Performance Analysis of Fast Handover for Hierarchical MIPv6 in Cellular Networks

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Abstract—Next-generation wireless networks present an all-IP-based architecture integrating the existing cellular networks with Wireless Local Area Networks (WLANs), Wireless Metropolitan Area Networks (WMANs), wireless ad hoc networks, Wireless Personal Area Networks (WPANs), etc. This makes mobility management an important issue for users roaming among these networks/systems. On one hand, intelligent schemes need to be devised to benefit the IP-based technology, on the other hand, new solutions are required to take into account global roaming among various radio access technology and support of real-time multimedia applications. This paper presents a comprehensive performance analysis of Fast handover for Hierarchical Mobile IPv6 (F-HMIPv6) using a proposed analytical model. Location update cost function, packet delivery cost function and total cost function are formulated respectively based on the fluid-flow mobility model. We investigate the impact of several wireless system factors, such as user velocity, user density, mobility domain size, session-to-mobility ratio on these costs, and present some numerical results.

Keywords—next-generation wireless networks; mobility management; fast handoff; performance analysis.

I. INTRODUCTION

In the new era of Internet, mobile users freely change their point of attachment to the Internet. Under this circumstance, mobility management is a crucial issue to keep track of users’ current location and correctly deliver packets to them. So far, several schemes have been proposed to address this issue within the Internet Engineering Task Force (IETF), and many works are still in progress. The baseline mobility management protocol is called Mobility support in IPv6 (MIPv6) [1] which handles the routing of IPv6 packets to Mobile Nodes (MNs) that are away from their home network. To do so, a Home Address (HoA) is assigned to each MN as a permanent identity. While located in a visiting network, the MN has to acquire a Care-of-Address (CoA) on the new attached link. This address can be configured either stateless [2] or stateful [3] and used to identify the MN’s current location within the Internet topology.

After formulating a new CoA in the visiting network, the MN needs to perform Duplicate Address Detection (DAD) procedure [4] to verify the uniqueness of its new IP address. Moreover, in order to correctly deliver packets to a roaming MN, a binding between the MN’s HoA and its CoA is created and managed by a mobility agent called Home Agent (HA). Consequently, each time the MN changes its location, it has to update this binding at its designated HA. And packets destined to a roaming MN are intercepted by the HA and tunneled to the MN’s new location, this operational mode is called tunnel mode in MIPv6. As the tunnel mode introduces a triangular problem, MIPv6 defines a Route Optimization (RO) mode to enable any Correspondent Node (CN) to bind MNs’ HoAs with their CoAs, thus packets can be sent to an MN’s new location via a direct path. However, for security concerns, a Return Routability (RR) procedure is required between the MN and the CN before updating the binding cache at the CN. The RR procedure consists of HoA-test and CoA-test, aims to verify whether the specific MN possesses the proclaimed HoA and CoA or not, and ensuring authorization of subsequent binding updates (BUs) to the CN.

An almost universally recognized fact is that the mobility management procedure in MIPv6 involves long handover latency, higher signaling overhead which needs to be improved to meet the requirement of future wireless networks. In this context, Hierarchical Mobile IPv6 (HMIPv6) [5, 6] and Fast handovers for Mobile IPv6 (FMIPv6) [7, 8] are proposed separately by the working groups of IETF.

