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Efficient Management of Fast Handoff in Wireless Network Mobility (NEMO)

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. In this paper, we propose fast NEMO (FNEMO) to reduce the handoff latency and packet losses experienced in NBS protocol. FNEMO brings in the concept of IP pre-fetching and advance-registration to acquire care-of-address for the anticipated future cells. Numerical analysis shows that FNEMO can support higher vehicle speed than that in fast MIPv6 (FMIPv6) and still has significantly low signaling overhead.**

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 mobile nodes (MN) forming a network. When the vehicle moves, all MNs 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 MNs inside the vehicle. These protocols require MNs to be sophisticated enough to perform mobility related functionalities. But, given MNs like PDAs which are not powerful enough, it is not always expected from each MN 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 move detection resulting in high handoff delay and packet loss.

The IETF has recently standardized NEMO basic support (NBS) protocol [2] to provide Internet access to the MNs 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 to its home agent (HA). This elaborate handoff process introduces considerable delay entailing packet loss [1] that hampers user experience in Internet access. So a faster handoff mechanism is needed, which can reduce both handoff latency and packet loss.

In this paper, we propose fast NEMO (FNEMO) to improve the handoff performance of NBS protocol. The FNEMO introduces IP pre-fetching and advance-registration, whereby an MR, in anticipation, can obtain and register 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. Through numerical analysis, we find the maximum allowable speed of an MR (and hence of the associated vehicle) for providing uninterrupted service to the MNs in the vehicle. Also, we compare FNEMO with fast MIPv6 (FMIPv6) [9] in terms of maximum allowable speed of an MR, signaling cost required to perform the fast handoff operation, handoff latency, and packet loss.

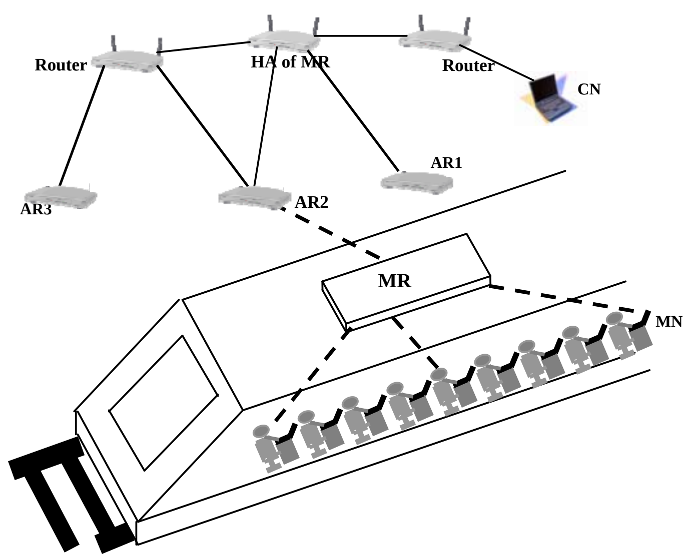

Figure 1: NEMO connectivity model

The rest of the paper is organized as follows. Section II contains a summary of fast handoff protocols for both terminal and network mobility. In Section III, we provide a detailed description of FNEMO. Section IV provides a comparative analysis of maximum vehicle speed, signaling cost, handoff latency, and packet loss for FNEMO and FMIPv6. Finally, Section V concludes the paper.

II. Related Works

A. Fast handoff for terminal mobility

FMIPv6 [9] utilizes link layer (i.e., layer 2 or L2) trigger to anticipate the handoff. Whenever L2 trigger occurs, the MN 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 MN, 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 MN. On entering the new cell, the MN sends an unsolicited neighbor advertisement (UNA) to the NAR. The MN 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 MN moves very fast, the MN may not be able to send the FBU from PAR's area resulting in higher handoff delay and more packet losses.

B. Fast handoff for NEMO

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 and acknowledge is for/from an MR. The proposed protocol introduces a new entity called Information Server (IS) for each AR that keeps information about the neighboring ARs. The protocol creates a neighboring network report (NNR) cache at the MN 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 cache. When the MR detects that it is moving to a new network then 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. As it introduces new entity for each AR and cache for each MN, the cost of deployment becomes very 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 the binding update to its HA. The protocol does not anticipate handoff and hence 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.

In this paper, we propose FNEMO to reduce the handoff latency and the number of packet losses to zero during high speed movement of an MR. FNEMO 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 reduces the number of control packets to perform the handoff operation.

