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Mobility Management Scheme Based on Smart Buffering for Vehicular Networks

Nihal H. A. Mohammed
Electrical Engineering Department, Faculty of Engineering, Port -Said University, Port -Said, Egypt.
sotasasa@yahoo.com

Heba N. El-Moafy
Electrical Engineering Department, Faculty of Engineering, Port -Said University, Port -Said, Egypt.
hebanashaat@eng.psu.edu.eg

Salah M. Abdel-Mageid
Systems and Computers Department, Faculty of Engineering, Al-Azhar University, Cairo, Egypt.
smageid@azhar.edu.eg

Mahmoud I. Marie
Systems and Computers Department, Faculty of Engineering, Al-Azhar University, Cairo, Egypt.
marie@azhar.edu.eg

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Abstract – Mobility management in vehicular networks is our case study is to provide internet connectivity without any interruption and with no packet loss, even in V2I (Vehicular to Infrastructure) or V2V (Vehicular to Vehicular) communications. Handover delay is one of critical parameters in QoS measurements in addition to packet loss, throughput and data transmission delay. In this paper, the idea of Smart Buffering is proposed to enhance HI-NEMO protocol. In this extension of NEMO, the combining cross-layer mechanism and resource allocation have been performed. It is used to reduce latency and packet loss during handovers with high performance in its proactive mode. However, it is noticed that packets loss exists in its reactive mode during the period of link down in small coverage cell radius of base station during vehicle movement. Smart Buffering mechanism mostly prevents packet loss by buffering lost candidate packets in Root FMA (Foreign Mobile Agent), forwarding and reordering it in new FMA. It also performs redundant packet removing in Root FMA. Mathematical analysis proves that Enhanced HI-NEMO protocol prevents packet loss during reactive handover and gives optimal throughput with supporting high velocity vehicles.

Index Terms – Vehicular Networks, Network Mobility, NEMO BSP, Smart Buffering and HI-NEMO protocol.

1. INTRODUCTION

Nowadays, vehicular ad-hoc networks (VANET) take place in research topics [1-6]. Mobility management is an important issue in VANET. In the past, the basic protocol of network mobility introduced by (IETF), it is so called NEMO BSP, was introduced with several drawbacks. Many researches come to find some solutions for those drawbacks such as: (1) triangle routing and passing through HA, (2) capsulation and decapsulation that leads to packet overhead and (3) increased latency in handover. The solutions [7, 8] introduce route optimization settlement to reduce the packet transfer delay and getting over HA problem. Furthermore, the researchers exploit the advantages of Multi-homing as mobile node is enabled to use multiple access networks concurrently to perform smooth vertical handoff [9]. This study is an example of the solutions that improve handover delay and QoS parameters by speeding up handover procedure, or data transmission delay; or both of them. However, in all these researches there is still exists a packet loss during the period of link layer handover ($\mathbf{L_2}$ handover), recognition of the new path and having a new IP address [10].

HI-NEMO protocol [11, 12] has been introduced as an extension of NEMO-BS to also improve handover latency and QoS parameters supporting high velocity vehicles. It minimizes the number of packet losses in its proactive mode. CNs could transmit data to Mobile Network Nodes (MNNs) even they are not updated by new address bindings. In addition, it uses Foreign Mobile Agents (FMAs) instead or accesses routers used in NEMO BSP, cross layering designed protocols and Resource Reservation Protocol (RSVP); all provide fast QoS provisioning. However, there is still packet loss.

In this paper, proactive and reactive modes of HI-NEMO protocols are studied with respect to Simple Straight Model (SSM). It shows that proactive mode is semi-optimal in reducing handover delay, packet loss and End-to-End packet delivery. However, reactive mode records packet loss during

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the period of recognition of new path; especially when the vehicle is moved in small cell radius coverage area of base station (BS). Consequently, this packet loss threats critical application because it doesn't allow any data distortion.

Enhanced HI-NEMO (EHI-NEMO) is our proposed protocol which is created to solve this problem using Smart Buffering scheme [14]. Smart buffering in Root FMA prevents packet losses in the reactive HI-NEMO protocol; even it is small, compared with NEMO BSP as the vehicle moves with specific speed, which is computed in this paper. In this protocol buffered packets pass through previous FMA as long as recognition of new path is not completed. It also deals with redundant packet removing in Root FMA and adjusting packet ordering in a new FMA (nFMA), plus the creation of QoS policy is applied.

The rest of this paper is organized as follows; Section 2 explains related works such as NEMO BS and HI-NEMO. Section 3 describes the proposed scheme, section 4 describes the performance analysis of two protocols and proposed protocol, Section 5 describes numerical results used to implement mathematical models, section 6 gives the conclusion of all work.

2. RELATED WORK

Formerly, existing protocols such as MIP and MIPv6 are concerned with host mobility; however, with the large spread of IP devices carried by people in transportation systems, network mobility becomes the main purpose of many researches. Therefore, many network mobility protocols such as NEMO BSP and HI-NEMO have been introduced. In what follows, those protocols are illustrated.

2.1. NEMO BSP

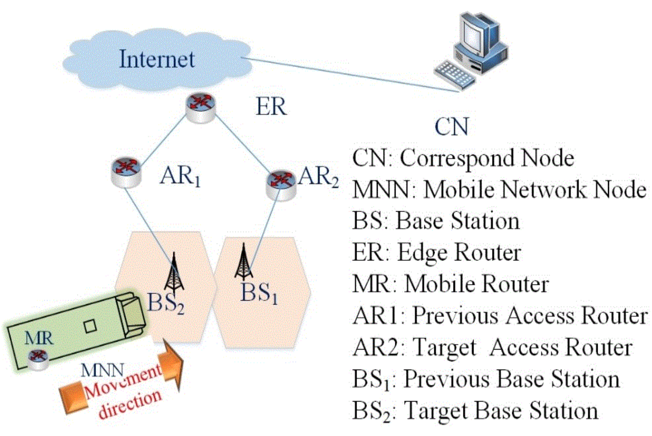

Figure 1 NEMO BS Architecture

NEMO BSP is the basic protocol of network mobility introduced by (IETF) in 2003. As shown in Figure 1, MR acts like a gate way with other internet components and it is concerned with providing internet connectivity with all MNNs in the moving vehicles. Home agent (HA) must exist to maintain all MR IPs, in this way HA can reach MR anywhere and anytime. New care for address is taken from target router by sending request message from target base station where this delay is called movement detection delay (MD), then MR proves this new IP uniqueness by duplicating address detection delay (DAD), and the last process is to bind this new address in HA by registration delay. All these delays increase handover delay besides the problem of using bi-directional tunnel when sending data between HA (those packets have to pass on) and MR after handover is processed.

