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An Enhanced NEMO Protocol for Efficiently Managing both Handoff Performance and Route Optimization in Mobile Networks

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Abstract— **Fast handoff in network mobility (NEMO) is very crucial for providing uninterrupted Internet services to the users in quickly moving vehicles. However, the NEMO basic support (NBS) protocol takes comparatively long time to complete the handoff process resulting in large number of packet drops. Also in NBS protocol all packets to/from the mobile router (MR) passes through its home agent (HA) resulting in high latency in data transfer. In this paper, we propose fast and route optimized NEMO (FRONEMO) to reduce the handoff latency and packet loss, and also to eliminate triangular routing problem experienced in NBS protocol. To reduce handoff latency and packet loss, the FRONEMO brings in the concept of IP pre-fetching and advance-registration to acquire care-of-address for the anticipated future cells. Additionally, FRONEMO uses a prefix delegation technique to perform route optimization using a small number of control packets. Numerical analysis shows that though FRONEMO supports higher vehicle speed than that in fast handover for MIPv6 (FMIPv6), it has significantly low handoff latency, low signaling overhead, lower packet loss and higher throughput. It also reduces overhead during route optimization process.**

Keywords - Network Mobility; MIPv4; MIPv6; FMIPv6; fast handoff.

I. INTRODUCTION

In recent years, providing seamless Internet connectivity to the passengers of fast moving vehicles (e.g., trains, buses etc) has become an active research area [1]-[5]. A vehicle may contain a large number of network nodes (NNs) forming a network. The NNs could be local fixed nodes (LFNs) or visiting mobile nodes (VMNs). When the vehicle moves, all NNs in the network move as a single unit, which is referred to as network mobility (NEMO) [2]. The terminal mobility protocols, such as Mobile IPv4 (MIPv4) [6], Mobile IPv6 (MIPv6) [7], and Hierarchical MIPv6 (HMIPv6) [8], could be used to provide uninterrupted Internet connectivity to the NNs inside the vehicle. These protocols require NNs to be sophisticated enough to perform mobility related functionalities. But, given the NNs like PDAs which are not powerful enough, it is not always expected from each NN to manage its own mobility. Also, these protocols depend on the network layer router advertisement (RA) from the access router (AR) of the foreign network for movement detection resulting in high handoff latency and packet loss.

The IETF has recently standardized NEMO basic support (NBS) protocol [2] to provide Internet access to the NNs inside a moving network. The NBS protocol uses a specialized router, known as mobile router (MR), which is responsible for managing the mobility of the entire moving network. The MR is connected to an access router (AR), which, in turn, is connected to the correspondent node (CN) in the wired network (Figure 1). When the vehicle moves from one location to another, the MR changes its point of attachment to the Internet resulting in IP-level handoff. According to the NBS protocol, the MR obtains a care-of-address (CoA) from the AR in the visited network and registers the CoA with its home agent (HA). This elaborate handoff process introduces considerable delay entailing packet loss [1] that hampers user's experience in Internet access. So a faster handoff mechanism is needed, which can reduce both handoff latency and packet loss. Also, whenever HA is updated, a bi-directional tunnel is established between MR and its HA (Figure 1). So, all packets to/from the MR passes through the HA, resulting in high latency in data transfer.

In this paper, we propose *fast and route optimized NEMO* (FRONEMO) to improve the handoff performance and to optimize route for NBS protocol. To implement fast handoff, the FRONEMO introduces IP pre-fetching and advance-registration technique, whereby an MR, in anticipation, obtains and registers new CoA to be used in the potential future location. The objective is to perform handoff operation with minimum (ideally zero) packet loss for high speed vehicles. The FRONEMO uses a route optimization technique to deliver packets directly from/to an NN to/from CN without going through the HA of MR. Through numerical analysis, we find the maximum allowable speed of an MR (and hence of the associated vehicle) for providing uninterrupted service to the NNs in the vehicle. Also, we compare FRONEMO with fast MIPv6 (FMIPv6) [9] [3] in terms of maximum allowable speed of an MR, handoff latency, signaling cost (required to perform the fast handoff operation), packet loss during handoff procedure, maximum achievable throughput, and route optimization overhead.

The rest of the paper is organized as follows. Section II contains a summary of fast handoff protocols and route optimization techniques for NEMO. In Section III, we provide a detailed description of FRONEMO. Section IV provides a comparative analysis of maximum vehicle speed, handoff latency, signaling cost, packet loss, throughput and route optimization overhead for FRONEMO and FMIPv6. Finally, Section V concludes the paper.

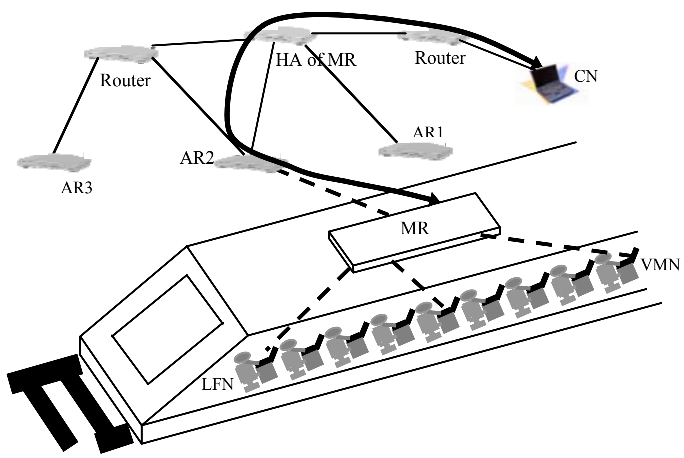

Figure 1: NEMO connectivity model

II. Related Works

A. *Fast handoff for NEMO*

Although FMIPv6 [9] was designed to improve handoff performance in terminal mobility, it can be used in NEMO with minor extensions as discussed in [3]. It utilizes link layer (i.e., layer 2 or L2) trigger to anticipate the handoff. Whenever L2 trigger occurs, the MR sends router solicitation for proxy advertisement (RtSolPr) to the previous AR (PAR) requesting new AR (NAR) information. The PAR sends proxy router advertisement (PrRtAdv) to the MR, which updates the CoA and sends fast binding update (FBU) to the PAR. The PAR then sends handoff initiate (HI) request to the NAR. The NAR replies with status of the request using handoff acknowledgement (HAck) packet. On receiving the HAck packet, the PAR sends fast binding acknowledgement (FBack) to the MR. On entering a new cell, the MR sends an unsolicited neighbor advertisement (UNA) to the NAR. The MR then sends a binding update to its HA to complete the registration process. FMIPv6 can perform the handoff process with zero packet loss only if the prediction about NAR is successful. However, it generates high signaling overhead because a large number of control packets are exchanged during the handoff process. Moreover, if the MR moves very fast, it may not be able to send the FBU from PAR's area resulting in higher handoff delay and more packet losses.