HMIPv6 is designed to reduce the signaling cost and location update delay outside a local mobility domain which is controlled by a Mobility Anchor Point (MAP). While entering a MAP domain, an MN receives router advertisements containing information about local MAPs from the new Access Router (AR). Then the MN formulates two CoA: an on-link CoA (LCoA) and a regional CoA (RCoA) within the selected MAP domain. Afterwards, a Local Binding Update (LBU) is sent to the MAP to bind the MN’s LCoA with its RCoA. Upon receipt of a successful Binding Acknowledgment (BA), the MN sends a BU to the HA to create or update the binding of its RCoA with the HoA at the HA, the HA then replies with a BA to the MN. In case of RO, the RR procedure is performed to create a Binding Management Key (KBM). Subsequently, the MN sends a BU to each CN using the KBM, and the CN binds the MN’s HoA with its RCoA. As a result, packets destined to the MN are intercepted by the MAP, encapsulated and forwarded to the MN’s on-link address. And movement within the MAP domain merely incurs LBU at the MAP without further propagation of location update to the HA and every CN, thus significantly minimizes the signaling loads and micro-mobility related handoff delays.
Due to the lengthy, handicapped handoff procedure, MIPv6 is regarded unanimously as inappropriate for fast handover support in IPv6-based mobile networks. In this case, FMIPv6 is designed to enable an MN to rapidly detect its movement and to formulate a prospective IP address when still connected to its current AR. This protocol also offers the MN the opportunity to utilize available link layer event notification (triggers) to accelerate network layer handoff [9]. Hence, delays due to network prefix discovery and new CoA generation are completely eliminated during handoff. Moreover, a bidirectional tunnel is setup between the previous AR (PAR) and the new AR (NAR) to avoid packet drops. And the PAR binds an MN’s previous CoA with its new CoA. Therefore, packets addressed to the MN are intercepted by the PAR, tunneled to the NAR, and no BUs are necessary to the HA and each CN during handoff. However, due to the utilization of pre-handover triggers, the performance of FMIPv6 is dramatically depends on the trigger time, thus becomes unreliable when the pre-handoff trigger is delivered too closely to the actual link switch [9].

Both FMIPv6 and HMIPv6 are designed in their own ways to improve MIPv6 performance in terms of signaling overhead and handover aspects, thus makes it necessary to combine these two schemes together. However, simple superimposition of FMIPv6 over HMIPv6 induces unnecessary processing overhead for re-tunneling at the PAR and inefficient usage of network bandwidth [10-12], thus an effective integration called Fast handover for Hierarchical MIPv6 (F-HMIPv6) is designed to enable an MN to exchange handoff signaling message with a local MAP and to establish bidirectional tunnel between the MAP and the NAR, instead of between the PAR and the NAR. Fig. 1 shows the location update procedure of F-HMIPv6 in case of intra-domain movement.

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### II. FLUID-FLOW MOBILITY MODEL

To evaluate the performance, we assume an IPv6-based wireless cellular network shown in Fig. 2. The innermost cell 0 is called the center cell; cells labeled 1 formed the first ring around cell 0, and so on. To simplify the analysis, we assume that each MAP domain has the same number of rings and each AR only controls one cell. Using the fluid-flow mobility model, the movement direction of an MN in a MAP domain is distributed uniformly in the range of $(0,2\pi)$. Let $v$ be the average speed of an MN, $R_c$ and $R_d$ be cell crossing rate and domain crossing rate, respectively. $L_c$ and $L_d$ denote the perimeters of a cell and a MAP domain with $R$ rings. Therefore, their expressions are given as follows:

$$R_c = \frac{\rho v L_c}{\pi}$$  \hspace{1cm} (1)

$$R_d = \frac{\rho v (2R+1)L_c}{\pi} = \frac{\rho v (2R+1)L_c}{\pi}$$  \hspace{1cm} (2)

### III. COST FUNCTIONS

To analyze the performance of F-HMIPv6, we focus on location management procedure which is further split into location update procedure and packet delivery procedure. We also assume that F-HMIPv6 supports route optimization.

#### A. Location Update Cost

Generally, an MN performs two types of movements: intra- and inter-domain movements. Accordingly, two location
update procedures are performed: intra-domain case and inter-domain case which includes intra-domain and legacy MIPv6 location update. Let \( \kappa, \tau \) denote the unit transmission costs in a wireless, wired link respectively, \( d_{x-y} \) the hop distance between \( x \) and \( y \), \( P_z \) the processing cost at network entity \( z \), the corresponding signaling load functions are expressed as follows:

\[
C_{\text{inter-domain}}^z = 7\kappa + 9\tau * d_{AR-MAP} + 3P_{\text{MAP}} + P_{AR}
\]

\[
C_{\text{inter-domain}}^z = C_{\text{inter-domain}}^z + C_{\text{MIPv6}}^z
\]