NEMO BSP suffers from the following drawbacks:

- Latency in the period of radio link handover (L_2 handover) in which the MR has to register with the new base station. This happens during the period of network attachment and having a new IP address (L_3 hand over). Also, there is a delay in sending router solicitation, advertising messages to have new IP, duplicating address detection messages to verify the uniqueness of this IP (1-2 sec) and registration or HA with this new IP with its binding update and acknowledge messages.
- Triangular routing latency and passing all packets on HA every time.
- Packets loss due to those above latencies.
- Packets overhead and bottleneck due to IP-IP tunneling process, capsulation and de-capsulation of packets from HA to MR; detailed explanation found in [15- 18].

2.2. HI-NEMO

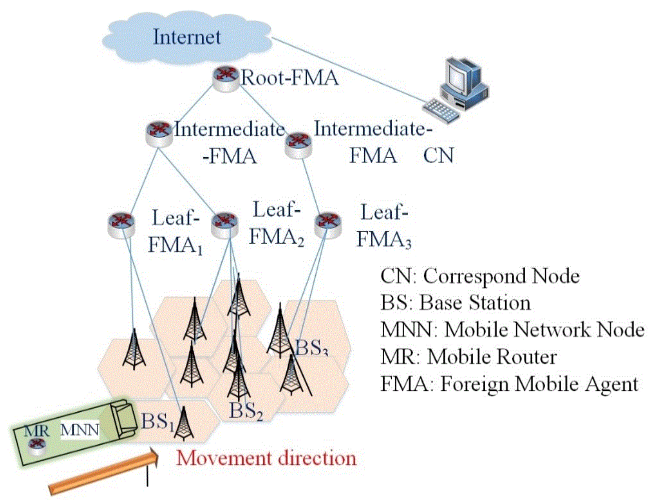

Figure 2 HI-NEMO Architecture

Another protocol began in 2008 to enhance QoS parameters with different features and architecture called HI-NEMO protocol. In this scheme, as in Figure 2, its designs based on using Foreign Mobile Agents (FMAs) are connected by a high speed wired network with functional module instead of routers, in addition to hierarchical routing of these FMAs because of its benefits in decreasing routing tables and reducing message signals. Instead of using traditional layer protocol as in NEMO BSP, cross layer is used with resource reservation protocol in Root FMA which acts as an edge router to make great enhancement in QoS parameters.

All FMAs between the Root-FMA and the leaf-FMA are called intermediate-FMAs. Assuming that, there will be one base station center network cell with wireless connection between Mobile Router and wired connection with other FMA [18]. Furthermore, a distinguish between two types of handover in the Hi-NEMO operations - proactive and reactive - which speed up the handover process is illustrated in [11, 12] and [13].

Mathematical analysis, used here during straight line mobility models, proves that HI-NEMO protocol is optimal in its proactive mode where its features eliminate handover latency and in turn eliminate packet loss. There isn't any triangular routing exists and no packets overhead because of the absence of tunneling and capsulation, and also in its reactive mode. It is noticed that there is a packet loss during the period or radio link of configuration of new base station even it is small but still critically important to send Data during this period, which leads us to think of our proposed scheme.

3. THE PROPOSED SCHEME

With the great performance differences between NEMO BS and HI-NEMO protocols, there is still packet loss in HI-NEMO reactive handover during the period of down link and up link of BS_2; although it is very small. Our key idea is to use seamless handover scheme to speed up handover and minimize packet loss using buffering during reactive HI-NEMO handover with no tunneling between target AR and previous AR. This work is so called Enhanced HI-NEMO (EHI-NEMO). The proposed algorithm for EHI-NEMO is illustrated as follows.

The Proposed Algorithm for EHI-NEMO

```
CN(c) sends a Packet (p);
IF proactive Handover Completed THEN
    BS (t) passes Packet (p) to MNN (n);
ELSE
    BS(s) sends buffer Request to ROOT;
    IF L2DisconnectPeriodCompleted THEN
        IF reactiveHO Completed THEN
            AR(t) sends FRMmessage to ROOT;
            BS(t) passes packet (p) to MNN (n);
        ELSE
            AR(s) sends packet (p) to MNN (n);
ELSE
    Packet (p) is buffered at Root;
```

The main idea of the proposed algorithm is adding a Smart Buffering in FMA that consists of three functional parts:

1. Packet buffering in a Root FMA according to BRM (Buffer request Message) as long as L_2 handover is not finished yet, is based on the receiving signal strength (RSS) for the packets from the serving BS (BS(s))
2. Packet forwarding via previous FMA as long as L_2 handover is completed, but a discovery of a new path using reactive handover protocol is not finished yet.
3. Packet reordering is done in new target FMA according to information given from Fetch Reply Message (FRM) coming from target FMA, and removing redundant packets which may be duplicated during part 1 and 2. This is done according to information coming from L_2 handover.

The last two parts distinguish smart buffering from ordinary buffering.

4. ANALYTICAL ANALYSIS

In this section, an analytical model is proposed for our work considering four metrics: handover delay, packet loss rate during handover, transmission delay and throughput. All abbreviations for studied parameters are illustrated in Table 1.

Notations	Description
r	Cell radius
T_2	Link delay
T_3	Layer three delay
T_{MD}	Movement detection delay
T_0	Initial timeout value
T_{AVG}	average amount of time spent in timeouts
T_{PROP}	Propagation delay
x_{a_b}	Number of wired hops from node a to b
T_{RA}	Router advertising delay
P_w ,P_{wl}	Probability of packet loss for wired and wireless link
Q_w ,Q_{wl}	Average queuing delay at each wired and wireless node.
λ_P	Packet arrival rate
S_{BRM}, S_{DATA}	Packet size for buffer request and fetch request message and data

