in Section VI. The conclusion is given in Section VII.

II. FMIPv6 Overview

FMIPv6 is a MIPv6 handover enhancement that reduces the handover latency and minimize the packets loss. This is accomplished by combining pre-registration, buffering and tunneling between access routers. In pre-registration phase, the MN has the ability to anticipate the handover and prepare its registration with New Access Router (NAR) and configuration its New Care-of-Address (NCoA).

Figure 1 shows the components involved in FMIPv6. The FMIPv6 handover procedure can be initiated either by the Mobile Node (MN), or by the network. For a MN initiated handover (i.e. it is the MN that takes the decision to move from one attachment point to another) the MN issues a Router Solicitation for Proxy Advertisement (RtSolPr) message to its current AR, i.e., Previous Access Router (PAR), in order to obtain information about its neighboring Access Points (AP)/Access Routers (ARs). For 802.11 networks, the RtSolPr message contains a list of APs that the MN can detect. The PAR replies with a Proxy Router Advertisement (PrRtAdv) message which will contain a list of IPv6 information for each AR relative to each AP. This information includes the IPv6 link-local addresses of the ARs and, if available, global IPv6 prefixes with which the MN can auto-configure a global Care-of-Address (CoA).

Upon receipt of the PrRtAdv, the MN should make a decision (e.g., based on the lower-layer information, such as Received Signal Strength) as to which AP to associate with. The MN then sends a Fast Binding Update (FBU) to the PAR indicating which AP it is about to associate with (and thus which NAR it will connect to). The Handover Initiate (HI) and Handover Acknowledge (HAck) messages are to verify that the correct IPv6 configuration data is present. Upon receiving of the HAck, the PAR then establishes a binding between Previous CoA (PCoA) and New CoA (NCoA), then being able to tunnel any packets bound to the NCoA. Thus during the handover, (i.e. once the FBU has been sent to the PAR by the MN), the PAR forwards packets from the MN's PCoA to the NCoA via a bi-directional tunnel. The NAR buffers these packets until the MN arrives on its new link and then delivers them to the MN. The MN announces its presence on the new link by sending a Fast Neighborhood Advertisement (FNA) message to the NAR. Once attached to the new link, the MN still uses the bi-directional tunnel and sends packets with source address PCoA in the reverse tunnel, until it has completed the MIPv6 registration procedure. Note that the usual MIPv6 handover procedure for performing CoA registration with the Home Agent (HA) and Correspondent Nodes (CNs) occurs after the FMIPv6 procedure. For network initiated handover, the process is similar except that the PAR initiates an unsolicited PrRtAdv to the mobile node first.

In this way, any packet that would possibly be lost during a handover are buffered by the NAR and delivered to the MN when it arrives to the new link. Furthermore, communication with CNs can continue via the bi-directional tunnel thus avoiding the usual latency effect due to performing the MIPv6 BU procedure. However, as mentioned above, when lots of mobile nodes request fast handover simultaneously, it may cause handover congestion with regard to buffer and tunneling bandwidth consumption.

In the next section, we introduce the basic idea to use dynamic pricing strategy to control user behavior and reduce the congestion caused by fast handover.

III. Basic Idea

In this paper, an extension of FMIPv6 is proposed to solve the above mentioned problem, i.e., congestion and performance degradation caused by handover congestion. In the extension, a Pricing Function (PF) is added onto the access routers to dynamically control the fast handover load, hence the performance of the network and access routers get improved. FMIPv6 is modified to be able to deliver dynamic pricing information to those mobile nodes that request fast handover service. And an economic market model is proposed to determine the optimized price.

When a mobile node is registering with the Access Router for fast handover, the pricing information is sent to it by the router via a modified FMIPv6 message. The mobile node then decides whether to accept the price based on its traffic load at that time. As shown in figure 2, if the mobile node is willing to accept the specified price, the access routers will provide fast handover service, i.e., tunneling and buffering the packets sent to the mobile node during the handover process. If the mobile node doesn't accept the price, then it will instead revert to the standard mobile IPv6 [1] handover service provided by the network provider. No tunneling and buffering will be provided by the access routers. Some traffic of the mobile node will be lost during the handover process.

