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Analytical Model to Reduce the Handoff Latency for Next Generation Wireless Networks

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Abstract:- Mobile Computing is becoming increasingly important due to the rise in the number of portable computers and the desire to have continuous network connectivity to the Internet irrespective of the physical location of the node. Mobile IP is a solution for mobility support in the global Internet. The mobile node can experience disruptions or even intermittent disconnections of an ongoing real-time session due to handovers. This can heavily affect user satisfaction when traffic on the network is high. Therefore, this handoff delay needs to be minimized to provide good-quality VoIP (Voice over internet protocol) services. There are two solutions have been proposed to reduce the handoff delay of Mobile IP, *Fast Handovers for Mobile IPv6* (FMIPv6) and *Hierarchical Mobile IPv6* (HMIPv6) are actively developed by the Internet Engineering Task Force for future IPv6 networks. The objective of this proposed work to focus on the analytical modeling of next generation networks protocols, F-MIPV6 and HMIPV6 using IEEE 802.11based wireless local area networks. Our simulation model considers various factors from both link layer and network layer which influence the handoff delay. The outcome of this work focused on determining the probability distribution of the handoff latency occurring within the certain range based on the offered traffic load and network conditions. Performance analysis is carried out and numerical results are obtained using MATLAB 7.0.4. It is shown that the proposed model reduces the handover delay by 48%.

I. INTRODUCTION

Internet and Mobile Phones are easiest way to fulfill the need for quick and reliable access to information. However, today, the Internet does not provide any means to handle mobility. Actually, there is no means to stay permanently connected to the Internet while moving. On the other side, the use of Mobile Phones provides the ability to communicate with people anytime and almost anywhere in the world, and offers us a reliable (i.e. no disruption) communication while moving from one point to another. However, Mobile Phones are designed to carry voice, and do not allow us to exchange data easily.

Logically, the next idea is to combine the advantages of both the Internet and Mobile phones that is quick and reliable access to information, and mobility facilities. Extensive research in the past and present has attempted to add mobility support in the Internet. The majority of the conceptual problems preventing the Internet to handle mobility have been solved and this will finally result into a new, upgraded version of Internet.

Network mobility first saw support in the IP realm with the advent of Mobile IPv4 [1] Mobile Routing, part of the Mobile IPv4 standard released in 1993. From the name it might seem like Mobile Routing is the one standard solution for IPv4 network mobility, but a number of other less researched possibilities. It was originally planned to port Mobile IPv4 Mobile Routing to Mobile IPv6. Developers gradually realized, however, that the transition was not trivial because Mobile IPv6 [2] includes destination options like the home address option and protocol extensions like Route Optimization that complicate network mobility. The Internet Engineering Task Force (IETF) began an effort to develop IPv6 as successor to the IPv4 protocol and IPv6 specification was approved by IETF in 1997.

The first solution created from the efforts of IETF was Mobile IPv4. In MIPv4, a mobile node (MN) changes its addresses dynamically as it changes the points of attachment. The address that is dynamically assigned in a foreign network is called Care-of-Address (CoA) [4]. MIP, the first viable mobility solution was not without drawbacks and limitations. MIPv4 may use long paths because of the triangle routing. In addition, it has problems such as security violations and depletion of available addresses.

To reduce the latency and packet loss, many authors have suggested their ideas for optimizing the protocol. Some concentrated on the link-layer [5] to detect the movement of Mobile Nodes (MN) as early as possible, others focused at network-layer to accelerate the binding update process by buffering and simulating packets. Some of the schemes developed so far related to minimizing the delay (latency) in Mobile IP are described as follows:

The Fast Handover Protocol (FMIPv6) [6] was an extension of Mobile IPv6 that allows an access router (AR) to offer services to an MN in order to anticipate the layer-3 handover. The movement anticipation was based on the layer-2 triggers. MN has the possibility to prepare its registration with new access router (NAR) and obtain its new care-of-address (NCoA) while still connected to its previous access point (PAR). Moreover, MN can instruct the PAR to forward packets addressed to its PcoA to its NCoA.

