Qualitative and Quantitative Survey of Network Mobility (NEMO) Protocols

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Abstract
Providing uninterruptable communication services to mobile nodes poses serious challenges. On one side exchange of control messages for handoff should be as fast as possible; one the other side the delivery of data must also be as fast as possible. These challenges require efficient handoff and route optimization protocols. Both these challenges are augmented further by the limited energy supply to the mobile devices, thus, requiring the protocols to exchange minimum number of control messages. So, if a group of mobile devices moving a single unit, giving rise to network mobility (NEMO), it would be energy efficient if one specialized router, called mobile router (MR), exchanges all the control messages on behalf of the mobile devices. In other words, an efficient NEMO protocol can solve the issues. Depending upon the applications, however, NEMO protocol may requires only efficient handoff protocol or route optimization protocol. In this paper, the NEMO protocols are categorized into four types and the performance of NEMO protocols are evaluated based on the services provided to the applications. Evaluation is done qualitatively and then quantitatively to justify the decisions on which NEMO protocol can be deployed to satisfy a particular application.

Keywords-Network mobility, NEMO, survey.

1. Introduction

In recent years, providing seamless Internet connectivity to the passengers of moving vehicles (e.g., trains, aircraft etc) forming an in-vehicle network or *mobile network*, has become an active area of research [53][32][56][37][24]. A vehicle may contain a large number of mobile devices (network nodes, ***NNs***) and in general, the NNs could be local fixed nodes (***LFNs***) [18] or visiting mobile nodes (***VMNs***). When the vehicle moves, all NNs in the network move as a single unit, resulting network mobility (***NEMO***) [15] (figure 1). Since each of the NN are independent, they perform handoff or route optimization with their correspondent node (***CN***) when the mobile network moves from coverage area of one access router (***AR***) to another. The exchange of control messages (called protocol data units, ***PDU***s) is performed according to the deployed host mobility protocol(s). If the number of NNs is high, then the exchange of control PDUs can put overhead on the infrastructure network and can also results power drainage from each of the NNs. Therefore, the NEMO could be managed by a specialized router, known as mobile router (***MR***) which exchanges the control PDUs on behalf of the NNs that is, the MR performs the handoff or route optimization (or both). Moreover, the MR could drive its energy requirement from the energy supply system of the vehicle. Efficient mobility management in NEMO scenario requires use of NEMO protocol that decreases the number of PDUs to be exchanged, and hence reduces energy consumption of the NNs. These advantages have led to many implementations, namely, NEML [26][46], CALM architecture [16] etc.
Depending upon the application, an MR, and hence the deployed NEMO protocol can either perform efficient handoff or route optimization or both. Moreover, a NEMO protocol can be deployed in either internet layer (L3)[64][34][45][39][12][40][49][1], transport layer (L4)[30][21][29] or application layer (L5) [25][61][7][63][10][27] of the Internet; additionally, there could be security issues in NEMO [42][22][3][57][35][17][66][4][54][13][48][55][31][36][50][20][8][6][33][2][38]. Given the hour-glass model of TCP/IP [5], and the fact that L4 and L5 layers protocols cannot operate without internetworking (L3 functionality), the deployment of suitable L3 NEMO protocol is vital. Thus, it is the L3 NEMO protocols, by exchanging control packets efficiently, that should provide seamless communication services to the higher layer protocols. Moreover, there is more infrastructure based network than ad hoc network. These two facts justifies to focus on the L3 NEMO protocols. In this paper, some of the known infrastructure based L3 NEMO protocols

are investigated and classified into four different types, Type I through Type IV, based on the sub-layers of L3 (explained in section 2.1) that they can operate (a survey on vehicular ad hoc network can be found in [9]). Also we have not considered security related issues since the security solutions are enhancement of the NEMO protocols [8][6]. This work differs from the survey work of [41][65] is that: in [41] route optimization solutions are analyzed, and both route optimization and fast handoff protocols are analyzed; [65] concerned on the host mobility protocols that can be extended, NEMO implementations and deployment issues, however, this notion is extended to analyze the protocols that have been extended and results of their deployments are examined. First, a qualitative analysis of NEMO protocols is carried out based on applicable entities, affected network entities and required software changes. It is found that the software changes are more for Type II than Type IV protocols and highest for Type III protocols both in MR and infrastructure network. Next quantitative analysis is done on the mobility management protocols for NEMO, where the performance of the NEMO protocols is measured in terms of handoff latency, packet loss duration and packet delivery delay. A NEMO protocol must achieve good performance results for all performance parameters. From the analysis we found that the NEMO protocols operating at different sub-layers of L3 achieve different performance results with respect to different performance parameters: for example, Type III and IV NEMO protocols achieve low packet delivery delay, Type II and III NEMO protocols achieve low handoff delay; on the other hand, Type I protocols introduce high handoff and packet delivery delay. Hence none of the protocols can support efficient mobility management for all applications. So, the applications are identified for each type of NEMO protocols, and a possible implementation strategy is suggested for NEMO protocols to satisfy all applications.

2. Classification and Overview of NEMO Protocols

2.1. Classifications of NEMO Protocols

An L3 NEMO protocol performs handoff to restore last hope communication between MR and an AR, and then it performs route optimization which optimizes route (through AR) from MR to CN. Therefore, L3 can be viewed as consisting three sub-layers, mandatory handoff (***HO***) sub-layer, optional route optimization sub-layer (***RO***) and ICMP sub-layer (figure 2). The HO-sub-layer allows the mobile network to attach at different points of the Internet. The ICMP sub-layer generates router advertisement (***RA***) ICMP packets to signal handoffs. Only after HO-layer completes its procedure for handoff, RO-layer can start its procedure for route optimization. The RO-sublayer performs route optimization to reduce data transfer delay by bypassing the home-agents from the data transfer path.

The HO-Layer can receive trigger from either L2 (for fast handoff) or from ICMP (normal handoff). Depending upon which sub-layer the NEMO protocol targets, they can be categorized into four types:

- *Type I*: NEMO Protocols targeting HO-sub-layer and ICMP sub-layer; for example, The IETF standard NBSP [2] is an example of Type I NEMO protocols. These protocols use RA packets from ICMP sub-layer to detect movements and hence lead to normal handoff. Due to delay in receiving advertisement (after L2 handoff) these protocols incur high handoff latency. Since the RO-sub-layer is not used the packet delivery delay is also very high. These protocols are suitable for handoff tolerant and delay tolerant applications, such as web-browsing, e-mail etc.
- *Type II*: NEMO protocols targeting HO-sub-layer only. These protocols use L2 trigger for move detection and hence leads to fast handoff. These protocols do not use functionalities of RO-sub-layer resulting high packet delivery delay. So these protocols are suitable for delay tolerant applications like banking transactions and file transactions, where the integrity of data transfer outweighs the fast response from server.
- *Type III*: L3-NEMO Protocols targeting both HO and RO sub-layers, that is, the NEMO protocols aiming for both fast handoff and route optimization. Obviously, the handoff delay and packet delay are reduced

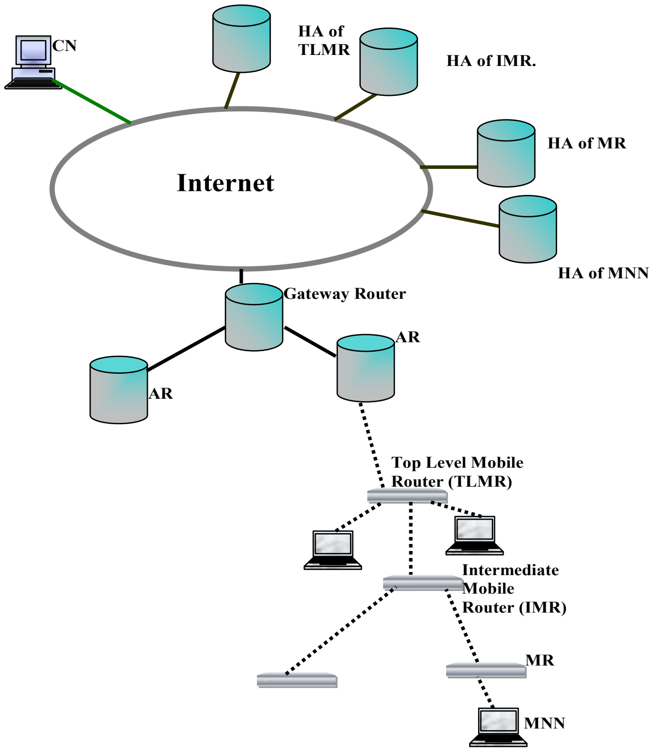

Fig 1. A Network Mobility (NEMO) Scenario.

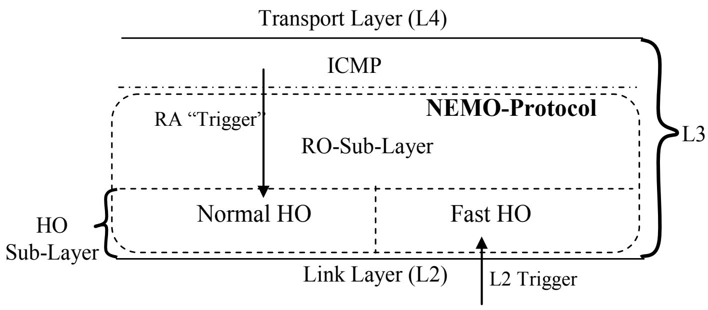

Fig 2. Layered structure of an L3-level NEMO Protocol.

significantly. These protocols are for applications those are neither packet delivery delay tolerant nor handoff delay tolerant.

