Indonesian Journal of Electrical Engineering and Computer Science
Vol. 8, No. 2, November 2017, pp. 522 ~ 532
DOI: 10.11591/ijeecs.v8.i2.pp522-532

Performance Analysis of HRO-B+ Scheme for the Nested Mobile Networks using OPNet

Shayma Senan[1], Aisha Hassan A. Hashim[2]
Department of Electrical and Computer Information, Faculty of Engineering,
International Islamic University Malaysia, 53100 Kuala Lumpur, Malaysia
*Corresponding author, e-mail: shay_sinan@yahoo.co.uk[1], aisha@iium.edu.my[2]

Abstract

As a demand of accessing Internet is increasing dramatically, host mobility becomes insufficient to fulfill these requirements. However, to overcome this limitation, network mobility has been introduced. One of its implementation is NEMO Basic Support protocol which is proposed by Internet Engineering Task Force (IETF). In NEMO, one or more Mobile Router(s) manages the mobility of the network in a way that its nodes would be unaware of their movement. Although, it provides several advantages, it lacks many drawbacks in term of route optimization especially when multiple nested mobile networks are formed. This paper presents a new hierarchical route optimization scheme for nested mobile networks using Advanced Binding Update List (BUL+), which is called HRO-B+. From performance evaluation, it shows that this scheme performs better in terms of throughput, delay, response time, and traffic, and achieves optimal routing.

***Keywords**: Mobile IPv6, Network Mobility (NEMO), Route Optimization, OPNet*

1. Introduction

Since the last decade, mobile communication industry has achieved a huge development. The usage of the Internet in cooperation with the mobile communication technology created an enormous demand for more extensive and innovative support of mobility [1].

In practice, to adopt network mobility, many methods and protocols were proposed and examined. Most of these proposals can be distinguished under either of the two main types of mobility management. First type is single mobile units that roam and change their point of attachments to the network. On the other hand, an entire mobile network that keeps the communication sessions of its units while they are moving between multiple subnets within the network [2]. One example of the second type is NEMO Basic Support [3] which is the most common mobile network protocol. It's an IP layer technology that has the advantages of Mobile IPv6 [4], although it has many problems such as pinball routing problem and Binding Update storm.

In this paper, a new route optimization scheme based on hierarchical structure using Advanced Binding Update List (BUL+) which is called HRO-B+ is introduced, evaluated and analyzed. HRO-B+ provides an efficient NEMO solution with optimal routing and seamless handoff. The reminder of this paper is organized as follows. In section 2, NEMO is introduced with its advantage and drawbacks. Related works to this research is discussed in section 3. Section 4 covers the design of the proposed scheme HRO-B+. In section 5, performance evaluation of NEMO BS, ROTIO, and HRO-B+, is displayed and analyzed. In section 6, the results obtained from the simulation are discussed. Finally section 7 concludes the research findings.

2. Network Mobility

In order to provide ubiquitous communication to a network of moving nodes, NEMO basic support protocol has been proposed and standardized by Internet Engineering Task Force (IETF) [3]. NEMO BS protocol provides network mobility support to IPv6, as it's considered an extension of Mobile IPv6. A NEMO has a router (one or more) named mobile router (MR) that

Received July 15, 2017; Revised September 20, 2017; Accepted October 13, 2017

connects it to the Internet and one or many mobile network nodes (MNN) that are attached to the MR. From its home network, the MR is assigned with a fixed IP address called home address (HoA). When any node in the Internet (called correspondent node (CN)) sends packets to a MNN that is located in a NEMO, the communication will be through the HoA of its MR. In basic NEMO, a CN will always sends packets to the Home Agent (HA) of MR first [5]. In case the MR is in its home network, the packets will be forwarded by its HA to the MR directly, then the MR will send the packets to the destination node (MNN). If a MR is away from its home link, a care of address (CoA) will be assigned to the MR from the foreign network. The HA will be informed about the MR's new location through a Binding Update (BU) message containing the new CoA of the MR. then the HA will map the MR's HoA with new CoA. When MR is in a foreign network, HA is unable to send CN's packets to the MNN directly, as the HA of the MR will intercept the packets. The packets will be encapsulated by HA and sends to destination address, i.e. MR's CoA. Lastly, after establishing HA-MR tunnel, the encapsulated packet will be forwarded by HA to MR's CoA. MR will decapsulate the received packets from the HA, then forwards the original packets sent by the CN to MNN [6]. In summary, all packets sent by CN is encapsulated by the HA and send through HA-MR tunnel to the MR as shown in Figure 1.

