Performance Evaluation of Multihomed NEMO

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***Abstract*—Mobile networks can be formed in bus, train, aircrafts, satellites with a wide variety of on-board IP-enabled devices and Network Mobility (NEMO) protocols are required to support uninterrupted services to ongoing sessions. Earlier works have not demonstrated seamless handover for NEMO architecture. In this work, we proposed a handover scheme for NEMO that exploits the multi-homing feature of the Mobile Router and uses make-before-break strategy to ensure seamless handover for NEMO. Using experimental testbed, we have presented a thorough handoff performance evaluation of multihomed NEMO and compared it with basic NEMO. Results demonstrate that the proposed multihomed NEMO outperforms the basic NEMO while achieving seamless handover.**

***Index Terms*—NEMO, experimental evaluation, testbed, multihoming, handoff performance, mobility management.**

I. Introduction

Mobile networks can be formed with IP-enabled devices including laptops, PDAs, or networks of sensors deployed in vehicles, such as, aircrafts, satellites, buses, trains, etc. Internet Engineering Task Force (IETF) has standardized NEtwork MObility Basic Support Protocol (NEMO BSP) [1] to facilitate continuous Internet connectivity of hosts in such a network.

In a mobile network, Mobile Router (MR) acts as the gateway for all its nodes, connects them to the global Internet, forwarding signaling traffic as well as data traffic to the desired remote hosts. Mobile router usually has higher transmission capability and are usually powered by the vehicle. In basic NEMO, the MR uses single interface to connect to the access network. During handover, the MR has to break the connection with the old access network before establishing a connection ('break-before-make') with new access network, resulting in high handover latency and packet loss. Applications that are highly sensitive to delay and packet loss are badly affected due to NEMO protocol operation. Therefore, it is essential to ensure seamless handover of NEMO.

Original NEMO supported only one (primary) care-of-address to be registered with its home agent (or correspondent node). However, multiple physical interfaces in the MR (i.e., multihomed NEMO) can benefit from increased availability, fault tolerance, load balancing, and flow distribution through simultaneous wireless access, thereby reducing the delay and packet loss during handoff. Recently, IETF has proposed extension to NEMO allowing Multiple Care-of-Addresses registration (MCoA) [2] without specifying the way to exploit it for seamless handover. The MCoA registration policy can be used to establish a new connection before breaking the old one, known as *make-before-break* strategy.

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There have been several works related to NEMO with MCoA. Pan et al. [3] proposed a capacity-aware MCoA framework to choose the preferred (highest bandwidth) link, with no experimental validation. Romain [4] demonstrated the fault-tolerance and load-balancing of NEMO MCoA with an experimental testbed although the handover was not seamless. Chen et al. [5] proposed a handover algorithm for NEMO in a heterogeneous environment and analyzed the performance through experimentation. Sazzad et al. [6] compared the performance of NEMO with a transport layer mobility protocol using experimental testbed. Petander et al. [7] measured the handoff performance and routing overheads of multihomed NEMO through experimentation. However, they [6], [7] did not use MCoA registration feature of NEMO. The authors are not aware of any thorough experimental evaluation of NEMO MCoA that exploits the make-before-break strategy. Our work *differs* from the previous works in a way that we have used a cross layer approach to exploit the extension of multihomed NEMO and presented a thorough analysis of experimental results demonstrating seamless handover of NEMO.

Our *objective* of our work is to exploit the multihoming feature of NEMO to achieve seamless handover and to demonstrate it through experimentation. Our proposed scheme is a cross layer approach which senses link layer signal strength in the overlapping area and makes the soft handover decision, thereby reducing delay and packet loss during handoff.

Our *contributions* in this paper are (i) propose the system framework for NEMO MCoA that exploits 'make-before-break' strategy to achieve seamless handover through multihoming, and (ii) evaluating the handover performance of the proposed scheme and comparing it with NEMO through real experimental testbed.

Our experimental results validates that our proposed scheme outperforms basic NEMO in terms of handoff delay, round trip time and throughput– three major performance metrics for any mobility management scheme.

The rest of the paper is organized as follows. In section II, basic NEMO architecture is explained, followed by our proposed scheme in Section III. In Section IV, the experimental setup for basic NEMO and NEMO MCoA are described, followed by the results in Section V. Finally, we conclude the paper in Section VI.