Hierarchical Mobile IPv6 (HMIPv6) [7] divided the Internet into administrative domains which were managed by Mobility Anchor Points (MAP). HMIPv6 aimed to reduce the amount of signaling between the MN and its correspondent nodes (CN) during a handover, and to improve the performance in terms of handover speed. In HMIPv6, the MN sends Binding Updates (BU) to the local MAP rather than the home agent (HA) and CNs, which are typically further away. Moreover, only one BU message needs to be transmitted by the MN before traffic from the HA and all CNs is re-routed to its new location, regardless of the number of CNs that MN is communicating with.

Seamless Internet Protocol (S-MIP) [8] provided a novel architecture that builds on top of the hierarchical approach and the fast handover mechanism, in conjunction with a newly developed handoff algorithm based on pure software-based movement tracking techniques. S-MIP introduced a new entity in the network, the Decision Engine (DE) that was similar to a MAP in its scope and makes handover decision for its network domain. S-MIP provides improvement in both delay and packet loss, however, the operation of DE entity was difficult to simulate in test-bed and therefore the evaluation for this framework is not clear so far.

Jung *et al.* [9] proposed a combination of the Fast Handovers and Hierarchical Mobile IP extensions to Mobile IPv6. The scheme is called Fast Handover for Hierarchical Mobile IPv6 (F-HMIPv6). When a MN enters a new MAP domain, it first performs the HMIPv6 registration procedures with HA and MAP. Later, when MN moves from a PAR to a NAR

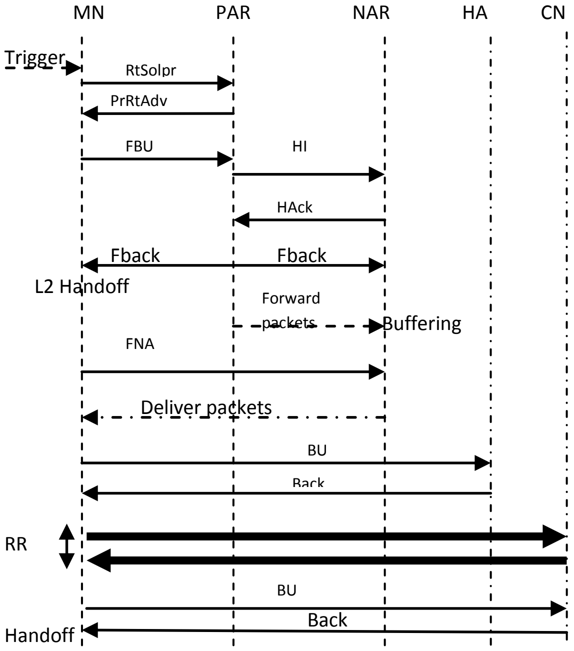

Fig.1. Fast hand over for Mobile IPv6.

Within the MAP domain, it will follow the local Binding Update Procedure of F-HMIPv6. During the handover, data packets sent by CNs were tunneled by MAP toward NAR via a bi-directional tunnel, similarly to the FMIPv6 procedure. It should be noted that no bi-directional tunnel was established between PAR and NAR. IDMP [10] was a two-level hierarchical approach to provide mobility support for MNs in IP-based mobile networks. The first hierarchy consisted of different mobility domains. The second hierarchy consisted of IP subnets within one domain. It reduced both the global signaling load and update latency.