- *Type IV*: L3-NEMO Protocols targeting RO-sub-layer only; for example, all L3-NEMO route optimization protocols belong to this category. These protocols are suitable for handoff delay tolerant applications such as online gaming.

Each of these types of NEMO protocols requires difference performance requirements. The performance requirements can be graphically shown in figure 3. In the figure, the categories of NEMO protocols are mapped in two-dimensional plane.

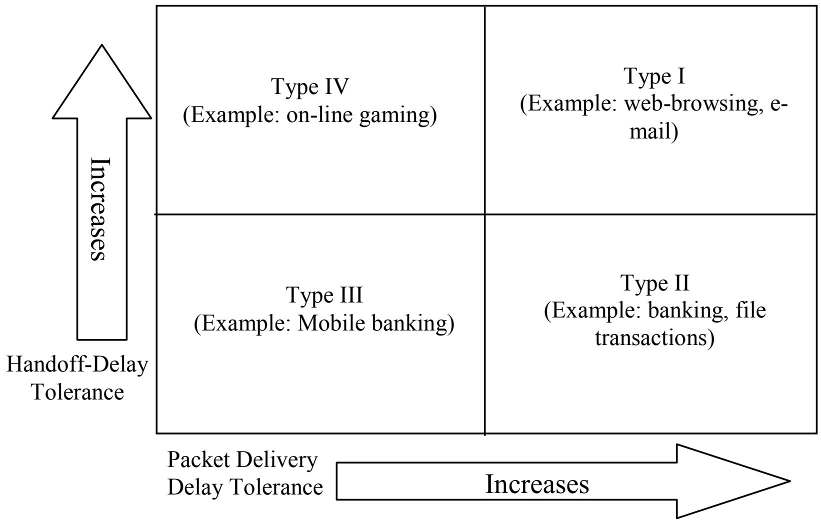

Fig 3. Mapping of NEMO protocol categories into 2-D plane.

2.2. Description of NEMO Protocols

In this section we describe some novel NEMO protocols for each category mentioned in section II.A. For type I we describe NEMO Basic Support protocol (***NBSP***) which is a de-facto standard to support network mobility. The protocols in type II through IV consider NBSP as the basic protocol and add new features and functionalities in it to reduce handoff latency or packet delivery delay or both. It is believed that the protocols described in this section laid the foundation of research in network mobility.

2.2.1. Type I NEMO Protocols.

2.2.1.1. NEMO Basic Support Protocol (NBSP)

NBSP-enabled MR [15], after detecting movement though L3 advertisement (which happens only after L2 handoff) and CoA formulation using DAD [47], sends binding update (***BU***) message to it's HA and obtains binding acknowledgement if BU is successful which results in creation of a bi-directional tunnel between the CoA of MR and HA.

The MR, by performing BU with it's HA instead of all MNN perform BU with their HA and CN, limits the number of signaling messages in the mobile network and reduces energy consumption of the MNN. Moreover, the approach also hides mobility of the MR from its MNN and sub-level MR.

The protocol suffers from sub-optimal routing of packets since the routing uses repeated tunnels (equal to the number of IMR) and encapsulation (also equal to the number of IMR). Thus, the packet delivery happens through the path (figure 1) MNN→MR→IMR…→TLMR→HA_TLMR→….HA_IMR→ HA_MR→CN. This increases packet delivery delay. Moreover, the late movement detection using L3 advertisement and uses of DAD significantly increases the handoff delay.

2.2.2. Type II NEMO Protocols

Although there are many host–mobility protocols for fast handoff [37][24], few has been proposed for NEMO. We will discuss three protocols [64], [34] and SLNEMO [19] that uses link-layer (L2) level trigger to anticipate handoff. [64] uses 802.16 based fast handoff whereas [34] and SLNEMO uses L2-level messages to perform most of the handoff procedures of L3-level handoff.

2.2.2.1. 802.16 based Fast Handoff

In this protocol [64] MR uses IEEE-802.16-trigger [52] to anticipate handoff. After receiving L2-trigger, the MR sends Fast Binding Update (***FBU***) [37] to it's HA. The HA performs the binding update with new AR (***NAR***), as in FMIPv6 predictive mode [37] and the MR performs the L2-handoff as in IEEE 802.16.

The protocol performs L2 and L3 handoff in parallel by separating the entities that performs the respective handoff. The L2 handoff is processed by entities in mobile network whereas L3 handoff is process by entities in infrastructure network.
The advantage of the protocol lies in the success of anticipation, which if successful, the handoff delay will not depend upon on delay in receipt of RA (~30ms [32]) and L2 handoff delay (~50ms [43]).
Since the protocol does not perform route optimization hence the signaling packets for handoff procedure and data packets between MNN and CN will be sub-optimally routed through tunnels as in NBSP, thus increasing the overall delay in packet delivery through the Internet. Moreover, if CN lies inside the mobile network, the packets will be routed in the same manner as in other packets, thus introducing unnecessary delay.

2.2.2.2. Cross Layer Design for Fast Handoff

The protocol [34], apart from anticipating handoff from L2 trigger to perform fast handoff, sends L3 handoff signaling messages in L2 handoff signaling messages in re-association phase. It also uses a cache of IP addresses in each AR (MR in case of nesting level greater than 1) to overcome dependency on duplicate address detection (***DAD***) [47][58][32] packets for uniqueness of new CoA (***NCoA***).
The advantage of this protocol is that the L3 and L2 handoffs are performed simultaneously which reduces L3 handoff delay. Also the protocol no longer needs to use DAD which intern tries to reduce the delay in acquiring NCoA.
The disadvantage of this protocol is that although the delay in acquiring NCoA is reduced, the protocol has to perform the binding update message with it's HA by sending signaling messages through tunnels in the Internet (as in NBSP). This increases the handoff delay when the nesting level is greater than 1 and hence the packet loss duration is increased.

2.2.2.3. SLNEMO

SLNEMO assumes that for a large duration of time, the topology of a mobile network does not change. This situation is applicable for cruise ships or passenger vehicles like buses, where the commuters does not usually change place (so does the mobile nodes with them) during their journey. Apart from extending FMIPv6, it also extends HMIPv6. So the TLMR is responsible for performing handoff with MAP [56] upon receiving L2 trigger (thus initiating fast handoff) and sends BU packet and local BU (***LBU***) packet to the HA of TLMR and MAP (under which the TLMR currently resides, called previous MAP or ***pMAP***) respectively. The CoA and local CoA (***LCoA***) for TLMR are obtained by the pMAP from the predicted AR. To ensure zero packet loss, the pMAP buffers the packets for TLMR so that the buffered packets can be transferred to the AR under which the TLMR actually moves and exchanges the buffered_packets_send_request (***BPSR***) and buffered_packetssend_request_response (***BPSRR***) control packets with the pMAP.

The scope of SLNEMO is limited since it is not adaptive to topological changes under TLMR. Moreover, like the fast handoff NEMO protocols, the control packets are exchanged using tunnels.

2.2.3. Type III NEMO protocols.

The protocol by Mussabir et. al [49], FRONEMO [45], and FHE2ERO [44] comes under this type that use both L2-level trigger for fast handoff and utilizes modified form FMIPv6 to achieve route optimization, except FHE2ERO which extends PMIPv6 [23][62].

2.2.3.1. Fast and Route Optimization by Mussabir et. Al.

[49] proposes to use a new entity called Information Server (***IS***) for each AR (or MR in case the nesting level is greater than 1) that keeps information about the neighboring ARs' QoS parameters, is introduced. After handoff MR registers with IS. Each MR maintains a neighboring network report (***NNR***) cache for storing both L2 and layer-3 (L3) information.
The protocol, using L2 trigger, NNR, extending FMIPv6 in predictive mode and querying IS tend to support fast QoS based intelligent handoff. Also the route optimization till nesting level 1 is achieved.

The advantage of the protocol lies in QoS based intelligent handoff thus providing better support to the application level. Moreover, use of 802.21 MIH [28], makes the protocol is independent of physical layer parameters. The protocol also inherits zero-packet loss advantage of FMIPv6 operating in predictive mode.
One of the disadvantages of the protocol is the dealing with case of selection of multiple next/new ARs (***NAR***s) due to varying QoS requirements of multiple applications. The protocol also suffers from binding update storm due to extension of FMIPv6. Also the pin-ball routing problem comes to play when nesting level becomes greater than 1.

2.2.3.2. FRONEMO

Unlike the [49], FRONEMO does not use any QoS related handoff activity, rather uses the geographic coordinate system like GPS to assist predictive mode. MR maintains three CoAs, namely, Past CoA, Present CoA and Future CoA (***FCoA***) to perform predictive handoff where after each handoff Present CoA becomes PastCoA , FCoA becomes the Present CoA. Each AR is assumed to be GPS enabled and the ARs coordinate is advertised in RA, which MR uses to formulate the FCoA. For route optimization, the MR maintains a unique list of CNs so that during route optimization process, the number of control packets is reduced.
Since MR uses prediction to fetch the FCoA, the handoff delay is reduced if prediction is successful. The delay in route optimization is also reduced due to lesser number of control packets exchanged. However, the protocol works as in NBSP if the prediction is not successful or the nesting level goes beyond 1.

