Cost Analysis of a Three Layered MIPv6 (TLMIPv6) Mobility Model and HMIPv6

Nitul Dutta
Computer Engineering Department,
Sikkim Manipal Institute of Technology, Sikkim
India
Email: nituldutta@gmail.com

Iti Saha Misra
Electronics and Telecommunication Engineering
Jadavpur University, Kolkata,
India
Email: itisahamisra@yahoo.co.in

Abstract - In this paper cost analysis of a three-layer hierarchical model and HMIPv6 is done. The objective of this work is to examine the signaling cost, tunneling cost and packet dropping probability at top level anchor agents of a Multi-level (3 levels) architecture and HMIPv6 and to observe in what scenario multiple levels of hierarchy can give better performance over HMIPv6. Analysis of both the models revels that neither of the model is suitable for all scenarios. There are certain scenarios where the three layer architecture is suitable than HMIPv6. When both the speed and density of mobile node is high, large BU signal is generated and traverse the entire local network in HMIPv6. But due to the presence of intermediate anchor agents these signal overloads only a portion of the local network. So, in such situations TLMIPv6 outperforms HMIPv6. In the first part of the paper, above mentioned parameters are evaluated mathematically and then they are verified by *ns-2* simulation. A comparative analysis is presented at the end of the paper to provide an insight under what scenarios three layer model perform well.

Keywords: Mobile, Mathematical Analysis, Hierarchical.

I. INTRODUCTION

In mobile network, when an MN stay away from its original location, it has to send binding update (BU) messages to its home agent (HA) and correspondent node (CN). HA and CN have to acknowledge the BU messages using binding acknowledgement (BACK) messages. Also, when binding lifetime expires, binding information is to be refreshed by exchanging binding refresh (BR) and BACK messages. All the mobility management strategies try to minimize the signaling cost either by minimizing the number of control messages, or reducing the size of the message or by restricting the movement of the control messages within a specific region. Studies show that the reduction of the signaling load associated with IP mobility management is a challenging job [18],[19]. A lot of alternative strategies have been proposed recently to reduce the signaling load in IP-based wireless networks [6], [16], [19-23]. There are few problems and scenarios, which may be caused by increased signaling load generated by the binding related messages. One of the problems introduced by the increased signaling load is reduced scalability. When large number of MNs visits a foreign network, the signaling load of binding update is higher. Therefore, the increased signaling load may cause reduced scalability in terms of the overall network resources [2], [4], [5]. Higher signaling load may increase processing overhead at the mobility agents such as the HA, CN and MAP. This processing may introduce a considerable delay in the network [24], [25]. To provide higher degree of scalability, and handling of both slow and fast moving MNs efficiently, anchor agents (like MAP in HMIPv6) may be placed hierarchically in the local domain either to form a pyramid structure [5] or a tree [11]. Although, hierarchical arrangement of anchor agents minimize the signaling overhead due to location update in one hand, it increases the tunneling cost and cost of binding refresh in the other hand. That is why; a balance in both is essential for acceptance of hierarchical architecture for mobility management in IP based network. The number of layers could not be increased to a large value nor, a very small value helps us to provide acceptable hierarchy. Establishing an optimized value for level of hierarchy in the architecture is really a challenging job. Our earlier work [1] an *n*-layered architecture is analyzed mathematically with the value of $n=6$. The results obtained in this analysis shows optimal values for handoff latency, signaling cost and tunneling cost with $n=3$. That is why, here we extended the work of [1] by evaluating the cost of both three layer model and HMIPv6 using the same network and mobility scenario to give an insight possible deployment of three layer model along with the HMIPv6. Intention is also made to establish the model as pyramid like structure with a value for number of lower anchor agents under a higher layer agent. A study to see, in what situation the three-layer model may outperform the HMIPv6, is been made in this paper. A similar method of comparison as [4] is used. The following assumptions are made during the discussion of the work:

- An optimized value of binding lifetime as proposed in [10].
- Lower layer anchor agents under a single higher layer agent are limited

- Distance between any two consecutive layers is as equal as possible and measured in terms of hop count.

II. RELATED WORK AND MOTIVATION

There exists lot of work on mobility related issues for IP based wireless networks. All these work mainly deals with minimized handoff latency, signaling cost of packet delivery and location update, packet tunneling cost etc. This section discusses few of them and some issues that they have not covered; which motivate us to carry out this work. The work done in [10] is one of the frequently referred papers where a hierarchical architecture is presented in order to show the behavior of MIPv6. A mathematical analysis is proposed in this model where anchor agents are organized as tree. They have suggested an optimal level of hierarchy that gives best performance in terms of cost of location update and packet delivery. An investigation of session to mobility ratio (SMR) and their impact on total cost and optimal hierarchy also been done in the paper. But this work has not discussed anything about mobility pattern of mobile nodes and their impact in deciding optimal layers of hierarchy for optimized performance. When an MN visits a foreign network it has to inform HA about its new location using BU messages. BU messages carry binding lifetime, which indicates how long that binding association would be valid. An optimal value of the binding lifetime may significantly reduce the signaling overhead for location management. Because a short binding lifetime may increase the binding association update rate and large value of binding lifetime may produce inconsistency in location information. In paper [9], a method of calculating optimal binding lifetime has been discussed. Here, the optimal binding lifetime is shown as a function of user mobility, traffic workload, and network structure. An algorithm for dynamically setting the binding lifetime in MIPv6 based network is proposed based on an analytical model. The numerical results of the system simulation are also demonstrated. Optimal binding lifetime according to [9] is used calculate BR cost during handoff. There is another set of papers that compare various mobility management architectures. They compare different hierarchical architectures for IP based mobile network. Paper [6] presents a comparison of IP routing in mobile environments. Four protocols are considered, Mobile IP, Mobile IP with paging support, Mobile IP Regional Registration and Mobile IP Regional Registration with paging support. The comparison is done by mathematical model and simulation with signaling costs as metric. There is another set of papers [2], [4], and [6] that compare various mobility management architectures. They aimed at comparing different hierarchical architectures or mobile IP architecture without hierarchy.

