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Dynamic Location Area Management Scheme with Combining CGA and CBI for Hierarchical Mobile IPv6*

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Abstract - Internet engineering task force (IETF) has proposed Mobile IPv6 (MIPv6) in order to offer mobility service to a mobile node. Whenever a mobile node moves another foreign network, it must register its location to the home agent and the correspondent node in MIPv6. Hierarchical MIPv6 (HMIPv6) which introduces a mobility anchor point (MAP) is the proposed protocol to reduce a frequent location registration in MIPv6. In HMIPv6, all traffics toward a mobile node must be transmitted through a MAP. In the case that there are a lot of MNs in a MAP domain, overhead for the packet process should occur in the MAP. Hence, it is necessary to keep MNs from crowding at one MAP. In this paper, we propose the dynamic location area management scheme to reduce overhead of MAP. The MN newly entering into the MAP domain selects the MAP that manages the smallest numbers of MNs. We consider packet processing time in the MAP as evaluation element. As a conclusion, our proposed scheme can reduce the average amount of time a packet spends in the MAP.

Keywords: Location registration, Mobile Anchor Point, HMIPv6, MIPv6

1 Introduction

Mobile internet protocol version 6 (MIPv6) is the protocol which is proposed by Internet engineering task force (IETF) to offer mobility service based on internet to IPv6 node with mobility [1][2]. In MIPv6, a home address (HoA) is assigned to a mobile node (MN) within home network of the MN. Then the MN communicates with the CN using the HoA. In the case that an MN moves to a foreign network leaving the home network, the MN generates care-of address (CoA), using prefix, within router advertisement (RA) message of the foreign network, which is used in the foreign network [3][4][5]. Then the MN registers its location information, binding HoA and CoA in binding update (BU) message, to the HA. After doing above processes, it is possible for the MN to communicate wherever it moves. However, MIPv6 has such a problem that overhead for location registration increases, because an MN registers its location information to the HA whenever it moves another foreign networks. Above problem of MIPv6 can be solved by considering locality of an MN. So, IETF has proposed hierarchical MIPv6 (HMIPv6) which introduces mobility anchor point (MAP) to reduce overhead for location registration [6]. At this time, the MAP performs as the HA to MNs in the MAP domain. An MN entering into the MAP domain generates and mobile CoA (RCoA) and on-link CoA (LCoA) by using prefix of the MAP and prefix of the access router (AR), respectively. In the case that an MN moves to another subnet within the MAP domain, RCoA is not changed and LCoA is changed by using a prefix of subnet. Then the MN does not register its location information to the HA, but the MN registers its location only to the MAP. Hence, location registration cost of HMIPv6 is less than that of MIPv6. It is because, in HMIPv6, the MN does not send BU message to the HA whenever it moves to another subnets within the MAP domain. However, packet processing cost of MAP increases if there are a lot of MNs in MAP domain because all packets which are sent and received by the MN pass the MAP.

Castelluccia has showed that high traffic load happens in the MAP and such load causes high packet delivery cost when the number of regional networks managed by the MAP is large [7]. Observing that the feature of mobility pattern is very habitual, Kong has proposed that the cell which a mobile node stays for a long time and often can be selected as potential home cell for the MN [8]. And Park has proposed the proactive load control scheme to reduce the ongoing MN dropping probability while keeping the new MN blocking probability [9]. Although above models are well-defined to reduce overhead of MAP domain, they do not consider in the case that MNs crowd to one MAP. Since packet processing cost increases in the MAP when the number of MNs which is managed by the MAP is increases, it needs some method to keep MNs from crowding at one MAP. In this paper, we propose the dynamic location area management scheme to reduce overhead of MAP, i.e. the average amount of time a packet spends in the MAP, which is thronged by many MNs. From now on, in this paper,

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packet processing time in the MAP represents the average amount of time a packet spends in the MAP. We make MAPs around the domain offer HMIPv6 to the MN within the domain. And the MN entering the MAP domain chooses the MAP which manages the smallest number of MNs. Then the MN sends BU message to the selected MAP. As a result, we can show that our dynamic location area management scheme can reduce the packet processing time in the MAP by showing both the graphs and the proofs. For performance analysis and evaluation element, we use Markov chain and packet processing time, respectively.