Cellular IP [11] was proposed to provide local mobility and handoff support for frequently moving hosts. It supported fast handoff and paging in CIP access networks. For mobility between different CIP networks, it could inter work with MIP to provide wide-area mobility support. It showed different wireless access networks connected to the Internet through a gateway. HAWAII [12] was a domain-based approach to mobility support. All issues related to mobility management within one domain were handled by a gateway called a domain root router. When an MH is in its home domain, packets destined to the MH are routed using typical IP routing. When the MH is in a foreign domain, packets for the MH are intercepted by its HA first. The

HA tunnel the packets to the domain root router serving the MH. When the MH moves between different subnets of the same domain, only the route from the domain root router to the BS serving the MH is modified, and the remaining path remains the same. Thus, during an intra domain handoff, the global signaling message load and handoff latency was reduced.

Optimized smooth handoff [13] proposed to solve the route optimization problem in MIPv6. As soon as the MN has obtained its new regional CoA, it will register this address with its GFA. After Binding Update, when a packet arrives in the previous FA, the binding cache is checked and the packet is tunneled to the new FA, who delivers it to the MN. However, packets arriving at the previous FA after the MN left and before the binding update message from the new FA received are lost. In order to avoid this packet loss, FAs are provided with a circular buffer referred to as the Forwarding Buffer.

In Optimistic F-HMIPv6 [14] framework (referred to as OF-HMIPv6), we removed the DAD function from NAR and get it done by MN, by combining these together with some necessary modifications to the handover protocol, provides a significant enhancement to Mobile IP performance**.**IPv6 provides a very flexible mechanism for hosts to configure their IP addresses automatically via the Neighbor Discovery procedure [15] and Stateless Address Auto configuration mechanism [16].

The host performing Duplication Address Detection sends a Neighbor Solicitation message to the Solicited-node multicast address including the tentative address in the Target Address field. The node may retransmit the probe multiple times, but each probe is separated by a specified timer.

After sending the DAD probe(s), the node waits for RetransTimer**,** whose value is one second, before it declares DAD process over. This time badly affects the handover's overall delay. Some schemes proposed to reduce latency using DAD were O-DAD, A-DAD, and P-DAD.

O-DAD [17] lets nodes use addresses before DAD has checked their uniqueness. If the DAD procedure later reports that an address is already in use, the mobile node using it must immediately de configure it. This can penalize both the mobile node (by breaking ongoing connections) and the node that rightfully owns the address (because it will receive misdirected packets). O-DAD is beneficial, use however, if address collision probability is low.

A-DAD [18] was proposed to automatically allocate a care-of IPv6 addresses (CoA) for the mobile nodes that want to be fast handover. Each access router maintains 'Passive Proxy Cache' of which each address is in advance generated and tested for its uniqueness by the access router. Also, the access router acts as 'Passive Proxy' for an address reserved in 'Passive Proxy Cache' in order not to affect the destination cache and neighbor cache of its neighbor nodes and not to disturb the normal CoA configuration procedure of the nodes. During L3 handover, a mobile node requests one of the duplication-free addresses reserved by its target access router.

After successfully acquiring the address, the mobile node assigns it on its interface which attaches to the new link, without the DAD. Consequently, the proposed scheme can completely take off the DAD procedure and hence the time involved in the existing L3 handover schemes.

The Proactive DAD [19] approach used topology information and layer-2 signals to predict the new network domains prior to or in parallel with layer-3 hand off. P-DAD doesn't require a reserve of IP addresses and thus better utilizes address space. Also P-DAD access routers need only maintain soft state. This scheme can significantly reduce both hand-off latency and packet loss as compared to O-DAD and A-DAD.