Above mentioned work have remarkable contributions but few factors are not addressed, which are sometimes become very crucial and could not be overlooked in all the scenarios of mobile environment. First, of all, most of the work does not consider of binding refresh rate for signaling cost computation. Secondly, due to unpredictable movement of MN in a uniformly distributed direction in the range of $[0,2\pi]$, considering only area crossing rate and user velocity is not sufficient to estimate the signaling cost for location update. Thirdly, most of the papers stated above, have not discussed the impact of user density and speed of the mobile node on signaling cost. The work in [4] which is the basis of our work has covered few points mentioned above. Optimized binding lifetime is not used in the paper and no assumption is made regarding the number of lower layer anchor agents that can be covered under a higher layer anchor agent. As a contribution of the work presented here we address the issues that are included in previous works. A three-layered hierarchical model is presented and comparison is made with HMIPv6. The performance of the proposed model is first examined analytically and later analytical results are verified by simulation results using ns-2. Binding refresh rate, which is dependent on the binding lifetime of a MN with its anchor agent, is considered for signaling cost calculation. Same user movement pattern and network scenarios are considered for both, the three layers MIPv6 and HMIPv6 during analysis.

III. NETWORK ARCHITECTURE

In this section a brief discussion of HMIPv6 and proposed three layer MIPv6 (TLMIPv6) architecture is given in terms signaling load due to mobility management.

A. Hierarchical Mobile IPv6

HMIPv6 [5] divides the network into two section, backbone domain and local domain. An anchor agent called Mobile Anchor Point (MAP) is placed at the boarder of the local domain. MAP is attached to both backbone and local domain. It provides transparency of visiting MNs to HA as well as to CN . When a MN visits a foreign network, it acquires a Care-of-Address (CoA) and a Regional CoA (RCoA) from Router Advertisement (RA) beacon. The address of MAP or the RCoA is notified to MN’s HA as well as to CNs if any, by sending BU message. Both, the HA and CNs acknowledge MN for its BU request. Once this process of request and acknowledge is over, MAP receives all packets on behalf of the MN as long as it stays within its service area. The MAP encapsulates and forwards them directly to the MN’s current address. If the MN changes its current address (i.e. LCoA) within the same MAP, HA or CNs (if any) need not be updated because HA and CNs are aware only of RCoA not LCoA and the RCoA does not change as long as the MN moves within the same MAP domain. It minimizes the signals in the backbone network.

B. Three layered MIPv6: TLMIPv6

The architecture proposed in this paper comprises of a backbone and a inside domain (Fig. 1). The inside domain is subdivided into local, regional and global domains. We put three different anchor agents (anchor points) to cover these three regions. An agent called MAP as in HMIPv6 covers local domain, a Regional MAP (or RMAP) covers a regional domain and a Global MAP (or GMAP) [5] covers a global domain. We also use the term domain to mean a global domain. A GMAP advertise its IP address (GCoA) in its domain and all RMAPs under it use this address as GCoA. Packet sent by a CN to MN is either tunneled via HA or by CN itself to GMAP. GMAP sends the packet to a particular RMAP under which the MN is currently located. If the GCoA changes, then MN has to send a binding update (BU) message to HA. So, this scheme drastically reduces the signaling overhead in the backbone network. RMAP controls number of MAPs and MAP controls number of ARs. The address of a RMAP is known as RCoA, all MAPs within the same RMAP advertise the same RCoA. The IP address of a MAP is called the CoA. A MAP provides CoA, RCoA and GCoA to an MN. In a foreign network, MN configures its LCoA by address auto-configuration [10] and gets its CoA, RCoA and GCoA from the router advertisement message. MN has to bind its GCoA with HA and CNs (if any) with the help of binding update (BU) request message. Both the HA and CN acknowledges the BU request to MN through GMAP, RMAP and MAP. The binding life time and hence the binding refresh process discussed in context with HMIPv6 is also applicable in this new model and may overwhelm the backbone network in the situation defined there.

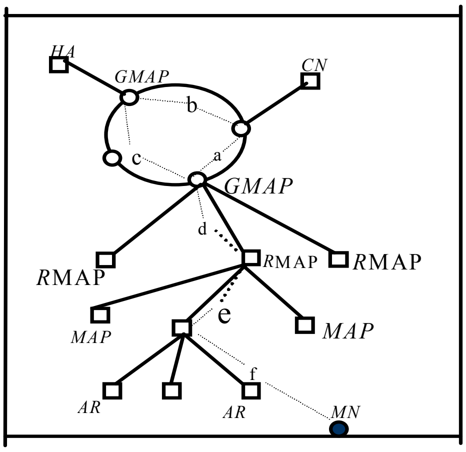


Fig. 1. TLMIPv6 Network Model

IV. SIGNALING LOAD IN TLMIPV6

With reference to Fig. 1 let us discuss the signaling load in the proposed model. To evaluate the signaling cost of HMIPv6 using the same network model, GMAP plays the role of MAP and all other anchor agents are general IP routers. Both HA and CNs are located in different networks than MN's visited network. The labels *a, b, c, d, e,* and *f* are distance in terms of hop counts between agents as shown in Fig. 1.

Three network ratios n_m , n_r , and n_g are introduced to observe the benefit of placing intermediate anchor agents in the local domain in comparison with HMIPv6. The network ratio n_m indicates the advantage of placing a MAP in the local domain in terms of distance traversed by the BU/BACK messages. It is calculated as the ratio of distance from the MAP to boundary of the local domain (i.e. $e+d$ in Fig. 1) to the distance from the MN to the boundary of the local domain (i.e $f+e+d$) because in the BU/BACK message has to traverse from MN to GMAP (where MAP is located in HMIPv6), i.e. $f+e+d$ in terms of number of hops. Hence, the gain is e+d and ratio is $(e+d)/(f+e+d)$. The network ratio n_r inside the regional domain is calculated as $d/(f+e+d)$ and $n_g=1$, since for both the architecture BU messages has to traverse same distance if the GMAP is required to be updated. These ratios n_m, n_r and n_g are between 0 and 1. A value of 1 indicates no gain at all. We assume the value of n_m and n_r as 1 for HMIPv6. The list of parameters used in this paper is provided in Table I.

Table I : List of parameters used

Parameter
n: Number of layers in the architecture
m: Number of MNs in a cell
N: Number of cells under a MAP
l_c *: Perimeter of a cell in meters*
l_r *: Perimeter of RMAP*
l_d *: Perimeter of a coverage of GMAP*
u_a*: Cost of acquiring LcoA by MN*
τ *: Cost of transmission per byte in wireless media*
ω *: Cost of transmission per byte in wired media*
ρ *: User density within a cell*
λ_s *: No of packets per session*
P_s*: Avereage Packet size*
d_T*: Tunneling bytes*
ε *: Fraction of CNs communicating with a visitor MN during handoff*
$\Re$ *: Weighted factor for BR cost*
a : Hop count between CN and GMAP
b : Hop count between CN and HA
c : Hop count between HA and GMAP
d : Hop count between GMAP and RMAP
e : Hop count between RMA and -MAP
f : Hop count between CN and GMAP
t_s*: Time to completely transmit a packet from MAP*
C_{ed} *: Cost of encapsulation and decapsulation*
q : Probability of a packet being sent to GMAP from CN without intervening HA

V. USER MOVEMENT AND MOBILITY MODEL

We assume that the cell changing process by MN is modeled as Markov process, where, a state in the process represents a cell. Transition diagram of cell changing process is depicted in Fig. 2. Based on this diagram, in the next subsections we will discuss MNs mobility pattern for both TLMIPv6 and HMIPv6 architecture.