This paper is organized as follows. In section 2, we describe both the location update procedure and introduce our proposed scheme in HMIPv6. In section 3, we define organized as follows. In section 2, we describe both the location update procedure and introduce our proposed scheme in HMIPv6. In section 3, we define analytic model for performance analysis by using Markov chain. In section 4, we describe result of performance analysis of the proposed scheme. Finally, we present both our conclusions and future work in section 5.

![Figure 1. Distributed HMIPv6 Architecture](image)

2 Related Work

In this section, we describe the location update procedure in HMIPv6 and the dynamic location area management scheme which is proposed in this paper and the scheme for security between MN and MAP in HMIPv6

2.1 Hierarchical Mobile IPv6

HMIPv6 is enhancement of Mobile IPv6 which is suggested to reduce the amount of signaling overhead and improve the performance of handover. When mobile node move locally, update is not required for HA and CNs. For limiting the amount of MIPv6 signaling outside the local domain, Mobility Anchor Point (MAP) is introduced in HMIPv6. Fig.1 consider a distributed HMIPv6 environment, where there may be constructed multiple independent MAPs which are in many ways similar to the one performed by the Home Agent. Acting as a local HA, the MAP receives all packets on behalf of the MN it is serving and encapsulates and forwards them directly to the MN's current address. If MN moves within local domain, it needs to bind the new address (new LCoA) with MAP. Hence, RCoA needs to be registered with the Correspondent Nodes and the Home Agent, when the MN moves outside a MAP domain.

There are significant recovery time of HA and MAP failure. Therefore, recovery time should be considered for disruption or disconnection that can affect user satisfaction of ongoing session between mobile and correspondent nodes.

![Figure 2. Location Registration Procedure of the Mobile Node in HMIPv6](image)

2.2 Location Update Procedure in Hierarchical Mobile IPv6

As illustrated in Fig.2 described the location update procedures, MN receives RouterAdvertisements containing information for one or more local MAPs. The MN should bind its current location(LCoA) with an address on the MAP's subnet(RCoA). When an MN enters into a MAP domain, it configures RCoA and LCoA [6]. And then the MN gives and takes a BU and BA message to the MAP, the HA and the CNs, respectively. Then, the MN completes location update. At this time, the MN registers its location
by RCoA to the HA and the CN. And the MN registers its location to the MAP by using both LCoA and RCoA. After this, all packets that are sent to the MN by the CN pass the MAP because they were sent to the RCoA of the MN. The MAP receiving packet finds LCoA that corresponds to RCoA of the MN and passes packet to the MN. In the case that an MN moves from AR1 to AR2 as shown in Fig.1, the MN generates again LCoA in AR2. And the MN registers its location only to the MAP because the CN sends packet to the MNs RCoA. Hence, the MAP manages MNs in the MAP domain and packet which is sent or received by the MN passes the MAP. And the packet processing cost of MAP increases if the number of MNs that MAP manages increases. So the number of MNs managed by MAP effects packet process time of MAP in HMIPv6.

![Message flows in Combining Cryptographically Generated Address and Crypto-Based Identifiers to Secure HMIPv6](image)

2.3 The Security between Mobile Node and Mobility Anchor Point in Hierarchical Mobile IPv6

The absence of any protections between MN and MAP may lead to malicious MNs impersonating other legitimate ones or impersonating a MAP. In this paper, we used the scheme [11] for solution for the security between MNs and MAPs as the method of authenticating MN’s identification without the public key infrastructure. In [11], this document describes a method for establishing a security association between the MN and the selected MAP in HMIPv6 and suggests a solution that is based on combination of the cryptographically generated address (CGA) and crypto-based identifiers (CBID) technologies as illustrated in Fig.3. Authors assume that the MN’s LCoA is always computed based on the CGA technology, in order to allow the MN to run the secure neighbor discovery procedure. In addition, they assume that MN can discover the presence of an HMIPv6 domain before sending a RStSol message. The suggested solution is described in the following steps:

- When the MN discovers that it has entered an HMIPv6 domain, it computes an LCoA address by using its CGA key pair and a CBID by hashing the CGA public key together with a 64-bit imprint.
- The MN inserts the CBID in the RStSol message, then signs the message as described in SEND and sends it to the AR.
- Upon receiving a valid RStSol message carrying a CBID, the AR replies immediately by sending a unicast RAdv message to the MN and in parallel, a PBT message to the MAP. For this purpose, the AR MUST compute a secret (Ks), encrypt it with the MNs CGA public key and sends it in the RAdv message. The AR MUST send Ks to the MAP in the PBT message, in addition to the MNs CGA public key, its LCoA and CBID. Note that it is assumed that the PBT messages are signed by the ARs.
- After receiving the PBT, the MAP creates a BCE for the MN, which will contain all parameters sent by the AR. Once the BCE is created, the MAP will wait for the owner of the LCoA to send the LBU message.

3 Proposed Model - Dynamic Location Area Management Scheme

As we describe in introduction, the MAP advertises its prefix in RA message periodically in order to get to know the MAPs prefix to the MN in MAP domain. We make a RA message arrive also at near the MAP domain when the MAP advertises its prefix. At this time, the MAP should send RA containing the number of MNs managed by the MAP. The number of MNs which the MAP manages may be contained within the mobility option in RA message. Then the MN entering into the MAP domain receives RA messages from several MAPs. And the MN decides to send the BU to some MAP after observing the number of MNs in RA message in Fig.5. Figure 4 describes the binding update procedure. In Fig.4, n denotes the number of MAPs which sends RA message to subnet. Then, the MN which enters above subnet receives n RA messages. After receiving RA messages, the MN observes what the MAP manages MNs for the smallest number. Then the MN sends the BU to a MAP which manages MNs for the smallest number. In the case that the number of MAPs satisfying above condition is more than 2, the MN sends BU to either MAPs satisfying above condition. By our proposed algorithm, we can show that packet processing time at the MAP is kept efficiently.
4 Analytic Model

A MAP manages the MN’s location registration in MAP domain. The number of MN’s packet which is managed by MAP affects the MAP’s load. Thus, the MAP’s load is influenced by the number of MN. For efficient selection of MAP which has a lower load by MN, we evaluate performance of the MAP using continuous time Markov chain in this section. In section 3.1 and 3.2, we consider the assumption for analytic model and illustrate the model for performance evaluation of MAP’s load.

4.1 Assumptions

We evaluate performance using continuous time Markov chain. In this paper, we assume the following conditions to develop the Markov chain model for analytic model.

- The arrival process for the packets follows Poisson distribution with rate of $\lambda$.
- The successive service times of the packets follow exponential distributions with rate of $\mu$.
- For the normalization, $\lambda$ is less than $\mu$.

In the case that the MN is performing the location registration in the MAP domain, we do not consider the distance between the MN and the selected MAP, but only focus on the MAP’s processing time for incoming MN’s packets.

4.2 Markov Chain Analysis

Figure 6 shows a state transition diagram in the Markov chain for Hierarchical MIPv6. In Fig.6, $\lambda$ means the packet arrival rate of MAP. At this time, we suppose that packet arrival rate per MN is fixed in the MAP domain. Then, we can say that the packet arrival rate of MAP is in proportion to the number of MNs in the MAP domain. If we set constant of proportionality be 1, the number of MNs in the MAP domain implies the packet arrival rate of MAP. Hence, we regard the number of MNs in the MAP domain as the packet arrival rate of MAP. State $i$ represents the number of packets in a MAP domain. $q(i, j)$ denotes the transition rate from state $i$ to state $j$. The transition rates in the Markov chain are as follows:

$$q(i, i+1) = \lambda \quad (i \geq 0)$$

$$q(i+1, i) = \mu \quad (i \geq 0)$$

(1)
where \( q(i, i + 1) \) and \( q(i + 1, i) \) are the transition rate from state \( i \) to state \( i + 1 \) and the transition rate from state \( i + 1 \) to state \( i \), respectively. The rate-equality principle yields the following set of balance equations [10]:

\[
\lambda P_0 = \mu P_1 \\
(\lambda + \mu)P_n = \lambda P_{n-1} + \mu P_{n+1} \tag{2}
\]

By Eq.(2), steady-state probability of Markov chain can be deduced as follows.