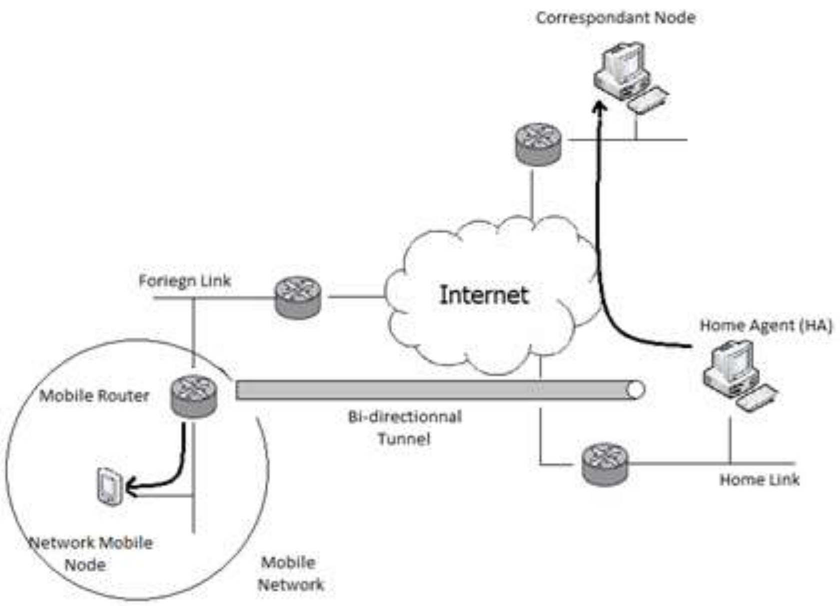

Figure 1. Tunnelling in NEMO BS

2.1 The Pinball Routing Problem in NEMO

In NEMO, MR can connect to the Internet through another MR forming a network topology called a Nested Mobile Network. For each level of a mobile network, new bi-directional tunnel will be established between the MR and its Home Agent (HA). This cause the Nested Mobile Networks suffer from the pinball routing problem (non-optimal routing problem). In NEMO, every mobile node (MR or MMN) has its own HA. The problem occurs when a CN sends a packet to the MNN, the packet has to go through the HAs of all MRs [3].

Figure 2 displays the pinball routing problem with four levels of nesting. Firstly, the packet sent by a CN to MNN is routed to HA4 (HA of MR4). The Binding Cache (BC) of HA4 has binding information that MR4 is below MR3. So the packet is encapsulated and routed to HA3 (HA of MR3). The HA3's BC has the information that MR3 is under MR2. As a result the packet is tunneled to HA2 (HA of MR2). At this point, HA2 contains binding information that MR2 is under MR1. Then the packet is encapsulated and resent to HA1 (HA of MR1). HA1 tunnels the received packet and delivers it to MR1. According to these procedures, the original packet is encapsulated four times. The MRs in the nested mobile routers decapsulate the packet and forward it to the MNN [7].

The pinball routing problem increased as the degree of nesting increases. The distances between HAs are also playing a big role in complicating the problem, as HA can be located anywhere in the world [8].

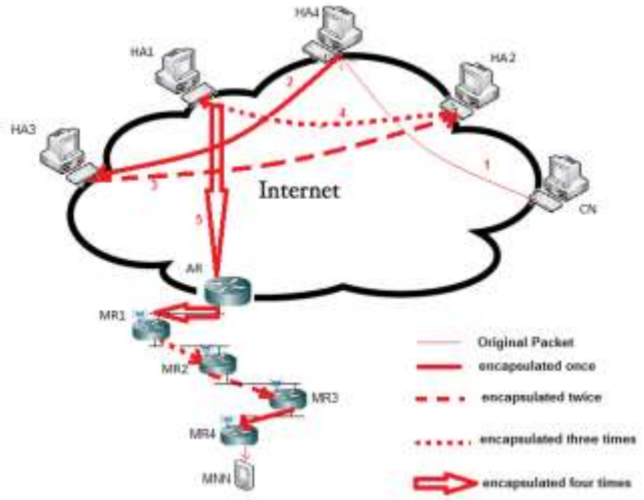

Figure 2. Pinball routing problem in nested mobile networks

3. Related Works

In order to provide a ubiquitous and efficient network, many researchers have been worked to solve the limitations of NEMO BS protocol. ARO [9] is using the route optimization technique of Mobile IPv6, which is further extended with an access router option. In ARO, the HAs of the MRs gather binding details one by one from upper level MRs and figure out the optimal path recursively. This method only needs few modifications in the current NEMO BS protocol. Nevertheless, because the route is optimized step by step, long convergence time is required, which is proportional to the nesting level. In this method, in order to deduce the optimal route to the MNN, the binding cache in the HA has to be checked repeatedly. In addition, level of nesting affects the number of recursive steps for each packet. Moreover, location privacy is not taken into consideration as the CN also involves in the route optimization process.