II. NEMO Architecture

Fig. 1 shows the architecture of a Mobile Network (MN) where MR acts as gateway for all the nodes inside the MN, known as Mobile Network Node (MNN). A mobile network can have different types of MNNs: Local Fixed Nodes (LFN), Local Mobile Nodes (LMN) and Visiting Mobile Nodes (VMN). LFNs do not move with respect to MN. All mobile nodes (LMNs and VMNs, MR) are MIPv6 capable. The MR attaches to the Internet through Access Routers (ARs). A mobile network is usually connected to a network called the home network where an MR is registered with a router called the Home Agent (HA). The HA is notified about the location of the MR, and redirects packets sent by the Correspondent Node (CN) to MNNs.

In NEMO BSP [1], the MR ensures connectivity of all hosts inside the MN when the MR changes its point of attachment to the Internet while moving from a home network to a foreign network. MR establishes a bidirectional tunnel with its HA to pass all the traffic between its hosts and the CNs. When MR changes its point of attachment, it acquires a new care-of-address from the visited foreign network. It then sends a Binding Update (BU) to its HA which creates a cache entry (which is the mapping of MRs home address to its care-of-address) and creates a bidirectional tunnel between HA and MR. When a CN sends a packet to a MNN, the packet is routed to the HA which looks at its cache entry and forwards the packet to MR using the bidirectional tunnel. Finally, MR receives the packet, decapsulates, and forwards it to the MNN.

III. Proposed Seamless Handover scheme for NEMO MCoA

Original NEMO basic support protocol allowed only one care-of-address registration per home address of a mobile router. Wireless devices available nowadays have multiple network interfaces that aim at constant connectivity with the Internet through different access technologies, such as, Wi-Fi, GPS, 3G networks. Recently IETF has proposed extension to NEMO allowing MCoA registration [2] of a MR's home address in the HA. However, the IETF RFC 5648 [2] has not specified the way to exploit MCoA feature to ensure seamless handover between wireless access networks.

We propose a cross layer approach that works in combination with MCoA registration policy to ensure seamless handover for multihomed NEMO in which the MR has multiple network interfaces that can acquire IP prefixes from ARs while residing in the overlapping radio coverage area. The MR then sends binding update to the HA to register the acquired CoAs in HA's binding cache (facilitated by IETF's MCoA registration policy [2]). This ensures establishing a new connection before breaking the old one (called *make-before-break strategy*). The new CoA is sent (through BU) to the CN so that traffic is sent through the new AR to avoid packet loss during handover. The MR also scans the link layer signal strength to make decision of handoff to the stronger access network. We name our proposed scheme as *M-NEMO* since it exploits the multihoming feature. The proposed soft handover

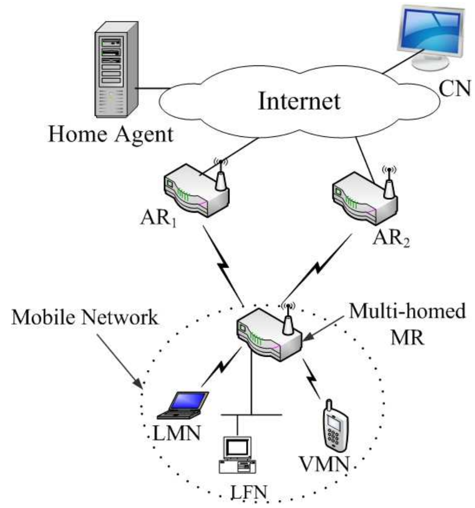

Fig. 1. Architecture of multi-homed NEMO.

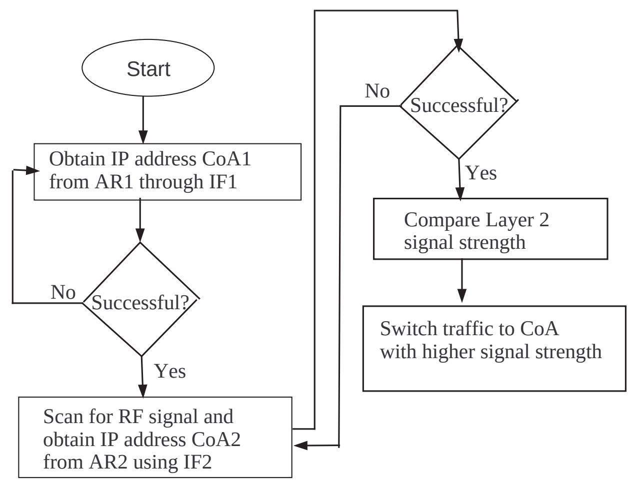

Fig. 2. Soft handover algorithm using M-NEMO.

process of M-NEMO is explained briefly using a flow diagram in Fig. 2. The MR obtains CoAs from ARs through MR's multiple interfaces and compares the link layer signal strength to make decision to handoff to the higher valued signal. This ensures least packet loss and delay during handoff.