Based on the signaling load functions, the location update cost per MN is expressed as follows:

\[
C^l = \frac{R_d * C_{\text{inter-domain}}^z + (N_{AR} * R_c - R_d) * C_{\text{inter-domain}}^z}{\rho * A(R)}
\]

Where \( N_{AR} \) is the number of ARs in a MAP domain, \( A(R) \) is the area of the MAP domain of \( R \) rings, \( \rho \) the user density in a cell, \( R_c \) and \( R_d \) be cell crossing rate and domain crossing rate, respectively.

**B. Packet Delivery Cost**

Let \( P_z \) be the processing cost at network entity \( z \), \( C_T \) the packet transmission cost from a CN to the MN, the packet delivery cost is expressed as follows:

\[
C^p = P_{MAP} + P_{HA} + C_T
\]

In F-HMIPv6, a MAP maintains a binding cache table for translation between MNs’ RCoAs and their LCoAs, same as at an HA for manages the binding between MNs’ HoAs and their CoAs. All packets addressed to an MN will be intercepted by an HA for manages the binding between MNs’ HoAs and their CoAs. All packets addressed to an MN will be tunneled to the MN’s new LCoA. Hence the processing cost at the HA is given by:

\[
P_{HA} = \lambda_p * \theta_{HA}
\]

Let \( \kappa, \tau \) denote the unit transmission cost in a wireless, wired link respectively, \( \lambda_s, \lambda_p \) the session arrival rate and the packet arrival rate, \( d_{x-y} \) is the distance between \( x \) and \( y \), the packet transmission cost is calculated as follows:

\[
C_T = \kappa * \lambda_s + \tau * (\lambda_s - \lambda_p) * (d_{CN-MAP} + d_{MAP-AR}) + \\
\tau * \lambda_p * (d_{CN-HA} + d_{HA-MAP} + d_{MAP-AR})
\]

**C. Total Cost**

Total cost is defined as the sum of location update cost and packet delivery cost, and it is expressed as follows:

\[
C^t = C^l + C^p
\]

**IV. NUMERICAL RESULTS**

In this section, we analyze the impact of various wireless system parameters on the above-mentioned costs. The parameters values are taken from [13-15], shown in Table 1.

<table>
<thead>
<tr>
<th>( \alpha )</th>
<th>( \beta )</th>
<th>( \lambda_s )</th>
<th>( \lambda_p )</th>
<th>( \theta_{HA} )</th>
<th>( \tau )</th>
<th>( \kappa )</th>
</tr>
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<tbody>
<tr>
<td>0.1</td>
<td>0.2</td>
<td>1</td>
<td>0.1</td>
<td>20</td>
<td>1</td>
<td>2</td>
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<table>
<thead>
<tr>
<th>( P_{HA} )</th>
<th>( P_{MAP} )</th>
<th>( P_{AR} )</th>
<th>( N_{CN} )</th>
<th>( L_c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>12</td>
<td>6</td>
<td>2</td>
<td>120 m</td>
</tr>
</tbody>
</table>

\[
\frac{d_{CN-HA}}{d_{HA-MAP}} \quad \frac{d_{CN-MAP}}{d_{MAP-AR}}
\]