RBU+ [10] is based on ARO, in which the optimal path is configured when the HAs received the BU messages. The binding information for the TLMR's CoA is recorded by the HAs through this recursive BU. In this approach ad hoc network routing is adopted inside the mobile network in order to manage the received packets at the TLMR. MRs can preserve a routing table (proactive) or create a routing path on demand (reactive). Despite that, RBU+ has many problems such as unguaranteed location privacy and a long convergence time that cause an extensive handoff disruption.

HMIP-RO [11] adopts the concept of a mobility anchor point (MAP) from Hierarchical MIPv6 [12]. The routing management is separated into two: inside the mobile network (MAP domain) and outside the mobile network (between CN and MAP). In this approach, the MAP advertisement messages are propagated by using a modified version of HMIPv6. However each MRs in the mobile network has two CoAs (as in HMIPv6): the regional CoA (from the MAP) and the on-link CoA (from its closest MR). Packets sent to a MR can be routed by the MAP since the HA of the MR is notified of the MR's regional CoA and the MAP is notified of the on-link CoA. However, this approach suffers from binding update storm upon handoff to a new MAP domain since the information of the new nested route will be propagated to the entire nested mobile network. Upon receiving this update, every MR and MNN in the nested mobile network will send BUs at the same time.

Another solution to pinball routing problem and multiple levels encapsulations is a routing optimization scheme based on hierarchical MIPv6 called HRO [13]. In this scheme, the

MAP is responsible for managing location handover, and thereby MAP domain deals with the most signaling messages locally.

Route optimization scheme in [14] provides two types of nodes: CRs (Corresponding Routers) and OLFNs (Optimization-capable Local Fixed Nodes). Since CR node is unavailable in the network always, this scheme may not be able to handle route optimization.

In [15], they proposed a new route optimization scheme by using two CoAs for each MR, as well as two types of entries in every MR's routing table. Regardless the nesting degree in the nested mobile networks, this optimized routing solution eliminates the tunnels altogether using only one BU message. Although the scheme achieves an optimal route and solve binding update storm, it's expected to have many problems during handoff especially TLMR's handoff.

4. Hierarchical Route Optimization Scheme using Advanced Binding Update List (HRO-B+)

In order to solve the main drawbacks of NEMO BS that are pinball routing problem and Binding Update storm, this paper proposed a route optimization scheme based on hierarchical structure with the use of novel advanced Binding Update List (BUL+).

The main enhancements that the proposed scheme (shown in Figure 3) does to the structure of NEMO BS will be in TLMR and MRs of the mobile network. No modifications are needed to any of CNs or HAs.

To localize signaling messages for handoff and optimize routing of the nested mobile networks, a Mobility Anchor Point (MAP) used in a hierarchical approach, like HMIPv6 [12], is proposed. However, for the nested mobile networks, the TLMR is proposed to be functioning like a MAP in HMIPv6. Thus, the entire nested NEMO becomes a local MAP domain. The MAP records the binding information for all MRs and MNNs, and provides optimized route from the CN to the MNN in the nested mobile networks