III. FNEMO

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. The high-speed vehicles move along a straight line.

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[1] Although the cells are hexagonal, it is easier to model them as circle to reflect uniform signal propagation from AR with omni-directional antenna. If c is the radius of the hexagon and r is the radius of the circle then $c = \frac{2}{3}r$ [11].

6. 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. Working of FNEMO

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. So, the MR announces its presence to the new CAR in the new cell. The entire mobility management process is shown in Figure 2.

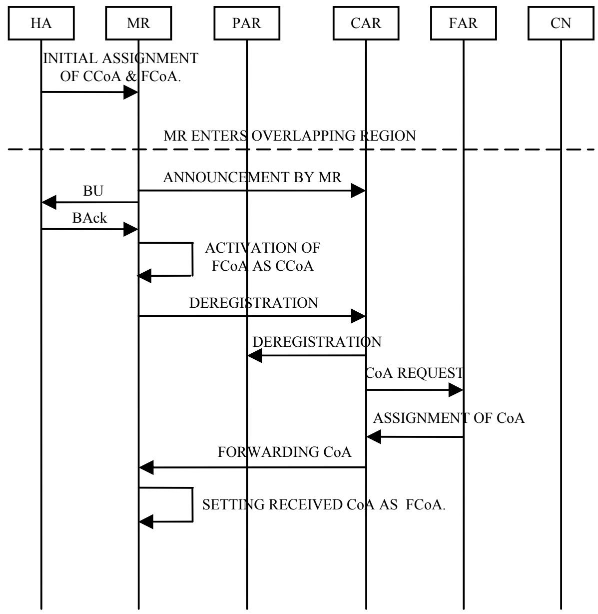

Figure 2: Timing diagram of FNEMO

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 is a modification of unsolicited neighbor advertisement [9] with a new sub-type. The announcement packet (format is shown in Figure 3) 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 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.

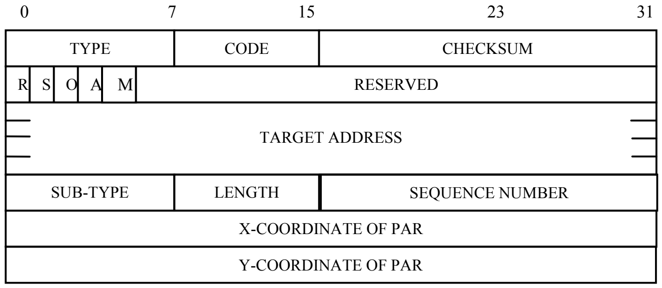

Figure 3: Format of announcement packet

B.2 Deregistration

Once the MR has updated its HA, it then sends a deregistration packet to the PAR through CAR. The deregistration packet uses modified IPv6 type 2 routing header (Figure 4) [7]. The IP address of CAR is put in the options field so that the packet first visits the CAR and then goes to the PAR. The rest of the de-registration process follows normal deregistration procedure of the NBS protocol.

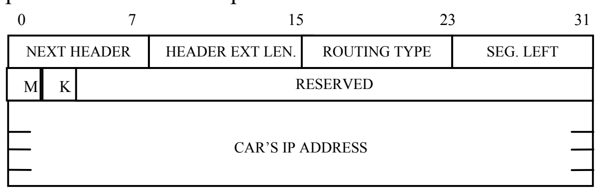

Figure 4: Modified type 2 routing header

B.3 IP pre-fetching and advance-registration

When the deregistration process is completed, the CAR derives the FAR using the algorithm shown in Figure 5. The input to the algorithm is the coordinate of neighboring ARs and the output is the coordinate of the FAR. So, the CAR can easily find out the IP address of FAR from table of binding (Assumption 4 in 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). If M=0, it indicates that the packet is sent from the CAR on behalf of the MR. If M=1, it indicates that the packet is sent by the MR. The reply from the FAR contains the assigned CoA. The format of the reply follows the format of HAck [9] and uses a new one-bit field M (Figure 7). 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), which sets it as FCoA[2]. 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.