| 6 | 6 | 4 | 2 |

**A. The Impact of the User Velocity on Location Update Cost**

Fig. 3 and Fig.4 demonstrate location update cost versus user’s average velocity with a MAP domain of one ring and six rings respectively. In this analysis, the user density is set as 0.0002. As lower velocity leads to a lower cell/domain crossing rate, results in less location update cost. In addition, F-HMIPv6 requires more signaling overhead than HMIPv6 (34.55% more for \( R=1 \) and 57.66% more for \( R=6 \)); compared to MIPv6 without RO, F-HMIPv6 presents 71.85% more location update cost for \( R=1 \) and 53.02% more for \( R=6 \); compared to MIPv6 requires more signaling overhead than HMIPv6 (34.55% more for \( R=1 \) and 57.66% more for \( R=6 \)). Comparing of the two figures, we find that the increasing of MAP size leads to significant reduction of location update cost in case of HMIPv6 and F-HMIPv6. This is because an MN served by a MAP with smaller domain size is more likely to perform inter-domain movements, results in higher update costs. Furthermore, Fig. 4 also shows that HMIPv6 delivers better performance than MIPv6; this means increasing domain size can significantly reduce location update cost.
B. The Impact of the User Density on Packet Delivery Cost

Fig. 5 and Fig. 6 show the variation of packet delivery cost as the average user density changes for a MAP domain with one ring and six rings respectively. Packet delivery cost increases linearly as the user density augments for HMIPv6 and F-HMIPv6; this is because the processing cost at the MAP, especially the lookup cost to check the binding cache table, is proportionally to the number of MNs in a MAP domain. The two figures also show that increasing MAP domain size leads to a rapid augmentation of packet delivery cost for F-HMIPv6 and HMIPv6, but has no influence on MIPv6; this is because the processing cost at the MAP, especially the routing cost, is proportional to the logarithm of the number of ARs in a MAP domain. Moreover, Fig. 6 shows that when the user density is larger than 0.002, both F-HMIPv6 and HMIPv6 require more packet delivery cost than MIPv6 protocol. However, F-HMIPv6 always delivers the same performance as HMIPv6 in terms of packet delivery cost.

C. The Impact of the Session-to-Mobility ratio on Total Cost

Fig. 7 and Fig. 8 illustrate the variation of total cost as the average session-to-mobility ratio changes for a MAP domain with one ring. The session to mobility ratio (SMR) is defined as the ratio of the session arrival rate to the user mobility ratio, it is analogous to the call-to-mobility (CMR) used in cellular networks for performance analysis. Under the fluid-flow model, the SMR is defined as $\frac{\lambda_s}{R_c}$, i.e. the session arrival rate divided by the cell crossing rate. As the value for $\rho$ and $v$ is fixed, and $R_c = \frac{\rho * v * L_c}{\pi}$, this leads to a fixed value of cell crossing rate, as a result, the augmentation of the SMR implies the increasing of session arrival rate, so the total cost increases. In case of $SMR \leq 1$, i.e. $\lambda_s \leq R_c$, location update cost is more dominant than packet delivery cost over the total cost, shown in Fig. 8. Under this circumstance, MIPv6 with RO requires the most total cost amongst all schemes. And the total cost in descent order is MIPv6 with RO, F-HMIPv6, MIPv6 without RO, HMIPv6. Moreover, as the value of SMR increases to be larger than 1, the impact of location update cost on the total cost reduces whereas packet delivery cost over the total cost becomes more important, shown in Fig. 7 by the curves' tendency. The more SMR, the more important packet delivery cost over the total cost is. Consequently, HMIPv6 and F-HMIPv6 merge to one curve. Because these two schemes employ the same packet delivery cost function. However, MIPv6 with RO yields the best performance among all, due to no additional processing cost at the MAP.
Fig. 9 and Fig. 10 also show the relationship between the total cost and the average session-to-mobility ratio for a MAP domain with six rings. The total cost increases as the SMR augments, the same observation as Fig. 7 and Fig. 8, except that increasing the MAP domain size leads to the augmentation of packet delivery cost, compared to MIPv6 without RO.

V. CONCLUSION

This article presents a comprehensive performance analysis of fast handover for hierarchical MIPv6 using an analytic model which is based on fluid-flow model. The impact of various wireless system parameters on the cost functions is evaluated. We find that F-HMIPv6 requires more signaling cost for location update, however delivers the same performance as HMIPv6 in terms of packet delivery cost. Further study will be carried out to evaluate the performance in terms of handoff blocking probability, handoff latency and packet loss rate.

REFERENCES