Performance Comparison between Multihomed Network Mobility Protocols

Md. Shohrab Hossain, Mohammed Atiquzzaman
School of Computer Science, University of Oklahoma
Norman, OK 73019.
Email: {shohrab, atiq}@ou.edu

William Ivancic
NASA Glenn Research Center
Cleveland, OH 44135.
Email: wivancic@grc.nasa.gov

***Abstract*—Network mobility (NEMO) protocols are required to maintain connectivity of ongoing sessions for mobile networks that can be formed in bus, train, aircrafts with a wide variety of on-board IP-enabled devices. However, basic NEMO suffers from large delay and packet loss and fails to ensure seamless handover. Multi-homed network mobility solutions can facilitate seamless handover of mobile networks by making use of multiple network interfaces of NEMO. Previous works have not evaluated and compared the performance of multi-homed network mobility protocols that work in two different layers: network layer and transport layer. In this work, we compare the performance of two multi-homed network mobility protocols that exploits make-before-break strategy to ensure seamless handover for NEMO. Using experimental testbed, we have presented a detailed performance evaluation of these two multihomed NEMO protocols. Results demonstrate that transport layer-based mobility solution performs better than network layer-based protocol when the handing off between heterogeneous-capacity networks.**

***Index Terms*—Mobile networks, mobility management protocol, experimental evaluation, SCTP, multihoming, handoff.**

I. Introduction

With the widespread deployment of WiMAX and LTE technology, next generation networks are gradually converging towards the all-IP network which will enable true global mobility and Internet connectivity to mobile devices. Mobile networks can be formed with IP-enabled devices including laptops, tablets, IP-cameras, sensors deployed in aircrafts, satellites, buses, trains, etc. NEtwork MObility (NEMO) protocol [1] has been standardized by Internet Engineering Task Force (IETF) to facilitate continuous Internet connectivity to hosts in such a network.

Mobile router, the key component in a mobile network, provides Internet connectivity to all the mobile network nodes. Basic NEMO protocol allows MR to connect to the access network through one physical interface which is less reliable. During the handover period, 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. Delay sensitive applications (e.g., voice-over-IP, video-on-demand) are affected badly due to NEMO protocol operation.

With the proliferation of various wireless access technologies, such as 802.11, WiMAX, GPRS, 3G, etc, mobile routers are expected to be equipped with multiple network interfaces that can facilitate increased availability, fault tolerance. This capability of communicating through multiple network interfaces is sometimes termed as *multihoming*. Multi-homed mobile routers can maintain seamless connectivity with multiple wireless access networks, thereby reducing the delay and packet loss during handoff. Therefore, we have proposed two multihoming-based network mobility protocols. One of them works in the network layer and uses IETF's Multiple Care-of-Addresses registration (MCoA) [2] policy that allows multiple care-of-addresses to be registered with its home agent. Other one is Seamless IP diversity based-network mobility protocol (SINEMO), a transport layer-based mobility solution. Though both protocols exploit multi-homing feature, there have been no experimental evaluation to figure out which one performs better during handover.

Several works on multihomed NEMO have been reported in the literature. Romain [3] demonstrated the fault-tolerance and load-balancing of NEMO MCoA with an experimental testbed although the handover was not seamless. Chen et al. [4] proposed a handover algorithm for NEMO in a heterogeneous environment and analyzed the performance through experimentation. Sazzad et al. [5] compared the performance of basic NEMO with SINEMO using experimental testbed. Petander et al. [6] measured the handoff performance and routing overheads of multihomed NEMO using an experimental testbed. However, they [5], [6] did not use MCoA registration feature of NEMO which caused large delay for NEMO. The authors are not aware of any experimental evaluation that compares two multihomed NEMO protocols (working in two different layers) to investigate their performance.

Our work *differs* from the previous works that we have exploited the multi-homing feature of mobile routers in two different layers to ensure seamless handover of NEMO and have built experimental testbed for comparing them in terms of their handoff performance.