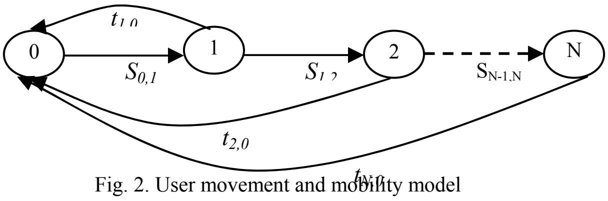


Fig. 2. User movement and mobility model

A. *Modeling user mobility in TLMIPv6*

A MAP in a three-layered model may have N number of cells under it. Out of N cells, the MN may visit k≤N cells before it moves to another MAP. State *0* indicates the MN stays outside the coverage of the current MAP. A transition of state from s_i to s_{i+1} for $i \leq l \leq k-1$, represents the changing of a cell by MN and, at this point MAP need to be updated. Transition from state *0* to *1* or *k* to *0* implies that MN is moving to a cell under new MAP, so RMAP update is required. The duration for which the MN stays under the coverage of the MAP no way influence a state transition. Again, MN can move only to its adjacent cell. Finally, MNs change its cell at a constant rate α. The location update process due to changing of MAP and RMAP may also be describe in the same way as that of the cell changing process. From RMAP point of view, the states in the transition diagram represent different MAPs. The number of states *k* is less than or equal to the total number of MAPs covered by the RMAP and determined by the ratio r_{RM}. Same explanation may also be made in terms of GMAP. When MN moves to a new GMAP, both HA and CNs need to be updated, hereby, injecting binding update signaling traffic in the back bone network.

The parameters l_c, l_s, l_r, and l_d are the perimeter of a coverage under cell, MAP, RMAP and GMAP respectively. Considering cell as the basic coverage area, other perimeters are calculated in terms of l_c as given bellow. The parameter l_s is determined by the number of cells included under the MAP which in turn measured by the parameter r_{MA}. Similarly, l_r, and l_d is determined by r_{RM} and r_{GR}.

So, $l_s = \frac{l_c}{r_{MA}}$, $l_r = \frac{l_c}{r_{RM} r_{MA}}$ and

$$l_r = \frac{l_c}{r_{GR} r_{RM} r_{MA}}$$

We assume random walk mobility model [14] with a speed of MN *v m/s* and that the MNs move in the uniform direction in [0,2π]. The symbols α, β, γ and η represents the rate of change of cell, MAP, RMAP and GMAP respectively and calculated as given under [10].

$$\alpha = \frac{\rho v l_c}{\pi} \text{...(1)}$$

$$\beta = \frac{\rho v l_s}{\pi} \text{....(2)}$$

$$\gamma = \frac{\rho v l_r}{\pi} \text{....(3)}$$

$$\eta = \frac{\rho v l_d}{\pi} \text{......(4)}$$

The parameters r_{GR}, r_{RM} and r_{MA} are used to calculate α, β, γ and η so that number of lower layer agents effect the handoff rate. The inclusion of term ρ (the user density) in calculation of α, β, γ and η reflects the effect of user density in handoff rate calculation. Although, there is *N* number of cells under a MAP, an MN may visit only *k* out of *N* number of cells before move to another MAP. So, number of cells visited by an MN, before moving to another MAP obeys Poisson's distribution with average cell changing rate α. The probability distribution $p_{ck}(t)$ indicates the probability of *k* number of cells visited by an MN within a certain time interval is expressed as

$$p_{ck}(t) = \frac{(\alpha t)^k e^{-\alpha t}}{k!} \text{.........(5)}$$

When an MN visits a foreign network it perform a binding registration with a BS in the new network. The first cell (i.e. BS) that it registers is assumed to be the state *1* in Fig. 2. State *0* indicates the location of a node in different MAP from the current one. The probabilities $p_{c1}(t)$, $p_{c2}(t)$, $p_{c3}(t)$,…… $p_{ck}(t)$ represents the probabilities of visiting *1,2,…,k* number of cells within a period *t,* then from law of probability we can have,

$$c(k) = p_{c1}(t) + 2p_{c2}(t) + \ldots\ldots + kp_{ck}(t)$$

The quantity *c(k)* represents the total number of cells visited by an MN under a MAP. Also, for every new cell visited by the MN, the MAP needs to be updated. This value of *c(k)* is been used to calculate location update cost of MAP in section VI. Again, from law of total probability,

$$p_{c0}(t) + p_{c1}(t) + \ldots\ldots + p_{ck}(t) = 1$$

and hence

$$p_{c0}(t) = 1 - \sum_{i=1}^{k} p_{ci}(t) \quad \text{……(6)}$$

$p_{c0}(t)$ represents the probability of an MN to leave the boundary of a MAP. At this moment RMAP need to be updated.

Similarly, $p_{mk}(t)$ represents the probability of visiting *k* number of MAPs by an MN before it moves to the coverage of new RMAP. Taking into account the MAP handoff rate β, $p_{mk}(t)$is calculated as

$$p_{mk}(t) = \frac{(\beta t)^k e^{-\beta t}}{k!} \text{...(7)}$$

and,

$$m(k) = p_{m0}(t) + 2p_{m1}(t) + \ldots\ldots + kp_{mk}(t)$$

is the total number of MAP visited by the MN under a RMAP. Also,

$$p_{m0}(t)+p_{m1}(t)+...+p_{mk}(t)=1$$

and

$$p_{m0}(t)=1-\sum_{i=1}^{k}p_{mi}(t) \quad .....(8)$$

The term $p_{m0}(t)$ represents the probability of an MN to leave the boundary of a RMAP where GMAP need to be updated.