2.2.3.3. FHE2ERO

In both FRONEMO and [49], the MR performs handoff in predictive mode. So, the MR is responsible for exchanging control packets and may not receive any control packets if the L2 handoff is not complete during the movement from one AR's domain to another. To solve this FHE2ERO, by extending PMIPv6, performs L2 and L3 handoff in parallel by making infrastructure (AR) to perform the handoff on behalf of MR when MR is performing its L2 handoff. Each MR advertises the CoA of TLMR. So, if an MR receives an RA during completion of L2 handoff such that the TLMR information is other than the predicted one, reactive mode of handoff starts where the MR now performs the handoff process. When control packet for binding update is sent, each of the MRs along the path to TLMR (the higher level MRs) stores the information of the MR into its cache, where the packets are buffered at predicted MR or AR. Also, during the binding update process the binding is formed between the CoA of TLMR and home address of MR at the HA of MR. This binding and the storing MR information in the caches of higher level MR achieves route optimization and intra-NEMO route optimization respectively. In addition, to reduce the number of binding update exchange when MR moves with the domain of TLMR (called local handoff), the binding update is performed with TLMR only.

Though the protocol is efficient in terms of reducing handoff delay and achieves route optimization and intra-NEMO route optimization, there is loss of packets if the prediction is not successful. Also, there is a security issue when the control pockets are snooped to create cache for facilitating *intra-NEMO route optimization* [51].

2.2.4. Type IV NEMO Protocols.

Several proposed NEMO route optimization protocols under this type from which we select three [39], [12] and [40]. These three protocols not only achieve route optimization but also achieve lesser signaling packet exchanges and intra-NEMO routing [65][51].

2.2.4.1. End-to-end Route Optimization

The protocol [39] uses two caches at each MR in the mobile network. First cache maintains information about nodes which includes the MNNs and sub-level MRs connected directly under it. The cache also contains a list of MNNs that resides in the mobile network under a sub-level MR. The second cache, maintains unique list containing information of CNs to which MNNs, directly under it, are communicating at present. The protocol assumes a tree topology of the mobile network with MRs at its node and the MR at the root of the hierarchy is the TLMR (figure 1). The CoA of TLMR is advertised by each MR. In the binding update message sent by MR, the source address is replaced by CoA of TLMR so that the binding at MR's HA contains the mapping between

home address (***HoA***) of MR and TLMR. The first cache is used by an MR in source-routing [39] of an incoming packet to an MNN and intra-NEMO route optimization. Thus, the path followed from CN to MNN is (figure 1) CN→HA_MR→TLMR→...→IMR→MR→MNN. The second cache is used by MR to perform binding update with CN on behalf of MNNs.
Since the CoA of TLMR binds with HoA of MR hence the number encapsulations and tunnels between CN and MNN is one. The use of second cache further eliminates routing through HA of MR (***HA_MR***). Using the first cache for intra-NEMO routing eliminates the need for a packet, with source and destination address in the mobile network, to go through tunnels involving the Internet.
Since the CoA of TLMR is advertised by MRs hence the mobility of the mobile network is exposed to the MRs and MNNs. Also, the formulation of CoA of MR goes in vain as the source address during binding update is replaced by CoA of TLMR thus making DAD (~500ms [49]) useless. The CN, on the other hand, have to use home address destination option [60] thus increasing packet overhead. Since MR performs the binding update on behalf of MNN with the CN, the protocol suffers from binding update storm.

2.2.4.2. Route Optimization Using Tree Information Option (ROTIO)

ROTIO [12], like in the previous protocol, assumes tree structure of MRs (figure 1) and maintains two caches at each MR. However, the first cache contains only the list of MRs under it and path to the MR. The second cache contains CoA of higher-level MRs. Using TIO [59] the HoA and CoA of TLMR and CoA of IMRs to an MR is advertised to the MR. A newly moved MR, detects its movement and after registering with TLMR, sends binding update message containing HoA of TLMR, thus forming binding map between HoA of MR, CoA of MR and HoA of TLMR.
The mapping containing HoA of MR and HoA of TLMR addresses the problem of route optimization so that the path followed by a packet from CN to MNN is (figure 1): CN→HA_MR→HA_TLMR→TLMR→…→IMR→MR→MNN. The first cache is used for source route from TLMR to MR. The first cache is also used for source routing of packet with source and destination address, both inside the mobile network, thus addressing the problem of intra-NEMO route optimization.
The advantage of this protocol is the limiting the number of encapsulation and tunnels from CN to MNN to two thus reducing the packet delivery delay. The number of encapsulation and tunnels in intra-NEMO routing is zero.
One of the disadvantages of this protocol, apart from late movement detection and delay in DAD, the optimal route from CN to MNN is not followed as in previous protocol. Moreover, use of TIO in router advertisement exposes higher level mobility to MR, and the sub-level MR and MNN.

2.2.4.3. Route Optimization using Hierarchical Algorithm

The protocol [40], as in previous two protocols assumes tree topology of MRs under an AR and also proposes to use TLMR as Mobility Anchoring Point (MAP) as in HMIPv6 [56]. The CoA of TLMR/MAP is advertised in the mobile network so that MR formulates LCoA and RCoA [56], and performs binding update as in HMIPv6. MR also maintains a cache that holds binding information of all MR under it.
The binding between RCoA of MR and HoA of MR results in route optimization, so that the path followed (figure 1) from CN to MNN is: CN→HA_MR→TLMR→…→MR→MNN. The cache information is used perform intra-NEMO route optimization using source routing, in which the MR first queries the TLMR regarding destination address to check whether the destination node exist within the mobile network. If the node exists within the mobile network then TLMR returns a path to it starting from TLMR. Thus, near optimal intra-NEMO route optimization is achieved.
The disadvantage of this protocol is the sub-optimal intra-NEMO route optimization where all the packets with source and destination in the mobile network have to go through the TLMR. Also for each packet delivery the MR have to query the TLMR for existence of destination node within the mobile network which increases packet delivery delay with increase of nesting level.

The discussed protocols are summarized in table 1.

Table 1. SUMMARY OF NEMO PROTOCOLS

Protocol Name	Type	Handoff Delay	Packet Delivery Delay
NBSP	I	High	High
802.16 Based Fast Handoff [64]	II	Low	High
Cross Layer Design for Fast Handoff [34]	II	Low	High
SLNEMO	II	Low	High
Mussabir et. al [49]	III	Low	Low
FRONEMO	III	Low	Low
End-to-end Route Optimization [39]	IV	High	Low
ROTIO	IV	High	Low
Route Optimization using Hierarchical Algorithm [40]	IV	High	Low

3. Qualitative Comparison of NEMO Protocols

Various enhancement of NBSP, discussed in section 2, primarily attempt to improve the performance on one account or the other by modifying the functionality of one or more entities in their L2 or L3 or both. Typically, these affected entities include MNN, AR, HA, CN and any other entities that is proposed to be deployed. We discuss the modifications proposed in each type of NEMO protocol with reference to the basic functionalities found in NBSP.

3.1. Analysis for Type II NEMO protocols

For 802.16 based fast handoff, since the PAR advertises the neighborhood L3 properties in L2 message hence change is affected in both L2 and L3 of AR and MR. Also MR needs to send FBU and HA need to accept it and exchange HI, HAck and FBU (and no more BU and BAck), hence L3 of HA is also affected. There is no change required for CN and MNN since they are transparent to NEMO.
Cross Layer Design for Fast handoff require change of L2 message since the address request is made in the re-association message of L2 to NAR. Also NAR uses a cache to eliminate DAD. No change is required for MNN, HA or CN since BU message format remains unchanged.

3.2. Analysis for Type III NEMO protocols

The protocol by Mussabir et al. requires modification in L2 layer of MR for sending L2 trigger to L3 of MR. Also, the MR needs to exchange messages as in FMIPv6 resulting affect in L3 of AR and MR. Since the BU messages are identical to NBSP and MIPv6 hence no change is required for HA, MNN or CN.

3.3. Analysis for Type IV NEMO protocols

All the NEMO protocols for Type IV namely End-to-End Route Optimization, ROTIO and Route Optimization using Hierarchical Algorithm uses route optimization techniques and uses modified L3 messages. Hence none of the entities' L2 is affected. The L3 of MRs are affected since it needs to maintain modified cache for information of sub-level MR and MNN and might have to maintain the route to them (in case of Route Optimization using Hierarchical Algorithm).

Qualitative analysis of the NEMO protocols in terms of affected network entities is summarized in table 2.

3.4. Observations on NEMO protocols

Based on description and qualitative comparison between L3 NEMO protocols, following observations can be stated with respect to the NBSP:

Table 2. MODIFICATION OF ENTITES OF NETWORK

Protocol Name	**Affected Entities**					
	MNN	**MR**	**AR**	**HA**	**CN**	**Other Entities (if added)**
802.16 Based Fast Handoff [64] (FH802.16)	No	L2, L3	L2, L3	L3	No	No
Cross Layer Design for Fast Handoff [34] (Cross)	No	L2, L3	L2, L3	No	No	No
SLNEMO	No	L2, L3	L3	No	No	MAP
Mussabir et. al [49] (Mussabir)	No	L2, L3	L2, L3	No	No	Yes; IS
FRONEMO	No	L2, L3	No	No	No	No
FHE2ERO	No	L2, L3	L3	L3	No	No
End-to-end Route Optimization [39] (E2ERO)	No	L3	No	No	Yes	No
ROTIO	No	L3	No	No	No	No
Route Optimization using Hierarchical Algorithm [40] (ROH)	No	L3	No	No	No	No

(1) Type II protocols need software changes in L2 and L3 layer, type IV protocols requires software change in L3 only and type III protocols requires software changes in L2, L3 and deployment of an extra entity in infrastructure network. Thus deployment cost for type III protocol is highest followed by type II and type IV protocols respectively.