Our *objective* of our work is to investigate (through experimentation) the handover performance of multihomed network mobility protocols operating in two different layers to figure out which one performs better and possible reason behind it.

Our *contributions* in this paper are (i) building linux-based experimental testbed for performance comparison of two multi-homed network mobility protocols that exploits 'make-

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before-break' strategy, and (ii) illustrating and analyzing their handover performance in terms of throughput, delay, queue occupancy and retransmissions.

Our experimental results demonstrate that even though both multihomed network mobility protocols ensure seamless handover in homogeneous environment, transport layer-based mobility protocol performs better than network layer-based protocol when the handing off between heterogeneous-capacity networks.

The rest of the paper is organized as follows. In section II, multi-homed NEMO architecture is explained, followed by SINEMO architecture in Section III. Section IV describes the experimental setup for multihomed NEMO and SINEMO, In Section V, the experimental results are presented. Finally, we conclude the paper in Section VI.

II. Multi-homed NEMO Architecture

Fig. 1 shows the architecture of a Mobile Network (MN) where Mobile Router (MR) acts as a 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 get attached to the Internet through Access Routers (ARs).

Each mobile network has a home network where the Home Agent (HA) keeps location information of the MR. The HA is notified about the location of the MR, and redirects packets sent by the Correspondent Node (CN) to MNNs.

Original NEMO basic support protocol allowed only one care-of-address registration per home address of the MR. 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, IETF RFC [2] has not specified the way to exploit MCoA feature to ensure seamless handover between wireless access networks.

We propose a network mobility scheme that exploits MCoA registration policy to ensure seamless handover for multi-homed NEMO. The MR uses multiple network interfaces to 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 this scheme as *M-NEMO* since it exploits the multihoming feature.

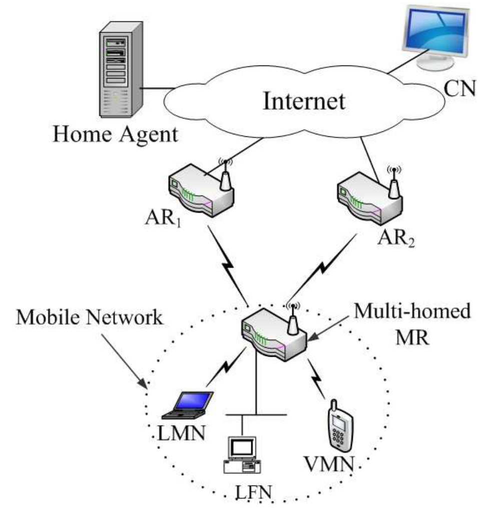

Fig. 1. Architecture of multi-homed NEMO.

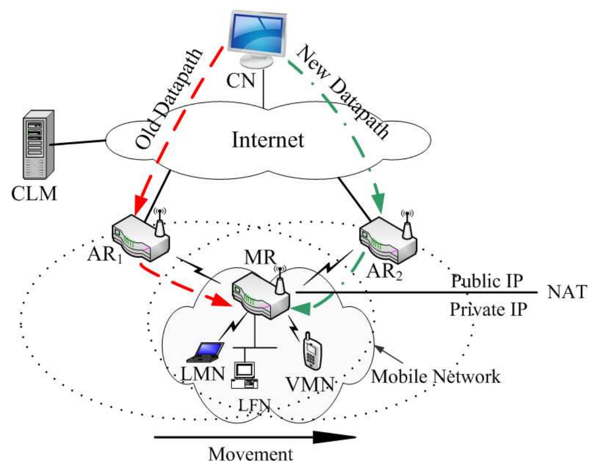

Fig. 2. Architecture of SINEMO.

