Mobile Router Technology Development

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ABSTRACT

Cisco Systems and NASA have been performing joint research on mobile routing technology under a NASA Space Act Agreement. Cisco developed mobile router technology and provided that technology to NASA for applications to aeronautic and space-based missions. NASA has performed stringent performance testing of the mobile router, including of the interaction of routing and transport level protocols. This paper describes mobile routing, the mobile router, and some key configuration parameters. In addition, the paper describes the mobile routing test network and test results documenting the performance of transport protocols in dynamic routing environments.

1. Introduction

Cisco Systems and NASA Glenn Research Center have been performing joint networking research under a NASA Space Act Agreement to apply Internet technologies and protocols to aeronautic and space-based communications. Cisco Systems developed the mobile router (MR) during this time and provided the technology for both the commercial and government markets. The technology was given to NASA for evaluation of its applicability to NASA's aeronautic and space-based networks. By performing joint testing of the mobile router, NASA was able to provide input about applications and requirements. Cisco was then able to modify the code where appropriate to address those needs and requirements. This paper will describe mobile routing, the mobile router, the test network, and the performance of transport protocols in dynamic routing environments.

2. MOBILE IP OVERVIEW

Mobile IP [1] is a routing protocol that allows hosts (and networks) to seamlessly "roam" among various IP subnetworks. This is essential in many wireless networks. In a wired network, mobile IP can be used where the mobile node simply wishes to maintain its network identity, since the mobile node is always contacted through association of its home IP address.

There are three basic elements in the mobile IP: the home agent, the foreign agent, and the mobile node. The Home-agent (HA) is a router on a mobile node's home network that tunnels datagrams for delivery to the mobile node when it is away from home. The Foreign-agent (FA) is a router on a remote network that provides routing services to a registered mobile node. The Mobile-node (MN) is a host or router that changes its point of attachment from one network or subnetwork to another. [1]

3. MOBILE ROUTER OVERVIEW

The mobile router is software code that resides in a network router. It is part of the mobile IP standards specification. A mobile router allows entire network(s) to roam. Hence, a device connected to the mobile router does not need to be a mobile node because the mobile router is providing the roaming capabilities.

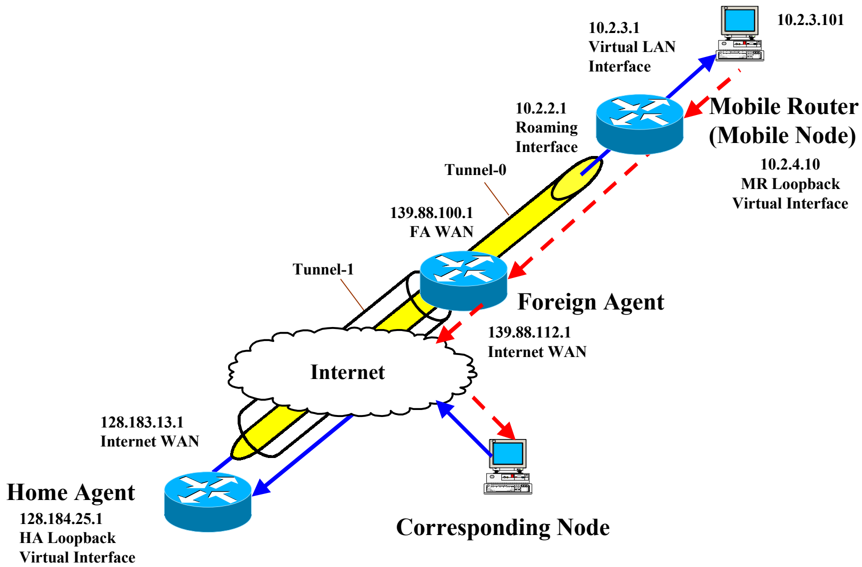

Figure 1. Mobile Router Tunneling

Cisco Systems has recently implemented mobile router code. NASA Glenn and Cisco, through a Space Act Agreement, have been performing joint research and validation tests on this code, which became part of the Cisco Systems Internetworking Operating System (IOS) in the second half of 2001. The mobile router is currently being deployed for a static network, which only supports stub routers. Future implementations will support dynamic networks.