1. Let (p_x,p_y) be the coordinate of PAR. Let (α,β) be coordinate of the CAR. The CAR finds the straight line $L^{/}(x,y)$ perpendicular to $Lp(x,y)=ax+by+c=0$ that passes through (α,β).
2. Set minimum distance, M: =+infinity and FAR: = Not-Defined.
3. For each (α_1,β_1) [co-ordinate of the neighbor of CAR], do the following:
   a. If sign $(L^{/}(\alpha_1,\beta_1))$!= sign$(L^{/}(p_x,p_y))$ [The AR lies on the other side.]
      i. Find $M^{/}$:= mod$(L(\alpha_1,\beta_1))$/sqrt$(b^2 + a^2)$
      ii. [The equation of the straight line perpendicular to Lp(x,y) is L'(x,y) = bx-ay+constant = 0 and this equation is satisfied by (α,β). So the constant can be obtained] If $M^{/} < M$, then:
         1. Set M := M'
         2. Set FAR := (α_1,β_1)
4. Output FAR

[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.

Figure 5: Algorithm for finding FAR

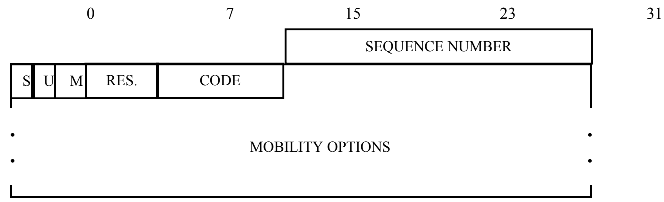

Figure 6: Request for CoA

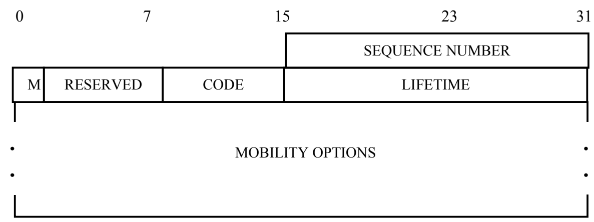

Figure 7: Reply from FAR

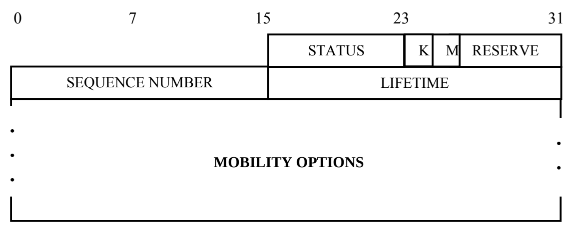

Figure 8: Reply from CAR to MR

IV. Performance Analysis of FNEMO

To analyze the performance of FNEMO, we follow the approach presented in [11]. In particular, we provide analysis for finding maximum speed of a vehicle, V_{max}, signaling cost incurred by the protocol, handoff latency, and packet loss to perform fast handoff. The model used in our analysis is shown in Figure 9. In Figure 9, Q_P, Q_C, and Q_F denotes the past, current, and future cell, respectively. The Points A, B, and C are the position of the PAR, CAR and FAR respectively. The point E and I are the midpoint of the overlapping region between Q_P and Q_C, and between Q_C and Q_F respectively.

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 9. From Figure 9, we have the following set of equations:

$$The\ inter-AR\ distace = |AB| = |BC| = d \tag{1}$$

$$The\ radius\ of\ each\ cell = |AG| = |DB| = |BJ| = |HC| = r \tag{2}$$

$$|DG| = |HJ| = 2|DE| = 2|EG| = x \tag{3}$$

$$|EF| = |IK| = d_h \tag{4}$$

$$|FG| = |KJ| = z = \frac{x}{2} - d_h \tag{5}$$

$$|DF| = |HK| = y \tag{6}$$

$$y = \frac{x}{2} + d_h \tag{7}$$

As given in [11],

$$x = 2r * \sin\left(\cos^{-1}\left(\frac{1.732 * \left(c + \left(4r^2 - 3c^2\right)^{0.5}\right)}{4r}\right)\right) \quad (8)$$

$$c = \frac{2}{3} r \quad (9)$$

and,

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

where k is the environment specific attenuation characteristics [11].