III. SINEMO Architecture

Fig. 2 shows the architecture of SINEMO [7] which is a transport layer-based mobility solution for mobile network. SINEMO is based on Stream Control Transport Protocol (SCTP) which supports multi-homing in an association. SINEMO also exploits the multi-homing feature of MR, enabling MR to be connected simultaneously to two wireless access networks. A Central Location Manager (CLM) keeps the location information of the MR. The MR acts as a Local Location Manager (LLM) by keeping the IP addresses of the hosts inside the MN. Upon arrival in a new subnet, MR acquires its own public IP address and one or more IP address prefixes for serving the MNNs. MR reserves a public IP address for each MNN which only uses private addresses for connectivity. After handover, only public IP addresses are modified at MR, the private addresses of the MNNs remain unchanged. MR thus hides mobility from the MNNs. The readers can refer to [7] for more details of SINEMO handover and location management.

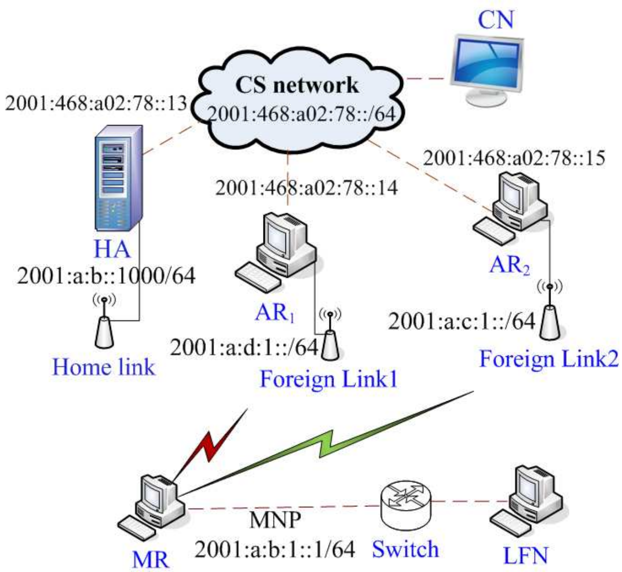

Fig. 3. Experimental testbed for M-NEMO.

IV. Experimental Setup

For the performance evaluation of M-NEMO and SINEMO, we have used linux-based experimental testbeds. The testbed setup along with hardware and software configurations for M-NEMO and SINEMO are described in the following subsections.

A. M-NEMO Testbed Setup

Fig. 3 shows the experimental testbed for M-NEMO with single level of nesting. Table I summarizes the hardware and software configuration of the devices used in the M-NEMO testbed. The experimental testbed of M-NEMO (Fig. 3) consists of a home network (which advertises the home prefix 2001:a:b:0::/64), and two access routers, AR_1 and AR_2 that advertises two foreign prefixes (2001:a:d:1::/64 and 2001:a:c:1::/64, respectively), CN, MR and LFN.

To capture the real network phenomena, the access networks (home or foreign) and the CN are connected to the University of Oklahoma's Computer Science (CS) operational network that carries production traffic. 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 the home and foreign network, and handover data were captured using *wireshark* network protocol analyzer. The MR is 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 the ARs.

B. SINEMO Testbed setup

SINEMO experimental testbed is shown in Fig. 4. Table II summarizes the hardware and software configurations of the devices used in the SINEMO testbed.

SINEMO does not have any concept of the home network. The testbed architecture for SINEMO has of two