(2) Since route optimization of nested NEMO requires CoA binding with CoA of TLMR at HA of MR, which again requires advertisement of TLMR address (HoA or CoA) in the mobile network. Thus, for nested NEMO of level greater than 1, it is not possible to achieve route optimization without exposing the mobility of the mobile network.

4. Quantitative Comparison of NEMO Protocols

In this section quantitative analysis is performed based on network model as shown in figure 1. The comparison is done in terms of handoff delay, packet delivery delay and packet loss duration during handover. The developed model for comparative analysis is a simple one; this will give two advantages: (1) simple model will identify the network related stochastic parameters that affect the performance of a protocol; (2) the model can be scaled to develop more complex model [21] [11] to find average handoff and packet delivery delay. Among the discussed protocols in section 2.2, we select FH802.16, [34], [49], [39], ROTIO and ROH. SLNEMO and FRONEMO are not analyzed because the protocols have not considered the nested NEMO scenario. Moreover, FHE2ERO has been analyzed mathematically and since the model for analysis is based on similar assumptions, therefore making its analysis redundant.

4.1. Assumptions

(1) The mobile network is nested, containing m number of MRs arranged in the form of a binary tree. TLMR is assumed to be at level 1.

(2) The TLMR is connected to one of the AR and the AR is connected to a gateway router (GR) using a wired connection.
(3) The GR is connected to the internet.
(4) All AR under GR is connected using wired network and all communications between ARs is done through GR. GR is connected to the Internet.
(5) The MR under observation is at lowest level, level L.
(6) CN is connected directly to the Internet
(7) All the intermediate MR's (MRs at level k, where $1<k<L$) HA are connected directly to the Internet.
(8) The communication delay between k-th level MR and k+1-th level ($1\leq k\leq L-1$) is same as communication delay between k-th level MR and (k-1)-th level MR ($1<k<L$) and is same in both the directions. This is also equal to communication delay between an MR and MNN directly under the MR.
(9) The communication delay between HA of one MR to another MR through Internet is same communication delay between CN and GR, which is same as communication delay between GR and HA of any MR.

4.2. Notations

The notations used in quantitative analysis are shown in table 3 [32][43].

Table 3. NOTATIONS USED IN QUANTITATIVE ANALYSIS

Notation	Significance	Assumed Value
MR_k	MR at level k, where $1\leq k\leq L$	_
HA_k	Home Agent of MR_k	-
T_{L2}	Delay in L2 handoff.	50 ms
T_{adv}	L3 advertisement interval.	30ms
T_{DAD}	Delay in DAD.	500 ms
T_{net}	Communication delay between MR_k and MR_{k+1}= Communication delay between TLMR and AR.	6 ms
T_i	Communication delay between GR and CN	1088 ms
T_w	Communication delay between AR and GR.	2 ms

4.3. Definitions

(1) *Handoff Delay (h)*: It is the interval between the connection break-up at L2 to getting acknowledgement from the appropriate entities. For example, handoff delay can start from start of L2 handoff and can end at notification to HA of MR_L.
(2) *Packet Delivery Delay (δ)* is defined as latency in sending packet from CN to MNN of MR_L.
(3) *Packet Loss Duration (γ)* is taken as interval between the connection break-up at L2 to packet-redirection notification to appropriate entity.

4.4. Analysis for Type I NEMO Protocols

4.4.1. Analysis of Handoff Delay

For NBSP, handoff delay consists delay in L2 handoff (T_{L2}) + delay in receiving L3 advertisement ((T_{adv} +T_{net})/2) + delay in DAD (T_{DAD}) + delay in exchanging BU and BAck with HA of MR (L times T_{net} + T_w+ L times T_i + L times T_{net} + T_w+ L times T_i). Thus expression for h_{NBSP} is,

$$h_{NBSP} = \frac{T_{adv} + T_{net}}{2} + T_{DAD} + (LT_{net} + T_w + LT_i + LT_{net} + T_w + LT_i) \ .$$

This can be simplified as,

$$h_{NBSP} = (\frac{4L+1}{2})T_{net} + 2LT_i + 2T_w + T_{DAD} + T_{L2} + \frac{T_{adv}}{2} \quad (1)$$

4.4.2. Analysis of Delay in Packet Delivery

For NBSP the packet delivery delay will happen through tunnels between the IMRs and their corresponding HAs. The latency from CN to MR_L (and finally to MNN) will include latency from CN to HA of MR_L (T_i), latency from HAof MR_L to HA of TLMR (L times T_i), latency from TLMR to MR_L (L times T_{net}), latency from MR_L to MNN (T_{net}). Thus the packet delivery delay from CN to MNN for NBSP, δ_{NBSP}, is given by:

$$\delta_{NBSP} = T_i + LT_i + LT_i + T_i + T_w$$

$$\text{Or, } \delta_{NBSP} = (L+1)T_{net} + (L+1)T_i + T_w \quad (2)$$

4.4.2. Analysis of Packet Loss Duration

For NSBP, the packet loss duration will contain delay in L2 handoff, delay in receiving RA, delay in DAD, and delay in exchanging BU and BAck (L times T_{net} + T_w+ L times T_i + L times T_{net} + T_w+ L times T_i). Thus the packet loss duration for NBSP will be same as delay in handoff. So,

$$\gamma_{NBSP} = (\frac{4L+1}{2})T_{net} + 2LT_i + 2T_w + T_{DAD} + T_{L2} + \frac{T_{adv}}{2} \quad (3)$$

4.5. *Analysis for Type II NEMO Protocols*

4.5.1. Analysis of Handoff Delay

For FH802.16, the handoff delay starts from sending MOB_MS_HO-RFO message to getting FBAck from HA of MR. Let $h_{802.16}$ denote the handoff delay for the protocol. Then $h_{FH802.16}$ includes delay in sending MOB_MS_HO-RFO (T_{net}) + delay in sending FBU from MR_L to MR_L's HA (L times T_{net} +T_w+L times T_i)+ delay in sending HI to NAR (which will be another MR, for L>1; so, (L-1) times T_{net} +T_w+(L-1) times T_i)+ delay in DAD + delay in sending HAck from NAR to HA of MR_L ((L-1) times T_{net} +T_w+ (L-1) times T_i) + delay in sending FBAck to NAR ((L-1) times T_{net} +T_w+ (L-1) times T_i)+ delay in L2 handoff + delay in getting FBAck from NAR to MR. Thus, the equation for $h_{FH802.16}$ is given by:

$$h_{FH802.16} = T_{net} + (LT_{net} + T_w + LT_i) + \{(L-1)T_i + T_w + (L-1)T_{net}\} + T_{DAD} + \{(L-1)T_{net} + T_w + (L-1)T_w\} + T_{L2} + T_{net}$$

$$\text{Or, } h_{FH802.16} = (4L-1)T_{net} + (4L-3)T_i + 4T_w + T_{DAD} + T_{L2} \quad (4)$$

For Cross Layer Design for Fast Handoff, the handoff interval (h_{cross}) starts from getting beacon to sending re-association request (6 times T_{net}) + delay in sending re-association response (T_{net}) + delay in L2 handoff + delay in exchanging BU and BAck with HA_L (L times T_{net} + T_w+ L times T_i+ L times T_i+ T_w+ L times T_{net}). The time for DAD is not used since the protocol uses a special cache to eliminate it. Thus expression for h_{cross} is given by:

$$h_{cross} = 6T_{net} + T_{net} + T_{L2} + (LT_{net} + T_w + LT_i) + (LT_i + T_w + LT_{net})$$

$$\text{Or, } h_{cross} = (2L+7)T_{net} + 2LT_i + 2T_w + T_{L2} \quad (5)$$

The comparison graph of handoff delay of type II protocols with NBSP is shown in figure 4. It is to be noted that in the figure (and in the subsequent figures), FH802.16 is labeled as 802.16BWA since the protocol uses specific services of IEEE 802.16.