In [3], the authors have proposed an extension to FMIPv6 for NEMO. They use one R bit in FBU and FBack to indicate that the binding update (BU) and acknowledgement is from/fof an MR. The proposed protocol introduces for each AR a new entity called Information Server (IS) that keeps information about the neighboring ARs. The protocol creates a neighboring network report (NNR) cache at the MR for storing both L2 and layer 3 (L3) information in an attempt to reduce L3 anticipation. The MR first registers itself to the current AR and finds the IS. The MR then retrieves the neighboring network information from the IS and keeps it in its NNR cache. When the MR detects that it is moving to a new network, it collects dynamic information of the candidate network and takes an intelligent handoff decision. After that it performs usual FMIPv6 operations. The proposal is novel one for reducing handoff latency and reducing control signals at network layer. However, as it introduces a new entity for each AR, the cost of deployment becomes high.

In [5], the authors have proposed to use a 1 Gbps infra-red communication device (IR-CD) [10] attached to the MR by two cables, namely data cable and control cable. The IR-CD detects L2 handoff and sends a control frame via control cable to the L2 of MR indicating that the link layer is down. The L2 of MR passes the information to the network layer (L3) of MR. When a new link is detected, the IR-CD informs the L2 of MR via the control cable. The L2 of MR, in turn, passes this information to the L3 of MR. Then, the L3 of MR sends router solicitation (RS) to the AR. The AR replies with a RA. The MR updates the CoA and sends a BU to its HA. The protocol does not anticipate handoff and hence is bound to use the RA from new AR. This happens because infrared communication link cannot receive RA from more than one AR. However, due to the high data rate link, the delay is reduced. Thus, the protocol is more dependent on the physical link than the actual mechanism of the protocol itself.

B. *Route optimization for NEMO*

In [11], the authors have used path control header (PCH), a hop by hop destination header [12], which delegates the hierarchical route to the CNs. In this approach, after PCH is sent to CNs through a correspondent router (CR), the CR requests BU with MR using binding request (BR) packet. Then the MR performs BU with CR. Although the proposal achieves route optimization, the delegation process introduces high header overhead. Also, use of CR makes the deployment costly.

MIRON [13] uses type 2 routing header [7] to eliminate the encapsulation overhead. In this proposal, the MR performs the route optimization process (BU with the CNs) on behalf of each NN inside the vehicle. The route optimization procedure is similar to that of MIPv6. The MIRON also uses type 2 routing header to send and receive data packets to/from CN from/to NN inside the vehicle. Although the approach is novel, it suffers from large header overhead because when each of the *n* LFNs communicate with *m* CNs, the number of control packets to perform route optimization becomes significantly high. Moreover, the MIRON is applicable only when all NNs are LFNs.

In comparison, FRONEMO employs altogether different approach to reduce the number of packet losses to zero during high speed movement of an MR. It uses the concept of IP pre-fetching and advance-registration and hence can achieve zero packet loss handoff at very high speed movement of the MR. Also it uses a route optimization technique to reduce packet delivery cost to/from CNs. Thus, it reduces the number of control packets to perform the handoff and route optimization operations.

III. FRONEMO

A. *Assumptions*

1. For the sake of simplicity, we have assumed that the cells are circular and overlapping[1].
2. The ARs are placed at the center of the cells.
3. The ARs know their Cartesian coordinate (p_x, p_y) signifying their geographic location in the cell.
4. Periodically, the neighboring ARs exchange their co-ordinate and IP address. The ARs maintain a table of binding of IP address and coordinate.
5. At any point of time, an MR, has three CoA, namely, past care-of-address (PCoA) used in the previous cell, current care-of- address (CCoA) which is in use in the current cell and future care-of-address (FCoA) to be used in the next cell.

B. *Handoff Management*

Initially, when the MR is in the home network, it collects two IP addresses, namely CCoA (home address) and FCoA, which are derived by the CAR using IP pre-fetching mechanism described later. The MR continuously monitors the signal strength received from the CAR and all possible FARs. If the MR finds that the difference in signal strength received from CAR and FARs has reached some threshold value, *h*, it concludes that a handoff is about to take place [14]. So, the MR announces its presence to the new CAR in the new cell. The entire handoff management process is shown in Figure 2.

B.1 Presence announcement

The MR announces its presence to the CAR in the new cell by sending an announcement packet that contains the coordinate of the PAR. The announcement packet (format is shown in Figure 3) is a modification of unsolicited neighbor advertisement [9] with a new sub-type. It uses two new bits A and M. If A is set to 1, it signifies that the MR is already assigned a CoA to be used in this cell. If M is set to 1, it signifies that the announcement is made by an MR. The MR obtains the coordinates of the CAR from the advertisements of the CAR. The coordinates are in IEEE 32-bit floating point format. The MR then sends a

[1] Although the cells are hexagonal, it is easier to model them as circle. If c is the radius of the hexagon and r is the radius of the circle then $c=(2/3)r$ [14].

BU to the HA. The procedure of BU to the HA is same as in the NBS protocol. Once the HA is updated, the MR performs the following mapping of IP addresses:

$$CCoA \rightarrow PCoA,\ FCoA \rightarrow CCoA$$

It is to be noted that the presence announcement functionality should be completed when the MR resides in the overlapping region, i.e., the speed of the vehicle is within the maximum allowable speed.

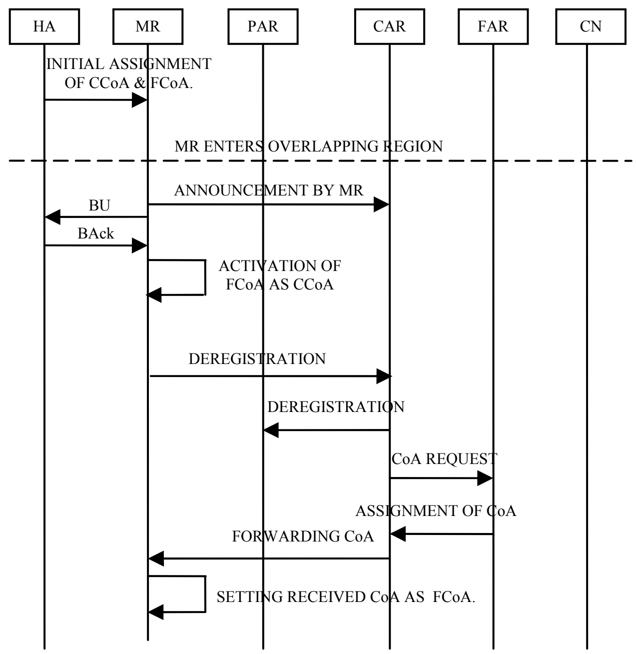

Figure 2: Timing diagram of fast handoff mechanism in FRONEMO

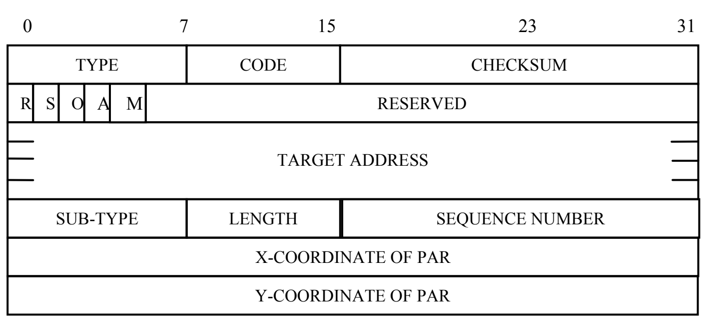

Figure 3: Format of announcement packet

B.2 Deregistration

After sending the presence announcement packet, the MR completes the BU process with its HA as in NBS protocol. After BU and route optimization process (described later), the MR sends to the PAR through CAR a deregistration packet that uses modified IPv6 type 2 routing header (Figure 4) [7] and a mobility header of new type (Figure 5). The destination address of the deregistration packet is set to the IP address of the CAR, and the IP address of the PAR is put in the option field of the routing header so that the packet first visits the CAR and then goes to the PAR. The rest of the deregistration process follows normal deregistration procedure of the NBS protocol. Then the MR derives a FAR using a prediction algorithm based on history of past handoffs of the MR and received signal strengths [15][16].