TABLE I
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

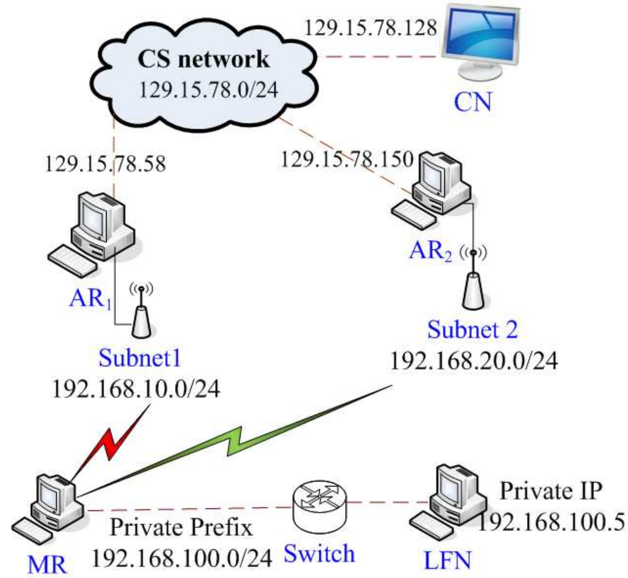

Fig. 4. Experimental testbed for SINEMO.

subnets: subnet 1 and subnet 2, and they advertise the prefix 192.168.10.0/24 and 192.168.20.0/24 [1], respectively. The MR acquires public IP address and prefixes from these two subnets depending on its physical location. However, the MR only provides private addresses (192.168.100.0/24) for its LFN as shown in Fig. 4. Thus, the MR performs address translation for the LFN to delivery its packets.

V. Results

In this section, we present our experimental results. To measure the handover performance of the two protocols, we have conducted experiments considering two scenarios: i) handover between homogeneous-capacity networks, and ii) handover between heterogeneous-capacity networks. For homogeneous scenario, we have conducted the experiment using access networks having similar capacity whereas for

[1]It may be noted that 192.168.0.0/16 is reserved as private IP address by IANA. However, we have used two such prefixes for subnet 1 and subnet 2 assuming them to be public IP prefix for our experimental purpose only.

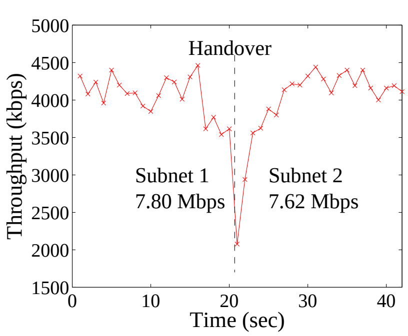

Fig. 5. Throughput at LFN for M-NEMO handover between homogeneous capacity networks.

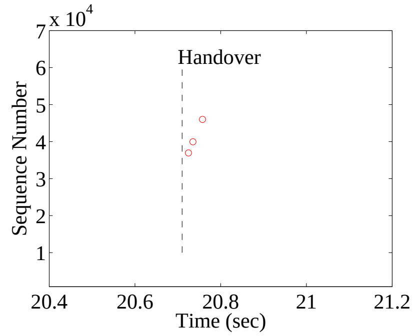

Fig. 6. Retransmissions at CN during M-NEMO handover between homogeneous capacity networks.

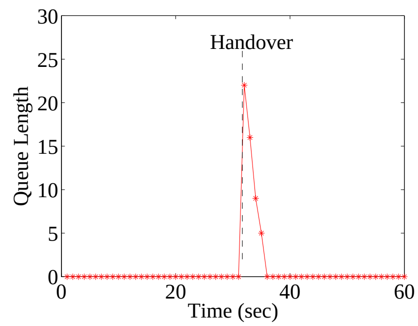

Fig. 7. Queue length at AR_2 during M-NEMO handover between homogeneous capacity networks.

TABLE II
CONFIGURATION OF DEVICES FOR SINEMO TESTBED.

No	Device Type	Software Configuration	Hardware Configuration
1	MR	FC5 + iptables	CPU: Intel Pentium 4, 2.20 GHz, 512 MB RAM, NIC: 802.11 based Netgear MA111
2	LFN	FC5 + lksctp-tools 1.0.6	CPU: Intel Pentium 4, 1.73 GHz, 1 GB RAM
3	AR_1	FC6 2.6.18-1 kernel + radvd-1.0	CPU: Intel P4, 1.50 GHz, 512 MB RAM
4	AR_2	FC6 2.6.18-1 kernel + radvd-1.0	CPU: Intel P4, 1.73 GHz, 512 MB RAM
5	APs	Channel 6 and Channel 11	DLink WBR-1319
6	CN	FC5 + lksctp-tools 1.0.6	CPU: Intel Celeron, 2.8 GHz, 512 MB RAM

the second scenario, we have chosen to handoff from high capacity to low capacity network to find out the impact of handover on the network components, such as, AR, CN and LFN. For all the experimental run, CN acts as the data source sending packets of size 1500 bytes to the LFN which acts as the data sink. The mobile network is moved from subnet 1 to subnet 2 to measure handoff performance.