\[
P_n = \left( \frac{\lambda}{\mu} \right)^n \cdot P_0, \quad \text{for } n \geq 1 \tag{3}
\]

And since \( \sum_{n=0}^{\infty} P_n = 1 \), by Eq.(3), \( P_0 \) is as follows.

\[
P_0 = 1 - \frac{\lambda}{\mu} \tag{4}
\]

Then by Eq.(3) and Eq.(4), the average number of packets in the MAP clearly is given by following equation.

\[
E(N) = \sum_{n=0}^{\infty} nP_n = \frac{\lambda}{\mu - \lambda} \tag{5}
\]

Now, we can get packet processing time in a MAP as follows.

**Figure 7. Effect of \( \alpha \) packet processing time (\( \lambda_1 = 24 \), \( \lambda_2 = 28 \))**

\[
W(\lambda, \mu) = \frac{E(N)}{\lambda} = \frac{1}{\mu - \lambda} \tag{6}
\]

### 4.3 Effect of Increasing Packet Arrival Rate

Let \( \lambda_1 > 0 \) and \( \lambda_2 > 0 \) such that \( \lambda_1 < \mu \) and \( \lambda_2 < \mu \). Then, the following formula is always satisfied.

\[
2W\left( \frac{\lambda_1 + \lambda_2}{2}, \mu \right) \leq W(\lambda_1, \mu) + W(\lambda_2, \mu) \tag{7}
\]

**Proof.** Since \( \lambda_1 < \mu \) and \( \lambda_2 < \mu \), by Eq.(6), \( W(\lambda_1, \mu) > 0 \) and \( W(\lambda_2, \mu) > 0 \). Since \( \frac{2ab}{a+b} \leq \frac{a+b}{2} \), for all \( a > 0 \) and \( b > 0 \), \( 2\cdot W(\lambda_1, \mu) \cdot W(\lambda_2, \mu) \leq W(\lambda_1, \mu) + W(\lambda_2, \mu) \) is satisfied. Now, we can easily solve above inequality.

The result of Eq.(7) means that when \( \lambda \) is near to \( \mu \) lead to a large increase in \( W \), for the fixed \( \mu \). For example, we suppose that there are two MAPs, i.e. MAP1 and MAP2. Suppose that the number of MNs in the MAP1 domain, i.e. \( \lambda_1 \), be 20 and the number of MNs in the MAP2 domain, i.e. \( \lambda_2 \), be 24. Then, \( W(22, \mu) + W(22, \mu) < W(20, \mu) + W(24, \mu) \). Eq.(7) implies the following corollary, which illustrates the selection of MAP that has a lower load by MN.
Corollary 1  Let \( \lambda_1 > 0, \lambda_2 \geq 0 \) and \( \alpha = \lambda_2 - \lambda_1 \) such that \( \lambda_1 < \mu, \lambda_2 < \mu \) and \( \lambda_1 \leq \lambda_2 \). Suppose that the arrival rate of packet increases as many as \( \alpha \). Then \( W(\lambda_1, \mu) + W(\lambda_2, \mu) \) has the unique minimum value when \( \lambda_1 = \lambda_1 + \alpha \) and \( \lambda_2 = \lambda_2 \).

Proof. Suppose the Corollary 1 is false. Then, there are \( p \geq 0 \) and \( q \geq 0 \) such that \( p + q = \alpha \) and
\[
W(\lambda_1 + p, \mu) + W(\lambda_2 + q, \mu) < W(\lambda_1, \mu) + W(\lambda_2, \mu) = 2W(\lambda_2, \mu).
\]
By Eq.(7),
\[
2W(\lambda_2, \mu) \leq W(\lambda_1 + p, \mu) + W(\lambda_2 + q, \mu).
\]
For satisfying above inequality, we conclude that \( \lambda_1 + p = \lambda_2 + q \), \( p = \alpha \) and \( q = 0 \), which is a contradiction.