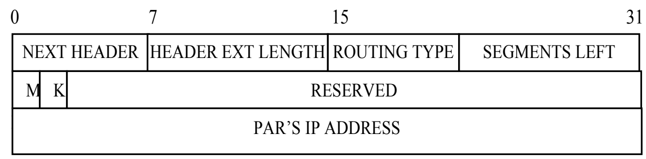

Figure 4: Modified type 2 routing header

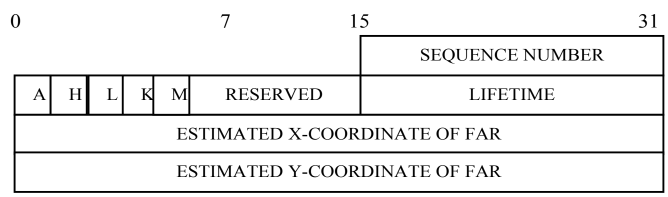

Figure 5: Mobility header of deregistration packet

B.3 IP pre-fetching and advance-registration

After receiving the mobility header (Figure 5), the CAR finds the IP address of the FAR by looking into the table of bindings of IP address and coordinate of ARs (assumption 4 of Section IIIA). Then the CAR sends a packet to the FAR requesting for CoA allocation. The format of the packet is same as HI packet [9] and uses a new one-bit field M and a new option where necessary information for registration is included to perform advance registration (Figure 6). The mobility fields contain the home address of the MR. If M=1, it indicates that the packet is sent from the CAR on behalf of the MR. If M=0, it indicates that the packet is sent on behalf of an MR but the MR is acting as mobile node (MN). The reply from the FAR contains the assigned CoA in the mobility options field (Figure 7). The format of the reply follows the format of HAck [9] and uses a new one-bit field M. The value of M is copied from the CoA request packet (Figure 6). Then, the CAR forwards the allocated CoA to the MR (Figure 8). For this purpose, the format of FBack [9] is modified to include a one-bit field M. The value of M is copied from the reply packet (Figure 7). The sequence number is copied from the announcement packet of Figure 3. The mobility options contain the IP address of the FAR and the assigned CoA. The MR sets the received CoA as FCoA[2].

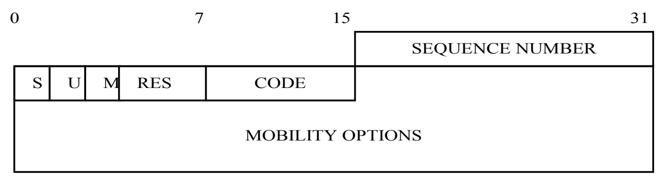

Figure 6: Request for CoA

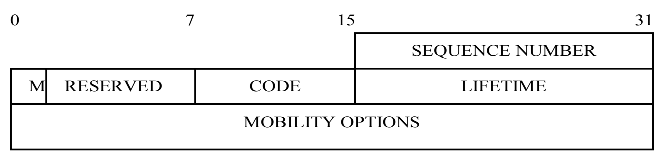

Figure 7: Reply from FAR

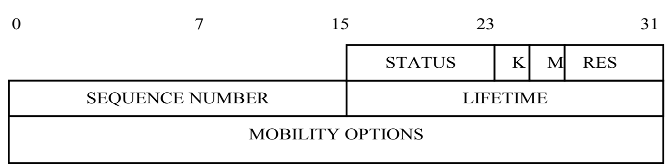

Figure 8: Reply from CAR to MR

C. *Route Optimization*

For a quick look at the route optimization technique the entire process is shown in Figure 9. At any point of time, two types of NNs can be present in a vehicle: LFN and VMN. The network prefix used by the LFNs is similar to that of the home network prefix of the MR. When a VMN enters the vehicle, it uses MIPv6 to obtain a CoA and update its HA. When the MR enters a new cell, it obtains a network prefix from the AR. Then the MR internally assigns the obtained CoA (i.e., new IP (NIP) address) to each NN. For this purpose, the MR maintains a table that maps home address, CoA (no CoA for LFNs), and NIP for each NN (Table 1). When next handoff takes place, the MR updates the table by changing the NIP only. Once the table is

[2] If IP pre-fetching fails, then, on entering the new cell, the MR sends an announcement packet with A bit set to 0 which signifies that the MR is not assigned CoA in the current cell. The assignment of CoA then follows the normal procedure of NBS protocol.

updated, the MR sends a route optimization (RO) packet to all CNs[3]. The format of the RO packet is shown in Figure 10. The RO packet is a destination option header [7] with a new destination header type. The M bit is set to 1 if the RO packet is sent by an MR. The bit is set to 0 if the packet is sent by an MN.

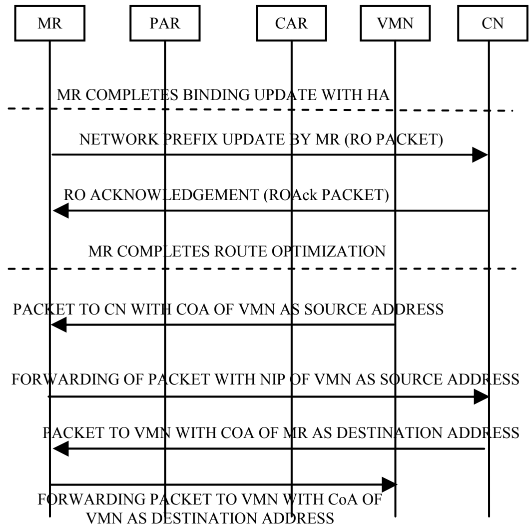

Figure 9. Route optimization and packet delivery in FRONEMO

Table 1: Mapping between NNs home address, CoA, and NIP

Home Address of NN	**CoA**	**NIP of NN**
NN_1 (LFN)		NIP_1
. .	. .	. .
NN_k (VMN)	CoA_k	NIP_k

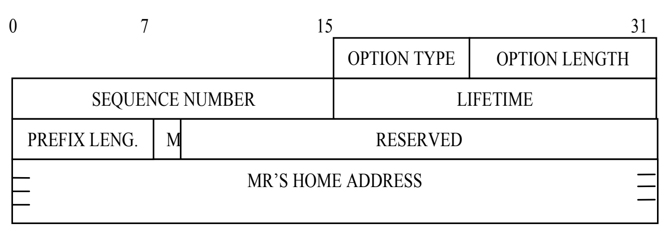

Figure 10: RO packet format

[3] The MR maintains a list of CNs with which the NNs communicate. To build the table, the MR checks the destination address of all outgoing packets.