Mobile router code allows a router to be a mobile node. The difference between a mobile host and a mobile router is that once the mobile router has registered with the home agent, the home agent will inject the mobile router's networks into the home agent's routing table and redistribute these routes. This implementation is fully compliant to the RFC 2002 standard. No alteration to the specification is necessary to achieve this static networking.

Figure 1 depicts mobile IP operation when the mobile node is a network. The operation is nearly identical to that of a mobile IP for a single host. The exceptions are that two tunnels are established: one between the home agent and foreign agent (Tunnel1), and one between the home agent and mobile router (Tunnel0). The home agent will perform two encapsulations of any packet destined for the mobile router and forward all packets for the mobile network to the foreign agent. The foreign agent will perform one de-encapsulation and pass the packets to the mobile router. The mobile router performs the second de-encapsulation and forwards the packets to the devices on its networks. As the mobile router moves, it will register its whereabouts with its home agent via various foreign agents. Thus, a mobile router is a mobile node; however, the node is a network rather than a single host.

The mobile router has a number of features that make it applicable to a variety of networks and applications.

The mobile router can have multiple roaming interfaces. This allows for connection to a variety of different wired and wireless links.

The mobile router can perform smooth handoffs, preferred path routing, and priority routing.

The home agent can be configured for hot-standby. This is extremely important. If the home agent were to experience a catastrophic failure, all routes would be lost. Hot-standby was demonstrated by pulling the power plug on the active home agent and noting restoration time. Restoration was nearly instantaneous.

The mobile routing protocols perform well in long delay environments. Testing of the mobile router capabilities over links with round trip time delays in excess of 3 sec was performed. This delay is far greater than a double geostationary satellite hop.

As of April 2001, Internet protocol security (IPSec)[1] between the foreign agent and mobile router, multicasting, and unidirectional link routing (UDLR)[2] were still being addressed. Currently, security between the mobile router and home agent is performed using the 128-bit message digest algorithm (MD5). Security can also be implemented between the foreign agent and home agent via IPSec and/or by the establishment of access lists in the home agent.

4. MOBILE ROUTER OPERATIONS

4.1 Agent Discovery

Agent discovery is a key function of mobile routing, both for mobile hosts and mobile routers. For many network architectures that utilize mobile routers, optimal configuration of agent

[1] The IPSec protocol provides secure, interoperable communication across a network, transparent to the application.

[2] UDLR is a mechanism to emulate bi-directional connectivity between nodes that are directly connected by a unidirectional link.

discovery and advertisement could result in improved system performance or lower communication costs. Therefore, agent discovery will be discussed in detail here. Issues include

- Speed of FA discovery (initial registration)
- Who pays for the Wide-Area Network (WAN) RF bandwidth
- Cost of RF bandwidth

System performance and communication cost optimization is performed by adjustment of various timers in the MR and FA, as well as by enabling or disabling foreign agent advertisements and mobile router solicitations. Having the MR periodically solicitate or decreasing the interval between the FA advertisments will speed up FA discovery at the expense of increased bandwidth utilization. This may not be desirable for expensive or bandwidth-limited wireless connections. Thus, great care should be utilized when configuring the mobile network.

An MR discovers an FA by receiving agent advertisements on its interfaces configured for roaming. Agent solicitation may also be configured on an MR interface that does not expect periodic agent advertisements from FAs.

An MR will send out agent solicitations to find FAs

- If the interface is configured for roaming;
- If the MR's roaming interface comes up;
- If there is a retransmission after no advertisement is heard;
- Before advertisement expiration.