II. ANALYTICAL MODEL

A. Fast Handovers for Mobile IPv6 (F-MIPv6)

FMIPv6 [5] is an extension of Mobile IPv6. It allows an MN to anticipate an L3 handoff based on L2 triggers. An L2 trigger contains information on the MN link layer connection and on the link layer identification of different entities. F-MIPv6 uses L2 triggers to optimize the MN movements in two ways: anticipated handoff and tunnel-based handoff. In this paper, we focus on anticipated handoff, as tunnel-based handoff is unfeasible for some L2 technologies [13]. The anticipated handoff procedure of F-MIPv6 is shown in Fig. 1. When an MN receives an L2 trigger, it sends a Router Solicitation for Proxy (RtSolPr) to the old AR (oAR) with an identifier of the attachment point to which it wants to move.
The oAR replies with a Proxy Router Advertisement (PrRtAdv) containing a recommended new CoA (nCoA) as well as the IP and link layer addresses of the new AR (nAR). At the same time, the oAR sends a Handover Initiate (HI) message to the nAR indicating the MN's oCoA and the proposed nCoA. The nAR informs the oAR with a Handover Acknowledge (HACK) message indicating whether the proposed nCoA is valid or not. If the nCoA is valid, the oAR prepares to forward packets for the MN to the nCoA. Otherwise, the oAR prepares to tunnel packets for the MN to the oCoA at the nAR. As soon as the MN receives the PrRtAdv confirming the pending L3 handoff and has a nCoA, it sends a Fast Binding Update (F-BU) to the oAR informing the oAR to forward all the future packets to the nAR. The MN must send this message before breaking the connection to the oAR. The oAR sends a Fast Binding Acknowledgment (F-BAck) to both the MN and the nAR with the final

nCoA. This is also a point of releasing the MN's association with the oAR. When the MN arrives on the nAR, it sends a Fast Neighbor Advertisement *(F-NA)* requesting the nAR to forward packets destined to the nCoA of the MN. The nAR is also responsible for forwarding any packets destined to the oCoA of the MN after the MN has moved.

B. Hierarchical Mobile IPv6 (H-MIPv6)

H-MIPv6 [6] is designed to minimize the amount of signaling to CNs and to the HA by allowing an MN to locally register in a domain. The mobility management inside a domain is handled by a mobility anchor point (MAP). Subnets covered by one MAP form a micro network. Mobility between different MAP domains is handled by MIPv6. When an MN first arrives at a new MAP domain, it obtains a regional care-of-address (RCoA). The MN registers this RCoA with it's HA and CNs about its current location. When the MN moves from one subnet to another inside the same MAP domain, it obtains a local care-of-address (LCoA) from each AR and only the MAP has to be informed. When packets are sent from a CN to the MN, they are intercepted by the MAP which will route the packets inside the domain to the MN based on the LCoA. The handoff procedures of HMIPv6 for both micro-movements (moving inside a MAP domain) and macro-movements (moving between MAP domains) are shown in Fig. 2.

III. LATENCY IN MOBILE IPv6

*Registration Latency***:** The time taken for mobile node to obtain a new address and register it with the HA is the registration latency.

*Handoff Latency***:** When mobile node transfers packet from one foreign agent to another foreign agent, then the time lapse is termed as handoff latency [24] due to latency caused there is time lapse when there is no packet transfer thus causing reduction in efficiency. In Mobile IPv6 protocol, each mobile node is identified by a set of IP addresses [21].

When in the home network, a Home Agent assigns a local address to the mobile node and it is always reachable via it's HA. When the node is away from its home, it obtains a Care of Address from the foreign router and registers this CoA with it's HA. The job of the HA is to intercept any packets destined for the mobile node while it is roaming in a foreign network and tunnel it to the mobile node [22].

The inherent problem in this is that, a timely configuration of CoA is required for continuous communication. The time taken for mobile node to obtain a new address and register it with the HA is the overall handoff latency. The handoff latency is the primary cause of packet loss in a network.