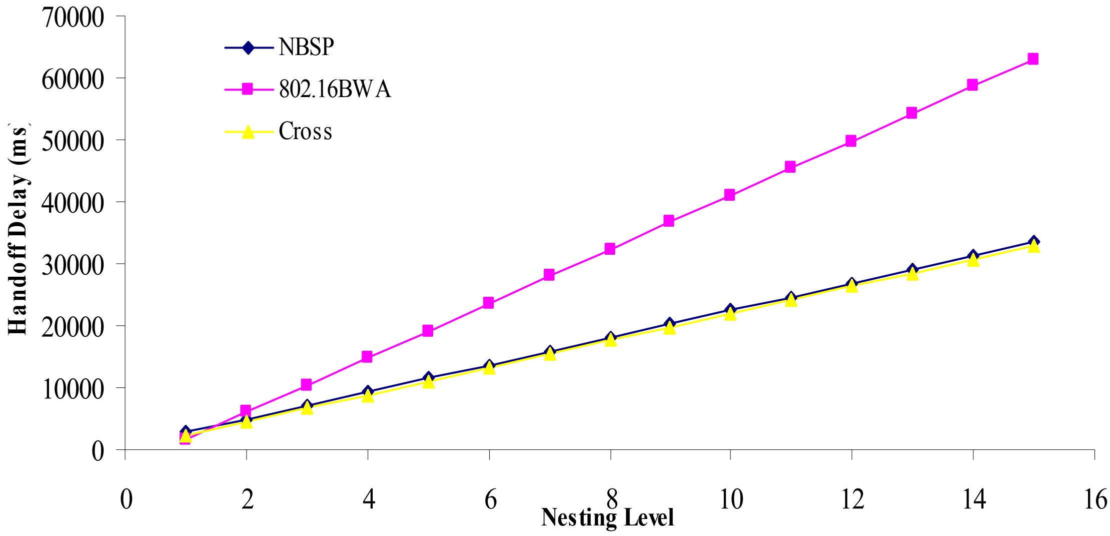

Figure 4: Handoff Delay Comparison between type II protocols with NBSP.

Figure 4 shows that the handoff delay is lowest for FH802.16 based Fast Handoff till L=1. For L>1, the same protocol performs worst and this increases with L. This degrading performance of the protocol is attributed to exchange of FBU, HI and HAck packets through tunnels. Cross Layer Design for Fast Handoff performs the best in terms of handoff delay for L>1. This is attributed to early handoff detection, merging some of the L2 message in L2 handoff messages thus eliminating need for extra L3 handoff messages. All of the type II protocols still suffer from exchange of BU and BAck messages through tunnels.

4.5.2. Analysis for Delay in Packet Delivery

For FH802.16, the packet delivery will happen through tunnels. So, any delivery from CN to MNN of MR will include delay from CN to HA of MR + delay through(L-1) HA ending at HA of TLMR + delay from HA of TLMR to GR + delay from GR to AR + delay from AR to MR + delay from MR to MNN. Thus delay for this protocol ($\delta_{FH802.16}$) is given by:

$$\delta_{FH802.16} = (L+1)T_{net} + (L+1)T_i + T_w \tag{6}$$

For Cross Layer Design for Fast Handoff, since there is no route optimization the packet delivery will also happen through tunnels of though intermediate MRs (IMR) and HA of IMRs. Hence, the packet delivery delay (δ_{cross}) for this protocol will have same expression as in $\delta_{802.16}$.

$$\delta_{cross} = (L+1)T_{net} + (L+1)T_i + T_w \tag{7}$$

The equations for delay in packet delivery are identical to equation 2, thus supporting the fact that type II protocols only aims for handoff delay and with respect to packet delivery there is no gain.

4.5.3. Analysis for Packet Loss Duration

For FH802.16, the packet loss duration is the duration from initiate to send MOB_MS-HO-RSP by MR to AR (or higher level MR) to the duration of receiving the HAck from NAR (or new MR) by the HA of MR. This duration ($\gamma_{FH802.16}$) is difference of time duration for handoff and time duration of sending FBAck from HA of MR and L2 handoff by MR ((L-1) times T_i+T_w+(L-1)T_{net}+T_{L2}+T_{net}). Thus, expression for $\gamma_{FH802.16}$ is:

$$\gamma_{FH802.16} = h_{FH802.16} - [(L-1)T_i + T_w + (L-1)T_{net} + T_{L2} + T_{net}]$$

This can be simplified using equation 4 as,

$$\gamma_{FH802.16} = (3L-1)T_{net} + (3L-4)T_i + 3T_w + T_{DAD} \tag{8}$$

For Cross Layer Design for Fast Handoff the duration for packet loss (γ_{cross}) includes the time duration from sending probe request by MR to receipt of BU by HA of MR. This includes delay in sending probe request + delay in receiving probe request + delay in sending authentication message+ delay in receiving authentication message + delay in re-association request (along with delegation of PCoA and PAR's IP address) + delay in receiving re-association response + delay in sending BU to HA. Thus, expression for γ_{cross} is:

$$\gamma_{cross} = 6T_{net} + LT_{net} + T_w + LT_i$$

$$\text{Or, } \gamma_{cross} = (L+6)T_{net} + LT_i + T_w \tag{9}$$

The comparison graph for packet loss duration is shown in figure 5.

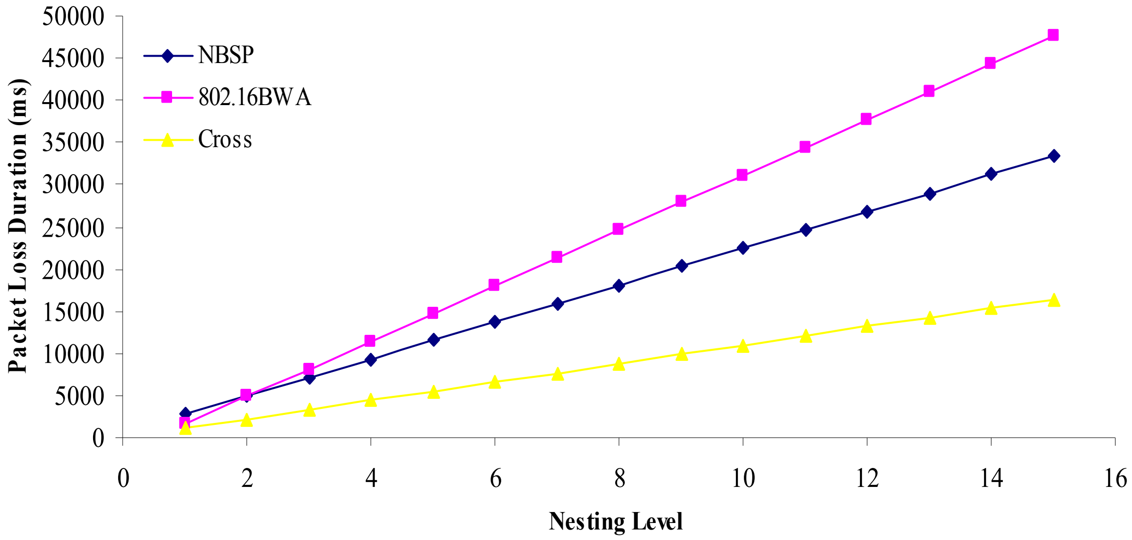

Figure 5: Comparison of packet loss duration with NBSP for type II protocols.

Figure 5 shows that packet loss duration for Cross-Layer Design for Fast Handoff is lowest among all mentioned type II protocols. This happens because Cross Layer Design for Fast Handoff performs handoff faster by eliminating DAD. However, FH802.16 has lower packet loss duration with respect to NBSP only for L=1 and for L>1 the performance falls significantly. The reason behind this is high latency in exchange of fast handoff packets through tunnels thus delaying the formation of tunnel between HA of MR and NAR resulting packet loss.

4.6. Analysis for Type III NEMO Protocols

4.6.1. Analysis of Handoff Delay

For protocol proposed by Mussabir et. al, the route optimization, although valid for L=1 but the route optimization will not work for L>1 thus, the route from MR to HA will contain tunnels. Thus, handoff delay for this protocol h_M contains delay in sending candidate query request (T_{net}) + delay in sending query for resources to neighboring router (T_{net} or T_w if L=1)+ delay in getting query resources response from neighboring router (T_{net} or T_w if L=1) + delay in sending candidate query response to MR (T_{net}) + delay in sending FBU from MR to higher level MR (T_{net}) + delay in sending HI to neighboring router (T_{net} or T_w if L=1) + delay in receiving HAck (T_{net} or T_w if L=1) + delay in sending FBack to MR (T_w) + delay in L2 handoff (T_{L2})+ delay in sending BU to MR's HA (L times T_{net} + T_w + L times T_i) + delay in getting BAck (L times T_i + T_w + L times T_w) + delay in exchanging BU and BAck with CN (L times T_{net} + T_w + (L+1) times T_i) + ((L+1) times T_i + T_w + L times T_{net})). Thus expression for h_M is,

$$h_M = \begin{cases} (4L+4)T_{net} + (4L+2)T_i + 8T_w + T_{L2}\,;(L=1) \\ (4L+8)T_{net} + (4L+2)T_i + 4T_w + T_{L2}\,;(L>1) \end{cases} \tag{10}$$

The comparison of handoff delay of the type III protocol with NBSP is shown in figure 6.