A. Handover between homogeneous capacity-networks

To measure the downlink bandwidth of the ARs, we used *iperf* network performance measurement tool. For the M-NEMO testbed, the subnet 1's capacity was 7.80 Mbits/sec and subnet 2 capacity was 7.62 Mbits/sec whereas for the SINEMO testbed, subnet 1 and subnet 2's capacities were 7.75 Mbits/sec and 7.50 Mbits/sec, respectively.

1) Performance of M-NEMO: To measure the performance of M-NEMO handover in homogeneous scenario, we measured throughput at the LFN as shown in Fig. 5. Throughput is the rate at which payload data are received at a node. We analyzed the *wireshark* capture data to measure LFN's throughput.

The variations in the throughput graph within an access network are caused by the data congestion resulting from cross traffic in CS operational network. The throughput in M-NEMO does not drop to zero during the handoff period (from t = 20.692 sec to t = 20.769 sec) which is 79 ms. This is because the MR gets connected to both the ARs using its two network interfaces. Hence, when the mobile network moves away from previous AR (i.e., AR_1), it can still send data traffic through the new AR (i.e., AR_2).

Fig. 6 shows the number of data packets (only three) retransmitted by the CN and Fig. 7 shows the queue build up in the AR_2 during M-NEMO handover between homogeneous networks. As we can see that there is not many packets queued in the AR_2 buffer during the M-NEMO handover. This verifies that M-NEMO handover is not affected much by the handoff between homogeneous networks. Since there is very small difference between the capacity of the networks, the TCP source (CN) does not have to adapt with the bandwidth of the new access network, resulting in a smooth handover.

2) Performance of SINEMO: Fig. 8 shows the throughput at LFN for SINEMO tested during handover between AR_1 and AR_2. Similar to M-NEMO result, the throughput in SINEMO does not drop to zero during the handoff period (from t = 16.692 sec to t = 16.738 sec) which is 46 ms. Since SINEMO also exploits make-before-break strategy, there is no impact on the SCTP source (CN) due to the SINEMO handover between homogeneous networks and it can be verified from Fig. 9 which shows no segment is retransmitted at CN during this handover. The queue length at the AR_2 is also quite small (see Fig. 10). So the concurrent users in the new access network is not affected much by the SINEMO handover for homogeneous scenario.

B. Handover between heterogeneous capacity-networks

Next, we use different capacity access networks to investigate how M-NEMO and SINEMO performs in the heterogeneous scenario. To set up such scenario in our experimental testbed, we used Linux *tc* command to downgrade the bandwidth of AR_2 subnetwork.

1) Performance of M-NEMO: Fig. 11 shows the throughput at LFN for M-NEMO when the mobile network moves from the high capacity network (7.80 Mbps) to the low capacity network (720 Kbps). Though the handoff shown in Fig. 11 seems to be smooth, there are issues that affect the overall performance of the access network and other network users.

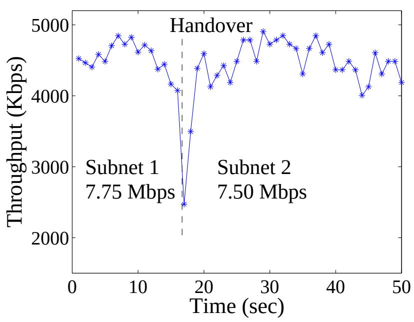

Fig. 8. Throughput at LFN for SINEMO handover between homogeneous capacity networks.