Finally, $p_{gk}(t)$ the probability of k number of RMAPs visited by an MN in duration t is expressed as

$$p_{rk}(t)=\frac{(\gamma t)^{k}e^{-\gamma t}}{k!}...(9)$$

Total number of RMAPs visited by the MN under a GMAP is

$$r(k)=p_{r0}(t)+2p_{r1}(t)+.....+kp_{rk}(t)$$

Also from the law of probability,

$$p_{r0}(t)=1-\sum_{i=1}^{k}p_{ri}(t) \quad ......(10)$$

Where, $p_{r0}(t)$ represents the probability of changing the current GMAP. In such situation, the binding update messages is sent to the HA and CN.

B. Modeling user mobility in HMIPv6

In HMIPv6 architecture when an MN changes a cell, it updates the MAP. We assume the same cell-changing rate as in TLMIPv6 and all the probability functions derived are equally applicable to HMIPv6 model. The only difference occurs, when MN changes the MAP, according to HMIPv6 model it has to update HA and CN.

VI. MATHEMATICAL ANALYSIS

The analytically derivation of location update costs (i.e., the sum of the binding update costs and the binding refresh costs), packet tunneling costs, inside domain signaling costs, outside domain signaling costs, and total signaling costs, generated by an MN during its average domain residence time in three layered model and HMIPv6 is done in this section. The user mobility and network models given in the previous section is the basis of this analysis. We differentiate the following three binding-related messages:

- BU Message, which is generated by an MN's subnet crossings
- BR Message, which is periodically generated whenever the binding lifetime is close to expiration
- BACK Message, which is an acknowledgement message for the BU or the BR message

A. A. Analysis for TLMIPv6

On movement of the MN from one place to another in the foreign network it traverses through different anchor agents. Depending upon its new position, it has to update MAP, RMAP or GMAP as well as HA and CNs by exchanging BU/BACK messages. Signaling cost is determined by the size of BU/BACK and the distance traversed by each of them. Hence, the distance (in terms of hops) of the anchor agent to whom MN sends the BU message in an important parameter to increase or decrease the signaling cost. Again, when an MN stays for long time it has to send BR messages periodically to the relevant anchor agents to keep its binding alive. BR is also acknowledged accordingly using BACK message. This refreshing of binding information is as costly as that of the binding update process. Therefore, the total signaling cost S_u may be assumed as comprises of two different components. The first component represents the cost incurred due to binding update process, denoted by B_u and the second component represents the cost incurred due to binding refresh process and denoted by B_r. So, mathematically,

$$S_u=(1-\Re)B_u+\Re B_r...(11)$$

Where, $0<\Re<1$ is a constant assign some weight age of binding refresh cost. The idea behind the use of this weight age factor $\Re$ is that, binding refresh cost involve only when an MN stays for long time under the coverage of an agent. This long duration stay may be either due to very large coverage range of cells (or other anchor agents) or slow moving speed of the MN. When coverage area is not too large fast moving MN does not produce BR messages because before binding lifetime expires it crosses the range of the respective anchor agent. For fast moving MN, $\Re$ tends to zero hence a negligible contribution to the total cost *(S_u)* in equation (11) and increases the contribution with the decreasing of speed. We assume (in result section) $\Re=0$ for speed of MN *90km/hr* and *1* for speed *20km/h*. In the following subsections we will discuss both binding update *(B_u)* and binding refresh cost *(B_r)* separately

a. Binding Update Cost

When an MN enters a foreign network it first registers with the nearest BS. During the registration it has to acquire the LCoA, RCoA and GCoA by stateless auto configuration. Afterwards, when it changes a cell, only the LCoA changed which demands the updating MAP. We assume that the size of the BU and BACK message are same and it is of *s bytes*, the cost of transmission in wireless and wired media is τ and ω *unit per bytes* respectively. The cost of updating MAP during the stay of the MN within the coverage of MAP, which is denoted by C_{CM} is calculated as

$$C_{CM}=c(k)(u_m+u_a)n_m..(12)$$

Where u_a is the cost of acquiring LCoA (assumed constant), $u_m=2s\omega f$ is the cost of updating MAP and *m(k)* is the total number of cells visited by the MN before it leaves the MAP as given in section V, f is the distance to MAP from MN in terms of hops and n_m is the network ratio. Upon change of a MAP, MN has to update the RMAP by exchanging BU and BACK messages. The cost of updating the RMAP $C_{CR,}$ is calculated as

$$C_{CR} = m(k)u_r n_r ...(13)$$

where, $u_r=2s(f+e)$ is the cost of transmission of BU/BACK messages to MAP and all other parameters are as discussed in the earlier sections. Change of GMAP (C_{CG}) involve the update of both HA and al the CNs that a MN communicating with. Hence,

$$C_{CG} = r(k)u_g n_g + p_{r0}(t)(\varepsilon u_c + u_h.)...(14)$$

$u_h=2s\omega(f+e+d+c)$ and $u_c=2\omega s(f+e+d+a)$ is the cost of transmitting BU and BACK messages to GMAP , HA and CN respectively, ε is the number of CNs that communicating with MN.

b. Binding Refresh Cost

Every MN has to refresh its binding information before binding life time expires. The life time of the binding is determined at the time of registration of MN with the anchor agent. A long binding life time may lead to wrong information about the location of the MN and a very short binding lifetime may overwhelm the network by exchange of BU/BACK message. The work [8] provides a mathematical analysis of estimating optimal binding lifetime of MN. They have shown that the binding lifetime of MN is influenced by session arrival rate, speed of the MN and residence of MN under the coverage of an anchor agent. We have adopted the method stated in [8] to estimate an optimum binding lifetime. If an MN changes its anchor agent before the expiry of binding lifetime, then binding need not refresh.