IV. Experimental Setup

For performance evaluation of basic NEMO and M-NEMO, we have used linux based experimental testbeds which are described in the following subsections.

A. NEMO Testbed setup

There exists several open source implementation for Basic NEMO, e.g., NEPL [8], SHISHA [9], etc. For our NEMO testbed setup, we used the NEPL implementation since we are using a Linux based testbed for M-NEMO and NEPL is based on Linux platform unlike SHISHA which uses BSD platform. This ensures a fair comparison with M-NEMO testbed.

Fig. 3 shows the experimental testbed for basic NEMO with single level of nesting. Table I summarizes the hardware and

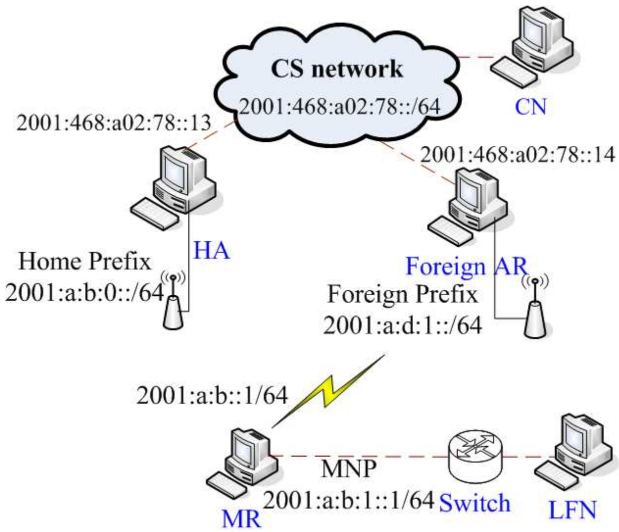

Fig. 3. Testbed Architecture for basic NEMO.

TABLE I
CONFIGURATION OF DEVICES FOR BASIC NEMO TESTBED.

No	Device Type	Software Configuration	Hardware Configuration
1	MR	Debian 2.6.22 Kernel + NEPL	CPU: Intel Pentium 4, 2.20 GHz, 512 MB RAM, NIC: 802.11 based Netgear MA111
2	LFN	FC5 + FTP Client	CPU: Intel Pentium 4, 1.73 GHz, 1 GB RAM
3	HA	Debian 2.6.22 Kernel + NEPL	CPU: Intel Pentium 4, 1.50 GHz, 512 MB RAM
4	AR_1	FC6 2.6.18-1 kernel + radvd-1.0	CPU: Intel P4, 1.50 GHz, 512 MB RAM
5	AR_2	FC6 2.6.18-1 kernel + radvd-1.0	CPU: Intel P4, 1.73 GHz, 512 MB RAM
6	APs	Channel 6 and Channel 11	DLink WBR-1319
7	CN	FC5 + FTP Server	CPU: Intel Celeron, 2.8 GHz, 512 MB RAM

software configurations of the devices used in NEMO testbed. To capture real network phenomena, the testbed is connected to the University of Oklahoma (OU) operational network that carries production traffic.

The testbed architecture of NEMO consists of home network (which advertises the home prefix 2001:a:b:0::/64), foreign network (which advertises the foreign network prefix 2001:a:d:1::/64), CN, MR, and LFN. The access networks (home or foreign) are connected to CS network. The global IPv6 prefix of the CS network is 2001:468:a02:78::/64. All the devices of the mobile network were placed on a trolley that was moved between home and foreign network, and handover data were captured using *wireshark* network protocol analyzer.

B. M-NEMO Testbed Setup

Fig. 4 shows the experimental testbed for M-NEMO and Table II summarizes the hardware and software configuration of the devices used in the testbed. Two access routers, AR_1 and AR_2 advertise two foreign prefixes (2001:a:d:1::/64 and 2001:a:c:1::/64, respectively). The MR is now equipped with two wireless NIC cards that can connect to both the foreign links simultaneously whenever the mobile network is in the radio coverage area of both ARs. In that case, the MCoA registration is done in the HA and we can verify the addresses through *bc* command in the HA as shown in Fig. 5.