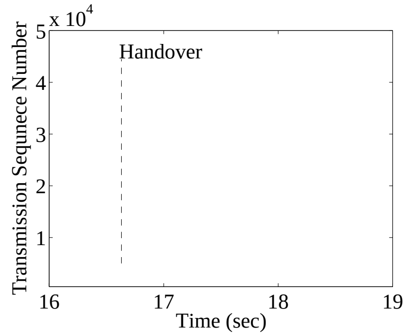

Fig. 9. Retransmissions at CN during SINEMO handover between homogeneous capacity networks.

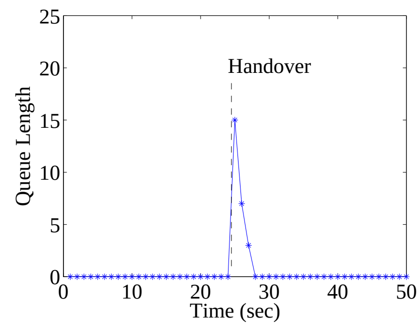

Fig. 10. Queue length at AR_2 during SINEMO handover between homogeneous capacity networks.

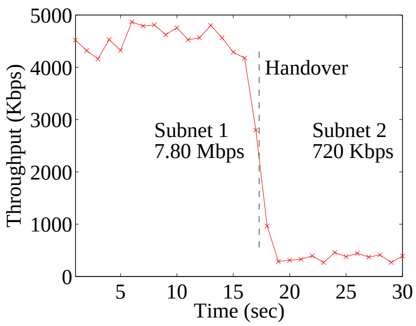

Fig. 11. Throughput at LFN during M-NEMO handover between heterogeneous capacity networks.

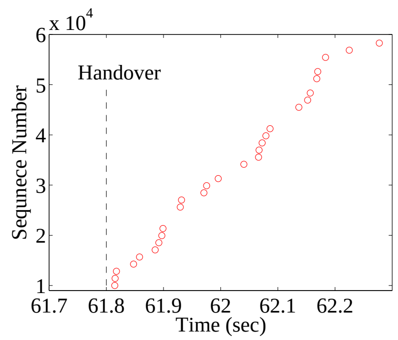

Fig. 12. Retransmissions at CN during M-NEMO handover between heterogeneous capacity networks.

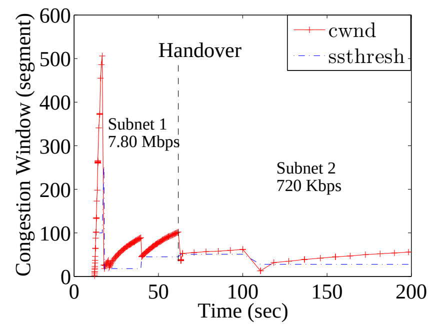

Fig. 13. Congestion window for TCP RENO data source at CN during M-NEMO handover between heterogeneous capacity networks.

Let us first analyze CN during M-NEMO handover. From Fig. 12, we find that CN retransmits 35 data packets (which is quite high) during M-NEMO handover period that is triggered at t = 61.8 sec. During high-to-low capacity handover, packets are dropped at LFN or they arrive out-of-order. Sometimes, duplicate packets arrive at LFN. As a result, the LFN notifies CN about this using duplicate ACKs which triggers such retransmission by the CN to recover from this problem. CN actually uses fast retransmit algorithm which decreases the congestion window (cwnd) size and slow start threshold (*ssthresold*) shown in Fig. 13.

It can be noted that a network layer-based protocol like M-NEMO cannot sense low-capacity of AR_2 during the handover. Therefore, it attempts to send traffic according to current cwnd which is invalid for the new access network (AR_2). This injection of large traffic by the CN increases the queue length of the AR_2 which is shown in Fig. 14 just after the handover. Such overloading of the access router will definitely affect the performance of other concurrent users who share this AR_2 during this handover period.