The optimized value of binding life time of MN with MAP is computed as

$$t_{om} = \frac{u_m}{p_{ck}(t)\lambda_s C_{pd-map} + p_{c0}(t)\lambda_m}$$

where, u_m is the cost of updating MAP, $p_{ck}(t)$is the probability of changing cells within a MAP, λ_s is the session arrival rate, $C_{pd-map}=(\omega+\tau)(d_{t-map}+p_s)$ is the packet delivery cost to MN from MAP, d_{t-map} is packet tunneling bytes from MAP to MN, p_s is the packet size in byes, λ_m is the estimated residence time of MN under MAP and calculated as $1/\beta$ *sec.* Other terms are as discussed in earlier sections. MN traverse $m(k)$ number of cells (section V) before move to another MAP. So, time required to cross a MAP, t_m is given by,

$$t_m = \frac{m(k)l_c}{v}\text{sec}$$

Also, a total of m_r times the MAP need to be refreshed and

$$m_r = \frac{t_m}{t_{om}}$$

Taking all the parameters calculated above the cost of MAP refresh is calculated as

$$C_{RM} = m_r u_m .... (15)$$

Similarly, $$t_{or} = \frac{u_r}{p_{mk}(t)\lambda_s C_{pd-rmap} + p_{m0}(t)\lambda_r}$$

where, u_r is the cost of updating RMAP , $p_{rk}(t)$is the probability of changing MAP within a RMAP, $p_{d-rmap}=f\omega(d_{t-rmap}+p_s)$, d_{t-rmap} is packet tunneling cost from RMAP to MAP, p_s is the packet size in byes, λ_r is the estimated residence time of MN under RMAP and calculated as $1/\gamma$ *sec.* MN traverse $r(k)$ number of cells (section V) before it moves to another RMAP. So, it needs t_r secs to cross a RMAP

$$t_r = \frac{r(k)l_s}{v}\text{sec} \quad r_r = \frac{t_r}{t_{or}}$$

Hence, a total of r_r times the RMAP need to be refreshed. Hence, the cost of RMAP refresh is calculated as

$$C_{RR} = r_r u_r .... (16)$$

Also,

$$t_{og} = \frac{u_g}{p_{gk}(t)\lambda_s C_{pd-gmap} + p_{g0}(t)\lambda_g}$$

where, u_g is the cost of updating GMAP , $p_{gk}(t)$is the probability of changing GMAP, $C_{pd-gmap}=e\omega(d_{t-rmap}+p_s)$, d_{t-gmap} is packet tunneling cost from GMAP to RMAP, λ_g is the estimated residence time of MN under GMAP and calculated as $1/\acute{\eta}$ *sec.* MN traverse $g(k)$ number of cells (section V) before it moves to another GMAP. So, it needs t_r secs to cross a RMAP

$$t_r = \frac{r(k)l_s}{v}\text{sec} \quad r_r = \frac{t_r}{t_{or}}$$

Hence, a total of g_r times the GMAP need to be refreshed. Hence, the cost of GMAP refresh is calculated as

$$C_{GR} = g_r u_g .... (17)$$

c. Packet Tunneling Cost

Packet tunneling cost is measured in terms of number of bytes added in the packet to tunnel from an anchor agent to another anchor agent. All data packets transmitted to MN need to be first tunneled to GMAP, GMAP tunneled to RMAP and RMAP tunneled it to MAP. Finally the packet is transmitted to MN via the AR. Every anchor agent adds equal number of bytes say d_t in the packet tunneled to lower anchor agent. Also, the tunneled packet is decapsulated and encapsulated at the anchor agent. So tunneling process involves an encapsulation and decapsulation cost say C_{ed}. When a CN wanted to communicate with any MN, it sends first few packets to MNs home agent if it is not aware of the MNs current location. Once the CN acquire MN's CoA, it sends packets directly to the MN. Let the probability of a packet being directly send to the MN via GMAP without intervening HA is q and through HA is *(1-q).* The cost of packet tunneling in TLMIPv6 is calculated as

$$C_{TU} = \lambda_s\{qC_d + (1-q)C_{id}\}..(18)$$

the term C_d indicates the cost of delivering the packet to MN without intervention of HA and calculated as

$$C_d = d_t\omega(a + d + e) + 3C_{ed}$$

because in this the packet is directly tunneled to GMAP from CN and then decapsulate and encapsulate three times at each of the anchor agents GMAP,RMAP and MAP. The term C_{id} indicates the transmission of the packet via HA and calculated as

$$C_{id} = d_t\omega(c + d + e) + 3C_{ed}$$

In this case the packet is first tunneled by HA to GMAP and encapsulated and decapsulated in the anchor agents.

B. B. Analysis for HMIPv6

Signaling cost for HMIPv6, denoted by S_{uh} is expressed mathematically as,

$$S_{uh} = (1 - \Re)B_{uh} + \Re B_{rh} ...(19)$$

a) Binding Update Cost for HMIPv6

All the assumptions made in the previous sections, hold good in this computation. The subnet crossing involves MAP update. The cost of updating MAP during the stay of the MN within the coverage of MAP, which is denoted by C_{CM-H} is calculated as

$$C_{CC-H} = c(k)(u_m + u_a)..(20)$$

Where u_a is the cost of acquiring LCoA (assumed constant), u_m=2sω(f+e+d) is the cost of updating MAP and *m(k)* is the total number of cells visited by the MN before it leaves the MAP as given in equation(), *(f+e+d)* is the distance to MAP from MN in terms of hops.

Upon change of a MAP, MN has to update the HA and CN. The cost of updating the RMAP $C_{CR,}$ is calculated as

$$C_{CG-H} = m(k)u_m + p_{m0}(t)(\varepsilon u_c + u_h.)...(21)$$

u_h=2sω(f+e+d+c) and u_c =2ωs(f+e+d+a) is the cost of transmitting BU and BACK messages to HA and CN respectively, ε is the number of CNs that communicating with MN.

b) Binding Refresh Cost for HMIPv6

Let the optimized binding life time for MAP (i.e. GMAP in TLHMIPv6) is t_{om}

$$t_{om} = \frac{u_m}{p_{ck}(t)\lambda_s C_{pd-map} + p_{c0}(t)\lambda_m}$$

Where λ_g is the estimated residence time of MN under the coverage of MAP and calculated as *1/β sec.* A MN traverse *c(k)* number of cells before move to another MAP. So, it needs t_{mh} secs to cross a MAP

$$t_{mh} = \frac{c(k)l_c}{\beta}\sec \quad m_{rh} = \frac{t_{mh}}{t_{om}}$$

Hence, a total of m_{rh} times the MAP need to be refreshed.

$$C_{MR-H} = m_{rh}u_m .... (22)$$

c) Packet Tunneling Cost for HMIPv6

If the probability of a packet being directly send to MN from CN without intervening HA is *q*, a packet is tunneled to the MN through HA is *(1-q).* The cost of packet tunneling is

$$C_{TU-H} = \lambda_s\{qC_{dh} + (1 - q)C_{idh}\}..(23)$$

the term C_{dh} indicates the cost of delivering the packet to MN without intervention of HA and calculated as

$$C_{dh} = d_t\omega(a + d + e) + C_{ed}$$

The term C_{idh} indicates the transmission of the packet via HA and calculated as

$$C_{idh} = d_t\omega(c + d + e) + C_{ed}$$

In this case the packet is first tunneled by HA to MAP.