The CN maintains a binding cache for all VMNs (as in MIPv6) which map the home address of a VMN to its CoA. In addition, the CN maintains another binding cache which maps the home address of an MR to its CoA (Table 2). When the CN receives a RO packet from an MR, it updates Table 2 and sends back RO acknowledgement (ROAck) packet to the MR. The format of ROAck packet is shown in Figure 11. The sequence number and M bit of ROAck are copied from the RO packet.

Table 2: MR cache list

Home Address of MR	**CoA of MR**
MR$_1$	CoA_MR$_1$
. .	. .
MR$_k$	CoA_MR$_k$

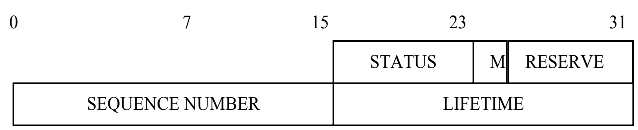

Figure 11: ROAck packet format

To send a packet to CN, the NN uses its CoA (if it is a VMN) or home address (if it is a LFN) as the source address and CN's address as destination address. The MR intercepts the packet and replaces the source address by NIP of the NN and adds a destination options header with new type (Figure 12). The CoA of VMN or the home address of LFN is put into the option header type. So, the source address is now topologically significant in the foreign network which eliminates ingress filtering problem [17].

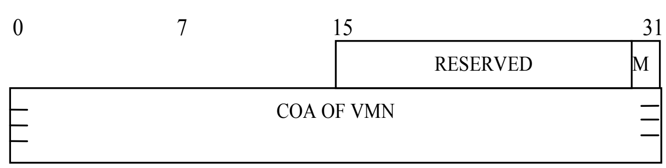

Figure 12: Destination option header for packet delivery from VMN to CN

When the CN receives the packet, it follows the steps given in Figure 13 to find out the destination address for the reply packet. To send a packet to VMN or LFN, the CN sets the MR's CoA as the destination address and its own address as the source address. The CN adds a destination options header with a new type (Figure 14). The CoA of the VMN or the home address of the LFN is put into the options header type.

When the MR receives the packet, it removes the destination options header and sets the destination address to the CoA of the VMN or the home address of the LFN. Note that for data transmission to/from VMN from/to CN, the use of home address of the VMN remains similar as in MIPv6.

IV. PERFORMANCE ANALYSIS

To analyze the performance of FRONEMO, we follow the approach presented in [14]. In particular, we provide analysis for finding maximum speed of a vehicle, V_{max}, handoff latency, signaling cost, packet loss incurred by the protocol to perform fast handoff, maximum achievable throughput, and route optimization overhead. The model used in our analysis is shown in Figure 15. In Figure 15, Q_P, Q_C, and Q_F denotes the past, current, and future cell, respectively.

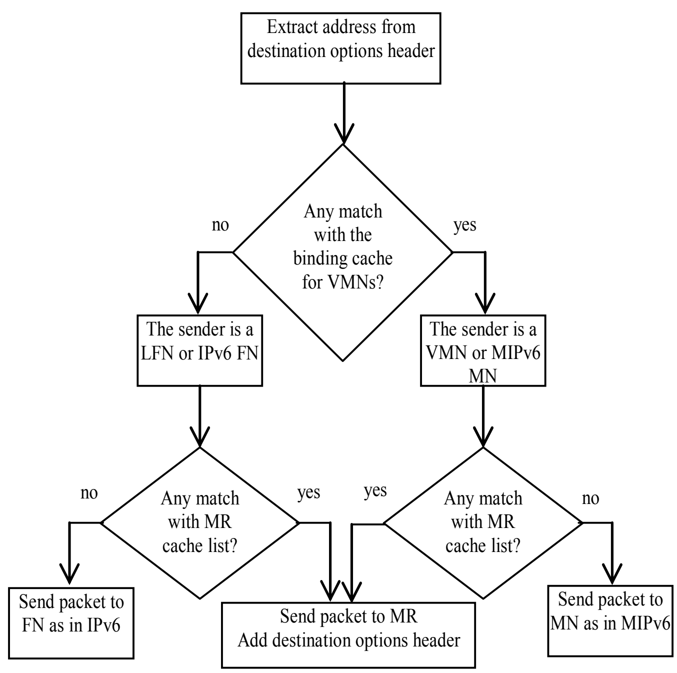

Figure 13: Finding destination address for reply packet

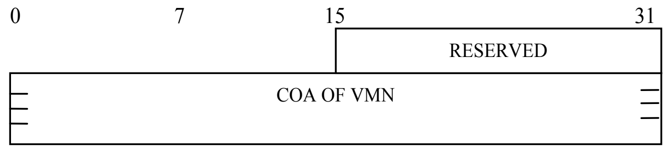

Figure 14: Destination options header for packet delivery from CN to VMN

When the MR finds that the difference in signal strength is equal to a threshold, h, it announces its presence to the CAR. Let us assume that the MR announces its presence at point F in Figure 15. From Figure 15, we have the following set of equations:

The inter-AR distance $=|AB|=|BC|= d$ (1)

The radius of each cell $= |AG| = |DB| = |BJ| = |HC| = r$ (2)

$$|DG| = |HJ| = 2*|DE| = 2*|EG| = x \quad (3)$$

$$|EF| = |IK| = d_h \quad (4)$$

$$|FG| = |KJ| = z = \frac{x}{2} - d_h \quad (5)$$

$$|DF| = |HK| = y \quad (6)$$

$$y = \frac{x}{2} + d_h \quad (7)$$

As given in [14],

$$c = \frac{2}{3}r \quad (8)$$

$$x = 2r * \sin\left(\cos^{-1}\left(\frac{1.732 * \left(c + \left(4r^2 - 3c^2\right)^{0.5}\right)}{4r}\right)\right) \quad (9)$$

$$d_h = \frac{d}{2} * \frac{-1 + 10^{\frac{h}{k}}}{1 + 10^{\frac{h}{k}}} \quad (10)$$

where k is the environment specific attenuation characteristics [14].