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P_{HI}	The additional processing time of Hi-NEMO messages, including searching the MR-list (negligible).
$B.W_w, B.W_{wl}$	Wired and wireless band width link
T_{HO-_NEMO}	Handover delay of NEMO BSP
T_{HO-EHI_NEMO}	Handover delay of EHI_NEMO
T_{new}	Time required for fetching buffered packets in root FMA
T_F	Time required for sending flushed Buffered Request/Replay message FRM
T_{fast}	Time required for buffering packet in root FMA
v	Vehicle velocity
BS_{EHI}	Required buffer space in EHI-NEMO protocol
$P_{L\,BSP}, P_{L\,HI}, P_{L\,EHI}$	Packet loss rate for NEMO BSP, HI-NEMO and EHI-NEMO
$T_{TH\,NBS}, T_{TH\,HI}, T_{TH\,EHI}$	Throughput for NEMO BSP, HI-NEMO and EHI- NEMO
$T_{HO_{NEMO}}$	Handover latency of NEMO BS
$T_{HO\_HI\ NEMO}$	Handover latency of HI-NEMO
$T_{HO\_EHI\ NEMO}$	Handover latency of EHI- NEMO
T_{DAD}	Duplicate address detection delay
T_{REG}	Registration delay
T_{PROC}	Processing delay
P	Probability of loss
y_{a_b}	Number of wireless hops from node a to b
T_{DATA}	Data Packet delivery delay
$T_{SIGNAL\,S}$	Signal transmission delay for packet with S size
S_{HI}	Packet size of signal messages of HI-NEMO protocol
T_{a-b}	Transmission delay from point a to by
μ_w, μ_{wl}	Average packet service rate of a wired and wireless node
P_{EHI}	The additional processing time of EHi-NEMO messages, including reordering the packets (negligible).
L_w, L_{wl}	Wired and wireless link latency
T_{HO-HI_NEMO}	Handover delay of HI_NEMO
λ_w, λ_{wl}	Packet arrival rate for wired and wireless link
T_B	Time required for sending Buffer Request/Replay message BRM
Tr_{CSM}, Tr_{SSM}	Cell resident time in CS Model and SS model
$T_{Tunnel}, T_{de-Tunnel}$	Processing time of capsulation and de capsulation
v_m	Max vehicle velocity
$P_{L\,BSP}, P_{L\,HI}, P_{L\,EHI}$	Packet loss rate for NEMO BSP, HI-NEMO and EHI-NEMO
$T_{DATA\,NBS}, T_{DATA\,HI}, T_{DATA\,EHI}$	End to end data packet delivery delay of NEMO BSP, HI-NEMO and EHI-NEMO
BS_{EHI}	Required buffer space in EHI-NEMO protocol

Table 1 Abbreviations

In the proposed analytical model, we assume that vehicular nodes move according to a Simple Straight Line Model (SSM), which is illustrated in [18-22] with circular and overlapping cells; each cell has central Base Station (BS). An Edge Router (ER) or Root near internet is connected with intermediate ARs (AR1 and AR2) which are wired connected with base stations, each in its subnet. Assuming that there are three wired connections from CN to BS (the first connection from CN to ER, the second connection from ER to FMA_2, and the last connection from FMA_2 to target BS in subnet 2) and one wireless connection from BS to MR.

4.1. Handover Delay

Firstly, the handover latency for the proposed scheme is derived as follows: handoff latency in NEMO BS includes the time from notifying or detecting the new link (after L2 handoff) up to getting back from CN (or HA). While handoff latency in HI-NEMO includes the time from notifying MR at AR_1 till recognition of MR in SW, that is suitable for the vehicle path. In this study, the handover latency exceeds HI-NEMO latency by the time required for control signals for smart buffering. The overall handoff latency as in NEMO BS [15] is described as follows:

$$T_{HO\_NEMO} = T_{l2} + T_{l3} \quad (1)$$

As shown in Figure 3, L3 handover delay consists of: Movement Detection delay T_{MD}; which equal $\frac{T_{RA}}{2}$, Duplicate Address Detection delay T_{DAD} and Registration delay T_{REG} [15, 16].

$$T_{l3} = T_{MD} + T_{DAD} + T_{REG} \quad (2)$$

$$T_{Signal\,(S)}\,(x\,,y)_{\,a\_b} = \begin{cases} T_0\left(2^{\left(\frac{P}{1-P}\right)} - 1\right) + x_{a\_b}\,t_w(S) + y_{a\_b}\,t_{wl}(S) & \text{If } p = 0 \\ x_{a\_b}\,t_w(S) + y_{a\_b}\,t_{wl}(S) & \text{If } p > 0 \end{cases} \quad (3)$$