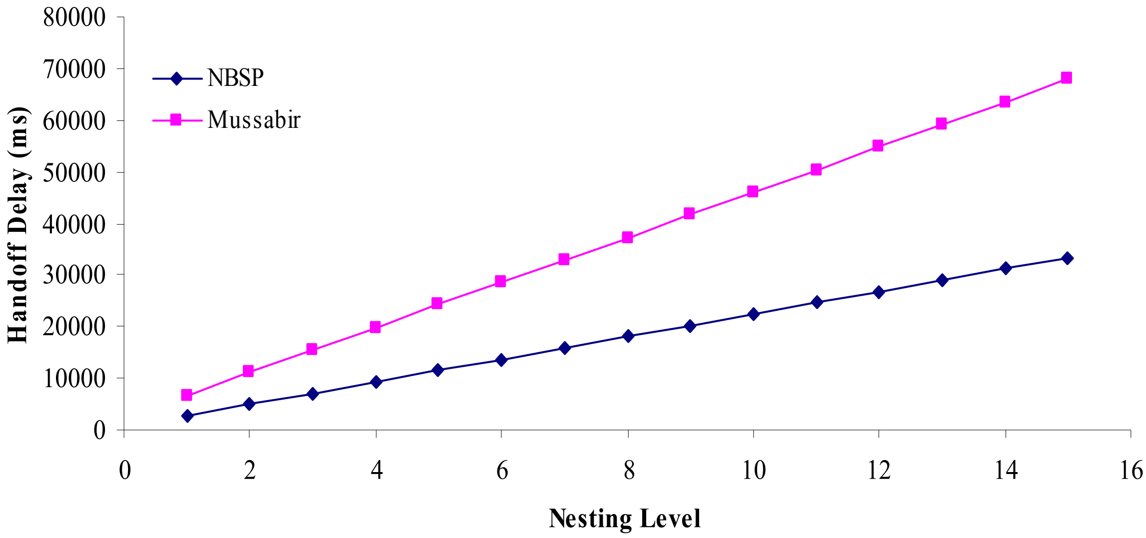

Figure 6: Comparison of type III protocol with NBSP.

Figure 6 shows an interesting variation since the protocols of type III are expected to have low handoff delay that NBSP. This is because of exchange of messages for query request and response before FBU and route optimization process which again exchanges packets through tunnels, thus adding to the handoff delay.

4.6.2. Analysis for Delay in Packet Delivery

For Mussabir et. al. the route optimization will work only for L=1. Thus, the packet delivery will happen through tunnels between IMRs and corresponding HA of IMRs. Thus the delay in packet delivery for Mussabir et. al (δ_M) is given by:

$$\delta_M = (L+1)T_{net} + (L+1)T_i + T_w \tag{11}$$

The packet delivery delay although expected to be lower for type III protocol but the protocol by Mussabir et. al is not able to do so because of exchange of packets through tunnels for L>1. Thus for any type III protocol to succeed, the issue of tunneling must be addressed.

4.6.3. Analysis for Packet Los Duration

For Mussabir et. al, the handoff process starts as soon as L3 gets the L2 trigger. The exchange of HI and HAck happens at (L-1) level and results in packet redirection so that the packets can be buffered at NAR (or new MR). Thus the packet loss duration for this protocol is zero. Hence,

$$\gamma_M = 0 \tag{12}$$

It is interesting to note that the type III protocol have high handoff delay and delay in packet delivery but manages to maintain zero loss to MNNs under MR. Though packet loss is zero but throughput will suffer since the packets are now buffered at NAR (or higher level MR) and thus, the scheduled arrival of packets will now be delayed.

4.7. Analysis for Type IV NEMO Protocols

4.7.1. Analysis of Handoff Delay

For E2ERO protocol, the handoff interval (h_{E2ERO}) includes from L2 handoff + delay in L3 detection ((T_{adv}+T_{net})/2) + delay in DAD + delay in sending LBU ((L-1) times T_{net}) to TLMR + delay in getting LBAck from TLMR ((L-1) times T_{net}) + delay in sending BU to HA (L times T_{net} + T_w+ T_i) + delay in getting BAck from HA of (T_i + T_w+ L times T_w). Hence, the expression for h_{E2ERO} is,

$$h_{E2ERO} = T_{L2} + + \frac{T_{adv} + T_{net}}{2} + T_{DAD} + (L-1)T_{net} + (L-1)T_{net} + (LT_{net} + T_w + T_i) + (T_i + T_w + LT_{net})$$

This can be simplified as,

$$h_{E2ERO} = (\frac{8L-3}{2})T_{net} + 2T_i + 2T_w + T_{L2} + T_{DAD} + \frac{T_{adv}}{2}$$

(13)

For ROTIO, the handoff delay includes delay in L2 handoff + delay in receiving advertisement (average of 0 and (L times the T_{net}+T_{adv}))+ delay is DAD + delay in sending delay in sending LBU ((L-1) times T_{net}) to TLMR + delay in getting LBAck from TLMR ((L-1) times T_{net}) + delay in sending BU to HA (L times T_{net} + T_w+ T_i) + delay in getting BAck from HA of MR (2T_i + T_w +L times T_{net}n if L>1 and T_i + T_w +L times T_{net}n if L=1). Note that the delay of receiving the BAck will be more than sending BU since the BAck will be router through HA or TLMR. Hence, the expression for h_{ROTIO} is,

$$h_{ROTIO} = \begin{cases} T_{L2} + \frac{T_{adv} + LT_{net}}{2} + T_{DAD} + (L-1)T_{net} + (L-1)T_{net} + (LT_{net} + T_w + T_i) + \\ (T_i + T_w + LT_{net}), \quad if\ L = 1 \\ T_{L2} + \frac{T_{adv} + LT_{net}}{2} + T_{DAD} + (L-1)T_{net} + (L-1)T_{net} + (LT_{net} + T_w + T_i) + \\ (2T_i + T_w + LT_{net}), \quad if\ L > 1 \end{cases}$$

Simplifying we get,

$$h_{ROTIO} = \begin{cases} (\frac{9L-4}{2})T_{net} + 2T_i + 2T_w + T_{L2} + T_{DAD} + \frac{T_{adv}}{2}, if\ L = 1 \\ (\frac{9L-4}{2})T_{net} + 3T_i + 2T_w + T_{L2} + T_{DAD} + \frac{T_{adv}}{2}, if\ L > 1 \end{cases}$$

(14)

For ROH protocol, the handoff delay (h_{ROH}) includes delay in L2 handoff + delay in receiving L3 advertisement ((T_{adv}+L times T_{net})/2) + delay in DAD + delay in sending LBU to TLMR ((L-1) times T_{net}) + delay in receiving LBAck from TLMR ((L-1) times T_{net}) + delay in sending BU to MR's HA (L times T_{net}+ T_w+T_i) + delay in receiving BAck (2 times T_i+ T_w+T_{net}). Thus expression for h_{ROH} is,

$$h_{ROH} = T_{L2} + \frac{T_{adv} + LT_{net}}{2} + T_{DAD} + (L-1)T_{net} + (L-1)T_{net} + (LT_{net} + T_w + T_i) + (T_i + T_w + LT_{net})$$

After simplification we get,

$$h_{ROH} = \frac{(9L-4)}{2}T_{net} + 2T_i + 2T_w + T_{L2} + T_{DAD} + \frac{T_{adv}}{2}$$

(15)

The comparison graph for handoff delay with NBSP is shown in figure 7. Note that in figure 7 and subsequent figures, plot for E2ERO is labeled as 'End-to-end' to signify that the protocol aims for end-to-end route

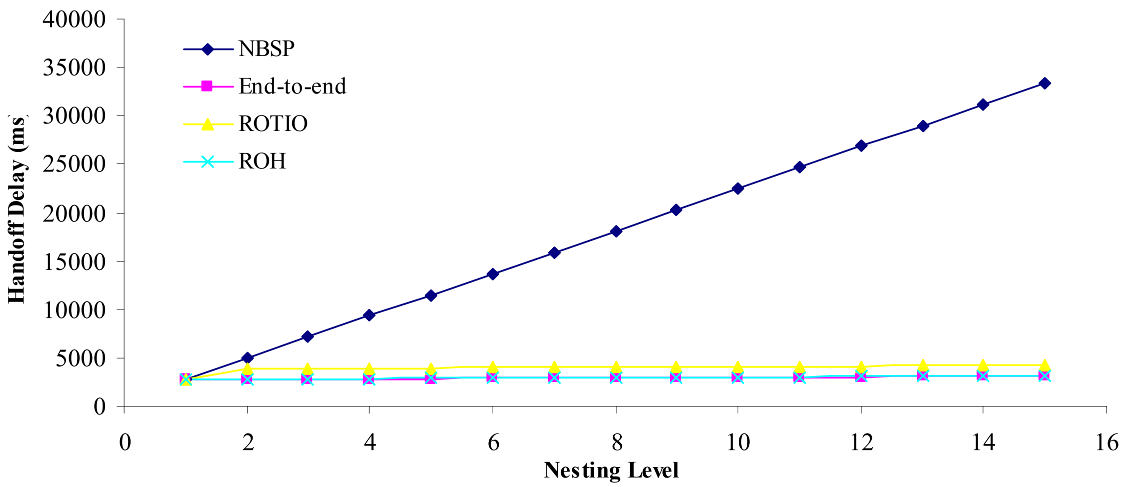

Figure 7: Comparison graph for type IV protocols.

optimization.

The figure 7 clearly shows the benefit of making number of tunnels between HA of MR and MR to a constant value. At L=1 type IV protocols and NBSP shows same performance. ROTIO performs the worst among the type IV protocols because of one additional tunnel between HA of TLMR and HA of MR.