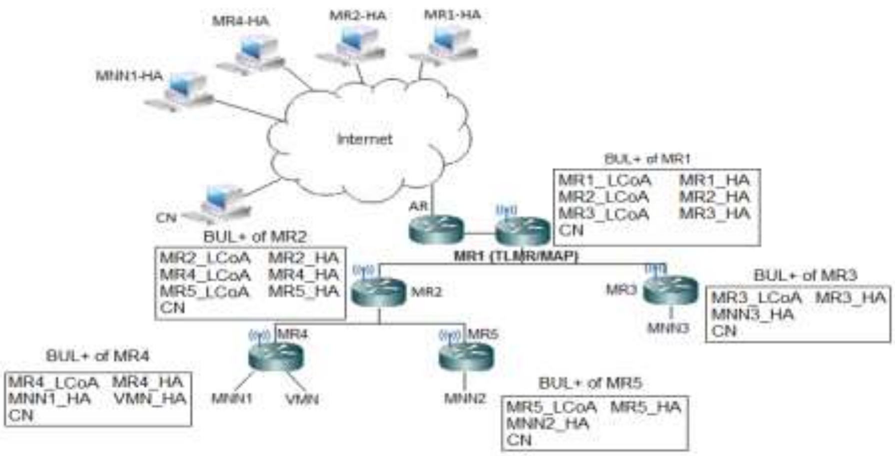

Figure 3. The architecture of HRO-B+ showing BUL+ in MRs

MR in the proposed scheme is assumed to have a BUL that can encapsulate packets and send to any node, beside sending to its HA. However, in the proposed scheme, a novel Advanced Binding Update List (BUL+) is introduced and built in each MRs of the nested NEMO in order to record information about all child MRs/MNNs located under each MRs. This information includes bindings sent to CNs addresses, HAs of MRs, and HAs of MNNs. The following pseudo codes shows how BUL+ is built in each MR of the nested mobile networks:

```
Algorithm begin
empty a stack;
set finished = false;
```

```
search a node in BUL+ with destination address == prefix of NEMO;
if (no node found){
      finished = true;
      use normal routing process;
} else {
push HoA_MR to stack;
while (not finished) {
      push LCoA of node to stack;
      get the LCoA prefix;
      search for a node in BUL+ with prefix == LCoA prefix;
      if (no node found) {
            finished = true;}
}}
C = 1; // C is the counter of MR/MNN number in the mobile network
while (not finished) { //record child details into BUL+ of node (MR)
      if (no node has unvisited child nodes) {
      child = one of the unvisited child nodes;
      get the prefix of child;
      push LCoA of child to stack;
      push HoA of child to stack;
      C = C +1; } // increase the counter by 1
else {
      finished = true; }// node has no unvisited child nodes
} // repeat the loop until all child nodes are recorded
Algorithm end
```

The Binding Update in HRO-B+ is done after a handover operation ends, when every MRs and MNNs get their new CoAs level by level in the nested mobile networks. Because the hierarchical structure has been proposed, MRs and MNNs in the nested NEMO will configure two CoAs: Regional CoA (RCoA) and On-link CoA (LCoA). RCoA is based on the TLMR (MAP)'s network prefix, whereas LCoA is based on its access router's network prefix (access router could be a MR or fixed router) as explained in [12].

After each MR has registered its CoAs, only one local binding update (LBU) will be sent to the MAP to update the nested NEMO topology. This LBU will keep the binding relationship between the LCoA of this MR and the home prefix. To build BUL+, each MRs will record the bindings of each MR/MNN located in its mobile network.

Lastly, each HA of MRs will receive a normal BU from the MAP in order to build an entry in the binding cache of MR's HA with the mapping between MR's HoA (Home Address) and its RCoA.

When the CN sends a packet to the MNN1 (as displayed in Figure 4), the packet will be received first by the HA of the parent MR (MR4 in this case). After that MR4's HA will search its binding cache to find the location of MR4 (the parent MR of MNN1). Knowing that the MR4 is located under the TLMR domain, the packet then will be encapsulated and forwarded to current location (CoA of TLMR).

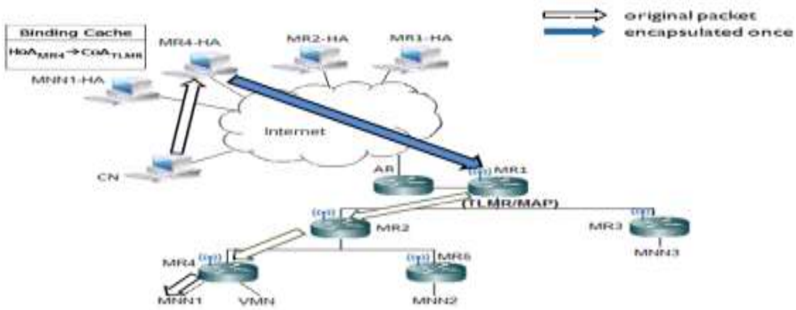

Figure 4. Forward routing path (CN-MNN1) in HRO-B+

When the packet arrives at the TLMR, it will be decapsulated and the TLMR will search its BUL+ to locate the way to the MNN1. By looking in the BUL+, the TLMR discovers that the MNN1 is under MR4, which can be reachable via MR2. Then the packet will be source routing to MR2. When MR4 receives the packet, it forwards the packet to MNN1. Thus, there will be only one level of nested tunnel which is between the parent MR's HA and the TLMR. This route optimization procedure achieves transparent mobility since BU messages are only sent at BU intervals. The following pseudo code described in details the route optimization stage:

```
Algorithm begin
// in forward route optimization, packets are sent from CN to MNN1
empty a stack;
set finished = false;
while (not finished){
search BC of CN for MNN1;
push HA address of parent MR to stack;
add to header of data packet;
send packet to HA of parent MR;
// the packet reach HA of parent MR
HA of parent MR receive a new packet;
search dest_addr of packet in BC; // dest_addr is destination address
which is CoA of MAP
push dest_addr to a stack;
encapsulate the packet;
pop dest_addr in stack to header of encapsulated packet;
send the encapsulated packet to dest_addr;
// the packet reach MAP domain
MAP receive a new packet;
MAP decapsulate the packet;
search BUL+ of MAP for dest_addr;
MAP forward the packet;
set dest_addr = LCoA of MNN1;
while (not finished){ //process at each MR in the nested NEMO till
MNN1
      search a node in BUL+ with prefix of dest_addr == prefix of
NEMO;
      if (no node found){
            use source routing to next MR;}
      else {
            forward packet to dest_addr;}
      }
} // repeat same steps for all packets send from CN to MNN1
Algorithm end
```