A table of available FAs and their associated Care-of-Addresses (COAs) are derived from agent advertisements heard on the MR's roaming interfaces. The MR then registers with the HA though one of the FAs listed in this table. The FA that the MR selects is known as the active FA, and the MR's connection to the active FA is known as the preferred path.

The selection of the active FA and preferred path is based on the MR's roaming interfaces. If more than one interface receives agent advertisements, the one with the higher roaming priority value is selected as active. If multiple interfaces have the same priority, the highest bandwidth is active. If interfaces have the same bandwidth, the highest IP address is active. The MR will then send a registration request bound for the HA to the active FA via the preferred path.

A learned FA entry is removed from the table when

- An unsolicited interface's advertisement ages out;
- Solicitation retransmissions max out;
- Roaming on the interface is deconfigured;
- Registration via an active FA to the HA ages out;
- Unrecoverable registration denials are received from HA;
- The mobile router is disabled;
- The interface where the FA was learned goes down;
- The user manually clears FA via the command line interface.

There are a variety of timers available to optimize network performance. There are three timers in the mobile router: agent solicitation, agent advertisement, and registration. The agent solicitation timer is for periodic transmission of solicitations generated by the MR. The agent advertisement timer is for aging out received advertisements from an FA. Both the agent solicitation and agent advertisement timers are used as watchdog timers for the MR's agent discovery of an FA. The registration timer is for periodic transmission of registration requests to the HA and is used as a watchdog timer for the registration between the HA and the MR. There are timers within the foreign agent to control the foreign agent advertisments. These timers are associated with the ICMP router discovery protocol (IRDP) configuration and include the minimum and maximum advertisement intervals and the holdtime, the time for which advertisements are valid. One timer is available on the home agent to globally control the maximum valid registration lifetimes of mobile hosts. This timer may also be configured in the FA and MR, but the lifetime of the registration will be set to the lesser of the 3 time settings.

4.2 Registration

After determining the preferred path, the MR will send a registration request to the home agent. Since the MR is attached to a foreign network, the registration request is sent first to the active FA, which then forwards the request to the home agent. Registration requests are only sent out to an active FA. The following events will trigger a registration request:

- If an FA advertisement is received from the MR and
- Movement from one FA to another has been detected;
- An FA reboot has been detected;
- The MR is currently isolated;
- An advertisment has been received from another FA that is connecting via a better interface (preferred path);
- If an active FA advertisement (IRDP lifetime) expires, and the MR chooses another learned FA to reregister through;
- If a registration timer expires due to retransmission or lifetime aging;
- If the hold down period on the FA expires;
- If the interface connected to the active FA goes down, and there are other FAs;
- If the MR configuration changes;
- If the MR has to recover from HA denial due to mismatched ID;
- If the MR has to recover from FA denial due to lower lifetime.