2) Performance of SINEMO: To measure the handover performance of SINEMO protocol, we performed similar experiment (high-to-low-capacity handover). Throughput at LFN for SINEMO is shown in Fig. 15 for similar high capacity (7.75 Mbps) to low capacity (708 kbps) network. The throughput reduces when the mobile network performs

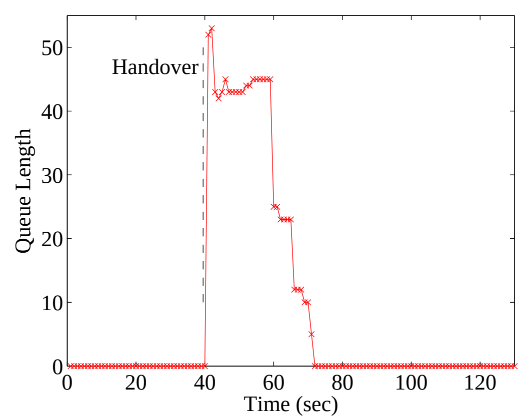

Fig. 14. Queue length at AR_2 during M-NEMO handover between heterogeneous capacity networks.

the handoff and remains stable after handoff.

To further analyze the SINEMO handover performance, let us analyze the number of segments retransmitted by the CN. In Fig. 16, we find that there was no retransmissions at all during the handover period, which implies that there was no packet loss, duplication during this period. This is because the CN (which is a SCTP source in SINEMO testbed) adjusts its data transmission rate by sensing the link capacity of the new access network, thereby adapting with the situation. The

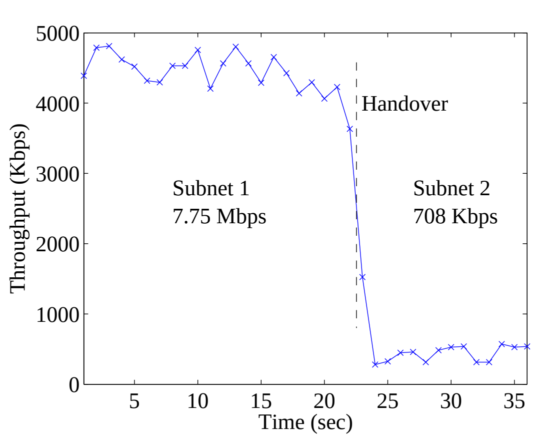

Fig. 15. Throughput at LFN during SINEMO handover between heterogeneous capacity networks.

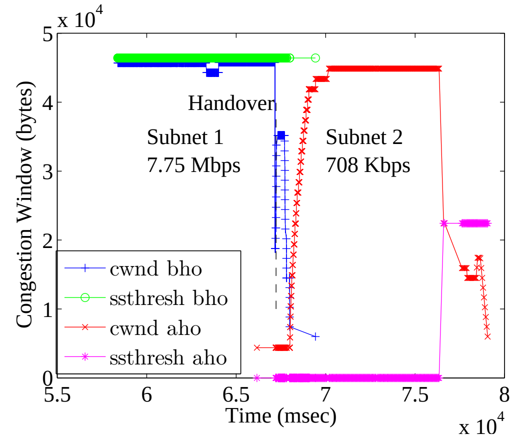

Fig. 17. Congestion window for SCTP data source at CN during SINEMO handover between heterogeneous capacity networks.

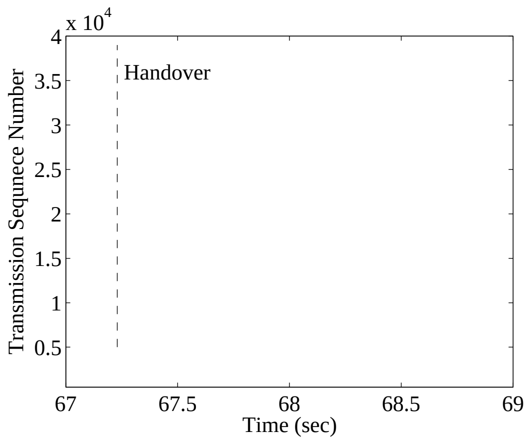

Fig. 16. Retransmissions at CN for SINEMO handover between heterogeneous capacity networks.