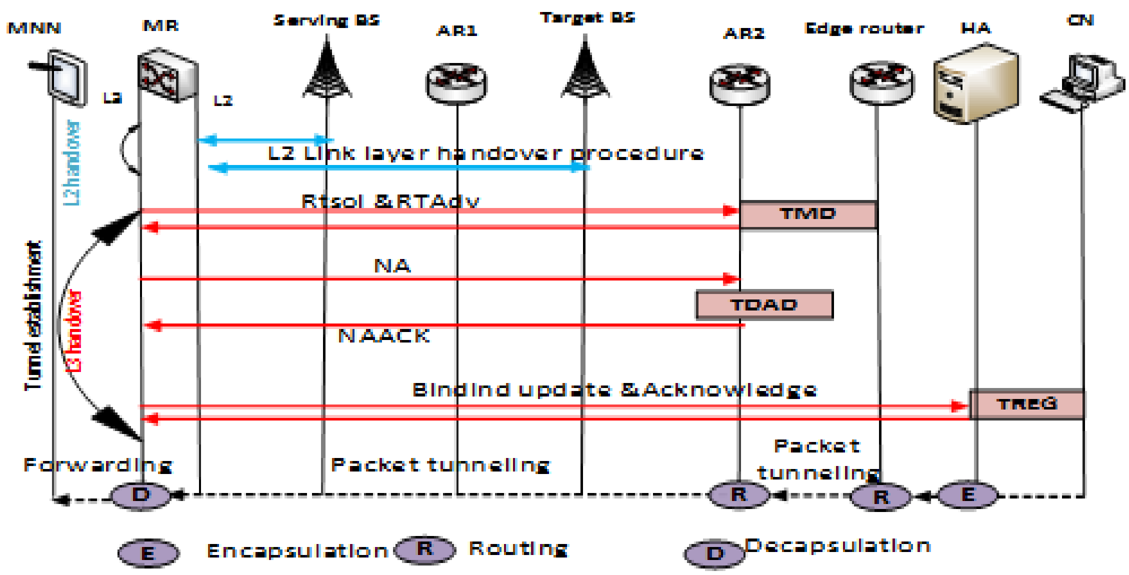

Figure 3 NEMO BSP Handover Timing Diagram

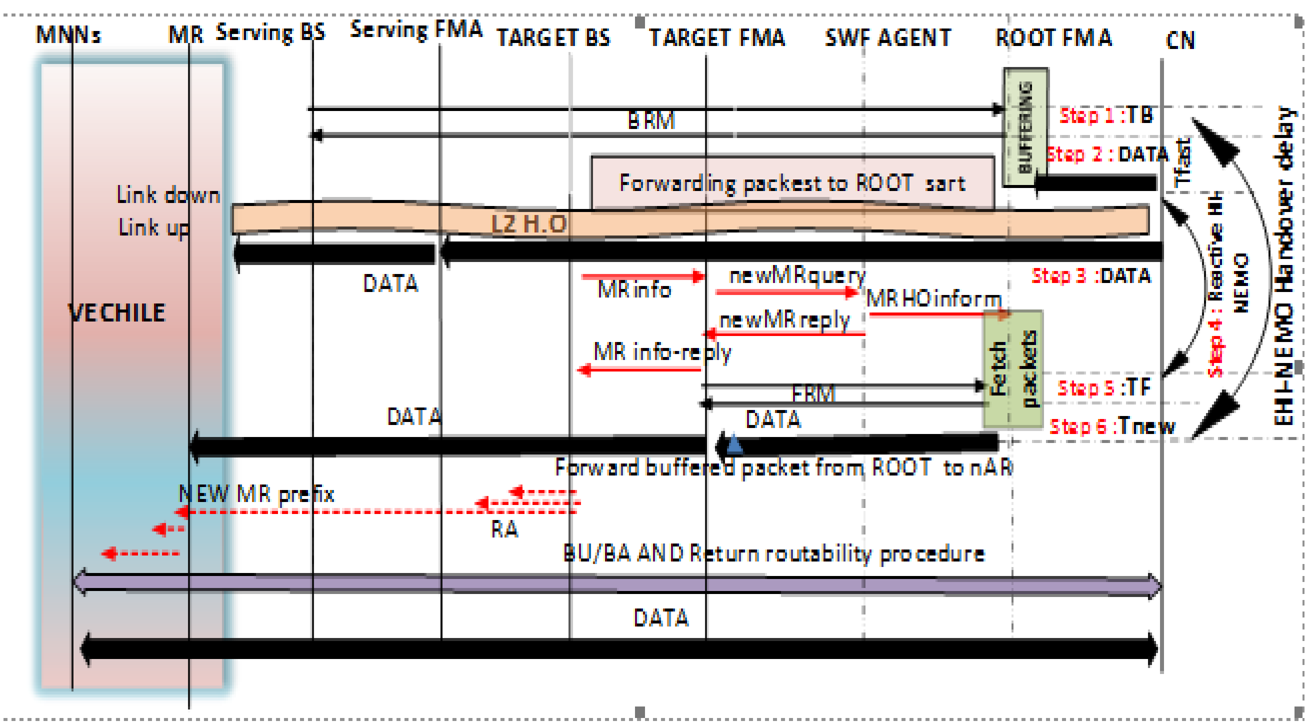

Figure 4 EHI-NEMO Handover Timing Diagram

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where t_w(S) refers to the delay for one hop wired link with (S) packet length. It consists of queuing delay (processing delay (T_{PROC})), propagation delay T_{PROP} ; it is the length of time the signal takes to travel from the sender to the receiver and it is called latency for wired and wireless link (L_w, L_{wl}), plus transmission delay from point (a) to (b) T_{a-b} . Also $t_{wl}(S)$ refers to the delay of wireless link [7], [15, 16].

$$t_w(S) = T_{PROC} + T_{PROP} + T_{a-b} \quad (4)$$

$$T_{PROC} = \begin{cases} Q_w = \frac{1}{\mu_w - \lambda_w} \\ Q_{wl} = \frac{1}{\mu_{wl} - \lambda_{wl}} \end{cases} \quad (5)$$

From equation (3) we can get:

$$T_{REG\,(BU+BA)}\,(x\,,1)_{MR-HA} = \begin{cases} x_{BS_{2HA}} \left[(t_w(S_{BU}) + t_w(S_{BA})\right] + \left[t_{wl}(S_{BU}) + t_{wl}(S_{BA})\right] & \text{If } p = 0 \\ T_{AVG} + x_{BS_{2HA}} \left[(t_w(S_{BU}) + t_w(S_{BA})\right] + \left[t_{wl}(S_{BU}) + t_{wl}(S_{BA})\right] & \text{If } p > 0 \end{cases} \quad (6)$$

Where

$$T_{AVG} = T_0 \left(2^{\left(\frac{P}{1-P}\right)} - 1\right) \quad (7)$$

So from equations (1), (3) and (6) handover delay for NEMO BSP (with **x** = number of wired link and y=1 and supposing p > 0) will be:

$$T_{HO\_BSP} = T_{L2} + T_{MD} + T_{DAD} + T_{REG(BU+BA)}\,(x.1)_{MR\_HA}$$
$$= T_{L2} + T_{MD} + T_{DAD} + T_{AVG} + x_{BS_2\_HA}\left[(t_w(S_{BU}) + t_w(S_{BA})\right] + \left[t_{wl}(S_{BU}) + t_{wl}(S_{BA})\right] \quad (8)$$

The proactive mode design requires little w ireless signaling and low possibility of failed negotiation as the opposite of reactive mode, which begin with L_2 handover. With smooth Handover, CNs could transmit Data to MNNs even they aren't updated by new address bindings. So it does not require time of CoA (care-of-address) configuration T_{CoA}, Duplicate Address Detection T_{DAD} or time of movement detection T_{MD}. HI-NEMO requires only the time of registration T_{REG} with processing time in each message.

Referring to [11, 12] and [13], Proactive handover latency in HI-NEMO can be calculated as:

$$T_{HO\text{-}HI\_NEMO}(\text{Proactive}) = P_{HI} + T_{MRHOnotify\,S_{HI}}\,(x\,,0)_{BS1-AR1} + P_{HI} * T_{MRHOnotify\,S_{HI}}\,(x\,,0)_{AR1-SWF} + T_{MRHOnotify\,S_{HI}}\,(x\,,0)_{SWF-AR2} + T_{MRHOnotify\,S_{HI}}\,(x\,,0)_{AR2-BS2} \quad (9)$$

Where P_{HI} is the additional processing time of HI-NEMO messages.