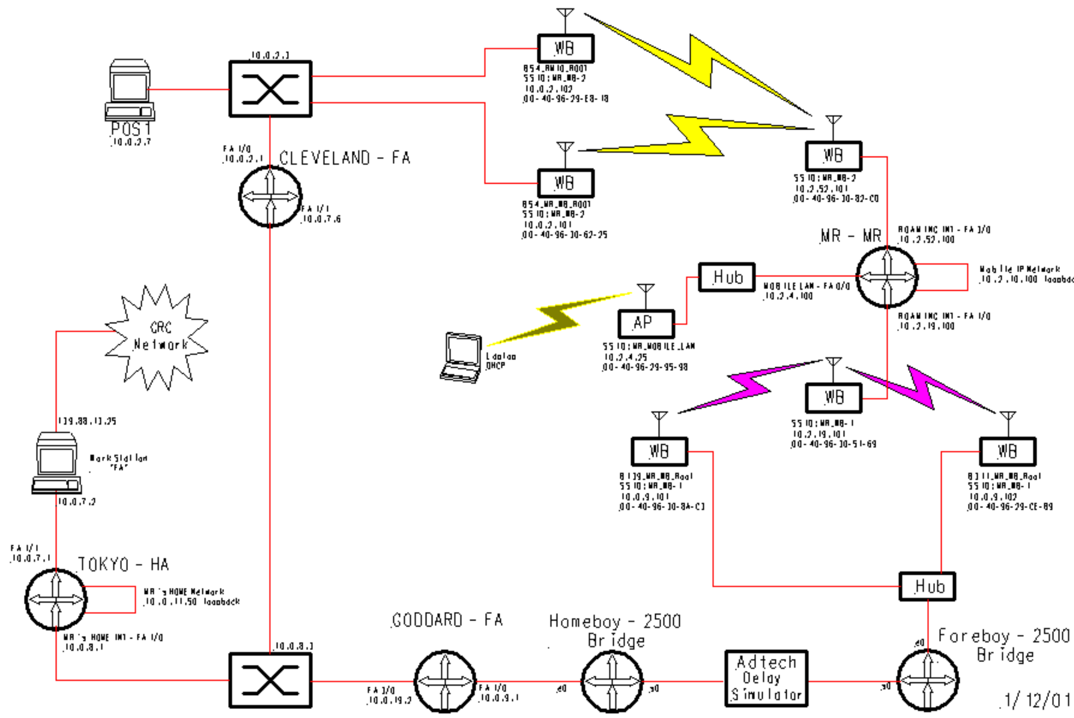

Figure 2. Mobile Router Test Network Configuration

5. TEST NETWORK

In order to test the mobile router in a relevant environment, a wired and wireless mobile testbed was developed at NASA Glenn. Figure 2 depicts the network configuration of that testbed. We have four mobile IP enabled routers: one home agent, two foreign agents, and one mobile router. Two additional routers, “homeboy” and “foreboy,” reside between the foreign agent and the wireless access point. These two routers are configured as bridges and are there simply to provide a serial interface for a satellite channel emulator. A linux workstation is connected to the home agent and performs network address translator (NAT) functions in order to allow routing from the 10.x.x.x network to the NASA Glenn network.

The satellite emulator is an Adtech SX/14 and provides both delay and error capability. We have used this unit in the mobile router testing to generate delay on the duplex path.

The mobile router resides in a half-rack roll-around cabinet [figure 3], which can be placed in the laboratory or on a van. The router is a Cisco 3640 with one 4-port serial network interface card (NIC) and 3 Ethernet NICs. Connections can be wired or wireless while in the laboratory, and wireless via 802.11 wireless Ethernet connections when run in the van. The mobile router LAN also has wireless capabilities as well as a wired hub. Dynamic host control protocol (DHCP) is running on the mobile router LAN in order to easily add application and test computers to the network. An uninterruptible power supply (UPS) allows for up to 2 hr of mobile operation when no other power is available. In addition, the UPS cleans up the power provided by a diesel engine in the van.

There are four wireless 802.11 wireless WAN connections, two for each foreign agent. One of the wireless connection antennas is located in the laboratory and is used when the mobile router is being tested there. There are three wireless connections placed on various buildings throughout the Glenn Research Center. One wireless antenna connects to the Cleveland foreign agent. The second two antennas are connected to the Goddard foreign agent and have the programmable delay unit in the path between the foreign agent and the mobile router. All connections are fiber-repeated back to the laboratory in order to keep the IP traffic off the production network. However, the system will be moved to the production network as performance testing is complete.