VII. ANALYTICAL RESULTS

The analytical results based on the discussions in section VI are presented in this section. The values for the fundamental parameters are given in the Table-II.

Table I : Parameters used

l_c	d_T	u_a	$\Re$	ε	κ	λ_s	τ	ω	P_s
200	*40*	*20*	*.35*	*5*	*10*	*10*	*20*	*10*	*512*
A	*b*	*c*	*d*	*e*	*f*	C_{ed}	*q*	ρ	*R*
5	*6*	*5*	*3*	*3*	*5*	*10*	*.20*	*15*	*.35*

A. Analytical results for location update cost

Although same amount of cell changing takes place in both the architectures, they will not equally spread in the local domain. For HMIPv6 the messages traverses entire local domain but in TLMIPv6 it traverses only a portion of the domain like within MAP, within RMAP or within GMAP. Fig. 3.(a) is the BU cost in the different regions of TLMIPv6 for varying speed of the MN.

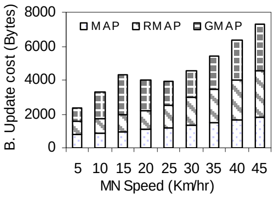


Fig. 3. (a) Region wise BU cost TLMIPv6

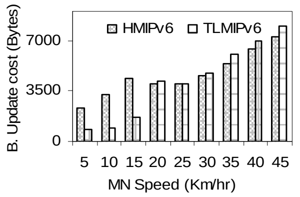


Fig. 3.(b) BU cost of TLMIPv6 of and HMIPv6

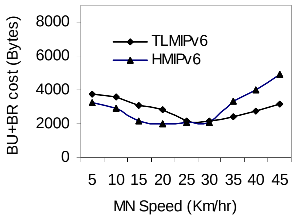


Fig. 4. BU+BR cost of TLMIPv6 and HMIPv6

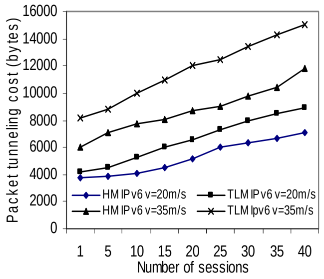


Fig. 5. Packet tunneling cost of TLMIPv6 and HMIPv6

C. Fig. 3.(b) is the location update cost in TLMIPv6 and HMIPv6. It shows that most of the cases the TLMIPv6 outperform HMIPv6. For TLMIPv6 control message does not visit the entire local domain. As mobility of the MN increases, the BU cost increases for both the protocol and at a speed of 25 km/hr *and higher, cost for both model is same, because in such situation MN changes its location more frequently performs large number of binding update. We assume that the number of cells under a MAP in HMIPv6 and GMAP in TLMIPv6 are equal. The cell coverage is* 200m *and MN density is* 15*MN per cubic km for both the architectures. Fig. 4 is the weighted total cost (BU+BR) as given in equation (11). For slow moving MN, BU cost is dominated by BR cost and for fast moving MNs this cost is dominated by the binding update cost. The weighted factor is* κ=0.57. *Up to a speed of* 25 *km/hr HMIPv6 generate fewer signals for binding management, this is because in TLMIPv6 architecture BR cost involves three refreshing costs for MAP, RMAP and GMAP. When speed of MN is higher than 25 km/hr the cost is almost similar, as in this range of speed, BR cost is less for both the architecture.*

B. Analytical results for packet tunneling cost

Packets destined to a visitor MN are tunneled through different anchor agents. Higher the hierarchy of anchor agent in the architecture, more the tunneling bytes added to the packet and hence, the cost of tunneling. Based on the tunneling cost evaluated mathematically in section VI a comparative discussion using graphs is given in Fig. 5 $v=20$km/hr and 5km/hr and probability $q=0.35$. Packet tunneling cost of TLMIPv6 is always higher than that of the HMIPv6. Because HMIPv6 uses only one tunneling whereas, the former tunnels three times. From packet tunneling point of view TLMIPv6 architecture is not advantageous over HMIPv6.

VIII. VALIDATION THROUGH SIMULATION

The analytical results are verified through simulation in *ns-2* environment. The simulation scenario is depicted in Fig. 8 with eight domains. The node 0.0.0 acts as CN. The node bearing address 4.0.0 is the HA whose nodes are visiting domain 4 i.e. 3.0.0, that is the domain covered by the Border Router 3.0.0. This domain has nine clusters (all clusters are not shown in the diagram) and all the Access Routers (AR) are shown in 9th cluster. The simulation code used is an extension of INRIA/Motorola MIPv6 [10] patch pack for ns-2 [11]. We have designed a Multi Layer Agent (MLA) module from the MIPv6Agent derived in that version. Some modifications have been made to the tcl library procedures as well as default values and trace files in order to implement our new agent. We have also introduced few new packet types in support of three-layer architecture. To observe the performance of our three layered model (TLMIPv6) MLA is placed in the intermediate router (IR) having address 3.7.0, 3.3.0, and 3.0.0. The visited MNs construct their care of address using stateless auto configuration [14]. We have used seven AR each of them representing a different IP subnet. To observer the simulation results the mobile nodes are uniformly distributed over the coverage area of AR and allowed to move according to the random walk mobility model [13].

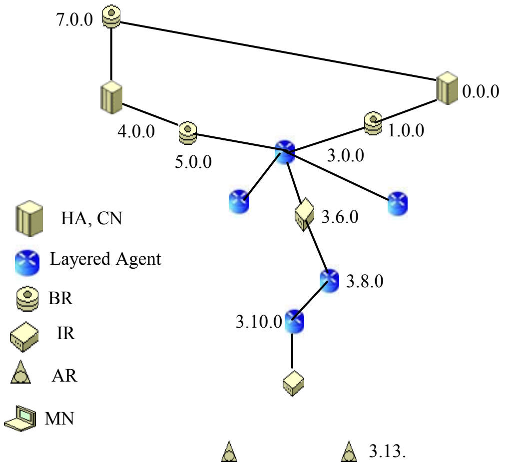
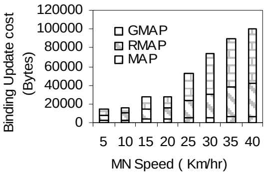


Fig. 8 Simulation scenario

A. Simulated location update cost

We count the total number of BU/BACK messages received by each of the anchor agent in the domain. The simulation program has been executed for duration of *200* secs with different speed of observed MN. The size of the BU/BACK messages is of *68* bytes. Fig. 9(a) shows the binding update cost due to exchange of BU/BACK messages between MN and MAP, MN and RMAP, and MN and GMAP separately for TLMIPv6 architecture. Slow moving MN sends lesser number of BU messages to higher layer anchor agents because it changes its agents less frequently. As soon as speed increases MN changes its anchor agents rapidly and hence the BU/BACK exchange increases. So, the cost of update, which is proportional to the number of BU/BACK messages exchanged, increases. In Fig. 9.(b) the total inside domain signaling cost is plotted. For TLMIPv6, it is the sum of BU messages received by MAP, RMAP and GMAP during the simulation period. For HMIPv6 it is the numbers of BU messages received by MAP which is located at the border of the domain.