4.7.2. Packet Delivery Delay Analysis

For End-to-end Route Optimization protocol, since the route is optimized and the binding update results binding entry of CoA or TLMR and home address of MR hence, the packet delivery from CN to MNN of MR will happen in the path CN→HA of MR→GR→AR→TLMR .. →MR→MN. Thus, the expression for packet delivery delay for the protocol will be (δ_{E2ERO}):

$$\delta_{E2ERO} = (L+1)T_{net} + 2T_i + T_w \quad (16)$$

For ROTIO the packet delivery delay (δ_{ROTIO}) will incur an additional delay of T_i for L>1 since the HA of MR is notified about the home address of TLMR, hence the packet from CN, after visiting HA of MR, will visit HA of TLMR. However, for L=1 no additional tunnel will be incurred. Thus, we have:

$$\delta_{ROTIO} = \begin{cases} (L+1)T_{net} + 2T_i + T_w, if\ L=1 \\ (L+1)T_{net} + 3T_i + T_w, if\ L>1 \end{cases} \quad (17)$$

For ROH protocol (δ_{ROH}), the packet delivery delay will have the same expression as in (δ_{E2ERO}) since the HA of MR is notified about the CoA of TLMR. Thus, we have:

$$\delta_{ROH} = (L+1)T_{net} + 2T_i + T_w \quad (18)$$

The comparison graph of packet delivery delay with for type IV protocols with respect to NBSP is shown in figure 8. From figure 8 we see that ROTIO has same packet delivery delay as in NBSP for L=1 and 2. This follows from equation 17 and 2 where $\delta_{NBSP} = \delta_{ROTIO}$ for L=1, 2. This is because for L=1, 2, number of tunnels from CN to MNN is 2 for ROTIO and NBSP. Also, ROH and End-to-End performs equally (and better than ROTIO) because of making the number of tunnels between MR and HA of MR equal to 1.

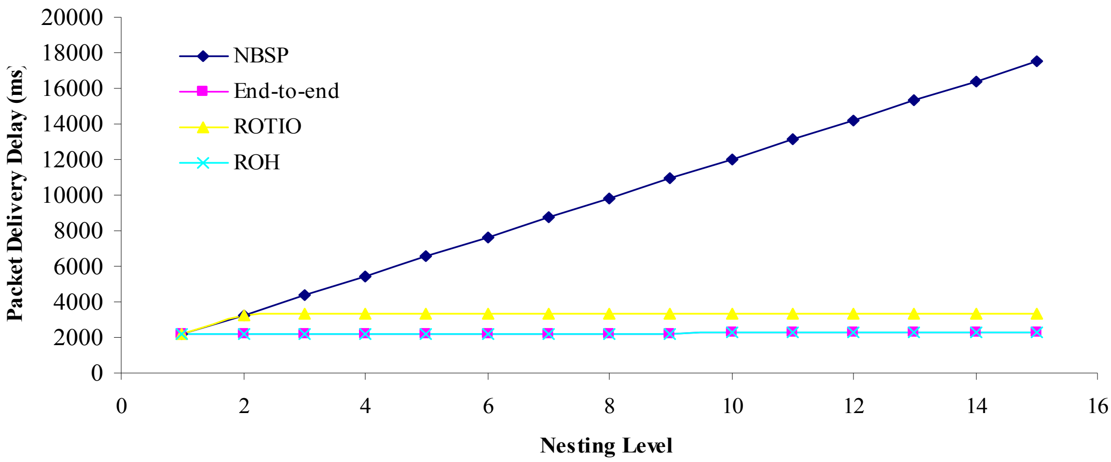

Figure 8: Comparison of packet delivery delay for type IV protocols with respect to NBSP.

4.7.3. Analysis for Packet Loss Duration

For End-to-end Route Optimization the packet loss duration ($\gamma_{end\text{-}to\text{-}end}$) is the time from start of L2 handoff to receipt of BU by MR of HA, which is equal to $h_{end\text{-}to\text{-}end}$ minus the delay in recipt of BAck by MR ($T_i + T_w$+L times T_{net}). Thus the expression for γ_{E2ERO} is:

$$\gamma_{E2ERO} = h_{E2ERO} - (T_i + T_w + LT_{net})$$

Using equation 13 and simplifying we get,

$$\gamma_{E2ERO} = (\frac{6L-3}{2})T_{net} + T_i + T_w + T_{L2} + T_{DAD} + \frac{T_{adv}}{2} \quad (19)$$

Similarly, for ROTIO, the packet loss duration γ_{ROTIO} is given by to h_{ROTIO} minus the delay in recipt of BAck by MR ($2T_i + T_w$+ L times T_{net} for L>1 and $T_i + T_w$+ L times T_{net} for L=1). Thus the expression for γ_{ROTIO} is:

$$\gamma_{ROTIO} = \begin{cases} h_{ROTIO} - (T_i + T_w + LT_{net}), if\ L = 1 \\ h_{ROTIO} - (2T_i + T_w + LT_{net}), if\ L > 1 \end{cases}$$

Simplifying using equation 14 we get,

$$\gamma_{ROTIO} = (\frac{7L-4}{2})T_{net} + T_i + T_w + T_{L2} + T_{DAD} + \frac{T_{adv}}{2} \quad (20)$$

Based on the same argument for End-to-End Route Optimization we have the expression for the packet loss duration, γ_{ROH}, for Hierarchical Algorithm for Route Optimization as:

$$\gamma_{ROH} = \frac{7L-4}{2}T_{net} + T_i + T_w + T_{L2} + T_{DAD} + \frac{T_{adv}}{2} \quad (21)$$

The comparison graph of packet loss duration for type IV protocols is given in figure 9.

From figure 9 it can be seen that all the type IV protocols have same performance in terms of packet loss duration although ROTIO showed worst in terms of handoff delay and packet delivery delay. This is due the fact that the packets get redirected just after sending a BAck with successful status (where ROTIO uses two tunnels and others use 1 tunnel).

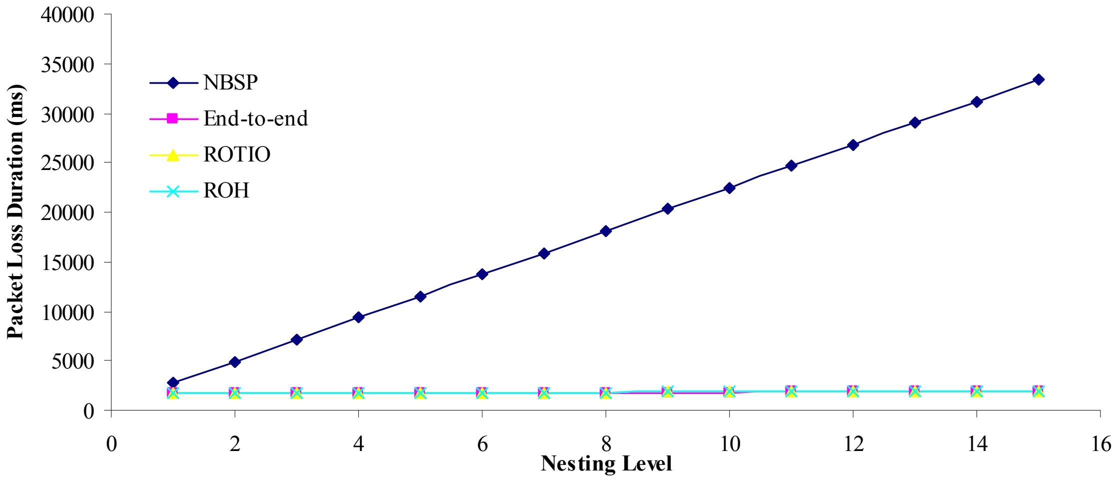

Figure 9: Comparison of packet loss duration of type IV protocols with NBSP.

4.8. Discussion on Handoff Delay

The handoff equations (1), (4), (5), (10), (13), (14) and (15) can be conveniently represented in matrix form as shown in table 4. The variation of handoff delay with nesting level for types I-IV is shown in figure 10. The values are referred from table 3. From figure 10 it can be observed that protocols belonging to Type I, II and II have high handoff delay due to passing of control message through multiple tunneling although type II protocols have least handoff delay for L=1. On the other hand, the handoff delay is lesser for NEMO protocols for Type IV protocols when L>1. This might appear a contradiction to expected behavior of type II and III protocols but actually the type II and fast handoff feature of type III protocol only acquires NCoA in fast way and uses additional control messages for the same also type III protocols uses route optimization process that exchanges the packets using tunnels.

Table 4. HANDOFF DELAY

Handoff Delay (h)	Network Parameters					
	T_{net}	T_i	T_w	T_{L2}	T_{DAD}	T_{adv}
NBSP	***(4L+1)/2***	***2L***	***2***	***1***	***1***	***0.5***
FH802.16	***4L-1***	***4L-3***	***4***	***1***	***1***	***0***
Cross-Layer Design for Handoff	***2L+7***	***2L***	***2***	***1***	***0***	***0***
Mussabir et. al.	***4L+4 (L=1); (4L+8) (L>1)***	***4L+2***	***8 (L=1); 4 (L>1)***	***1***	***0***	***0***
E2ERO	***(8L-3)/2***	***2***	***2***	***1***	***1***	***0.5***
ROTIO	***(9L-4)/2***	***2 (L=1); 3 (L>1)***	***2***	***1***	***1***	***0.5***
ROH	***(9L-4)/2***	***2***	***2***	***1***	***1***	***0.5***

4.9. Discussion on Packet Delivery Delay

The equations for packet delivery delay (equations 2, 6, 7, 11, 16, 17 and 18) of type I-IV protocols can be represented in tabular form in table 5. The comparison graph for delay in packet delivery delay is as shown in figure 11. The comparison graph shows benefit of route optimization in which the number of tunnels from MNN to CN is made a constant value. Only for L=1 all types of protocols give the same performance.

