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

by

Avik Mitra
Department of Information Technology Jadavpur University Kolkata, India

Bhaskar Sardar
Department of Information Technology Jadavpur University Kolkata, India

&

Debashis Saha
Professor, IIM Calcutta, Diamond Harbour Road, Joka P.O., Kolkata 700 104 India

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Avik Mitra
Department of Information Technology
Jadavpur University
Kolkata, India
avik.mitra2@gmail.com

Bhaskar Sardar
Department of Information Technology
Jadavpur University
Kolkata, India
bhaskargit@yahoo.co.in

Debashis Saha
MIS and Computer Science Group
IIM Calcutta
Kolkata, India
ds@iimcal.ac.in

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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

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/

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 PCoA, FCoA 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.

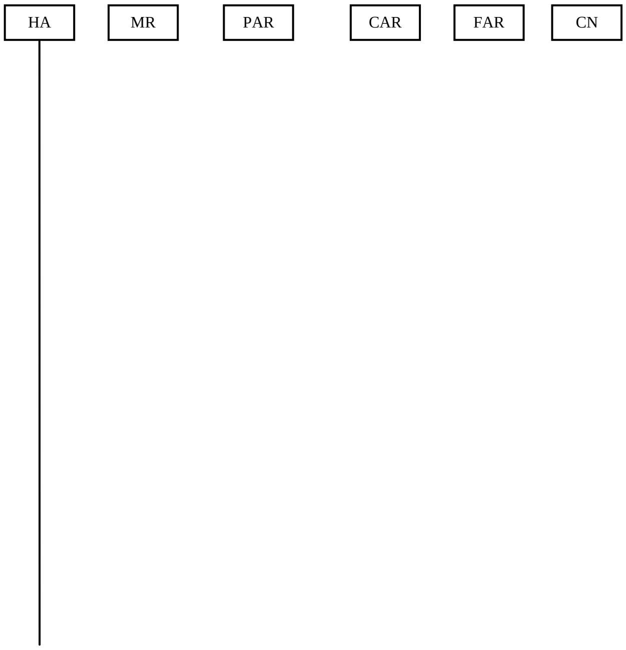

Figure 2: Timing diagram of fast handoff mechanism in FRONEMO

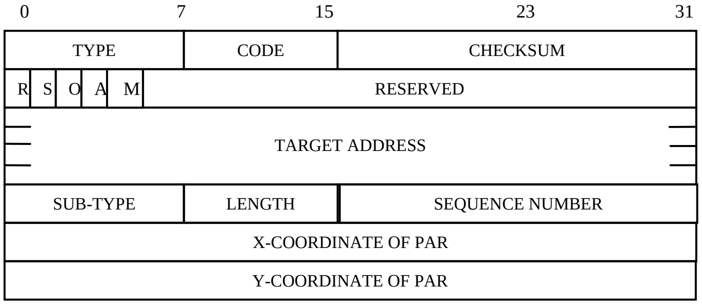

Figure 3: Format of announcement packet

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 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].

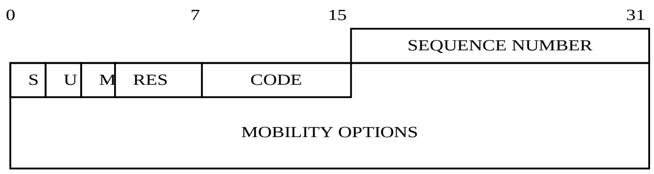

Figure 6: Request for CoA

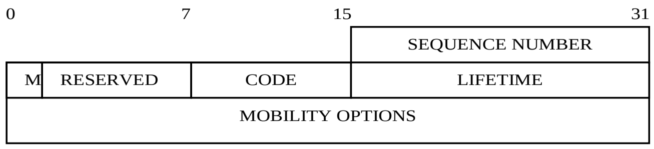

Figure 7: Reply from FAR

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.

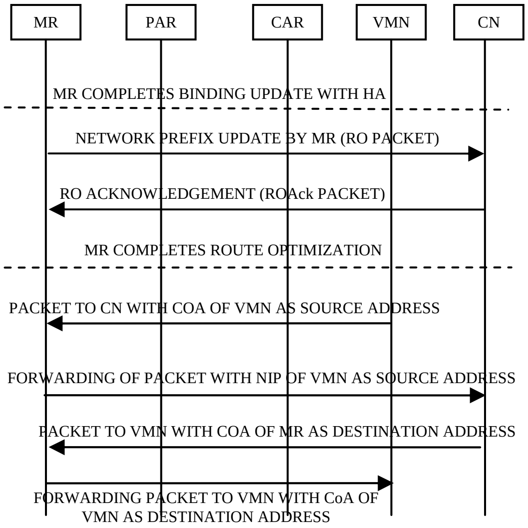

Figure 9. Route optimization and packet delivery in FRONEMO

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

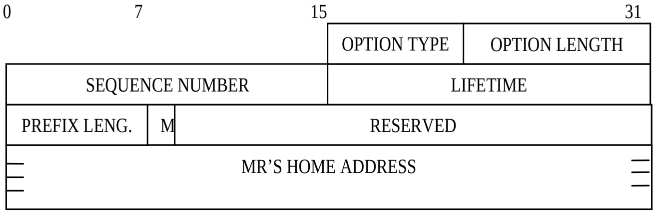

Figure 10: RO packet format

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[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