From Eq. (6) and supposing all HI-NEMO signals are equal(S_{HI}), the proactive handoff delay of HI-NEMO will be

$$T_{HO-HI_{NEMO}}(\text{Proactive}) = P_{HI} + x_{BS_{1AR_1}}\left(t_w\left(S_{HI-packet}\right)\right) + P_{HI} * x_{AR_{1SWF}}\left(t_w\left(S_{HI-packet}\right)\right) + x_{SWF_{AR_2}}\left(t_w(S_{HI-packet})\right) + x_{AR_2\_BS_2}\left(t_w(S_{HI-packet})\right) \quad (10)$$

With the same assumption, Handover delay in reactive mode can be formulated as:

$$T_{HO\text{-}HI\text{-}NEMO}(\text{Reactive}) = T_{L2} + P_{HI} + T_{MRinfo\,S_{HI}}\,(x\,,0)_{BS2-AR2} + P_{HI} * T_{newMRquery\,S_{HI}}\,(x\,,0)_{AR2-SWF} + T_{newMRreply\,S_{HI}}(x\,,0)_{SWF-AR2} + T_{MRinfo_{reply}\,S_{HI}}\,(x\,,0)_{AR2-BS2} \quad (11)$$

From (6) the reactive handoff delay of HI-NEMO will be:

$$T_{HO-HI\_NEMO}(\text{Reactive}) = T_{L2} + P_{HI} + x_{BS_2-AR_2}\left(t_w\left(S_{HI-packet}\right)\right) + P_{HI} * x_{AR_2-SW}\left(t_w\left(S_{HI-packet}\right)\right) + x_{SW-AR_2}\left(t_w(S_{HI-packet})\right) + x_{AR_2-\_BS_2}\left(t_w(S_{HI-packet})\right) \quad (12)$$

As in timing diagram in Figure 4, EHI-NEMO handover delay follows these steps:

1. When proactive handover failed, EHI-NEMO is activated and BRM (Buffering Request/Replay Messages) is sent from serving BS to Root in order to buffer incoming packet in Root, if disconnection period is not completed this period is denoted by T_B.
2. Incoming data are buffering in Root and this period is denoted by T_{fast}.
3. If disconnection period is completed (L_2) and recognition of new path is not finished yet by reactive HI-NEMO protocol, then incoming data will path through serving FMA (serving AR) to MR.
4. Recognition of new path is completed (with old IP address [12], [13]) by reactive HI-NEMO signals.
5. FRM (Fetching Request/Replay Messages) is sent from target FA to Root (T_F period).
6. Buffered packets are sent via the new path (T_{new} period) and redundant sent packet (according to step 3) is removed

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from Root, data reordering is done in target AR (FMA) according to information from FRM (Fetch Reply Message).

From Figure 4:

$$T_{HO-EHI\_NEMO} = T_B + T_{fast} + T_{HO-HI\_NEMO}(\text{Reactive}) + T_F + (T_{new} + P_{EHI}) \quad (13)$$

where P_{EHI} is the additional time required for reordering data packets in AR_2 , which is considered as processing delay.

From equation (6) and supposing p > 0

$$T_B = 2\, T_{BRM}\,(x, 0)_{BS_1-ROOT} = T_{AVG} + 2x_{BS_1-ROOT}(t_w(S_{BRM})) \quad (14)$$

$$T_{Fast} = T_{DATA}\,(x, 0)_{CN\_ROOT} = [x_{CN\_ROOT}(t_w(S_{DATA})] \quad (15)$$

$$T_F = 2\, T_{FRM}\,(x, 0)_{AR2\_ROOT} = 2x_{AR2\_ROOT}\,(t_w(S_{FRM})) \quad (16)$$

$$T_{new} = T_{DATA}\,(x, 0)_{ROOT\_AR2} + T_{DATA}\,(x, 1)_{AR2\_MR} = [x_{ROOT\_AR_2}\,(t_w(S_{DATA})] + [\,x_{AR2\_BS_2}\,(t_w(S_{DATA})) + t_{wl}(S_{DATA})] \quad (17)$$

4.2. Packet Loss Rate

Packet loss rate during handover is analyzed for different mobility models. Firstly. Random Simple Straight Model (SSM) is used as shown in Figure 5 [18], [20] and [22].

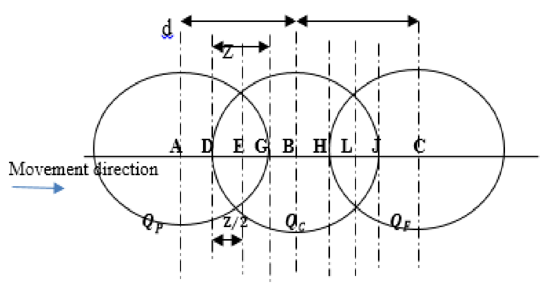

Figure 5 Simple Straight Model

In NEMO BSP, all packets destined for MNNs are lost during the handover period. The packet loss rate equals the packet loss duration; which is the handover time, divided on the cell resident time(Tr). Cell resident time equals the time required to travel the distance |GJ |. As in Figure 5 the packet loss rate during simple straight model will be: [26]

$$Tr_{SSM} = [{}^{2r - Z}/_{v}] \quad (18)$$

Where Z=|DG|=|HJ|=2*|DE|=2*|EG|

$$P_{L\,BSP}(SSM) = \frac{[T_{L2} + T_{MD} + T_{DAD} + T_{AVG} + x_{BS_2HA}\,[(t_w(S_{BU}) + t_w(S_{BA})] + [t_{wl}(S_{BU}) + t_{wl}(S_{BA})]]}{[{}^{2r - Z}/_{v}]} \quad (19)$$

In proactive mode of HI-NEMO, almost all packets sent from CN are delivered to MR with small amount of packet loss. This is due to the configuration of new path which is done during HI-NEMO layer 3 signals, rather than reactive handover that is done during layer 2. That makes the possibility of packet loss much larger, where the proposed protocol is applied.

$$P_{L\,HI}(SSM) = T_{HO\text{-}HI\_NEMO}(\text{Reactive}) / Tr_{SSM} \quad (20)$$

From equations (8) and (18) during reactive handover:

$$P_{L\,HI}(SSM) = \frac{[\,T_{L2} + P_{HI} + x_{BS_2-AR_2}\left(t_w\left(S_{HI-packet}\right)\right) + P_{HI} * x_{AR_2-SW}(\,t_w\left(S_{HI-packet}\right)) + x_{SW-AR_2}\left(t_w\left(S_{HI-packet}\right)\right) + x_{AR_2-BS_2}\,(t_w\left(S_{HI-packet}\right))]}{[{}^{2r - Z}/_{v}]} \quad (21)$$

In EHI-NEMO, packet loss rate will equal zero of buffering, the vehicle moves with specific velocity until maximum velocity v_m occurs; after this velocity no completion of handover occurs.