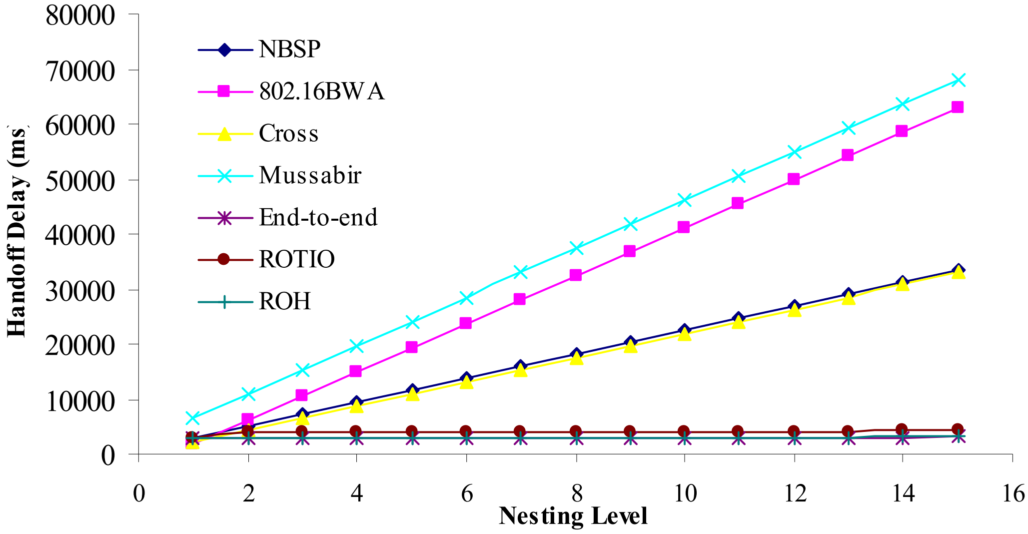

Figure 10. Comparison of Handoff Delay

Table 5. PACKET DELIVERY DELAY

Packet Delivery Delay (δ)	Network Parameters		
	T_{net}	T_i	T_w
NBSP	***L+1***	***L+1***	***1***
FH802.16	***L+1***	***L+1***	***1***
Cross-layer Design for Handoff	***L+1***	***L+1***	***1***
Mussabir et. al.	***L+1***	***L+1***	***1***
E2ERO	***L+1***	***2***	***1***
ROTIO	***L+1***	***2 (L=1); 3(L>1)***	***1***
ROH	***L+1***	***2***	***1***

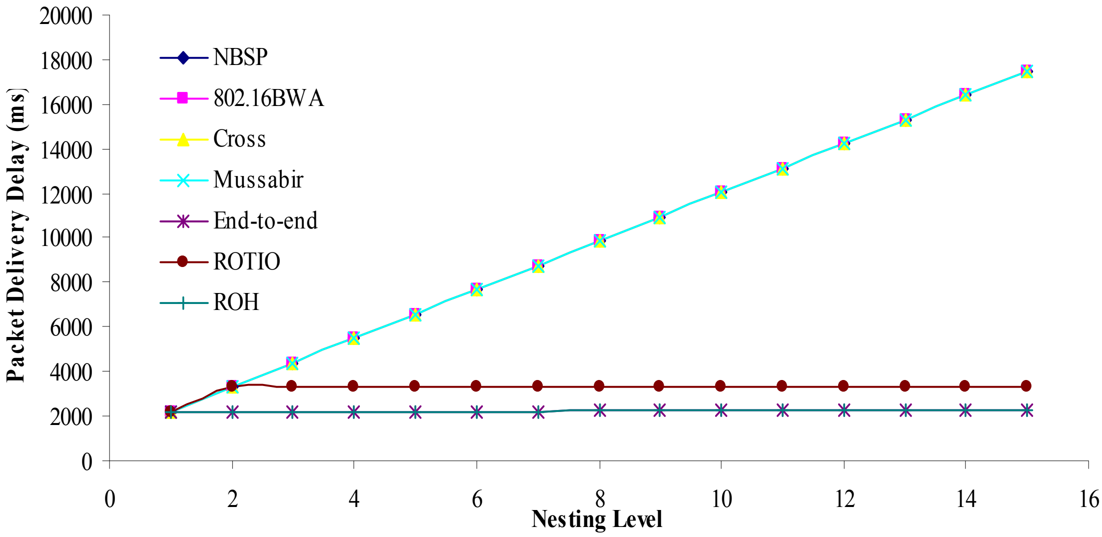

Figure 11. Variation of Packet Delivery Delay

4.10. Discussion on Packet Loss Duration

The equations for packet loss (equation 3, 8, 9, 12, 19, 20 and 21) are summarized in table 6. The variation in packet delivery duration with nesting level is shown in figure 12. From the figure it can be observed that packet loss duration for class III protocols is least among all the protocols. This is attributed to ability to redirect and buffer the packets at NAR (or higher level MR for L>1). We also see that benefit of class II protocols, in terms of packet loss duration, is limited to L=1 only and class IV clearly outperforms them for L>1 because class IV protocols sends the BU faster than class II protocols with constant number of tunnels.

Table 6. PACKET LOSS DURATION

Packet Loss Duration (γ)	Network Parameters					
	T_{net}	T_i	T_w	T_{L2}	T_{DAD}	T_{adv}
NBSP	*(4L+1)/2*	*2L*	*2*	*1*	*1*	*0.5*
FH802.16	*3L-1*	*3L-4*	*3*	*0*	*1*	*0*
Cross-layer Design for Handoff	*L+6*	*L*	*1*	*0*	*0*	*0*
Mussabir et. al.	*0*	*0*	*0*	*0*	*0*	*0*
E2ERO	*(6L-3)/2*	*1*	*1*	*1*	*1*	*0.5*
ROTIO	*(7L-4)/2*	*1*	*1*	*1*	*1*	*0.5*
ROH	*(7L-4)/2*	*1*	*1*	*1*	*1*	*0.5*

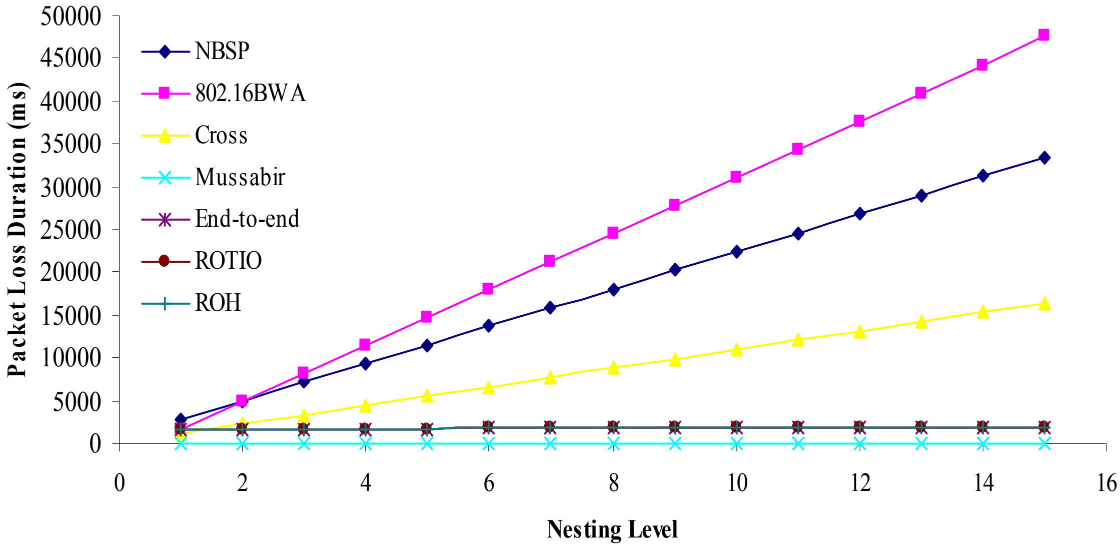

Figure 12. Comparison of Packet Loss Duration

5. Conclusion

This paper have classified L3 NEMO protocols into four types where the type I protocols aims for handoff, type II protocols aims for fast handoff, type III protocols aims for fast handoff and route optimization and type IV aims for route optimization only. Type II NEMO protocols acquire NCoA using fast mechanism but could not complete the overall handoff procedure in efficient manner when nesting level of NEMO exceeds 1. Thus, use of fast handoff NEMO protocols for delay tolerant applications is suggested if the nesting level in NEMO ensured to be limited to 1. Among the type II protocols, using Cross Layer Design for Fast Handoff is suggested since it performs best among them in terms of packet loss duration and handoff delay. Type IV NEMO protocols, on the other hand acquire NCoA lately but completes the overall handoff procedure relatively efficient manner because of route optimization techniques which avoids tunnels for BU and BAck messages to HA also and outperforms type II protocols for nesting level greater than 1 but at the cost of exposing mobility of top-level MR to lower levels. Type III NEMO protocol during acquisition of NCoA ensures packet redirection and buffering causing zero packet loss. This is helpful for very fast moving vehicles like high-speed trains or Internet service to civil aircrafts. For Type IV NEMO protocols, use of End to End Route Optimization algorithm is to be preferred since it performed best in terms of handoff delay and packet loss duration. Combining the best of both the type II and IV NEMO protocols can be implemented because that protocol will be effective in terms of handoff duration and the combination must ensure packet redirection at the start of handoff. Packer redirection will ensure lesser packet loss and fast handoff will ensure lesser degradation in throughput.

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