In case the mobile network topology changes due to handoff, the proposed scheme is designed to achieve seamless handoff. Because of MR handoff, new terms are defined which are a Handoff Leader MR (HLMR), Parent Mobile Router (PMR) and a Previous Parent MR (PPMR). HLMR is the root MR of the subnet that is going to leave the mobile network, whereas PPMR is the MR to which the HLMR was connected previously before leaving to a new network. There are two handoff types in the nested mobile networks:

1) Intra-NEMO handoff: it is when a layer 2 handoff trigger sends to a mobile subnet in the nested mobile networks from a different MR under its current MAP. When HMRA message received by HLMR of the subnet, HLMR will send one LBU to the MAP. This LBU consists of the home address of the new PMR. After the HLMR configures its new LCoA, all underlying MRs will send LBUs to update BUL+ contents of MAP.
2) Inter-NEMO handoff: similarly, inter-NEMO handoff will be executed if layer 2 handoff trigger received by a mobile subnet from a MR of a new NEMO, i.e. MR is moving outside the old NEMO (step 1 in Figure 5). A new BU message called a handoff BU, proposed by

[8], will be sent to HLMR of the mobile subnet once it recognizes its new connectivity (step 2 in Figure 5). Handoff BU will be used to inform PPMR about the new CoA of the HLMR in order to forward packets in transit to the HLMR. If a CN sends a packet (step 3 in Figure 5) before the HLMR reattach into the new NEMO (CN is unaware of the handoff operation yet), the packet is forwarded using the available binding information in the HA of the parent MR of MNN. However, the packet will reach PPMR (step 4 in Figure 5). Because PPMR has been updated about HLMR current location, the packet will be forwarded to HLMR (step 5 in Figure 5). When HLMR receives the packet, it'll resume sending the packet to the MNN by source routing (step 6 in Figure 5).

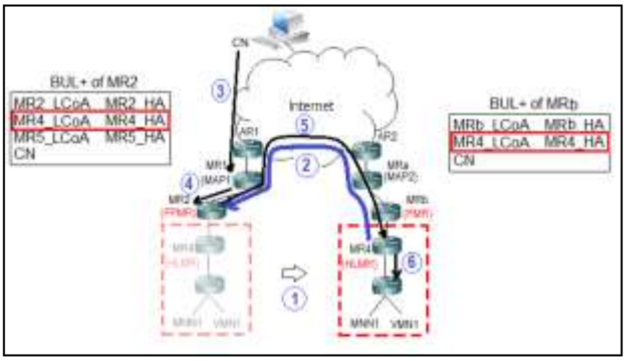

Figure 5. Inter-NEMO handoff

Simultaneously, on the new NEMO, the mobile subnet with HLMR reattaches with TLMR as its new MAP and configures a new CoA. Upon receiving LBU from HLMR, PMR will update its ABC by adding new entries of HLMR. Based on that, sending handoff BU of the HLMR once configuring its new CoA to the PPMR will reduce the packet loss. Moreover, since initializing the BU is performed only by the HLMR, no BU storm will take place.

At the same time, HLMR resumes sending HMRA message to configure the CoAs of all underlying MNNs and MRs. After each MRs (in the subnet of HLMR) gets a new CoA, a LBU will be issued to the new MAP in order to update its BUL+ with liking the MR's HoA to the new MR's CoA. Then the new MAP will send one normal BU message to CN to update binding of all MRs and MNNs under the mobile subnet of HLMR.

5. Performance Evaluation

In this section, the proposed HRO-B+ scheme will be compared with NEMO BS (standard) and ROTIO (benchmark) [8] by means of simulation. The network simulator OPNET Modeler [16] is used to simulate the three schemes and compare their performances. The coverage area of the whole network for all models is 10*10 Kilometers. Other simulation parameters are presented in Table 1.

Table 1. Simulation parameters

Simulator	OPNet 14.0
Coverage area	10*10 kilometers
Simulation time	1200 sec
Data Rate	11Mbps
Mobility model	Random way point
Traffic type	HTTP, Email, FTP, Voice
Traffic source	UDP-CBR

After setting the scenarios and running the simulations successfully, the results can be used to analyze the performance of the three scenarios.