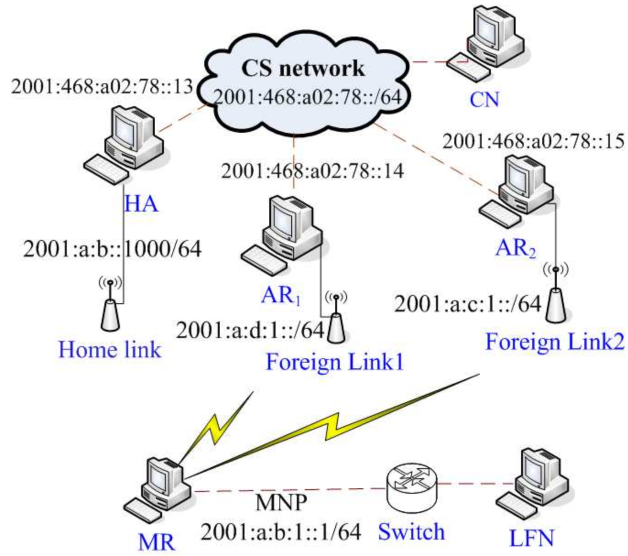

Fig. 4. Testbed Architecture for M-NEMO.

TABLE II
CONFIGURATION OF DEVICES FOR M-NEMO TESTBED.

No	Device Type	Software Configuration	Hardware Configuration
1	MR	Ubuntu 8.04 Kernel 2.6.23 + NEPL	CPU: Intel Core 2 Duo, 2.20 GHz, 2 GB RAM, NIC: 802.11 based two Netgear MA111
2	LFN	Windows XP + FTP Client	CPU: Intel Celeron, 2.19 GHz, 256 MB RAM
3	HA	Ubuntu 8.04 Kernel 2.6.23 + NEPL	CPU: Intel Core 2 Duo, 2.20 GHz, 2 GB RAM
4	AR_1	FC6 2.6.18-1 kernel + radvd-1.0	CPU: Intel P4, 1.50 GHz, 512 MB RAM
5	AR_2	FC6 2.6.18-1 kernel + radvd-1.0	CPU: Intel P4, 1.73 GHz, 512 MB RAM
6	APs	Channel 6 and Channel 11	DLink WBR-1310
7	CN	Windows Vista + FTP Server	CPU: Intel Core 2 Duo, 2.2 GHz, 2 GB RAM

V. RESULTS

The experimental results are presented in this section. We measure the throughput, RTT and handoff latency by analyzing the packet flows through *Wireshark* network protocol analyzer at the CN, MR and LFN.

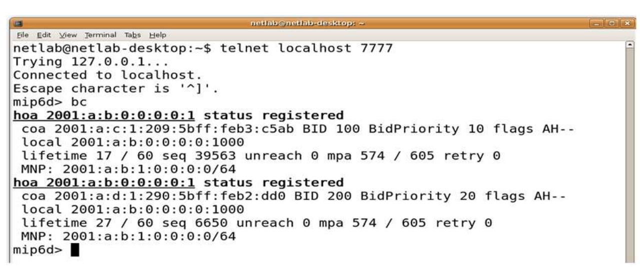

Fig. 5. Binding cache entry in Home Agent for M-NEMO.

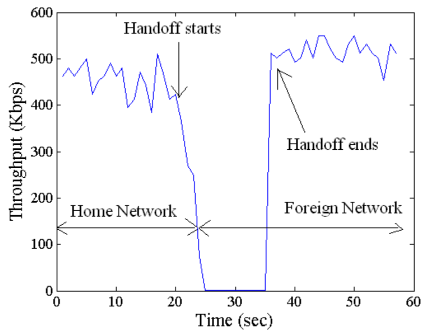

Fig. 6. Throughput at LFN for NEMO BSP.

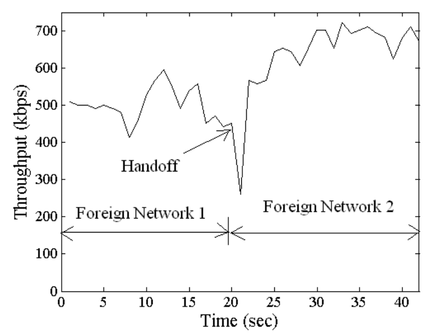

Fig. 7. Throughput at LFN for M-NEMO.