The price is set by the PF located in access router according to market model proposed below, in which the price varies with the change of measured fast handover load occurred in the access router. In FMIPv6 the main resources consumed

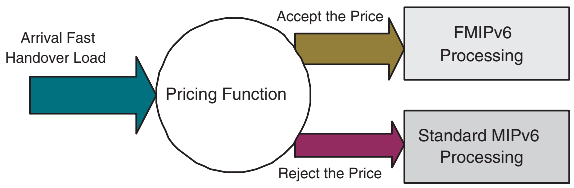

Fig. 2. Pricing Function.

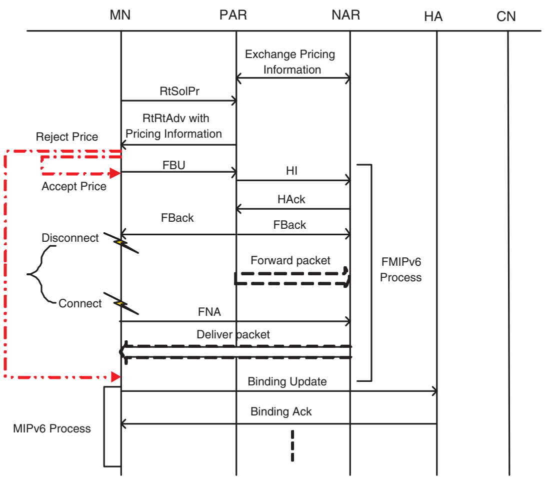

Fig. 3. Modified FMIPv6 Operation Process for MN initiated Handover.

by handover users are the bandwidth allocated for tunneling. Therefore in our work the fast handover load refers to the total bandwidth allocated for tunneling which is the sum of the traffic carried by each admitted fast handover user. The traffic of each mobile node usually varies and depends on upper layer application. Here we assume the traffic follows a specific distribution, e.g., normal distribution, exponential distribution, and etc. The general pricing rule is: when the total handover load is less than an optimal value, a normal price is charged to each handover user (or no charging). Normal price is the price that can be acceptable by all mobile users. When the load introduced by fast handover grows beyond the optimal value, dynamic peak-load price will be set by NAR and is exchanged with PAR, so the mobile node could get the pricing information from the PAR. It is worth noting that in our work the price is per bandwidth unit. So those mobile nodes having much traffic would pay more than those have less traffic and they are more likely to reject the price. In the next sections, the model of the charging strategy and user reaction are given in detail.

IV. The Modified Fast Handover for Mobile IPv6 Procedure

A. The General Procedure

Figure 3 shows the modified procedure of FMIPv6. Firstly, the pricing information needs to be exchanged between neighbor access routers. The information can be exchanged along with other information about neighbor networks. However, the method by which the access routers exchange information about their neighbors is not specified in FMIPv6. It can be specified by network operator.

Type	Length	Option-Code	Reserved
Pricing Information			

Fig. 4. Router Pricing Information Option.

If the handover is initiated by the mobile node, according to FMIPv6, firstly it sends a Router Solicitation for Proxy Advertisement (RtSolPr) message to Previous Access Router (PAR). The PAR replies with a Proxy Router Advertisement (PrRtAdv) message which contains all necessary information plus the dynamic pricing information of corresponding New Access Router (NAR). If the handover is initiated by the network, the PAR will send an unsolicited PrRtAdv message containing the pricing information to the mobile node. The price is set dynamically by NAR based on the handover load and pricing strategy. The real-time load on the network and access router introduced by fast handover requests can be measured easily with some existing mechanisms, e.g., SNMP. Based on received pricing information, along with current traffic load of itself, the mobile user then decides whether to accept the price.

If the price is accepted by the user, it sends a FBU message to the PAR to initiate fast handover as specified in FMIPv6 protocol. Then PAR and NAR will buffer and tunnel received packets for the mobile node during the handover interrupt. Hence the handover latency and packet loss will be minimized. If the user doesn't accept the price, it doesn't send the FBU message and reverts to the standard MIPv6 protocol. In other words, it only sends a Binding Update message after link-layer handover and IP layer preparation have been finished. Therefore, the mobile node experience longer handover latency and more packet loss.