Figure 6 illustrates the average of wireless LAN throughput of the three scenarios. Wireless LAN is used to represent each MRs of nested NEMO. The simulation starts at time 100 second. The graph increases sharply from 100 second to 6 minute, and then it increases slightly till the end of simulation at time 20 minute. The graph shows that NEMO BS, ROTIO, and the proposed scheme have approximately similar throughput. This is due to the fact that all scenarios are having the same number of MRs inside the nested NEMO.

Voice packet end-to-end delay for the three scenarios is presented in Figure 7. The delay is nearly equal, although the proposed scheme is slightly having less delay than the other two: NEMO BS and ROTIO. The delay starts from the beginning of the simulation at 100 second and remains almost around delay value of 0.065 second to the end of simulation at 20 minute.

The Email download response time (sec) which is displayed in Figure 8, defines as the time passed between sending a request in a packet and receiving its reply. The measurement of this time is from a request packet is sent by a client application to the server, to the time a response packet is received.

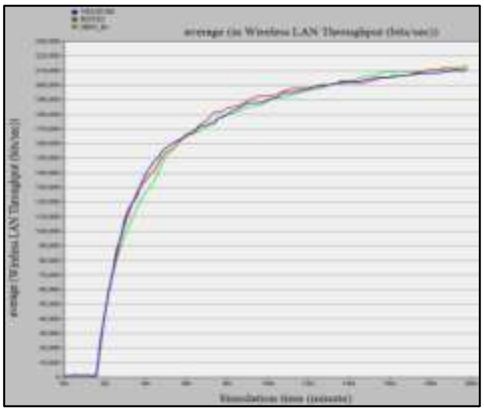

Figure 6. Average wireless LAN throughput

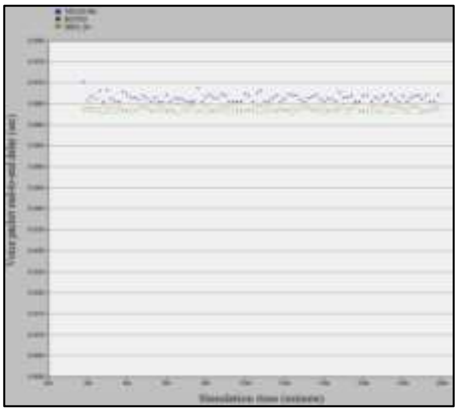

Figure 7. Voice packet end-to-end delay

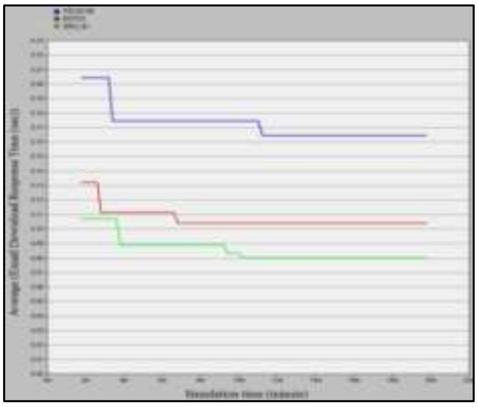

Figure 8. Average Email download response time

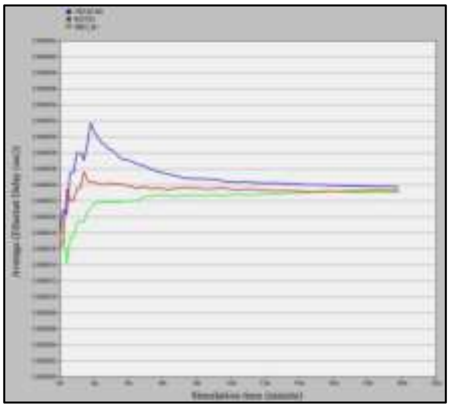

Figure. 9. Average Ethernet delay

As shown in Figure 8, the proposed scheme required less response time than NEMO BS and ROTIO. It can be seen that from 11 minute the average of response time decreases and becomes constant to the end of simulation, while the period before having variable and increased values for the response time. This is because after simulation start there are a lot of control messages being initiated between entities of the network and that increases the load on the network thus increases the response time. Figure 9 shows average Ethernet delay for the three scenarios. It is clear that the proposed scheme has less delay compared to NEMO BS and ROTIO, especially at the beginning of the simulation time where sending control packets is high.

Figure 10. Average TCP delay

Average TCP delay of the proposed scheme, ROTIO, and NEMO BS is illustrated in Figure 10. The proposed scheme performs better than NEMO BS and ROTIO. NEMO BS starts with very high TCP delay which is 0.10 second but it decline sharply to 0.5 second at simulation time 2.5 minute. After that, the TCP delay vibrates around value of 0.6 second to the end of simulation. Less than NEMO BS, ROTIO starts with TCP delay of 0.7 second but after 4 minutes of simulation the value decreases to about 0.4 second. The proposed scheme has the lowest TCP delay. It starts with 0 second at beginning of simulation and increases to 0.5 second then remains at 0.4 second starting from simulation time 4 minute to the end of simulation at time 20 minute. The high value of TCP delay for NEMO BS comes from the fact that NEMO BS has three HAs (in this scenario) compared to ROTIO (two HAs) and the proposed scheme (one HA). However, having more HAs in the network increases the control messages transmitted among these HAs and that would cause more TCP delay.