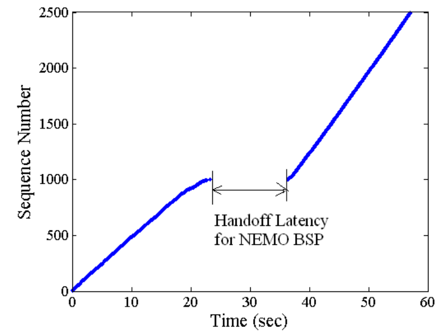

Fig. 8. TCP sequence numbers of data received at LFN in NEMO BSP.

A. Throughput

The rate at which payload data are received at any node is termed as its throughput. In our experiment, LFN receives data traffic from CN. We measure throughput at the LFN by analyzing the wireshark capture data.

Fig. 6 shows the throughput at LFN for NEMO BSP tested during handoff between home network and foreign network. The variations in throughput graph within a network is caused by the network congestion resulting from cross traffic in CS operational network. However, while the mobile network performs handover from the home to foreign network between t = 23 sec and t = 36 sec , the throughput (at LFN) becomes zero for about 13 sec (explained in Section V-B).

Fig. 7 shows the throughput at LFN for M-NEMO testbed. Unlike NEMO BSP, the throughput in M-NEMO does not drop to zero during the handoff period (t = 20.073 sec to t = 20.148 sec). This verifies that M-NEMO throughput is not affected by the handoff since communication can continue through MR's other network interface. Thus, M-NEMO is benefitted by the multihoming feature of MR unlike NEMO BSP.

B. Handover latency

Handover latency is defined as the time interval between the last data segment received through the old access network and the first data segment received through the new access network. In order to measure the handover latency of NEMO BSP, we analyzed the wireshark capture data at the LFN (see Fig. 8). As we moved from the home network to foreign network, the MR acquired CoA from the foreign network, sent binding update to HA (at t = 29.528 sec) and received the binding acknowledgement from HA (at t = 31.135 sec). We also found that the last data segment (with sequence number 999) received by the LFN through the old AP is at t = 23.2397 sec whereas the first data segment (with sequence number 1000) received through the new AP is at t = 36.1593 sec. Therefore, the handover latency is 12.9196 sec (36.1593 - 23.2397).

For M-NEMO, the TCP sequence numbers received at the LFN are plotted in Fig. 9. Initially, the MN was in the AR_1's radio coverage area, so the HA had only one binding entry in its binding cache. Next, we moved towards the AR_2. We found that the MR received the router advertisement from AR_2 at t = 11.5487 sec. This means that the MN entered the radio coverage area of AR_2 and acquired second CoA from AR_2 and notifies HA to register both CoAs. Thus, the make-before-break was achieved by the MR. At t = 20.0735 sec, LFN received the last packet (with sequence number 1021) through AR_1, and at t = 20.1484 sec, the first packet with sequence number 1022) through AR_2 arrived at the LFN. Therefore, the *handover latency for M-NEMO is 75 msec* (20.1484 - 20.0735). As in Fig. 9, there is almost no gap between sequence numbers during M-NEMO handover which verifies that LFN did not face in any disruption in receiving data segment during handoff. This essentially demonstrates the seamless handoff capability of M-NEMO through soft handover by exploiting MR's multihoming facility.

We ran experiments for 10 different trials and the average values of the handoff latencies are 12.96 sec and 75 ms for NEMO and M-NEMO, respectively. Using two-sample right-tail t-test, we found that the t-test rejects the null hypothesis with 5% significance level. The 95% confidence interval on the mean of the differences between NEMO and M-NEMO handoff latencies is at least 12.91 sec. Thus the hypothesis testing verifies that mean handoff latency of M-NEMO is much less than NEMO BSP.

C. Retransmissions during handoff

From our analysis, we found that a large number of packets were retransmitted by the CN due to the large handoff latency (connection disruption). This is shown in Fig. 10 where we find that data segments with sequence number 1000, 1001, and 1002 was retransmitted thrice, twice and twice, respectively. The following segments were retransmitted once. This forces CN to back off, and the timeout value for the TCP sender at CN is increased, thereby producing poor throughput at the LFN during handoff (see Fig. 6. However, this is not the case for M-NEMO testbed. As shown in Fig. 11, we can see that there were fewer number of retransmissions (10) than NEMO BSP testbed (28). Hence, the throughput of M-NEMO did not drop drastically during handoff.