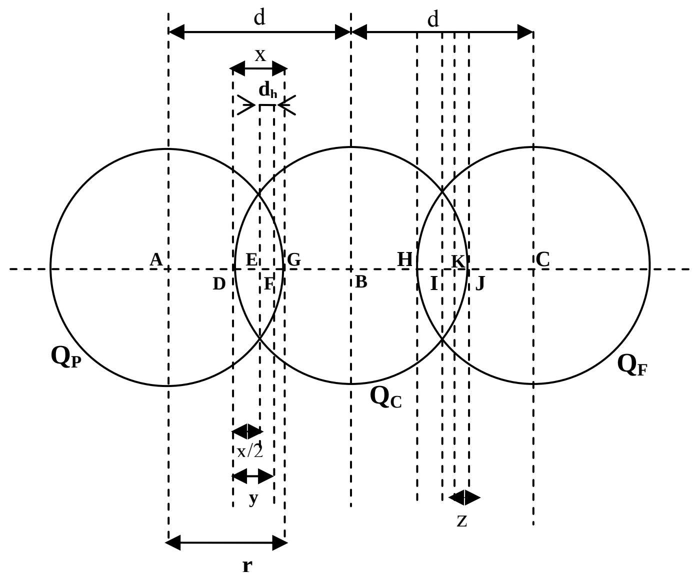

Figure 15: Reference diagram used for analysis

We assume that the vehicle is in cell Q_C and the MR has completed the deregistration process with the PAR. The CAR should request for new FCoA at point G and the MR should finish updating the CN by point K for successful handoff to cell Q_F. Let us denote by *T* to be the time taken by the MR to update the HA. For simplicity, let us assume that the time required to update the CN is also given by *T*. Now, the distance between G and K is:

$$|GK| = |GH| + |HI| + |IK|$$

$$= 2r - 2x + \frac{x}{2} + d_h$$

Using Equation (10) we get:

$$\left|GK\right| = (2r - 2x) + \frac{x}{2} + \frac{d}{2} * \frac{-1 + 10^{\frac{h}{k}}}{1 + 10^{\frac{h}{k}}}$$

$$= 2r - \frac{3}{2}x + \frac{d}{2} * \frac{-1 + 10^{\frac{h}{k}}}{1 + 10^{\frac{h}{k}}}$$

(11)

Let us define *m* as the delay between MR and AR, and 2*n* as the delay from AR to another AR[4]. Then, the time taken to complete a successful handoff, *t*, can be given as:

[4] Referring to Figure 1, the AR2-Router delay is n and the Router-AR3 delay is *n*. So, AR2-AR3 delay is 2*n*.

t = delay for FCoA request packet to reach FAR from CAR + delay for the packet containing FCoA to reach CAR from FAR + delay for forwarding FCoA to MR from CAR + time required for the MR to update its HA + time required for the RO packet to reach the CN[5]

So, we have $t=(3T/2)+m+4n$ (12)

Hence, we can write:

$$V_{\max} = \frac{|GK|}{t} \qquad (13)$$

Putting the values of $|GK|$ and t from Equations (11) and (12) respectively, and simplifying we get,

$$V_{\max} = \frac{2r - \frac{3}{2}x + \frac{d}{2} * \frac{-1+10^{\frac{h}{k}}}{1+10^{\frac{h}{k}}}}{\frac{3T}{2} + m + 4n} \qquad (14)$$

Equation (14) describes the relation between maximum speed of a vehicle, minimum required cell size, and the size of the overlapping region.

For FMIPv6 in predictive mode, let us define W_{max} to be the maximum speed allowed. For handoff from cell Q_C to cell Q_F, the MR sends RtSolPr packet at point K and receives FBack at point J. The distance covered during this interval, z, can be given as:

$$z = \frac{x}{2} - d_h = \frac{x}{2} - \frac{d}{2} * \frac{-1+10^{\frac{h}{k}}}{1+10^{\frac{h}{k}}} \qquad (15)$$

The time, t, needed to perform the handoff operation is:

$t = m$ (for RtSolPr) + m (for PrRtAdv) + m (for FBU) + $2n$ (for HI) + $2n$ (for HAck) + m (for FBack)

So, we have $t = 4m + 4n$ (16)

Thus, the maximum speed allowed in FMIPv6 is:

$$W_{\max} = \frac{z}{t} = \frac{\frac{x}{2} - \frac{d}{2} * \frac{-1+10^{\frac{h}{k}}}{1+10^{\frac{h}{k}}}}{4*(m+n)}$$

(17)

The variation of maximum allowable speed with cell radius, r, is shown in Figure 16. We use h=5dB, k=40dB, m=6ms, and n=2ms as in [14], and T=1014ms as in [18]. The plot shows that FRONEMO allows much higher vehicle speed than FMIPv6, e.g., for r=60m, FRONEMO allows a maximum speed of 254 km/h whereas FMIPv6 allows only 62 km/h. This increase in maximum vehicle speed in FRONEMO

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[5] We do not include the time required for the ROAck packet to reach the MR because when the CN receives RO packet it starts sending the packets to the new location of the MR.

compared to FMIPv6 is achieved by using IP pre-fetching and advance-registration mechanism of FRONEMO.

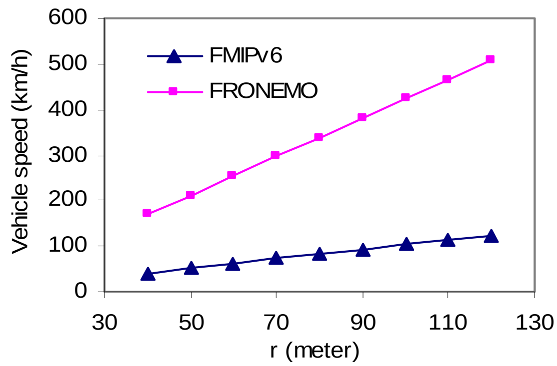

Figure 16: Variation of maximum speed with cell radius

A. *Analyis of handoff latency*

We define handoff latency as the time taken to exchange control packets to complete the fast handoff and route optimization process. For FMIPv6, the handoff latency includes the time from notifying or detecting the new link (after L2 handoff) to getting BAck from CN. For FRONEMO, the handoff latency includes the time from presence announcement to getting ROAck from the CN.

Let us define D_{FMIPv6} as the handoff latency in FMIPv6. D_{FMIPv6} will be lowest when FMIPv6 successfully does the handoff process in predictive mode, i.e., the speed of the vehicle is less than or equal to W_{max}. In this case, the handoff latency will include the delay in sending UNA, delay in completing binding update with the HA and delay in completing binding update with the CN. If the vehicle speed increases to ($z/2m$), the handoff latency will include additional delay factors such as m (for sending FBU), $4n$ (for exchanging HI and HAck), and m (for FBAck). If the vehicle speed becomes more than ($z/2m$) but less than or equal to (z/m), the handoff latency will be same. However, if the speed increases beyond (z/m), then the MR switches to the operatation of MIPV6 and D_{FMIPv6} will now include m (for router advertisement), T_{DAD} (for duplicate address detection), delay in completing BU with the HA and delay in completing BU with the CN. Thus, we have the following equations for D_{FMIPv6}.

$$D_{FMIPv6} = \begin{cases} m + 2T, & v \le W_{\max} \\ 2m + 4n + 2T, & W_{\max} < v \le \dfrac{z}{m} \\ m + T_{DAD} + 2T, & v > \dfrac{z}{m} \end{cases} \qquad (18)$$