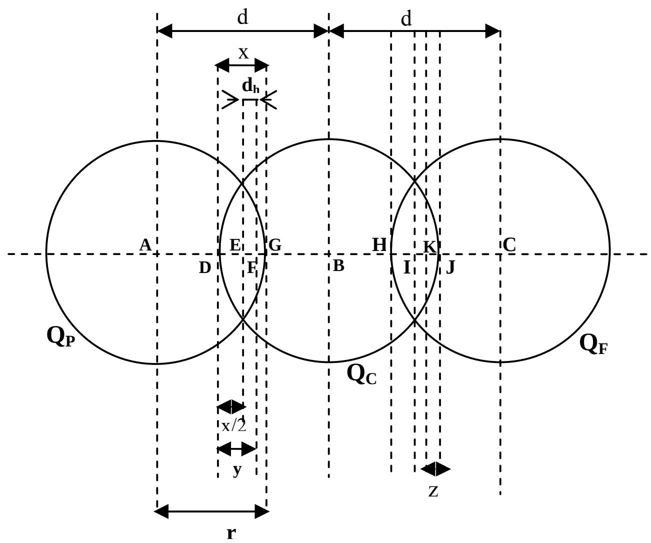

Figure 9: Reference diagram used for analysis

We assume that the vehicle is in cell Q_C and the MR has completed the deregistration process. The CAR should request for new FCoA at point G and the MR should finish updating the HA 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. Now, the distance between G and K is:

$$|GK| = |GH| + |HI| + |IK|$$
$$= 2r - 2x + \frac{x}{2} + d_h$$

Using Equation (10) we get:

$$|GK| = (2r - 2x) + \frac{x}{2} + \frac{d}{2} * \frac{-1 + 10^{\frac{h}{k}}}{1 + 10^{\frac{h}{k}}} \quad (11)$$
$$= 2r - \frac{3}{2}x + \frac{d}{2} * \frac{-1 + 10^{\frac{h}{k}}}{1 + 10^{\frac{h}{k}}}$$

Let us define *m* as the delay between MR and AR, and 2*n* as the delay from AR to another AR[3]. Then, the time taken to complete a successful handoff, *t*, can be given as:

[3] 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
So, we have

$$t = T + m + 4n \qquad (12)$$

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,

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

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

$$t = 4m + 4n \qquad (16)$$

Thus, the maximum speed allowed in FMIPv6 is:

$$W_{\max} = \frac{z}{t} = \frac{\frac{x}{2} - \frac{d}{2} * \frac{-1 + 10^{\frac{h}{k}}}{1 + 10^{\frac{h}{k}}}}{4 * (m + n)} \qquad (17)$$

The variation of maximum allowable speed with cell radius, r, is shown in Figure 10. We use h=5dB, k=40dB, m=6ms, and n=2ms as in [11], and T=100ms as in [12]. The plot shows that FNEMO allows much higher vehicle speed than FMIPv6, e.g., for r=60m, FNEMO allows a maximum speed of 951 km/h whereas FMIPv6 allows only 62 km/h. This increase in maximum vehicle speed in FNEMO compared to FMIPv6 is achieved by using IP pre-fetching and advance-registration mechanism of FNEMO.

A. Analysis of signaling cost

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

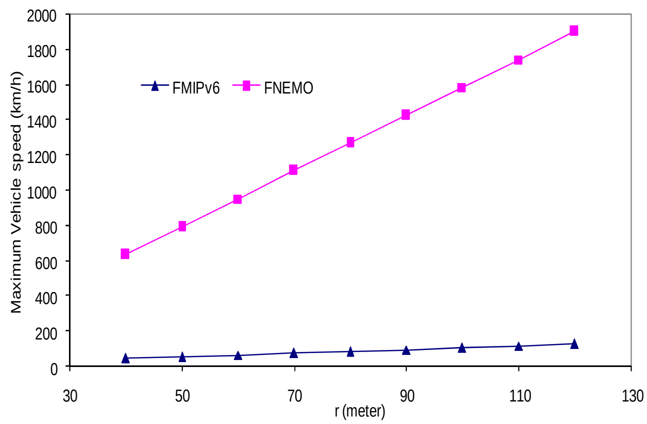

Figure 10: Variation of maximum speed with cell radius

Let us define T_{FMIPv6} and T_{FNEMO} as the time required for CoA assignment process of FMIPv6 and FNEMO 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 FAR. This situation occurs when the speed of the vehicle is more than W_{max} but less than or equal to $\frac{z}{2m}$. In this case, T_{FMIPv6} includes the delay in link layer handoff, T_{L2}. When the speed of the vehicle becomes more than $\frac{z}{2m}$, 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 $\frac{z}{m}$, then FMIPv6 switches to normal handover 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:

$$T_{FMIPv6} = \begin{cases} 4m + 4n, & v \le W_{\max} \\ T_{L2} + 4m + 8n, & W_{\max} < v \le \frac{z}{2m} \\ T_{L2} + 3m + 4n, & \frac{z}{2m} < v \le \frac{z}{m} \\ T_{L2} + m + T_{DAD}, & v > \frac{z}{m} \end{cases} \quad (18)$$