Lastly, Figure 11 and Figure 12 displayed average HTTP traffic sent and average HTTP traffic received respectively. The proposed scheme has less traffic in both cases than NEMO BS and ROTIO. In Figure 11, HTTP traffic sent increases from 2.4 packets/sec to 3.6 packets/sec approximately during the simulation time. On the other hand, in Figure 12, HTTP traffic received increases from around 2.2 packets/sec to about 3.2 packets/sec during the simulation time. By comparing the two figures, it is clear that traffic received is less than traffic sent. This is due to possible delays and retransmissions.

To compare the results obtained from simulation for NEMO BS, ROTIO, and HRO-B+, Table 2 displays average statistics values of performance metrics used in simulation.

Table. 2. Average statistics values to compare NEMO BS, ROTIO, and the proposed scheme.

Statistics	NEMO BS	ROTIO	HRO-B+
Wireless LAN throughput (bits/sec)	210,020	211,471	213,029
Voice packet end-to-end delay (sec)	0.066410	0.063922	0.063235
Email download Response time (sec)	0.16442	0.10395	0.08005
Ethernet delay (ms)	0.023709	0.023239	0.023111
HTTP traffic received (packets/sec)	3.1075	3.0833	2.8358
HTTP traffic sent (packets/sec)	3.476	3.4567	3.156
TCP delay (sec)	0.06070	0.04215	0.04727

Figure 11. Average HTTP traffic sent

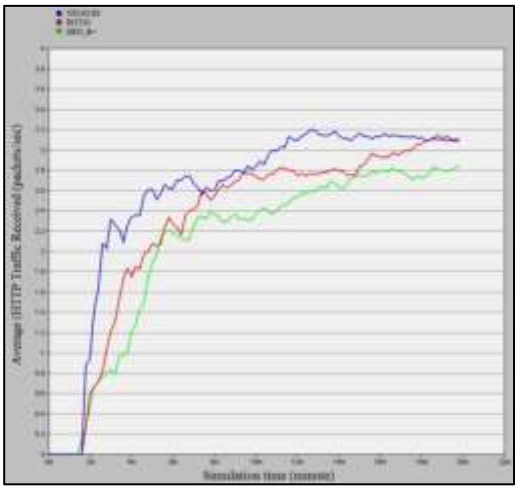

Figure 12. Average HTTP traffic received

6. Result Discussion

The simulation results show that the proposed scheme HRO-B+ has better performance than NEMO BS and ROTIO in terms of throughput, delay, response time, and traffic.

For throughput, the result shows that NEMO BS, ROTIO, and HRO-B+ have almost similar throughput. This is because that all of them are having the same number of MRs inside the nested NEMO. Nevertheless, the proposed scheme has 1.4% better throughput than NEMO BS and 0.7% better than ROTIO.

The voice packet end-to-end delay is approximately equal, although HRO-B+ is slightly having less delay than the other two: 4.8% less than NEMO BS and 1.07% less than ROTIO.

For the Email download response time, HRO-B+ required less response time than NEMO BS (51.3% less) and ROTIO (23% less). This is because after simulation start there are a lot of control messages being initiated between entities of the network and that increases the load on the network thus increases the response time. Hence, the proposed scheme has less number of entities in the network as it has one HA only.

For Ethernet delay, HRO-B+ has less delay compared to NEMO BS and ROTIO, especially at the beginning of the simulation time where sending control packets is high. HRO-B+ has 2.5% delay less than NEMO BS and 0.6% less than ROTIO.

The TCP delay obtained for HRO-B+ is better than NEMO BS and ROTIO. The high value of TCP delay for NEMO BS is because that NEMO BS has three HAs (in the simulation scenario) compared to ROTIO and HRO-B+. As a result, having more HAs in the network increases the control messages transmitted among these HAs and that would cause more TCP delay. However the proposed scheme has TCP delay 22.1% less than NEMO BS and 12% less than ROTIO.

Lastly, HTTP traffic sent and HTTP traffic received in HRO-B+ are less than that in NEMO BS and ROTIO. The proposed scheme has 8.7% HTTP traffic received less than NEMO BS and 8% less than ROTIO. For HTTP traffic sent, HRO-B+ has less than NEMO BS by 9.2% and less than ROTIO by 8.7%. By comparing the two traffics, it is found that the traffic received is less than the traffic sent. This is due to possible delays and retransmissions of packets.