Let us denote by $D_{FRONEMO}$ the handoff latency in FRONEMO. If the speed of the vehicle is less than or equal to V_{max}, the handoff latency will include m (for presence announcement) and delay for BU with the HA of MR. Increasing the vehicle speed beyond V_{max} will result in additional delay factor m (for router advertisement). Thus, we have the following equations for $D_{FRONEMO}$.

$$D_{FRONEMO} = \begin{cases} m + 2T, & v \le V_{\max} \\ 2m + 2T, & v > V_{\max} \end{cases} \qquad (19)$$

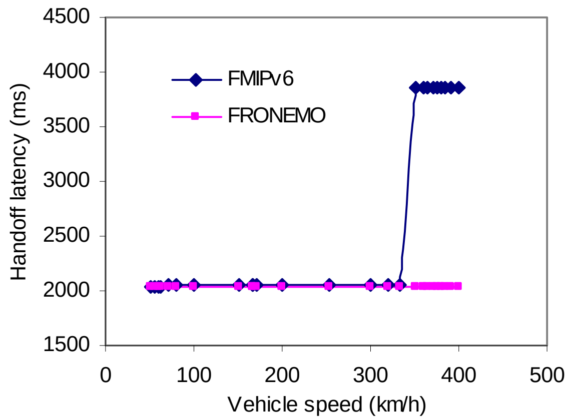

Figure 17: Variation of handoff latency with vehicle speed

Figure 17 shows the variation of handoff latency with the vehicle speed for r=60m and T_{DAD}=1825ms. From Figure 17, we see that the handoff latency for FMIPv6 is about 2034ms when the speed of the vehicle is less than or equal to 62 km/h (W_{max}). The handoff latency increases when the speed becomes more than 62 km/h and stays there until the speed of the vehicle becomes 332 km/h. However, beyond this speed, handoff latency includes T_{DAD} and hence the handoff latency increases significantly. For FNEMO, the handoff latency remains constant till 254 km/h speed (V_{max}). However, when IP pre-fetching fails (i.e., when the vehicle speed goes above 254 km/h) the handoff latency increases slightly due to address request by the MR.

B. *Analysis of signaling cost*

The signaling cost is defined as the time taken for the exchange of control packets to complete the handoff and route optimization process. In FMIPv6, the signaling cost includes the time from sending RtSolPr packet to receiving FBack packet and updating the HA and the CN. In FRONEMO, the signaling cost includes the time from requesting FCoA from FAR to forwarding the FCoA to the MR and updating the HA and the CN.

Let us define T_{FMIPv6} and $T_{FRONEMO}$ as the time required for CoA assignment process of FMIPv6 and FRONEMO respectively. T_{FMIPv6} is lowest when the speed of the vehicle is within the maximum allowable speed, W_{max}, so that the handoff process is successfully completed within the overlapping region. When the MR could not receive the FBack within the overlapping region, then it has to send a FBU again in the new cell and as a result, HI and HAck are exchanged again between the CAR and the PAR. This situation occurs when the speed of the vehicle is more than W_{max} but less than or equal to ($z/2m$). In this case, T_{FMIPv6} includes the delay in link layer handoff, T_{L2}. When the speed of the vehicle becomes more than ($z/2m$), then the MR will not be able to send the FBU from the overlapping region. In this case, T_{FMIPv6} will be lower than the previous case because no duplicate HI and HAck are exchanged. If the speed now increases beyond ($z/2m$), then FMIPv6 switches to normal handoff process of MIPv6 and T_{FMIPv6} will include the delay for duplicate address detection mechanism, T_{DAD}. So, if we denote the vehicle speed by v, then the expression for T_{FMIPv6} can be given as follows:

$$T_{FMIPv6} = \begin{cases} 4m + 4n, & v \le W_{\max} \\ T_{L2} + 5m + 8n, & W_{\max} < v \le \dfrac{z}{2m} \\ T_{L2} + 4m + 4n, & \dfrac{z}{2m} < v \le \dfrac{z}{m} \\ T_{L2} + m + T_{DAD}, & v > \dfrac{z}{m} \end{cases} \qquad (20)$$

In case of FRONEMO, $T_{FRONEMO}$ is lower if the speed of the vehicle is within V_{max} allowing successful handoff within the overlapping region. But, if the speed of the vehicle is more than V_{max}, then IP pre-fetching will fail. In this case, the MR explicitly requests the CAR for CoA allocation. So, $T_{FRONEMO}$ can be given as follows:

$$T_{FRONEMO} = \begin{cases} m + 4n, & v \le V_{\max} \\ T_{L2} + 2m, & v > V_{\max} \end{cases} \qquad (21)$$

Let us denote the signaling cost for FMIPv6 and FRONEMO by C_{FMIPv6} and $C_{FRONEMO}$, respectively. The signaling costs include the cost for updating the HA and the CN. Thus, we have the following Equations for the signaling cost in FMIPv6 and FRONEMO.

$$C_{FMIPv6} = T_{FMIPv6} + 2T \qquad (22)$$

$$C_{FRONEMO} = T_{FRONEMO} + 2T \qquad (23)$$

a b

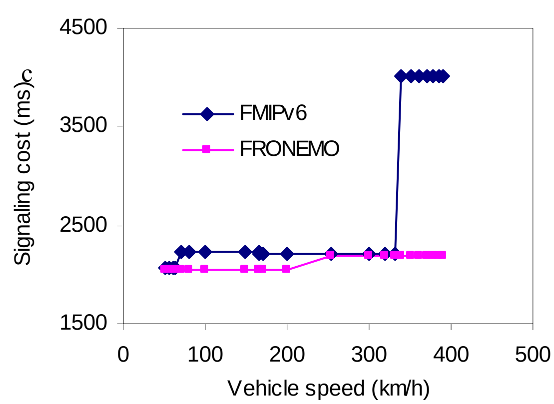

Figure 18: Variation of signaling cost with vehicle speed

Figure 18 shows the signaling cost as the speed of a vehicle changes in a cell with radius r=60m. The FRONEMO exhibits a constant signaling cost 2042ms for vehicle speed 0 to 254 km/h. As the vehicle speed becomes more than 254 km/h, the signaling cost increases to 2197ms. After that, increase in vehicle speed does not affect the signaling cost. For FMIPv6, however, the signaling cost increases as well as decreases with increase in speed of the vehicle. The first change (point a in Figure 18) occurs when the MR could not receive FBack resulting in exchange of FBU, HI, and HAck packets. The second change (point b) occurs when the MR could not send the FBU. We note that, in this case, the signaling cost is decreased because no additional HI and HAck packets are exchanged. The third change (point c) occurs when the MR could not send the RtSolPr packet from the overlapping region. After this change, the signaling cost no longer changes even if the speed of the vehicle increases.

C. *Analysis of packet loss*

During handoff, packet loss occurs if the PAR receives packets from the HA of MR but the MR has moved to the next cell and the packets are not forwarded to the CAR. The packet loss will continue to occur until and unless the CN is updated by the MR about its current location.