4.3. Maximum Allowable Vehicle Speed While Handover

For a successful handover and no more packet loss when the vehicle move from cell Q_C to cell Q_C , MR should complete the new path configuration with the minimum time required for that it leads us to the maximum velocity needed for the vehicle to pass from cell Q_C to cell Q_F through the overlapping region. From Figure 5, to calculate the maximum speed allowed (v_m^{NBSP}) in NEMO BSP for the vehicle in the SS model; assuming that the MR should request nCoA when he enters the overlapping region with Q_F , and supposing finishing handover with maximum speed when he finishes updating the HA at the end of this overlapping region, so:

$$v_m^{NBSP} = |HJ| / T_{HO\_BSP} \quad (22)$$

From Figure (5) and equation (8):

$$v_m^{NBSP} =$$

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$$Z \Big/ [T_{L2} + T_{MD} + T_{DAD} + T_{AVG} + x_{BS_{2HA}} [(t_w(S_{BU})+t_w(S_{BA})] + [t_{wl}(S_{BU})+t_{wl}(S_{BA})]] \quad (23)$$

In HI-NEMO (reactive) maximum speed will:

$$v_m^{HI\_NEMO} = |HJ|/T_{HO-HI_{NEMO}} \, (Reactive) \quad (24)$$

From Figure 5 and equation (9):

$v_m^{HI-NEMO}$(Reactive) =

$$Z \Big/ [T_{L2} + P_{HI} + x_{BS_2-AR_2}\left(t_w(S_{HI-packet})\right) + P_{HI} * x_{AR_2-SW}\,(t_w(S_{HI-packet})) + x_{SW-AR_2}\,(t_w(S_{HI-packet})) + x_{AR_2-BS_2}\,(t_w(S_{HI-packet}))] \quad (25)$$

Reactive EHI-NEMO buffering process is executed to eliminate packet loss as mentioned before, but velocity must be less than or equal maximum velocity, so:

$P^{Loss}_{EHI-NEMO} = 0$ if vehicle speed $v \leq v_m^{EHI}$

Assuming $\boldsymbol{P_{EHI}}$ equals zero, the time spent for successful handover with maximum speed and no packet loss at least:

$$T = T_B + T_{fast} + T_{HO-HI\_NEMO}(Reactive) \quad (26)$$

Then:

$$v_m^{EHI\_NEMO} = |HJ|/T \quad (27)$$

4.4. Analysis of Throughput During Handover

Throughput is defined as the successful delivered packets per time unit. The throughput during handover (packet/s) can be given as: [14]

$$T_{TH} = \boldsymbol{\lambda_p} * (1 - P_L)) \quad (28)$$

In NEMO BSP

$$T_{TH\,BSP}(SSM) = \lambda_p * (1 - P_{L\,NBS}(SSM)) \quad (29)$$

Where $P_{L\,NBS}$ (SSM) found in equation (19)

In HI-NEMO (Reactive mode)

$$T_{TH\,HI}(SSM) = \lambda_p * (1 - P_{L\,HI}(SSM)) \quad (30)$$

Where $P_{L\,HI}$ (SSM) found in equation (21)

EHI-NEMO throughput during handover rate equals λ_p , while the vehicle speed do not exceed v_m and there is no packet loss.

4.5. Analysis of End-to-End Packet Delivery Delay

To compute this delay, it requires summing all wired hops delays from CN to MNNs in addition to tunneling time and capsulation and de-capsulation process.

Then from equations (4)

$$T_{DATA} = (T_{PROC} + (T_{tunnel} + T_{de-tunnel})) + T_{PROP} + T_{a\text{-}b} \quad (31)$$

From equations (6)

$$T_{S\,DATA}(x,y)_{a_b} = x_{a_b}\left(t_w(S_{DATA})\right) + y_{a_b}\,t_{wl}(S_{DATA}) + (T_{tunnel} + T_{de-tunnel}) \quad (32)$$

In NEMO BSP the end to end data packet delivery delay will be (we have to pass on HA):

$$T_{DATA\,NBS} = T_{CN-HA\_MR} + T_{tunnel} + T_{HA\_MR-ER} + T_{ER-AR2} + T_{de-tunnel} + T_{AR2-BS_2} + T_{BS_2\_MR} + T_{MR-MN} \quad (33)$$

$$T_{DATA\,NBS} = x_{CN-BS_2}\,((t_w(S_{DATA})) + y_{BS_2-MNN}\,((t_{wl}(S_{DATA})) + (2 \times P_{ed}) \quad (34)$$

In HI-NEMO and in EHI-NEMO the path of end to end data packet delivery will be (there is no either tunneling nor passing on HA))

$$T_{DATA\,HI} = T_{DATA\,EHI} = T_{CN-ER} + T_{ER-AR2} + T_{AR2-MR} + T_{MR\text{-}MN} = x_{CN-BS_2}\,((t_w(S_{DATA})) + y_{BS_2-MR}\,((t_{wl}(S_{DATA})) \quad (35)$$

4.6. Required Buffer Space in EHI-NEMO

The buffer space required for EHI-NEMO during handover is proportional to handoff latency and packet arrival rate. So from Figure 4:

$$BS_{EHI} = \lambda_p * (T_{HO-EHI\_NEMO} - (T_B + T_{new})) \quad (36)$$

5. NUMERICAL RESULTS

Figure 5, assuming this P_{HI} and P_{EHI} , are negligible and the Parameter values used are adopted from [13,14, 18, 21, 25-28].

$P_w = 0$	$P_{wl} = 0.1$	S_{DATA}= 200 byte
T_{DAD} =500ms	$\lambda_w = 1$ $packets/ms$	$\lambda_{wl} = .1\,packets/ms$
L_W = 2ms	L_{Wl} = *10ms*	r =250,350,450,550 m
S_y=200m	S_x=200m	v =240,200,150 Km/h
S_{BU}=92 byte	$P_{HI} = P_{EHI} = 0$	S_{Ack}= 92 byte
S_{BRM}=92 byte	T_{L2} =50ms	P_{ed} =1ms
$T_0 = 1000ms$	a ,b =36Km	P_{ed} =1ms
BW_{wl} =11Mbps	BW_w = 100Mbps	T_{RA} = 30ms
U_{max}=2sec	K=5	

Table 2 The System Parameters' Values

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5.1. Handover Delay

Figure 6 shows a great decrease in HI-NEMO proactive and reactive handover delay rather than NEMO BSP. The main reason for this is the dispensing of duplicate address detection delay (T_{DAD}=500ms) in HI-NEMO. Also the absence of wireless connections in this handover makes it faster with probability of loss and the retransmission of signal packets is almost zero beside the registration delay of HA in NEMO BSP.