In case of FNEMO, T_{FNEMO} 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_{FNEMO} can be given as follows:

$$T_{FNEMO} = \begin{cases} m + 4n, & v \le V_{\max} \\ T_{L2} + 2m, & v > V_{\max} \end{cases} \quad (19)$$

Let us denote the signaling cost for FMIPv6 and FNEMO by C_{FMIPv6} and C_{FNEMO}, respectively. The signaling costs include the cost for updating the HA. Let us assume that the cost for updating the HA is *T*. Also, in FMIPv6 there is a binding update procedure to update the CN. For the sake of simplicity, let us assume that the cost for updating the CN is also given by *T*. Thus, we have the following Equations for the signaling cost in FMIPv6 and FNEMO.

$$C_{FMIPv6} = T_{FMIPv6} + 2T \tag{20}$$

$$C_{FNEMO} = T_{FNEMO} + T \tag{21}$$

Figure 11 shows the signaling cost as the speed of a vehicle changes in a cell with radius *r*=60m. The FNEMO exhibits a constant signaling cost 114ms for vehicle speed 0 to 951.2 km/h. As the vehicle speed becomes more than 951.2 km/h, the signaling cost increases to 162ms. 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 11) 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 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 vehicle could not send the RtSolPr from the overlapping region. After this change, the signaling cost no longer changes even if the speed of the vehicle increases.

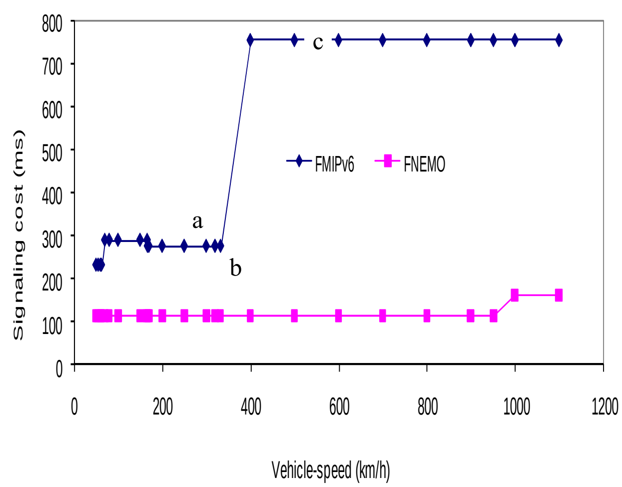

Figure 11: Variation of signaling cost with speed of a vehicle

B. Analysis of Handoff Latency

We define handoff latency as the time taken to exchange control packets to complete the handoff 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 FNEMO, the handoff latency includes the time from presence announcement to getting BAck from the HA of MR.

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 $\frac{z}{2m}$, then 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 $\frac{z}{2m}$ but less than or equal to $\frac{z}{m}$, the handoff latency will be same. However, if the speed increases beyond $\frac{z}{m}$, then the vehicle switches to the operation of MIPV6 and D_{FMIPv6} will now include m (for router advertisement), T_{DAD} (for duplicate address detection), delay in completing binding update with the HA and delay in completing binding update with the CN. Thus, we have the following set of equations for D_{FMIPv6}.

$$D_{FMIPv6} = \begin{cases} m + 2T, & v \le W_{\max} \\ 2m + 4n + 2T, & W_{\max} < v \le \frac{z}{m} \\ m + T_{DAD} + 2T, & v > \frac{z}{m} \end{cases} \qquad (22)$$

Let us denote by D_{FNEMO} the handoff latency in FNEMO. 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 binding update 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_{FNEMO}.

$$D_{FNEMO} = \begin{cases} m + T, & v \le V_{\max} \\ 2m + T, & v > V_{\max} \end{cases} \qquad (23)$$

Figure 12 shows the variation of handoff latency with the vehicle speed for r=60m and T_{DAD}=500ms. From Figure 12, we see that the handoff latency for FMIPv6 is about 206ms 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, however, the handoff latency is significantly lower than FMIPv6 because most of the operations for handoff are performed in advance by using IP pre-fetching and advance registration in the previous cell. Thus, the handoff latency is constant till 951 km/h speed (V_{max}). However, when IP pre-fetching fails (i.e., when the vehicle speed goes above 951 km/h) the handoff latency increases slightly due to address request by the MR.