For FMIPv6, no packet loss occurs when the speed of the vehicle is within W_{max}. When the vehicle speed is between W_{max} and ($z/2m$), still there will be no packet loss because the PAR has already started forwarding packets to the CAR (because exchange of HI and HAck is completed and a tunnel is established between the PAR and the CAR). When the speed of the vehicle is more than ($z/2m$) but less than or equal to (z/m), the vehicle has sent the FBU but due to non-establishment of forwarding tunnel between the PAR and the CAR, packets from the CN will be destined to the PAR resulting in packet losses. The duration for packet loss will be $T_{L2}+m+2n+2n=T_{L2}+m+4n$. If the vehicle speed goes above (z/m), the duration of packet loss will include T_{L2}, m (for router advertisement), T_{DAD}, T (for BU with the HA), and ($T/2$) (for sending RO packet to the CN). Thus, we have the following expressions for packet loss (L_{FMIPV6}) in FMIPv6.

$$L_{FMIPv6} = \begin{cases} 0, v \le \dfrac{z}{2m} \\ \lambda(T_{L2} + m + 4n), \ \dfrac{z}{2m} < v \le \dfrac{z}{m} \\ \lambda(T_{L2} + m + T_{DAD} + \dfrac{3T}{2}), \ v > \dfrac{z}{m} \end{cases} \quad (24)$$

where λ is the average packet arrival rate at the PAR.

For FRONEMO, there will be no packet loss if the speed of the vehicle is less than or equal to V_{max}. If the vehicle speed is more than V_{max}, on entering a new cell, the MR has to send an address assignment request to the CAR. After getting the CoA from the CAR, the MR updates the HA. Then the MR sends a RO packet to update the CN. So, the duration of packet loss includes T_{L2}, time required for CoA assignment ($2m$), time required for updating the HA (T), and the CN ($T/2$). Thus, we have the following expressions for packet loss ($L_{FRONEMO}$) in FRONEMO.

$$L_{FRONEMO} = \begin{cases} 0, \ v \le V_{\max} \\ \lambda(T_{L2} + 2m + \dfrac{3T}{2}), \ v > V_{\max} \end{cases} \quad (25)$$

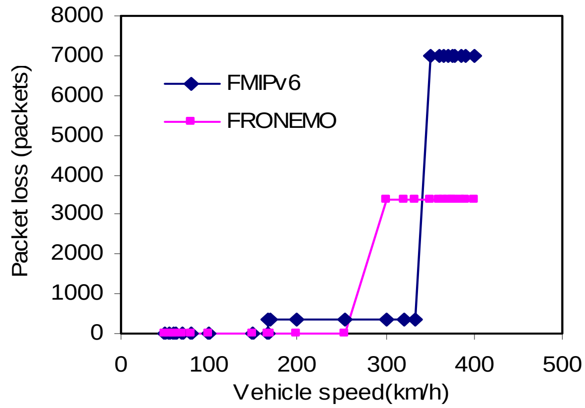

Figure 19: Variation of packet loss with vehicle speed

Figure 19 shows the variation in packet loss with the speed of a vehicle for r=60m and λ=2 packets/ms. From Figure 19, we see that in FMIPv6 there is no packet loss till 166 km/h speed. This is due to the fact that a tunnel was established between the PAR and the CAR. However, packet loss occurs when the speed goes above 166 km/h. This happens because the tunnel is established after the vehicle has moved to the new cell. Absence of a tunnel makes the PAR to send the packets in its own cell resulting in packet losses. The situation gets worsen when the speed goes above 330 km/h. In case of FRONEMO, there is no packet loss till 254 km/h (V_{max}) speed. However, beyond this speed the IP pre-fetching fails resulting in packet losses, but this loss is significantly lower than that in FMIPv6.

D. *Analysis of throughput*

We define throughput as the number packets successfully delivered to NNs in unit time. To calculate throughput, we consider the time gap (U) between two successive handoffs. Let us denote by L and λ, the number of packets lost and the average packet arrival rate at CAR respectively. Then, the throughput (ζ) can be given as:

$$\zeta = \frac{U\lambda - L}{U} \qquad (26)$$

Let us assume that U_{FMIPv6} denotes the time gap between two successive handoffs in FMIPv6. When the vehicle speed is within W_{max}, U_{FMIPv6} includes time for sending RtSolPr and PrRtAdv packet ($2m$), time for sending FBU (m), time for interchanging HI and HAck ($4n$), time for sending FBAck (m), time for L2 handoff (T_{L2}), time for updating the HA (T), and time for updating the CN (T). If the vehicle speed is between W_{max} and ($z/2m$), U_{FMIPv6} includes additional factors, namely, time for another FBU (m) and time for duplicate HI and HAck interchange ($4n$). If the vehicle speed is between ($z/2m$) and (z/m), the MR will not be able to send FBU from the overlapping region. So, U_{FMIPv6} will include time for RtSolPr packet (m), time for PrRtAdv packet (m), time for L2 handoff (T_{L2}), time for sending FBU (m), time for HI and HAck interchange($4n$), and time for updating the HA and the CN ($2T$). Increasing the vehicle speed beyond (z/m) will make the handoff procedure similar to MIPv6 and U_{FMIPv6} will include T_{L2}, m (for router advertisement), T_{DAD}, and $2T$ (for updating the HA and the CN). Thus we have the following expressions for U_{FMIPv6}.

$$
U_{FMIPv6} = \begin{cases} 4m + 4n + T_{L2} + 2T, & v \le W_{\max} \\ T_{L2} + 5m + 8n + 2T, & W_{\max} < v \le \dfrac{z}{2m} \\ T_{L2} + 4m + 4n + 2T, & \dfrac{z}{2m} < v \le \dfrac{z}{m} \\ T_{L2} + m + T_{DAD} + 2T, & v > \dfrac{z}{m} \end{cases} \quad (27)
$$

Putting the values of L_{FMIPv6} (Equations (24)) and U_{FMIPv6} (Equation (27)) in Equation (26), we get the throughput of FMIPv6 (ζ_{FMIPv6}) as follows:

$$
\zeta_{FMIPv6} = \begin{cases} \lambda, v \le \dfrac{z}{2m} \\ \lambda(\dfrac{3m + 2T}{T_{L2} + 4m + 4n + 2T}), & \dfrac{z}{2m} < v \le \dfrac{z}{m} \\ \lambda(\dfrac{T}{2T_{L2} + 2m + 2T_{DAD} + 4T}), & v > \dfrac{z}{m} \end{cases} \quad (28)
$$

Let us denote by $U_{FRONEMO}$ the time gap between the receipts of two successive ROAck packets from the CN in FRONEMO. If the vehicle speed is less than V_{max}, IP pre-fetching becomes successful and hence, $U_{FRONEMO}$ will be equal to the duration from requesting FCoA to the reception of ROAck packet. However, if vehicle speed goes beyond V_{max}, $U_{FRONEMO}$ includes an additional factor, namely, m (for receiving address from the CAR). Thus, the expressions for $U_{FRONEMO}$ can be given as follows:

$$
U_{FRONEMO} = \begin{cases} 4n + m + T_{L2} + 2T, & v \le V_{\max} \\ 4n + T_{L2} + 2m + 2T, & v > V_{\max} \end{cases} \quad (29)
$$