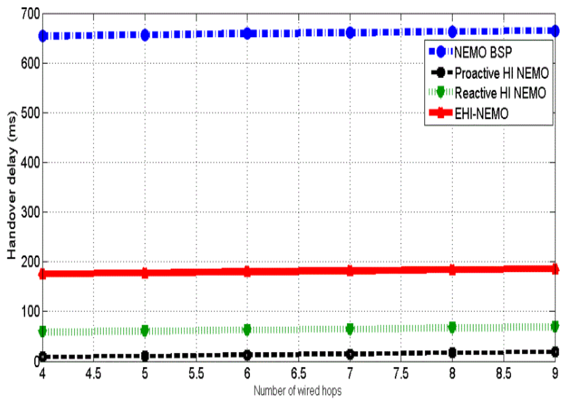

Figure 6 Handover Delay versus Different Number of Wired Hops

Concerning EHI-NEMO, there is slightly increase from HI-NEMO due to buffering but still much better than NEMO BSP.

5.2. Packet Loss

Packet loss rate during handover in straight model is shown in Figure 7. NEMO BSP is always significantly higher than that in HI-NEMO. When r =250m packet loss rate in NEMO BSP is 10.4% ; whereas that in reactive HI-NEMO is 0.86% with v=240 Km/h, and it will be smaller in proactive HI-NEMO and equal zero. EHI-NEMO with any velocity, till maximum velocity, is used with applications that do not allow any packet loss. Also notice that in NEMO BSP and HI-NEMO packet loss rate decreases when cell radius increases, and slightly increases when vehicle velocity increases; but it is still zero in EHI-NEMO till maximum velocity.

Figure 8 confirms that HI-NEMO and EHI-NEMO support high velocity vehicle in different cell radius even through it is decreased in EHI-NEMO than HI-NEMO. But it is still much higher than NEMO BSP. For example, when it is 245.89 Km/h in NEMO BSP with cell radius 250 m, it is 2825.83Km/h in HI-NEMO and 1075Km/h in EHI-NEMO.

Thus, HI-NEMO velocity almost increases 11.5 times than NEMO BS and in EHI-NEMO it almost increases 4.3 times. So, HI-NEMO supports high velocity vehicles. We calculate equations (19) and (21) using different velocity in each protocol ($V_{HI-NEMO}$ and $V_{\text{NEMO BS}}$). Using Table (2) and with three hops, it is noticed that $V_{HI-NEMO}$= 11.38 $V_{\text{NEMO BS}}$ which clearly indicates that HI-NEMO supports high velocity vehicles. By using Figure 8 and comparing maximum velocity between NEMO BS, HI-NEMO and EHI-NEMO; it is noticed that $V_{EHI-NEMO}$= 4.3 $V_{\text{NEMO BS}}$ and $V_{HI-NEMO}$= 2.6 $V_{\text{EHI-NEMO}}$

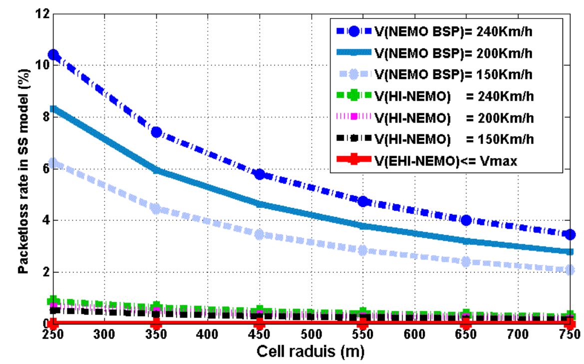

Figure 7 Packet Loss Rate (%) versus Different Number of Cell Radius

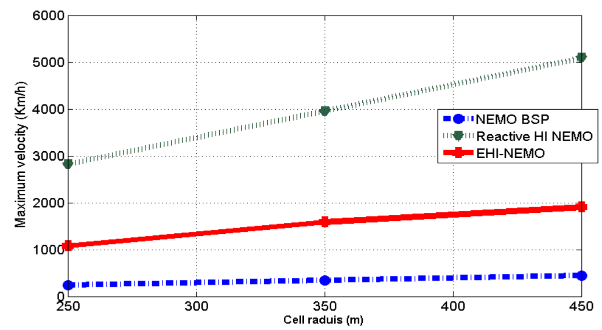

Figure 8 Maximum Velocity Required for the Completion of Handover of Cell Radius

5.3. Throughput

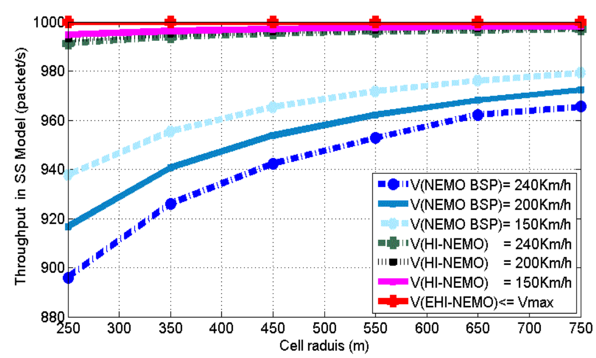

Figure 9 Throughput During Handover (packet/s) versus Different Radius Cell (m)

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Figure 9 shows the maximum achievable throughput during handover of NEMO BSP and reactive HI-NEMO. The reactive HI-NEMO can achieve much higher throughput than NEMO BSP due to the decrease in packet loss rate in reactive HI-NEMO. But, there is still a decrease in throughput especially in small cell radius and in faster vehicle. On the other hand, throughput is optimal in EHI-NEMO for all cell radius.

5.4. End-to-End Packet Delivery Delay

By using the network model in Figure 1 with excess of wired hops, there is noticed a difference in data delivery delay - approximately about 4 ms between NEMO BSP and other protocols shown in Figure 10; this is a result of a bi-directional tunnel between MR and HA_MR and the triangle routing in NEMO BSP (exceeding one wired hop). End to end data packet delivery in HI-NEMO is the same as EHI-NEMO where the sent packet uses the same path.