7. Conclusion

For a nested mobile network, inefficiency of the network is getting worse as the degree of nesting increases. This problem is called the pinball routing problem. However, the NEMO BS protocol requires to be enhanced using an appropriate optimized routing scheme. To solve the limitations of NEMO, this paper proposed the HRO-B+ scheme, which uses a hierarchical structure with Advanced Binding Update List (BUL+). HRO-B+ achieves an optimal routing between CN and MNN solving pinball routing problem by building advanced Binding Update List (BUL+) in each MRs in the nested mobile networks. Furthermore, the proposed BUL+ solves the Binding Update storm (signalling storm) through MR who sends one Binding Update message on behalf of its child MRs and MNNs. In addition, intra-NEMO routing (when MNN and CN are located in the same MAP domain) is solved by using the information about the network topology provided in TLMR (MAP). That will achieve Intra-NEMO routing locally, i.e. within the mobile network (MAP domain). The simulation results show that HRO-B+ scheme is more efficient than NEMO BS and ROTIO in terms of throughput, delay, response time, and traffic.

References

[1] Yuan Yang, Xiaonan Wang, Qi Sun, & Dong Wang. A route optimisation scheme for 6LoWPAN nested mobile networks. *International Journal of Mobile Network Design and Innovation*. 2016; 6(3).

[2] Senan, Shayma, Aisha Hassan A Hashim. Hierarchical Route Optimization Scheme Using Advanced Binding Update List (BUL+) for Nested Mobile Networks. *International Journal of Future Generation Communication and Networking*. 2017; 10(2): 55-64.

[3] Devarapalli, V Wakikawa, R Petrescu, A, P Thubert. 2005. NEMO basic support protocol". IETF. RFC3963. Available: http://www.ietf.org/rfc/rfc3963.txt.

[4] Johnson, D Perkins, C , J Arkko. Mobility Support in IPv6". IETF, RFC6274. 2011. Available: http://www.rfc-editor.org/rfc/rfc6275.txt

[5] Ryu, Seonggeun, Kyung-Joon Park, and Ji-Woong Choi Enhanced Fast Handover for Network Mobility in Intelligent Transportation Systems. *IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY*. 2014; 63(1): 357-371.

[6] Kabir, MH, Mukhtaruzzaman, M ,M Atiquzzaman. Efficient route optimization scheme for nested-NEMO. *Journal of Network and Computer Applications*. 2013; 36: 1039–1049.

[7] Yousaf, F, C Wietfeld. Solving pinball routing, race condition and loop formation issues in nested mobile networks. *Computer Networks*. 2012; 56: 1357–1375.

[8] Cho H, Kwon T, Y Choi. Route Optimization Using Tree Information Option for Nested Mobile Networks. *IEEE Journal on Selected Areas in Communications*. 2006; 24(9): 1717- 1724.

[9] Ng, C, J Hirano. Securing nested tunnels optimization with access router option. Internet draft. 2004. Available: http://ietfreport.isoc.org/idref/draft-ng-nemo-access-router-option

[10] Cho H, EK Paik, Y Choi. RBU+: Recursive binding update for end-to-end route optimization in nested mobile networks. Lecture Notes in Computer Science (LNCS). Berlin, Germany: *Springer-Verlag*. Jun. 2004; 3079: 468–478.

[11] Ohnishi H, K Sakitani, Y Takagi. HMIP based route optimization method in a mobile network. Internet draft. 2003. Available: http://ietfreport.isoc.org/idref/draft-ohnishi-nemo-ro-hmip.

[12] Soliman H, Castelluccia C, ElMalki K, L Bellier. Hierarchical Mobile IPv6 (HMIPv6) Mobility Management. IETF, RFC 5380. 2008. Available: http://www.rfc-editor.org/rfc/rfc5380.txt

[13] Wu H, J Lu. *Research on Routing Optimization in Nested NEMO*. in the proceedings of the International Conference on Electronics, Communications and Control (ICECC), China. 2011; 411–415.

[14] Kong R, Feng J, Gao R, H Zhou. A new route optimization scheme for network mobility: combining ORC protocol with RRH and using quota mechanism. *The International Journal of Communications and Networks*. 2012; 14(1): 91–103.

[15] Kabir, MH Mukhtaruzzaman, MM Atiquzzaman. Efficient route optimization scheme for nested-NEMO. *Journal of Network and Computer Applications* 2013; (36): 1039–1049.

[16] OPNET Simulator. OPNET Technologies, Inc. Bethesda MD. USA. Available: http://www.opnet.com/.