To deliver the pricing information to mobile users, a new Neighbor Discovery option, Router Pricing Information Option is added as illustrated in Figure 4. This option is included in the PrRtAdv message sent to mobile users.

Type: 25. The number is used to indicate this is a Router Pricing Information Option. It can be set to other number that has not been used by other Neighbor Discovery options.

Length: The size of this option in 8 octets including the Type, Option-Code, and Length fields.

Option-Code: 0.

Reserved: MUST be set to zero by the sender and MUST be ignored by the receiver.

Pricing Information: It contains the pricing information that is to be sent to the mobile node. The price is set per bandwidth unit.

For PrRtAdv message a new code value '5' is defined. A PrRtAdv message with Code 5 means that it contains the pricing information of NAR for fast handover.

Other messages and processes used in FMIPv6 are not modified.

B. Reduce frequency of price changing

One thing to be noted is that in a real network the arrival traffic load will change continually. If the price is changed as soon as the arrival traffic load changes, the price would change frequently. It would cause frequent signaling message exchange between access routers and mobile nodes and may introduce complexity into billing system. To solve the problem, one possible solution is that we could only change the price at a fixed interval (e.g., 15 minutes) which is selected by the network provider. Accordingly, the arrival load could then use the average arrival load during the past interval. Another possible solution is that the price is only changed and broadcasted to mobile user when the arrival load has reached a series of pre-defined discrete value. For example, suppose the capacity of the access router is 1.0 and the base load is 0.6. Then the price is only changed when arrival load is $(0.7, 0.8, 0.9, \ldots)$.

V. Economic Model

In our economic model, the price of fast handover depends on: pricing strategy (supply function), user reaction (demand function), and how the market operates. Demand function determines the price that the mobile users are willing to pay to obtain the fast handover service. Supply function determines how the price is set by the service or network provider.

A. Pricing Strategy

In our mechanism, the price is set based on the actual fast handover load in the access router. The actual load is introduced by those mobile nodes accepting the price. There is a base price p_b that is acceptable by all handover users. The base price is static when the handover load is lower than a pre-defined base load l_b. When the handover load exceeds the base load the price will be increased rapidly and even dramatically when the load is close to the maximum capacity. We adopt the hyperbolic growth in this case to reflect our price setting strategy. When the access router is heavily loaded, only few users will be willing to accept the price. The supply function of our pricing strategy can be written as:

$$P_l = \begin{cases} P_b, & if \quad l \le l_b \\ P_b \times \left(\dfrac{1-l_b}{1-l}\right)^n, & \text{otherwise.} \end{cases} \tag{1}$$

where l denotes the actual handover load and P_l is the price when the handover load is l, n is a integral parameter to control the steepness of the curve which is great than or equal to 1.

B. User Reaction

Let N denote the number of mobile nodes that request fast handover at time t. Let v_i represent the individual traffic load of handover user i. The traffic of all handover users follows a specific distribution (e.g., normal distribution). So the total arrival handover load can be written as $V = \sum_{i=1}^{N} v_i$. It is worth noting that L represents the actual handover load while V represents the arrival handover load. From the point of view economic literature, monetary incentive can influence the way that users consume resources and is usually characterized by demand functions which describe the reaction of users to the change of cost. Different demand functions have been proposed in the literature [7] [8]. In this paper, we improve the demand function in [8]. As stated above, the function adopted in [8] only depends on current price. But in reality, the users are more sensitive on total payment, not only the price. In our paper, the user reaction depends on the cost which is affected by both price and load. It can be described as below:

$$D(c) = \begin{cases} e^{-(c/c_b - 1)^m} & if \quad c > c_b \\ 1 & \text{Otherwise.} \end{cases} \tag{2}$$

where $D(c)$ represents the probability of the user will accept the specified handover cost. c_b is the normal cost that can be accepted by all users. And c is the cost charged to mobile users, it can be stated as $c_i = p \cdot v_i$. So the probability D can be rewritten as the function of current price p and traffic load v_i. m is the adjusting parameter to control the curve steepness and $m \ge 1$.

$$D(v_i, p) = \begin{cases} e^{-(p \cdot v_i/c_b - 1)^m} & if \quad p \cdot v_i > c_b \\ 1 & \text{Otherwise.} \end{cases} \tag{3}$$

From the above equations, we can conclude that the total actual handover load L can be stated as:

$$L = \sum_{i=1}^{N} D(v_i, p) \cdot v_i \tag{4}$$

Since function D is not a linear function. L can't be stated directly as a simple function of V. Here L is written as a general function of V:

$$L = g(V, p) \tag{5}$$

And the function $g(V, p)$ can be gotten by curve fitting and simulation.