Putting the values of $L_{FRONEMO}$ (Equation (25)) and $U_{FRONEMO}$ (Equation (29)) in Equation (26), we get the throughput of FRONEMO ($\zeta_{FRONEMO}$) as follows:

$$
\zeta_{FRONEMO} = \begin{cases} \lambda, & v \le V_{\max} \\ \lambda(\dfrac{4n + \dfrac{T}{2}}{4n + T_{L2} + 2m + 2T}), & v > V_{\max} \end{cases} \quad (30)
$$

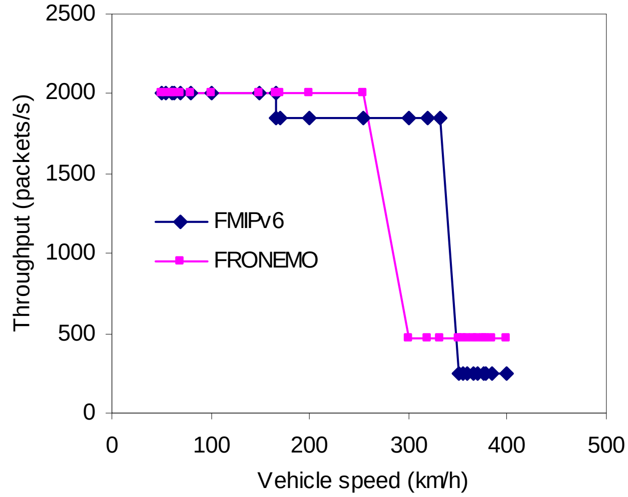

Figure 20: Variation of throughput with vehicle speed

Figure 20 shows the maximum achievable throughput of FMIPv6 and FRONEMO for r=60m and λ=2000 packets/sec [14]. From Figure 20, we see that FMIPv6 achieves a throughput equal to the packet arrival rate till 166 km/h speed. This is because there is no packet loss till 166 km/h speed. As packet loss starts to occur with increased vehicle speed, throughput starts decreasing and this degradation becomes significant when the vehicle speed crosses 332 km/h. For FRONEMO, since there is no packet loss till 256 km/h (V_{max}), it does not suffer from throughput degradation till 256 km/h speed. However, when the vehicle speed crosses V_{max}, throughput degrades but still higher than that in FMIPv6.

E. *Analysis of route optimization overhead*

We define route optimization overhead (ROH) as the total number of packets transferred during route optimization process. Let us assume that the vehicle contains μ NNs and each NN communicate with q CNs. In FMIPv6, an NN exchanges home test init (HoTI), care of test init (CoTI), home test (HoT), care of test (CoT), BU, and BAck packets with the CN to complete the route optimization process. So, ROH in FMIPv6 (H_{FMIPv6}) is calculated as

$$H_{FMIPv6} = 6q\mu \qquad (31)$$

However, in FRONEMO, the MR maintains a list of q CNs with which the NNs communicate. To perform route optimization the MR sends RO packet to each CN and receives ROAck packet from each CN. So ROH in FRONEMO ($H_{FRONEMO}$) can be given as:

$$H_{FRONEMO} = 2q \qquad (32)$$

From Equation (31) and (32), we can write:

$$\frac{H_{FMIPv6}}{H_{FRONEMO}} = 3\mu \qquad (33)$$

Equation (33) clearly indicates that ROH in FMIPv6 is significantly higher than FRONEMO and changes with change in the number of active NNs in the vehicle.

V. CONCLUSIONS

In this paper, we have proposed a modification of NBS protocol, called FRONEMO, to improve the handoff performance. FRONEMO utilizes the concept of IP pre-fetching and advance-registration to perform handoff operation without any delay and packet losses. It also introduces a route optimization technique to reduce packet transfer latency. The analysis presented in this paper clearly shows that the handoff latency and signaling overhead is very low for FRONEMO compared to FMIPv6. The throughout obtained by FRONEMO is also significantly higher than FMIPv6. Further, in comparison to FMIPv6, FRONEMO can support higher vehicle speed, making it suitable for deployment in high speed vehicles.

REFERENCES:

[1] P. Perera, V. Sivraman, and A. Seneviratne, "Survey on network mobility support", Mobile Computing and Communications Review, vol. 8, no. 2, pp 7-19. April 2004.

[2] V. Devarapalli, R. Wakikawa, A. Petrescu, and P. Thubert, "Network mobility (NEMO) basic support protocol", RFC 3963, January 2005.

[3] B. Mussabbir, W. Yao, Z. Niu, and X. Fu, "Optimized FMIPv6 using IEEE 802.21 MIH services in vehicular networks", IEEE Transactions on Vehicular Technology, vol 56, no. 6, pp 3397-3407, November 2007.

[4] H.Oh and C. Kim, "A robust handoff under analysis of unexpected vehicle behaviors in vehicular ad-hoc network", VTC 2010, pp 1-7.

[5] T. Arita and F. Teraoka, "A fast handoff mechanism using cross-layer collaboration for mobile networks in high-speed trains", Asia Future Internet Forum, Winter School, February 2010.

[6] C. Perkins, "IP mobility support for IPv4", RFC 3344, August 2002.

[7] D. Johnson, C. Perkins, and J. Arkko, "Mobility support in IPv6", RFC 3775, June 2004.

[8] H. Soliman, C. Castelluccia, K. Elmalki, and L.Bellier, "Hierarchical mobile IPv6 (HMIPv6) mobility management", RFC 5380, October 2008.

[9] R. Koodli, "Mobile IPv6 fast handoffs", RFC 5568, July 2009.

[10] Railway Technical Research Institute. http://www.rtri.or.jp

[11] J. Na, J. Choi, S. Cho, C. Kim, S. Lee, H.Kang, C. Koo , "A unified route optimization schme for network mobility", Personal Wireless Communication, LNCS vol 3260/2004, pp614-617, 2004.

[12] S. Deering, R. Hinden, "Internet Protocol, Version 6 (IPv6) Specification", RFC 2460, December 1998.

[13] C.J. Bernardos, M. Bagnulo, M. Calderon, "MIRON: MIPv6 route optimization for NEMO", ASWN 2004.

[14] N. V. Hanh , S. Ro, and J. Ryu, "Simplified fast handoff in mobile IPv6 networks", Computer Communications, vol 31, issue 15, pp 3594-3603, September 2008.

[15] G.Y. Liu, G.Q. Maguine, "A predictive mobility management algorithm for wireless mobile computing and communications", ICUPC 1995.

[16] R. Sanakar, N. Savkoor, "A combined prediction system for handoffs In overlaid wireless networks", IEEE ICC 1999.

[17] J. Schiller, "Mobile Communications", 2nd Edition, Addison-Wesley.

[18] G. Xie, J. Chen, H. Zheng, J. Yang, and Y. Zhang, "Handover latency of MIPv6 implementation in linux", IEEE GLOBECOM 2007.