Simulation shows a higher in HMIPv6 then the three-layered model.



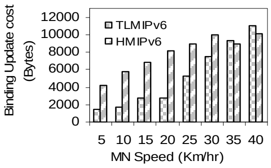
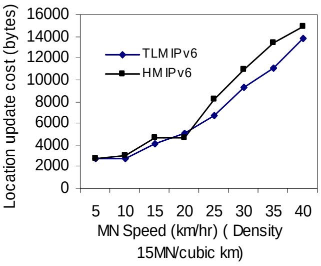


Fig. 9. (a) Region wise BU cost (TLMIPv6)

Fig. 9.(b) Comparative BU cost of HMIPv6 and TLMIPv6

Fig. 10 shows the signaling load in the backbone network for both TLMIPv6 and HMIPv6. The total number of BU messages received by the HA and the CN are calculated during the period of simulation with respect to MN speed. For both the model upto *20* km/sec speed, cost in the backbone network is same. For higher speed, three-layered model produce less signaling cost. The amount of BU in the backbone network is determined by the number of MNs that leaves the boundary of a GMAP not by the amount of visitor MNs located in the foreign network. So, the number of layers does not influence much in reducing the signaling load in the backbone network.



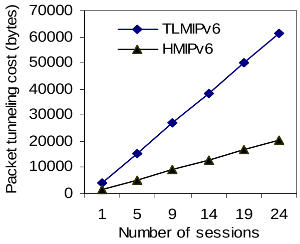


Fig. 10. Signaling load in the Backbone

Fig. 11. Packet tunneling cost of TLMIPv6 and HMIPv6

Fig. 11 presents the overhead incurred due to tunneling of packets to the MN via different intermediate anchor agents. The data is collected for various numbers of sessions with an average of *50* packets per session using FTP, CBR, Real-time audio, telnet and web application for observation of tunneling cost. The cost increases with the increase in session arrival rate for both the architecture. But in presence of three levels of hierarchy in TLMIPv6 the tunneling overhead is high compared to HMIPv6.

C. Packet delivery ratio with varying RMAP and MAP under a GMAP

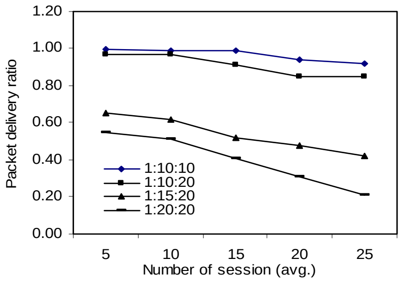


Fig. 12 Packet delivery ratio in TLMIpv6

Packet delivery ratio (PDR) is shown against different number of sessions per MN to understand the influence of lower layer anchor agent in three layered model. Different number of RMAP and MAP has been considered under a single GMAP. A fixed number of ARs (10) and visitor MN's (15) are used for simplicity of the computation. With the help of the plotted graph we wanted to show how many number of RMAPs under a GMAP and how many number of MAPs under a RMAP may be suitable for the three layered architecture with acceptable PDR. We have plotted four graphs to show PDR with GMAP: RMAP:MAP ratio as *1:10:10, 1:10:20*, *1:15:20* and *1:20:20.*

During the simulation period we allow *60%* of the MNs (9 out of 15) in each AR to send FTP data to CN. For each of the FTP connection PDR is calculated separately. The average of the PDR is been plotted in Fig. 12. Graph shows that, a ratio of *1:10:10* seems to be the best as it shows around *99 -100%* PDR. For the low loss sensitive traffic like stream traffic, ratio of *1:10:20* may be assumed suitable, as up to *3-5%* of packet loss is acceptable with good quality in such traffic. Since we are considering only elastic traffic, which highly sensitive to packet loss so the ration *1:10:10* is of much interest. With the help of the plotted graph we wanted to show how many number of RMAPs under a GMAP and how many number of MAPs under a RMAP may be suitable for the three layered architecture with acceptable PDR

IX. COMPARATIVE ANALYSIS AND CIONCLUSION

A comparative analysis of HMIPv6 and TLMIPv6 is presented in a tabulated form as a conclusion. Table III shows that, slow moving MN always produces higher BR traffic and when BR is high HMIPv6 shows better performance over TLMIPv6. But by considering the optimized value for different binding lifetime of anchor agents, TLMIPv6 produces less amount of BR traffic. Again, for slow moving MN, there is a high probability of the MN to stay within the same MAP and hence in such case BR traffic affects the entire local network but three layers model restrict the BU signals to a local domain only. So, in such case TLMIPv6 gives better performance. For MN with higher speed, more BU signals are generated and for that situation TLMIPv6 is preferred.

Table III: Comparison for BU and BR traffic

Speed	MN density	BR traffic	BU Traffic	Remarks
Low	Low	High	Low	Heavy BR detoriates the performance of TLMIPv6 so, HMIPv6 is preferred
Low	High	High	Moderate	All though BR is high, still higher MN density will generate high BU traffic for entire local network in HMIPv6. Hence TLMIPv6 is preferred.
High	Low	Low	High	TLMIPv6
High	High	Low	High	TLMIPv6

Table IV: Comparison for backbone traffic

Speed	MN Density	Traffic in the backbone		Remarks
		HMIPv6	TLMIPv6	
Low	Low	Low	Moderate due to BR traffic	HMIPv6
Low	High	High as more BU generated	Moderate due to BR traffic and may be controlled by adequate binding life time	HMIPv6/ TLMIPv6
High	Low	High	Low mostly for BU traffic	TLMIPv6
High	High	Very high	Moderate	TLMIPv6

Table V: Comparison on domain basis

Speed	Hops	Traffic in local network				Remarks
		HMIPv6	TLMIPv6			
			Local	Regional	Domain	
Low	Low	High	High	Low	Low	HMIPv6
Low	High	High	High	Moderate	Moderate	TLMIPv6
High	Low	High	High	Moderate	Moderate	TLMIPv6
High	High	Too High	High	High	Moderate	TLMIPv6