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

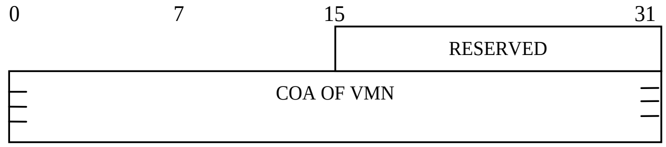

Figure 14: Destination options header for packet delivery from CN to VMN

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)

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

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

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

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

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

As given in [14],

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

$$x \quad 2r * \sin \quad \cos^{1} \frac{1.732 * \quad c \quad 4r^{2} \quad 3c^{2} \; ^{0.5}}{4r} \qquad (9)$$

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

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

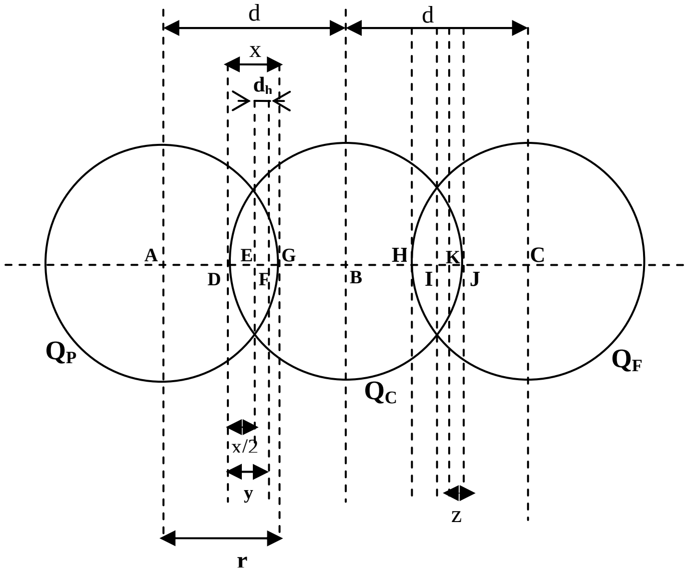

Figure 15: Reference diagram used for analysis

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:

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

$$= 2r \quad 2x \quad \frac{x}{2} \quad d_h$$

Using Equation (10) we get:

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

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

(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:

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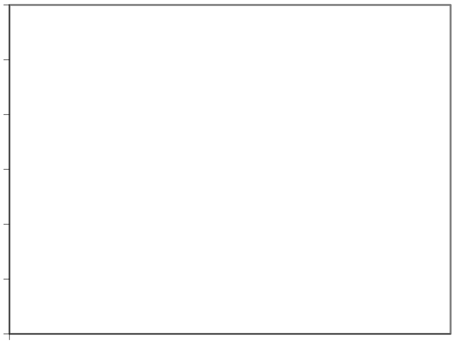
[4] Referring to Figure 1, the AR2-Router delay is n and the Router-AR3 delay is *n*. So, AR2-AR3 delay is 2*n*.

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

$$D_{FRONEMO} \qquad \begin{matrix} m \quad 2T, \quad v \quad V_{\max} \\ 2m \quad 2T, \quad v \quad V_{\max} \end{matrix} \qquad (19)$$



the MR will not be able to

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 th

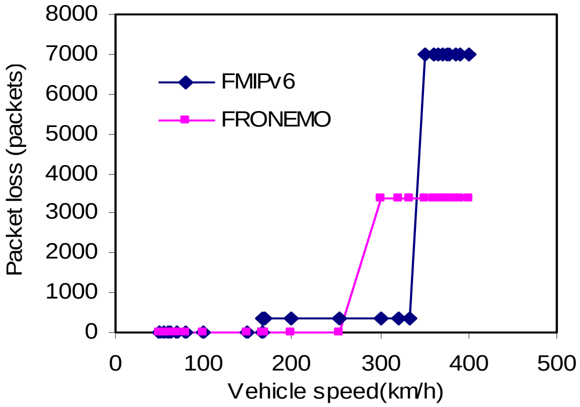


Figure 19: Variation of packet loss with vehicle speed

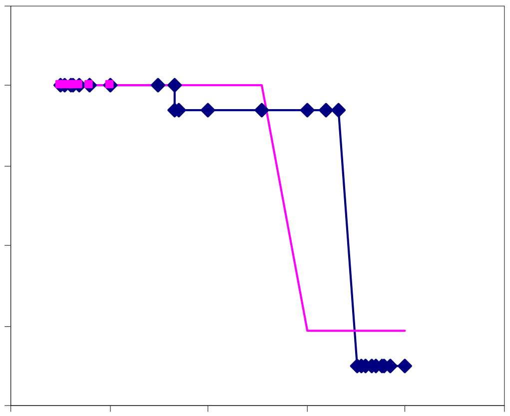
Figure 19 shows the variation in packet loss with the speed of a vehicle for r=60m and =2 packets/ms. From Figure 19, we see that in FMIPv6 there is no packet loss till 166 km/h speed. This is due to the fact that a tunnel was established between the PAR and the CAR. However, packet loss occurs when 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 , the number of packets lost and the average packet arrival rate at CAR respectively. Then, the throughput ( ) can be given as:

$$\frac{U \quad L}{U} \qquad (26)$$

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}.



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