C. Market Model

Having the supply function (1) and the demand function (4), we can model the system as a market as shown in Figure 5 in which the solid lines represent the demand functions (i.e., the reaction of the handover users for the price) for different arrival loads while the dotted line represents the supply function (i.e., how the network sets the price based on the handover load). From equilibrium pricing theory, given an arrival handover load we can see that there is an equilibrium price where the supply curve and demand curve intersect. In a real network environment, the arrival handover load changes over time. Hence, this results in a set of equilibrium prices over time as shown in Figure 5. This can be explained using excess demand analysis. When the price is lower than the equilibrium price, the excess demand is positive. This encourages the demand and therefore increases the price so that p moves toward p'. When the price is higher than the equilibrium price, the excess demand is negative, which decreases the demand and thus decreases the price so that p moves toward p' too. Figure 5

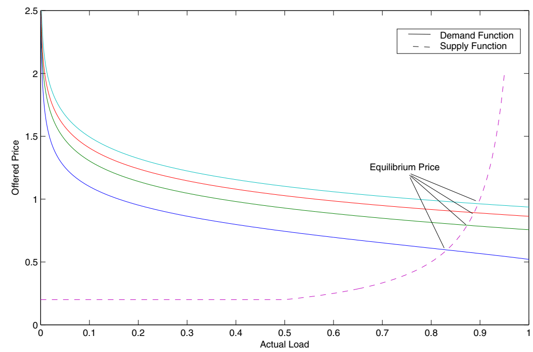

Fig. 5. Market Model.

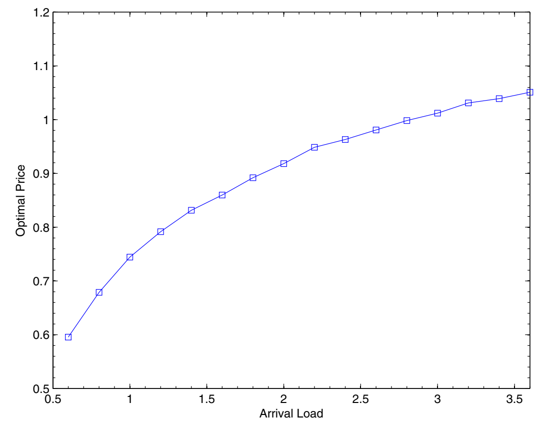

Fig. 6. Optimal Equilibrium Price of Given Arrival Load.

shows that different arrival handover loads (the arrival loads are 0.6, 1.2, 1.8, 2.4 respectively assuming the capacity is 1) cause the shift of the demand function and consequently generate a set of equilibrium prices for fast handover service. In this figure, the solid lines represents the supply function .

VI. Numerical Results

This section gives some numerical results gotten from the simulation done with Matlab. In the simulation, the traffic distribution of all handover requests follows normal distribution in which the number of total users is 100. The results for other distributions may be different and are not discussed here. For the parameters in Equation (1), the base price p_b is set to 0.2 and the base load l_b is set to 0.5. For the parameters in Equation (4), m is set to 2, and the normal cost c_b is set to 0.8.

In Figure 6, we can see that with the increasing of the arrival handover load, the calculated equilibrium price increases consequently. And when the arrival load gets higher, the increasing speed of optimum price get slower. Because in general the users are more sensitive on higher price. Price changing has more impact on user's reaction. Figure 7 shows the same trend as Figure 6, i.e., when the arrival load get higher, the increasing speed of the actual load get slower. We can get that as the increasing of arrival handover load, the actual load will approach the full load but can't reach the full load. That proves the effectiveness of our mechanisms.