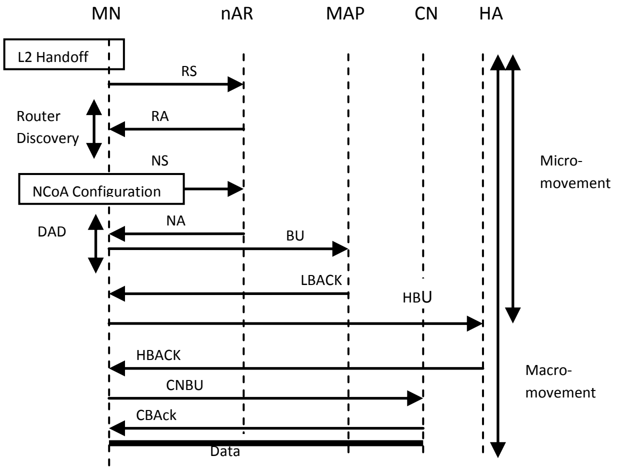

Fig. 2. Hierarchical Mobile IPv6 handoff

a. ANALYTICAL MODEL FOR FAST HANDOFF LATENCY ANALYSIS

In this section, we explain the proposed analytical model for handoff latency analysis of the two fast handoff protocols: FMIPv6 and HMIPv6. Mobile IP handoff delay is defined as the delay starting when the connection between the MN and the oAR breaks until the MN receives the first packet from the nAR. The proposed model considers all the factors from both L2 and L3 affecting the Mobile IP handoff delay.

A. F-MIPv6 Handoff Delay

Under the FMIPv6 protocol, the handoff delay is defined as the time duration from the MN receives the Fast Binding Acknowledgment (F-Back) from the oAR with which it is currently associated until the MN receives the Fast Neighbor Advertisement Acknowledgment (F-NAack) from the nAR [5].

From Fig. 1, the total handoff delay of FMIPv6, T_{FMIPv6}, can be represented as

$T_{FMIPv6}=T_{MN-AR}+T_{AR-MN}+T_{dis}$ (1)

T_{MN-AR}: delay for sending a signaling message from an MN to an AR, T_{AR-MN}: delay for sending a signaling message from an AR to an MN, T_{dis}: disconnection delay.

B. Signaling Delay from MN to AR (T_{MN-AR}):

Before an MN sends a signaling message to a corresponding AR; it spends some time on generating the message, accessing the wireless channel, and transmitting the message out. Hence, TMN−AR consists of the following delay components:

$T_{MN-AR}=T_{MN-serv}+T_{MN-col}+T_{MN-prop}$ (2)

where, $T_{MN-serv:}$ is message service delay which includes the message processing and transmission delay, T_{MN-col} is random delayed time due to collision avoidance for an MN to access the wireless channel, $T_{MN-prop}$ is propagation delay of the signaling message over the wireless link.

C. Signaling Delay from AR to MN **(T_{AR-MN}):**

After receiving the signaling message from the MN, the AR processes the message and generates a response. Similar to the above analysis, T_{AR-MN} can be expressed as:

$T_{AR-MN} = T_{AR-serv} + T_{AR-col} + T_{AR-prop}$. (3)

D. Disconnection Delay (T_{dis}):

Disconnection time refers to the time when the connection between the MN and oAR is released and before the MN sets up the new connection with the nAR. During this disconnection time, packets destined to the MN will be forwarded from the oAR to the nAR and buffered at the nAR.

There are two L_2 triggers used by ARs as a reference to break or start a link. The first trigger is the layer 2 link down trigger (L_2-L_D) which indicates that the L2 link between the MN and oAR is broken. When the oAR receives this trigger, it starts to forward the packets to the nAR through a tunnel. The second trigger is the layer 2 link up trigger (L_2-L_U) which occurs when the L_2 link between the MN and nAR is established. When the nAR receives this trigger, it begins to forward the buffered packets to the MN. Therefore, the value of disconnection time is the sum of the time it takes to receive the L_2-L_D and L_2-L_U triggers, *i.e.*

$T_{dis}=T_{L2-LD}+T_{L2-LU}$

(4)

E. H-MIPv6 Handoff Delay

H-MIPv6 divides the network into layers and regions. The handoff delay of HMIPv6 is defined as the time after an MN sends out the Local Binding Update (LBU) to a MAP until it receives the first data packet from the new subnet. From Fig. 2, the total handoff delay of HMIPv6 micro-movements (movements inside a MAP domain) can be represented as:

$T_{HMIPv6} = {\scriptstyle TMAP-AR} + T_{AR-MN}$ (5)

where, T_{MAP-AR} is delay for sending signaling messages from a MAP to an AR, T_{AR-MN}: delay for sending signaling messages from an AR to a MN. Similarly, the total handoff delay of HMIPv6 macro-movements (movements between MAP domains) can be represented as:

$T_{HMIPv6} = T_{MAP-AR} + T_{AR-MN}+ (T_{MN-CN}+T_{CN-MN})$ (6)

where, T_{MN-CN} or T_{MN-}: are delays for sending signaling messages from an MN to its CN or HA, respectively, T_{CN-MN} or T_{HA-MN}: delay for sending signaling messages from a CN or HA to the MN, respectively.

1) *Signaling Delay from MAP to AR (T_{MAP-AR}):* Under the HMIPv6 protocol, an MN sends a Local Binding Update (LBU) to the MAP informing about its movement to a new subnet. The MAP responses with a Local Binding Acknowledgment (LBAck) by sending a message to the nAR informing it about the handoff. T_{MAP-AR} consists of the following delay components:

$T_{MAP-AR} = T_{MAP-col} + n \cdot (T_{serv} + T_{prop})$ (7)

where, $T_{MAP-col}$ is random delayed time due to collision avoidance for a MAP to access the transmission medium. If the MAP and nAR are not connected through Ethernet or shared-medium local area networks, this delay is zero. T_{serv}: message service delay which includes the processing and transmission delay, Tprop: propagation delay of the signaling message over the one-hop wired link. n: number of hops between the MN and MAP. Here, we assume that the propagation delay over each one-hop wired link is the same. T_{AR-MN} can be obtained through eqn.3.

*2) Signaling Delay from MN to CN (T_{MN-CN})***:**

For macro-movements, the MN sends a CN Binding Update (CBU) to its CNs informing its movement before it can receive packets from the corresponding CN in the new subnet. T_{MN-CN} can be expressed as:

$T_{MN-CN} = T_{MN-AR} + T_{AR-CN}$

$=T_{MN-AR}+m. (T_{serv}+T_{prop})$ (8)

T_{MN-AR} can be obtained from eqn. 2. m is the number of hops between the MN and CN.

3) Signaling Delay from CN to MN (T_{CN-MN}): Upon receiving the CN Binding Update (CBU), a CN replies with a *CN* Binding Acknowledgment (CBAck). Similar to the above analysis, T_{CN-MN} can be constructed as:

$T_{CN-MN} = T_{CN-AR} + T_{AR-MN}$

$=m\cdot (T_{serv}+T_{prop}) +T_{AR-MN}$. (9)

IV. RESULTS

Handoff delays of FMIPv6 and HMIPv6 are discussed. Now, we examine each parameter and determine an appropriate model to represent the changing range of each parameter. The value of each parameter varies based on different forms: constantly, within a certain range, or randomly following a particular probability distribution.

*1) Service Delay***:**

Packet service delay includes the processing and transmission delay. The processing delay can be defined as the delay between the time a packet is correctly received and the time the packet is assigned to an outgoing queue for transmission. This delay depends on the processing speed of the node and the number of packets in the buffer of the node waiting for processing. Transmission delay is the time required to transmit the whole packet. It depends on the packet length and the link speed. We use the M/M/1 queuing model for the service delay by assuming that there is no packet loss at each node (MN or AR). The service delay is then the total time a packet spent in a M/M/1 system [24], *i.e.* $Tserv = \frac{1}{\mu-\lambda} = \frac{1/\mu}{1-\rho}$ (10)

where, $1/\mu$ is the mean packet transmission time. λ is mean packet arrival rate to a node, ρ *is* the utilization factor which is defined as $\rho = \lambda/\mu$.