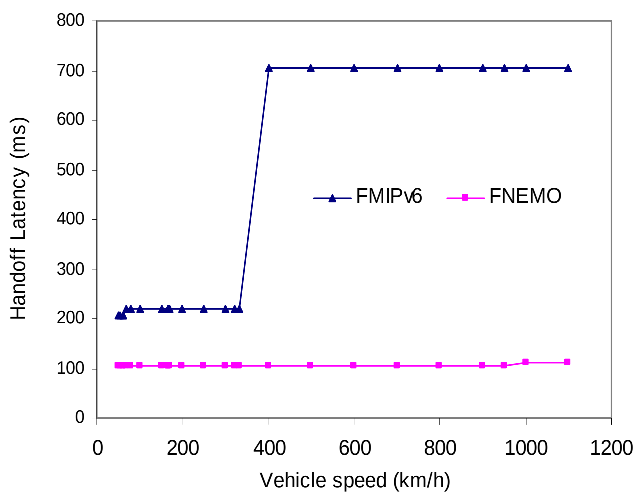

Figure 12: Variation of handoff latency with vehicle speed

C. Analysis of Packet loss

During handoff, packet loss occurs if the CAR receives packets from the HA of MR but the MR has moved to the next cell and the packets are not forwarded to the FAR. The packet loss will continue to occur until and unless the HA 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 $\frac{z}{2m}$, still there will be no packet loss because the CAR has already started forwarding packets to the FAR (because exchange of HI and HAck is completed and a tunnel is established between the CAR and the FAR). When the speed of the vehicle is more than $\frac{z}{2m}$ but less than or equal to $\frac{z}{m}$, the vehicle has sent the FBU but due to non-establishment of forwarding tunnel between the FAR and the CAR packets from the HA will be destined to the CAR 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 $\frac{z}{m}$, the duration of packet loss will include T_{L2}, m (for router advertisement), T_{DAD}, T (for completing BU with HA), and $\frac{T}{2}$ (for sending BU to CN). Thus, we have the following expressions for packet loss (L_{FMIPV6}) in FMIPv6.

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

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

For FNEMO, 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}, the MR has to send an address assignment request to the FAR. After getting the CoA from the FAR, the MR updates the HA. Thus, we have the following expressions for packet loss (L_{FNEMO}) in FNEMO.

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

Figure 13 shows the variation in packet loss with the speed of a vehicle for r=60m and λ=2 packets/ms. From Figure 13, 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 CAR and the FAR. 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 CAR to send the packets in the current cell resulting in packet losses. The situation gets worsen when the speed goes above 330 km/h. In case of FNEMO, there is no packet loss till 951 km/h (V_{max}). However, beyond this speed the IP pre-fetching fails resulting in packet losses, but this loss is significantly lower than that in FMIPv6.

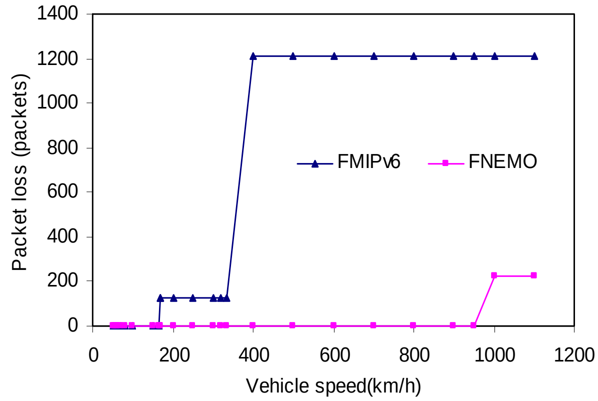

Figure 13: Variation of packet losses with speed of vehicle

V. CONCLUSIONS

In this paper, we have proposed a modification of NBS protocol, called FNEMO, to improve the handoff performance. FNEMO utilizes the concept of IP pre-fetching and advance-registration to perform handoff operation with reduced delay and packet losses. The analysis presented in this paper clearly shows that the signaling overhead is very low for FNEMO compared to FMIPv6. Further, in comparison to FMIPv6, FNEMO can support higher vehicle speed, making it suitable for deployment in high speed vehicles.

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