Fast Handover Dropping Probability

In our model, when the arrival handover load exceeds the capacity of the network and access router, optimal equilibrium price is charged to the handover user. Whether the user would accept the price is based on the probability calculated from demand function. If the user doesn't accept the charging, the fast handover is dropped by the user and standard handover process is reverted. Here we define the probability that users drop the fast handover and revert to standard handover process as Fast Handover Dropping Probability (FHDP). In the work of Li et al. [8], the dropping probability only depends on the price, so all handover users have the same probability when the price is specified. In our model, the dropping

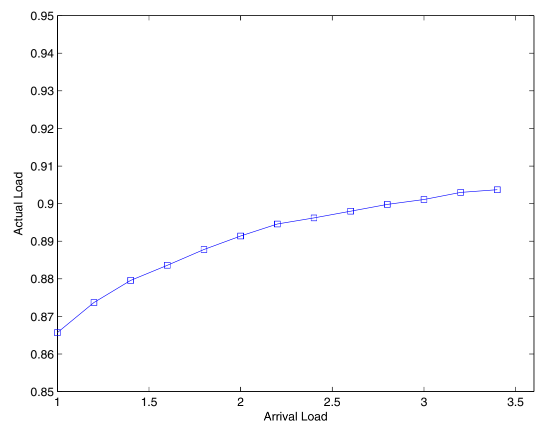

Fig. 7. Actual Load for Given Arrival Load.

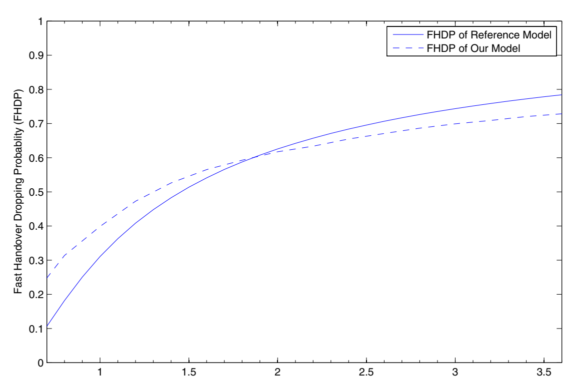

Fig. 8. Handover Dropping Probability Comparison.

probability depends on the cost, i.e., consequently depends on the individual traffic in addition to the price. For the mobile users have different traffic, the probability would be different if the price p is fixed. The total Fast Handover Dropping Probability should be the expected probability over all mobile users:

$$FHDP = \frac{1}{n} \sum_{i=1}^{N} D(v_i, p) \tag{6}$$

From the equation, we can see for specified arrival load, FHDP is highly related to the traffic distribution among handover users. In Figure 8, the numerical results of FHDP for our model and the reference model of [8] are shown, in which normal distribution is adopted. Since the parameters of our proposed model and reference model aren't the same exactly, in addition, the used traffic distribution also affects the simulation result, the absolutely value of FHDP of two models doesn't make much sense. However, by observing the trend of the two curves, it is worth noting that in our model when the arrival load (i.e., the congestion degree) increases, the FHDP of our model is less sensitive than that of reference model. On the other hand, when the arrival load is low, the FHDP of our model is more sensitive than that of reference model. It can be understood that in reference model all users have the same dropping probabilities, when total arrival load is low all users tend to accept the price. While in our model, even when total arrival load is low, there is probability that some users have high load that they don't want to accept the cost. For different traffic load distribution, the trend should be different. Actually, the reference model can be treated as a special case in our model, i.e., the traffic of all handover users follows uniform distribution. Our model reflects the real environment better and provides a more general understanding.

VII. Conclusion

In this paper, we propose applying dynamic pricing information to avoid handover congestion and improve user satisfaction for FMIPv6. We modified the standard FMIPv6 handover procedure and propose an economic model with regard to pricing strategy and user reaction. From the numerical result, we illustrate that a set of optimal equilibrium prices can be found to avoid and reduce possible fast handover congestion. Hence the network performance and service quality get improved. In addition, this model can be applied to other situations in which the resource is charged per unit [9]. In future, the impact of different traffic distributions is to be explored.

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