2) Collision / Back-off Delay:

Collision happens when multiple nodes try to access a shared link at the same time. For wireless links, the multiple access procedure follows the IEEE 802.11 CSMA (Carrier Sense Multiple Access) mechanism. Each node senses the carrier before its transmission. If the link is busy, the node waits for a random back-off period before trying to transmit again. This back-off time follows the equation: back-off time = CW · slot time, where CW represents the size of contention window in each node whose value is between CW_{min} and CW_{min}. In IEEE 802.11b, the slot time is 20μs and CW_{min} and CW_{max} are 31 and 1023, respectively. All the parameters are shown in Tables 1 and 2.

*3) Propagation Delay***:**

Propagation delays for wired and wireless links are different. The propagation delay for wired links depends on the distance of the connection. The IEEE 802.11 standard defines the propagation time over a wireless link, namely air propagation time, as the time for a transmitted signal to go from a transmitting station to a receiving station and its value should be less than or equal to 1μs.

4) Disconnection Delay:

Disconnection time in F-MIPv6 is the period that an MN is not connected to any AR. It is related to the L_2-L_D and L_2-L_U triggers. In [15], the disconnection delay is evaluated with different values of T_{L2-LD} and T_{L2-LU}. In this paper, T_{L2-LD} and T_{L2-LU} are assumed to be uniformly distributed between the minimum and maximum values of T_{L2-LD} and T_{L2-LU} used in [15]. T_{L2-LD} has a minimum and maximum value of 60 ms and 80 ms respectively, while T_{L2-LU} has a minimum and maximum value of 120 ms and 160 ms, respectively.

A. Results for 100 Samples:

From Fig. 3, it can be seen that Handoff Delay for FMIPv6 reduces to zero in 1.3 sec or the connectivity is achievable in less than 1.3 sec whenever the mobile node visits foreign network. This has led to an improvement of 43% when considered with its theoretical values. Thus FMIPv6 handoff delay varies in the range 0.2-1.5 sec.

From Fig. 4, it is observed that Handoff Delay for HMIPv6 (micro-movements) reduces to zero in 0.15 sec or the connectivity is achievable less than 0.15 sec whenever the mobile node visits a foreign network. This leads to an improvement of 90% when considered with its theoretical values.