D. Round Trip Time (RTT)

RTT is measured by the difference in time between the CN sending a packet and receiving the corresponding acknowledgement. In case of lost (data or acknowledgement) packets, the RTT takes time difference between successful reception

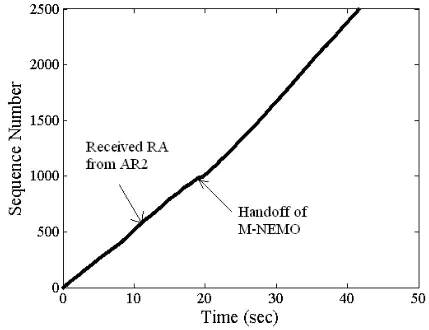

Fig. 9. TCP sequence numbers of data received at LFN in M-NEMO.

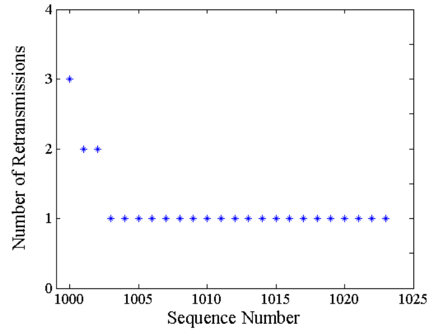

Fig. 10. Number of retransmissions during NEMO BSP handoff.

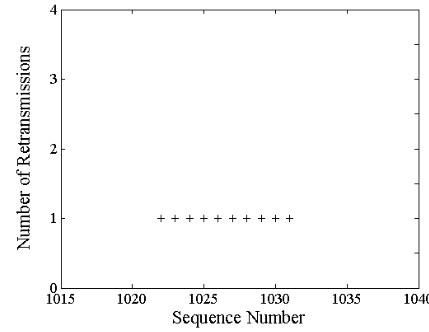

Fig. 11. Number of retransmissions during M-NEMO handoff.

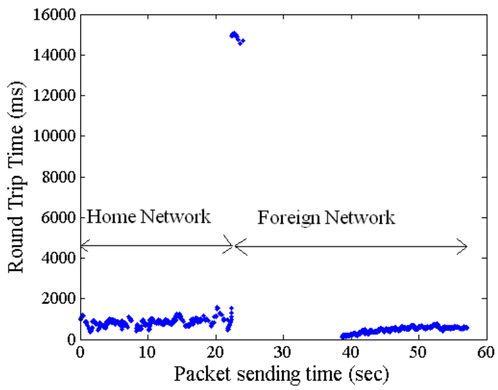

Fig. 12. RTT observed at the CN in NEMO BSP.

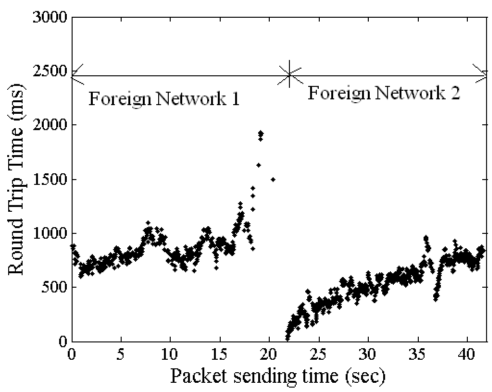

Fig. 13. RTT observed at the CN in M-NEMO.

time of Acknowledgement at CN and first time sent time of the data packet.

Fig. 12 shows the RTT between CN and LFN measured at CN for NEMO BSP. The gap in the RTT graph (between t = 23 sec and t = 36 sec) represents the handoff when the connection was interrupted. This disruption caused retransmission timeout at CN due to lost data or acknowledgement packets. So the CN started to retransmit those packets. Hence, we observe the sudden spike (of around 15 sec) in the RTT graph of NEMO. Packets transmitted during handover period suffer from large RTT which is also explained later in Fig. 10.

Fig. 13 shows the RTT between CN and LFN measured at CN for M-NEMO. The values of the RTT remains fairly stable during the handoff period (t = 20 sec) of M-NEMO. There are few small spikes due to the cross traffic from CS production network. The stability of RTT implies that packet loss during handoff is minimum, thereby confirming M-NEMO handover to be seamless.

VI. Conclusion

In this paper, we have proposed a seamless handover scheme for NEMO exploiting the multihoming feature of the mobile router. We have used experimental testbeds to measure the handoff performance (throughput, round trip time, and handoff latency) of multihomed NEMO and compared it with basic NEMO. Results show that basic NEMO and multihomed NEMO have handover delay of 13 sec and 75 msec, respectively. In addition, the throughput remains unaffected during handoff. Thus, our experimental results validates that our proposed scheme outperforms basic NEMO in terms of handoff delay, round trip time and throughput– three major performance metrics for any mobility management scheme.

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