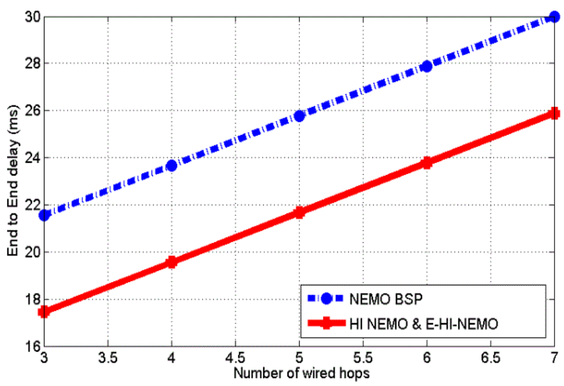

Figure 10 End-to-End packet delivery delay between NEMO BSP, HI-NEMO and EHI-NEMO

5.5. Required Buffer Space in EHI-NEMO

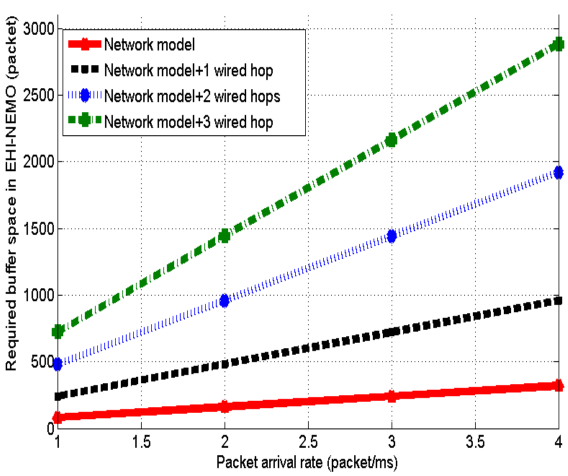

Figure 11 Required Buffer Space (packet) in EHI-NEMO versus Different Packet Arrival Rates (packet/ms) and Different Wired Hops.

Using equations (36) and parameters value in Table 2 help to estimate required buffer space in EHI-NEMO versus different packet arrival rates and different numbers of wired hops. It is noticed from Figure 11 that buffer space increases when packet arrival rate increases and also increases with the increase of wired hops because of increasing handover delay.

Results can be summarized in the following Table 3:

Criteria	NEMO BSP	HI-NEMO		EHI-NEMO
		Proactive mode	Reactive mode	
packet loss rate	$P_{L\,NBS}(SSM)\alpha$ $P_{L\,NBS}(SSM)\alpha$ It's about 10% when v =240 km/h and r = 250 m	Almost = 0	Almost is .8% when v =240 km/h and r = 250 m	= 0 if $v \le v_{max}$
Handover delay	Over 650 ms in three wired hops and increases .006% in every hop	About 6.3 ms in three wired hops and increases .3% in every hop	Increases 8% than proactive mode	Increases 2.5 % than HI-NEMO reactive mode
Throughput	Decreases as velocity increases and increases as cell radius increases Less than 90% arrive when v =240 km/h and r = 250 m	All packets approximately arrive	Over 99% arrive when v =240 km/h and r = 250 m	All packets arrive as long as the vehicle is within v_{max}
Supporting high velocity	❖ $V_{HI-NEMO}$= 11.7 $V_{NEMO\ BS}$ ❖ $V_{EHI-NEMO}$ = 3.7 $V_{NEMO\ BS}$ ❖ $V_{HI-NEMO}$ = 3 $V_{EH-NEMO}$			
End to End packet delivery delay	NEMO BSP increases over HI-NEMO and SMRT BUFFERING HI-NEMO by 1.22 %			

Table 3 Results Summarization

6. CONCLUSION

NEMO BSP suffers from handoff latency and packet loss. By using HI-NEMO with its hierarchical architecture, cross layer mobility management and resource reservation protocol in

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Root, all those reduce latency and packet loss during handovers. But there is still packet loss in reactive HI-NEMO especially in small BS cell radius which is critical in applications that required great accuracy with data sent. EHI-NEMO is proposed to absolutely prevent packet loss in reactive HI-NEMO as long as the vehicle is moving within maximum calculated speed which is still very high compared with NEMO BSP. Using smart buffering on Root FMA during the period of vehicle recognition of the new CoA when it moves to a new cell is the main idea of EHI-NEMO. The impact of cell residence time, cell radius and vehicle velocity on packet loss rate and throughput are studied on three protocols to prove that packet loss rate proportional reverse with cell radius, and proportional direct with vehicle velocity in the opposite of throughput. Smart Buffering also utilizes redundant packet removing in Root FMA and packet reordering in new FMA.

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Authors

Nihal H. A. Mohammed received M.Sc. degree in the Electrical Engineering Department, Suez Canal University, Egypt.in 1992, worked in General Authority for Educational Buildings since 1994 in the field of computer maintenance.

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Heba N. El-moafy is an assistant professor in the Electrical Engineering Department, Port Said University, Egypt. She received her B.Sc. and M.Sc. degrees in computer and control engineering, Suez Canal University, in 2001 and 2006, respectively. Her Ph.D. degree in computer and control engineering is received from Port Said University in 2011. Her research interests are in the area of computer networking, including mobile networks, handovers, and cloud computing.

Salah M. Abdel Mageid received his M.S. and Ph.D. in Systems and Computers Engineering from Al-Azhar University in 2002 and 2005, respectively. Since 2012, he is an associate professor in Systems and Computers Engineering at Al-Azhar University. He performed his post-doctoral research in 2007 and 2008 in the Computer Science and Engineering Department, School of Engineering, the Southern Methodist University at Dallas, TX, USA. He was a member of TEMPO (Tool for Extensive Management and Performance Optimization) project in Cairo University and Vodafone Egypt as an industrial partner in 2014 and 2015. His research interests include Mobile Computing, Cellular Networks, Sensor Networks, Cognitive Radio Networks, and Vehicular Ad-hoc Networks.

Mahmoud I. Marie received his B.Sc, M.Sc and PhD in electronic and communication engineering from Cairo University on 1972, 1981, 1985, respectively. Now he is a professor of communications at Computer and System Engineering Department Al-Azhar University, Cairo, Egypt. His fields of interest include digital communication, computer networks and protocols development.