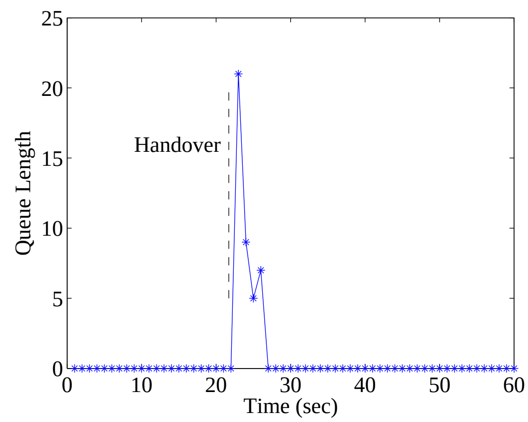

Fig. 18. Queue length at AR_2 for SINEMO handover between heterogeneous capacity networks.

congestion window for SINEMO is shown in Fig. 17 which have two sets of cwnd and ssthresh marked as *bho* and *aho*, meaning before handover and after handover, respectively.

Finally, Fig. 18 shows the queue length of the AR_2 during SINEMO handover and it is much smaller compared to N-NEMO handover scenario. This reduced queue length of the AR_2 will prevent performance penalty resulting from SINEMO handover unlike M-NEMO.

VI. Conclusion

In this paper, we have proposed a seamless handover scheme for NEMO exploiting the multihoming feature of the mobile router. We have built experimental testbeds to measure the handoff performance of multihomed NEMO and SINEMO, a transport layer-based mobility protocol. Results demonstrate that transport layer-based mobility solution performs better than network layer-based protocol when the handing off between heterogeneous-capacity networks. This is because SINEMO adjusts its data transmission rate by sensing the link capacity of the new access network, thereby adapting with the situation unlike multihomed NEMO.

References

[1] V. Devarapalli, R. Wakikawa, A. Petrescu, and P. Thubert, "NEtwork MObility (NEMO) basic support protocol," RFC 3963, Jan 2005.

[2] R. Wakikawa, V. Devarapalli, G. Tsirtsis, T. Ernst, and K. Nagami, "Multiple care-of addresses registration," IETF RFC 5648, Oct 2009.

[3] R. Kuntz, "Deploying reliable IPv6 temporary networks thanks to NEMO basic support and multiple care-of addresses registration," in *International Symposium on Applications and the Internet Workshops*, Hiroshima, Japan, Jan 15-19, 2007, pp. 19–27.

[4] X. Chen, H. Zhang, Y.-C. Chang, and H.-C. Chao, "Experimentation and performance analysis of multi-interfaced mobile router scheme," *Simulation Modelling Practice and Theory*, vol. 18, no. 4, pp. 407–415, Apr 2010.

[5] M. S. Rahman, O. Bouidel, M. Atiquzzaman, and W. Ivancic, "Performance Comparison between NEMO BSP and SINEMO," in *IEEE GLOBECOM*, New Orleans, LA, Nov 30- Dec 4 2008.

[6] H. Petander, E. Perera, K.-C. Lan, and A. Seneviratne, "Measuring and improving the performance of network mobility management in IPv6 networks," *IEEE Journal on Selected Areas in Communications*, vol. 24, no. 9, pp. 1671–1681, Sep 2006.

[7] P. Chowdhury, M. Atiquzzaman, and W. Ivancic, "SINEMO: An IP-diversity based approach for network mobility in space," in *Second IEEE International Conference on Space Mission Challenges for Information Technology (SMC-IT)*, Pasadena, CA, Jul 17-21, 2006.