In Table IV, analysis of the traffic generated in the backbone network due to BU and BR messages is shown. It shows that **when both MN speed and density is low**, HMIPv6 generate less traffic compared to TLMIPv6, So HMIPv6 is the preferred mobility model. For slower MN with higher MN density BR traffic is more. Taking optimized value of binding lifetime may control the BR traffic. In that optimized binding lifetime, TLMIPv6 may be preferred as it has less total signaling overhead as compared to HMIPv6. As speed of MN is high, despite of low density on MN more BU messages are generated. In this case both HMIPv6 and TLMIPv6 generates considerable amount of BU traffic. But in TLMIPv6 MAP, RMAP and GMAP may control traffic in the backbone network. Again when both the **speed and density is high, large** BU signal traverse the backbone network in case of the HMIPv6 but less BU traffic traverse through the backbone due to presence of MAP, RMAP and GMAP. So, in such situations **TLMIPv6 outperforms HMIPv6**.

Table V shows another comparison of traffic in the local network for various speed and distance between different anchor agents in terms of hop count. Lower hop counts in the local network indicate that MN is closer to GMAP. Slow moving MN produces high BR traffic. Since the BR traffic affects the entire network and for TLMIPv6 BR is always more than that of the HMIPv6 so HMIPv6 is preferred. But if hop count is high, the signaling traffic overwhelm the large portion of the local domain in case of HMIPv6 but in case of three layer traffic each section of the network that is local, regional and domain have different signaling traffic. In such situation TLMIPv6 outperforms HMIPv6. For MN with higher speed, which generates higher BU traffic, TLMIPv6 is good.

REFERENCES

[1] Nitul Dutta, Iti Saha Misra, "Mathematical Modeling of Hierarchical Mobile IPv6 Based Network Architecture in Search of Optimal Performance", IEEE Int. Conference ADCOM 2007 , pp. 599-605

[2] A Campbell et al. "Comparison of IP micro mobility protocols", IEEE Pers. Commun.,vol. 9. vol.9, pp.72–82, Feb. 2002.

[3] H. Soliman et al. "Hierarchical mobile IPv6 mobility management (HMIPv6)". Internet draft, 4(1), 2003.

[4] K. Kong et. al. "A comparative study of signaling load of MIPv6 and HMIPv6 : analytical approach", IEICE Trans. Inf. Syst., 89(1):139–149, 2006.

[5] Iti Saha Misra et.al. "An approach for Optimal Hierarchical Mobility Management Network Architecture", IEEE 63rd VTC vol. 1(1):481–485, 2006.

[6] T. Poungkong et.al. "A comparative analysis on signaling cost of mobile ip regional registration with paging support", IEEE Communications Society / WCNC, 4(1), 2005.

[7] PENG Xue-hai., "A modeling in HMIPv6 and Intelligent Mobility Management scheme", Proc. 14th IEEE International Symposium on Personal, lndoor and Mobile Radio Communication, 14(1):2823–2827, 2003.

[8] C. Perkins, "IP mobility support", IETF RFC, 1(1):6, 2002.

[9] Z. D. Wu. "An approach for optimizing binding lifetime with mobile IPv6", Proc.s of the 28th Annual IEEE International Conference on Local Computer Networks, 1(1), 2003.

[10] Sangheon Pack, "A Study On Optimal Hierarchy in Multi-Level Hierarchical Mobile IPv6 Networks1`", Globecom 2004.

[11] "Mobiwan: ns-2 extensions to study mobility in Wide-Area IPv6 Networks," http://www.inrialpes.fr/planete /mobiwan.

[12] "Network Simulator (ns), version 2," http://www..isi.edu/nsnam/ns.

[13] Chr.Bettstetter, H.Hartenstein, and X.P´erez-Costa, "Stochastic Properties of the Random Waypoint Mobility Model," ACM Mobicom Workshop MSWIM, 2002.

[14] S. Thomson, T. Narten, T. Jinmei, "IPv6 Stateless Address Autoconfiguration," IETF RFC 4862, Sep 2007.

[15] Introduction to Wireless and Mobile Systems, 2nd Edition, Dharma Prakash Agrawal, Qing An Zeng Chapter 5,pg. 108"

[16] J. Xie and I.F. Akyildiz, "A novel distributed dynamic location management scheme for minimizing signaling costs in Mobile IP," IEEE Trans. Mobilecom., vol.1, no.3, pp.163–175, July-Sept. 2002.

[17] S. Pack and Y. Choi, "Performance analysis of hierarchical Mobile IPv6 in IP-based cellular networks," Proc. PIMRC 2003, pp.2818– 2822, Sept. 2003.

[18] I.F. Akyildiz, J. Xie, and S.Mohanty, "A survey of mobility management in next-generation all-IP-based wireless systems," IEEEWireless Commun., vol.11, no.4, pp.16–28, Aug. 2004.

[19] X. Zhang, G. Castellanos, and A.T. Campbell, "P-MIP: Paging extensions for Mobile IP," Mobile Networks and Applications (MONET), vol.7, no.2, pp.127–141, March 2002.
[20] W. Ma and Y. Fang, "Dynamic hierarchical mobility management strategy for Mobile IP networks," IEEE J. Sel. Areas Commun., vol.22, no.4, pp.664–676, May 2004.
[21] Y. Bejerano and I.Cidon, "An anchor chain scheme for IP mobility management," Wirel. Netw., vol.9, no.5, pp.409–420, 2003.
[22] K. Kong, S. Roh, and C. Hwang, "History-based auxiliary mobility management strategy for hierarchical Mobile IPv6 networks," IEICE Trans. Fundamentals, vol.E88-A, no.7, pp.1845–1858, July 2005.
[23] Y. Lee and I.F. Akyildiz, "A new scheme for reducing link and signaling costs in Mobile IP," IEEE Trans. Comput., vol.51, no.6, pp.706–711, June 2003
[24] S. Pack, B. Lee, and Y. Choi, "Proactive load control scheme at mobility anchor point in hierarchical Mobile IPv6 networks," IEICE Trans. Inf. & Syst., vol.E87-D, no.12, pp.2578–2585, Dec. 2004.
[25] R. Wakikawa *et al*, "Enhanced mobile network protocol for its robustness and policy based routing," IEICE Trans. Commun., vol.E87-B, no.3, pp.445–452, March 2004.