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,

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

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

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

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 $1/ή$ *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

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

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), $u_m=2s\omega(f+e+d)$ 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

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

$u_h=2s\omega(f+e+d+c)$ and $u_c=2\omega s(f+e+d+a)$ is the cost of transmitting BU and BACK messages to 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 $1/\beta$ *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.

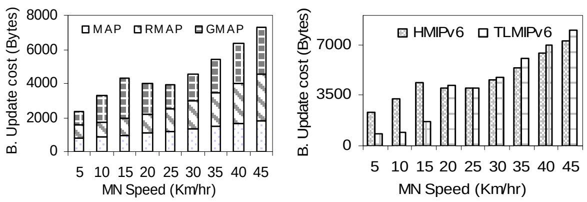


Fig. 3. (a) Region wise BU cost TLMIPv6 Fig. 3.(b) BU cost of TLMIPv6 of and HMIPv6

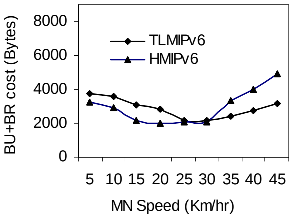


Fig. 4. BU+BR cost of TLMIPv6 and HMIPv6

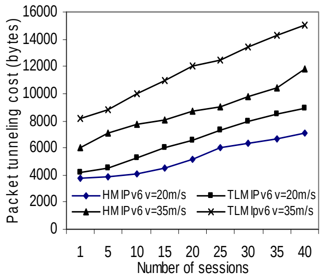


Fig. 5. Packet tunneling cost of TLMIPv6 and HMIPv6

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 *5*km/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].

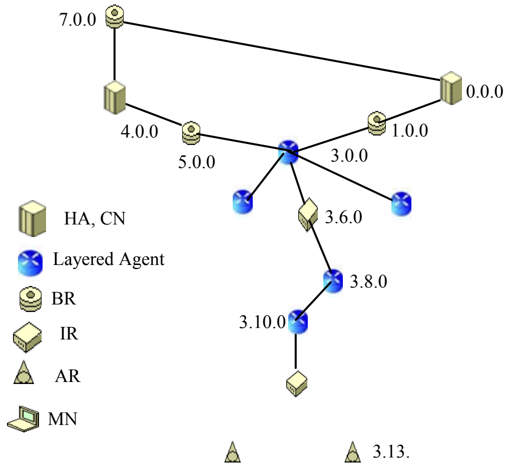


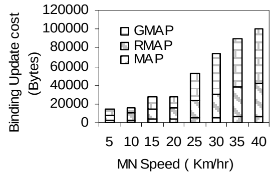
Fig. 8 Simulation scenario

5.0.1

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.



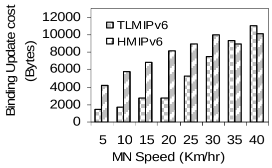
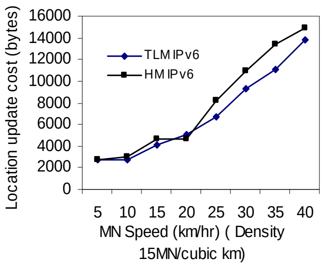


Fig. 9. (a) Region wise BU cost (TLMIPv6)   Fig. 9.(b) Comparative BU cost of HMIPv6 and TLMIPv6

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.



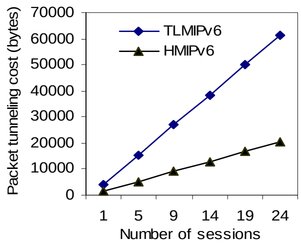


Fig. 10. Signaling load in the Backbone   Fig. 11. Packet tunneling cost of TLMIPv6 and HMIPv6

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

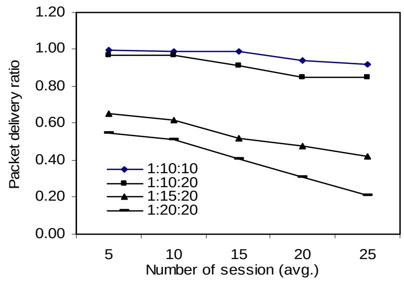


Fig. 12 Packet delivery ratio in TLMIpv6

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.

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