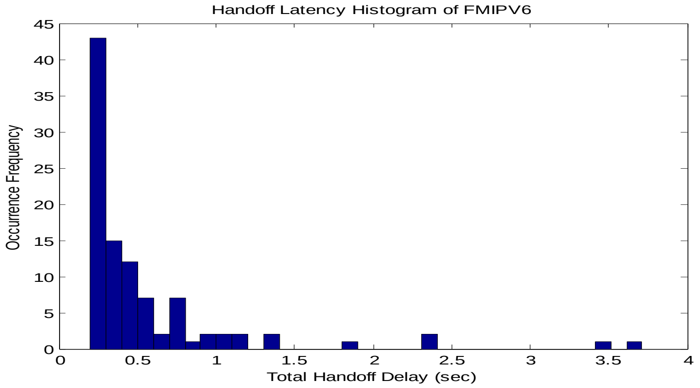

Figure 3: Histogram Plot of FMIPv6 for Latency Delay

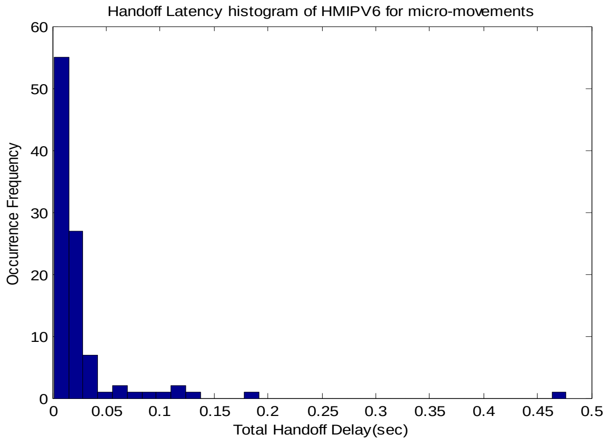

Figure 4: Histogram Plot of HMIPv6 (micro-movements) for Latency Delay

Similarly from Fig. 5, an improvement of 48% for handoff delay for HMIPv6 (macro-movements) can be observed. Thus by limiting the handoff management in local domain, the handoff delay of HMIPv6 protocol for micro-movements significantly reduced compared with that of FMIPv6.

Figure 6 shows that as the number of hops are increased total delay for HMIPv6 (macro-movements) also increases, HMIPv6 (micro-movements) shows a small increase in total delay and F-MIPv6 is almost independent of number of hops. The effect of FMIPv6 due to increased in number of hops can be understood as L2 layer is responsible for triggering handoff thereby neglecting the effect of L3 layer. The Table shows our result analysis for different experimental runs.

Figure 6: Graph of Latency vs. Number of hops

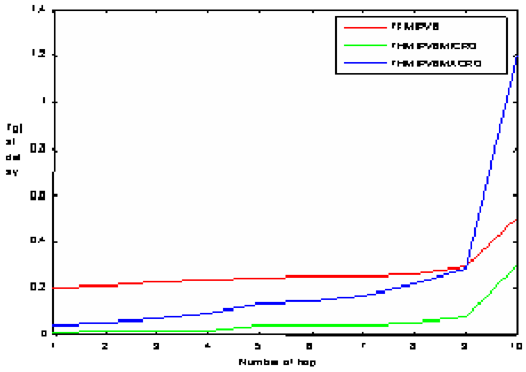

TABLE 1-- HAND-OFF PARAMETERS FOR SIMULATION.

Parameters	Value
Slot time	20µs
CW	31
Propagation speed	2×10^{8} m/s
L_2-L_d, L_2-L_u	[60 ms, 80 ms], [120 ms,160 ms]
λ (packet/second),ρ	[0, 1000], [0.1, 0.9]
One hop distance	1000
n, m	2,10

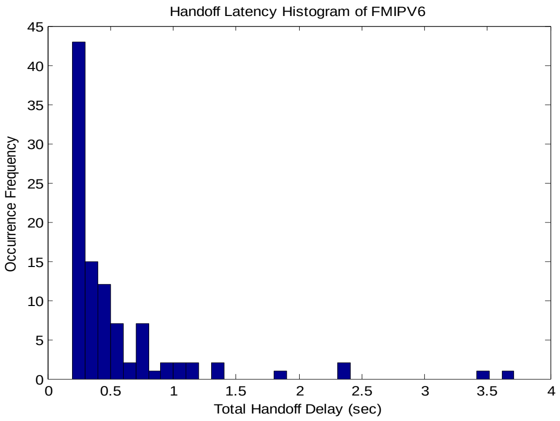

Figure 5: Histogram Plot of HMIPv6 for Latency Delay

TABLE 2 -- RESULT ANALYSIS OF DIFFERENT EXPERIMENTAL RUNS.

Protocol	Theoretical Handoff Delay	Obtained Handoff Delay	% Improvement in Handoff Delay
FMIPv6	2.3 sec	1.3 sec	43
HMIPv6(micro-movements)	1.5 sec	0.15 sec	90
HMIPv6(macro-movements)	2.8 sec	1.5 sec	48

V. CONCLUSION

In this paper we have proposed a new analytical model for MIPv6 protocols. Handoff latency is used as a performance measure. The significant results obtained are summarized as a new analytical model for FMIPv6 and HMIPv6 protocol has been proposed which shows a significant reduction in the handoff latency.

The proposed analytical model incorporates the influences of various factors from link layer and network layer. The probability distribution of handoff latency occurring within a certain range has been generated.

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