5 Numerical Results

This section, we evaluate the packet processing time based on the previous analytic model. The results of packet processing time for the analysis consider the affect of, and incoming MN in the MAP domain. For performance evaluation, we assume that there are two MAPs in MAP domain, i.e. MAP1 and MAP2. Also, we assume that arrival rate of packet per MN is same in the MAP domain. Then we can consider that the packet arrival rate of MAP implies the number of MNs in the MAP domain. Let packet arrival rate of MAP1 and MAP2 be \( \lambda_1 \) and \( \lambda_2 \), respectively, such that \( \lambda_1 > \lambda_2 \).

5.1 Effect of \( \lambda \)

Figure 7 describes the result of Eq.(7). In Fig.7, we assume that \( \lambda_1 = 24 \) and \( \lambda_2 = 28 \). And packet processing time is \( W(\lambda_1 + \alpha) + W(\lambda_2 - \alpha) \). When \( \lambda_1 = 30, 31 \) and 32 packet processing time decreases as \( \alpha \) is near to 2. Since \( \lambda_1 = \lambda_2 = 26 \) for \( \alpha = 2 \), packet processing time has minimum value, by Eq.(7). Also, \( \alpha \leq 2 \) implies that packet processing time increases and packet processing time is symmetric with \( \alpha = 2 \) when \( 0 \leq \alpha \leq 4 \). And we can observe that \( W \) decreases fast as the value of \( \mu \) decreases. This means that \( \mu \) is near to \( \lambda \), a slight decrease \( \mu \) leads to a large increase in \( W \), by Eq.(6).

5.2 Effect of Incoming MNs

Figure 8 describes the result of Corollary 1. In Fig.8, we assume \( \mu = 30, \lambda_1 = 24 \) and \( \lambda_2 = 26 \). And \( \lambda_1^{\text{**} \, \mu} \) means that \( \lambda_1 \) increases as the number of incoming MNs increases while \( \lambda_0 \) is fixed, i.e. \( 24 \leq \lambda_1 \leq 26 \) and \( \lambda_2 = 26 \). In other words, the new MNs entered into the MAP domain registers its location information to the MAP, Similarly \( \lambda_2^{\text{**} \, \mu} \) means that \( \lambda_2 \) increases as the number of incoming MNs increases while \( \lambda_1 \) is fixed. It is clear that packet processing time of \( \lambda_1^{\text{**} \, \mu} \) is less than that of \( \lambda_2^{\text{**} \, \mu} \), by Corollary 1. However, we can see that packet processing time of \( \lambda_2^{\text{**} \, \mu} \) increases faster than that of \( \lambda_1^{\text{**} \, \mu} \). Because \( \mu - \lambda_2^{\text{**} \, \mu} \) is less than \( \mu - \lambda_1^{\text{**} \, \mu} \) in Eq.(6), packet processing time of \( \lambda_1^{\text{**} \, \mu} \) increases slower than that of \( \lambda_2^{\text{**} \, \mu} \). Figure 9 shows the result of Corollary 1 similar to Fig.8.

In Fig.9, we assume that the arrival rate of packet in MAP\textsubscript{1}, \( \lambda_1 \), is 24 and the arrival rate of packet in MAP\textsubscript{2}, \( \lambda_2 \), is 26 and the packet processing rate at the MAP\textsubscript{1} and MAP\textsubscript{2}, \( \mu \), is 32. The difference between Fig.9 and Fig.8 is the value of \( \mu \), i.e. \( \mu = 30, 32 \). We can easily know \( W(\lambda_1^{\text{**} \, \mu}) < W(\lambda_2^{\text{**} \, \mu}) \), \( \mu \). And packet processing time in Fig.9 decreases slower than that in Fig.8, by Eq.(6), because the value of \( \mu \) in Fig.9 is larger than that of \( \mu \) in Fig.9.

6 Conclusion

In this paper, we propose dynamic location area management scheme to keep MNs from crowding at on
MAP. We use the average amount of time a packet spends in the MAP as performance estimation. Also, we develop Markov chain for analytic model. In our proposed scheme, we make the MN entering the MAP domain send the BU message to the MAP managing the smallest number of MNs. As a conclusion of this paper, our proposed scheme can reduce the average amount of time a packet spends in the MAP. We do not consider the distance between the MN and the selected MAP, but only see the packet processing time in the MAP. Hence, in our future works, we will consider distance between the MN and the MAP supporting dynamic location area management scheme in HMIPv6.

6 References