Figure 3. Mobile Router Rack

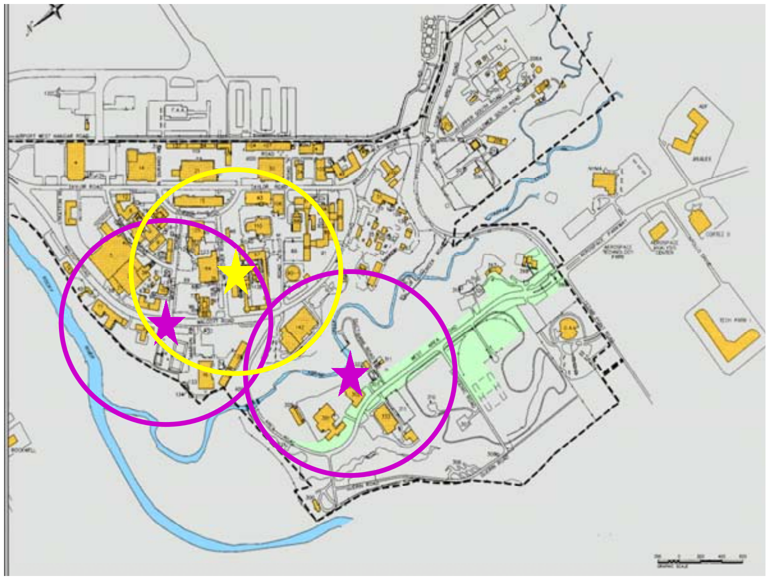

Figure 4. Wireless Ethernet Antenna Coverage

Figure 4 shows a map of the antenna locations and a rough coverage map. The sites were picked such that we would have simultaneous coverage at some times, thereby enabling testing of smooth handoffs and preferred path operation.

Figure 5. Dipole and Yagi Deployment

Figure 5 shows the various antennas deployed throughout the Glenn Research Center and on the mobile router test van. Dipole antennas are used on the buildings to provide circular coverage. Both yagi and dipoles are used on the van. Only one set is deployed at any one time. The yagis provide greater gain, but are directional. The yagi antennas enable us to test at farther distances if we wish, or to restrict coverage and force handoffs and loss of signal by positioning the yagi antenna away form the reciprocal signal.

6. HANDOFFS AND HOLDDOWN TIMERS

The mobile router only allows one active route between itself and the home agent. Whenever two or more paths are available for routing data between a mobile router and a home agent, only one is selected as the preferred path. If two or more paths are available, the preferred path always takes precedence. In a wireless network, there are situations where the nonpreferred path has significant RF signal strength, yet the preferred path has sufficient RF signal strength to register but be continuously fading in and out. This results in a "flapping interface," whereby the mobile router is continuously setting up and tearing down routes to the preferred path as the RF signal fades in and out. The result is very poor data transfer, even though a strong signal and path is available from the nonpreferred path. In order to reduce this problem, a hold down time is incorporated in the mobile router code and is set globally within the mobile router. The hold down timer is used to establish a predefined amount of time that an interface must be stable before it is declared usable. In order to test the hold down timer, we placed the van in a high-fade location. The preferred path had very little delay (10 to 40 msec) and 10 Mbps bandwidth. The non-preferred path had 700 msec delay and 128 kbps of bandwidth.

Figures 6 and 7 show a TCP transmission for the same amount of data with the hold down timer set to zero and 30 sec, respectively. In figure 6, the data is being transferred over the preferred path at all times, except during the initial 20 sec of transmission. The slope of the time/sequence plot shows this. The nontransfer time where the TCP retransmission timers begin is due to the flapping interface. Total transmission time when the hold down timer was set to zero was approximately 5 min, even though the transmissions occurred almost exclusively over the 10 Mbps link. In figure 7, the hold down timer was set to 30 sec. Nearly all the transmissions occurred over the 128 kbps 700 msec delay. Even with this lower bandwidth and additional delay, the same transmission only took a little over 2 min. Approximately 30 sec into transmission, the preferred path became active and then lost the signal. Thus, the RF signal strength for the preferred path was sufficiently stable for at least 30 sec before fading. Flapping of the interface occurred, but the problem was significantly reduced. Increasing the hold down time will improve the stability of the network. However, this also results in interfaces not being declared usable until the hold down time expires. Thus, great care should be taken when setting this timer.

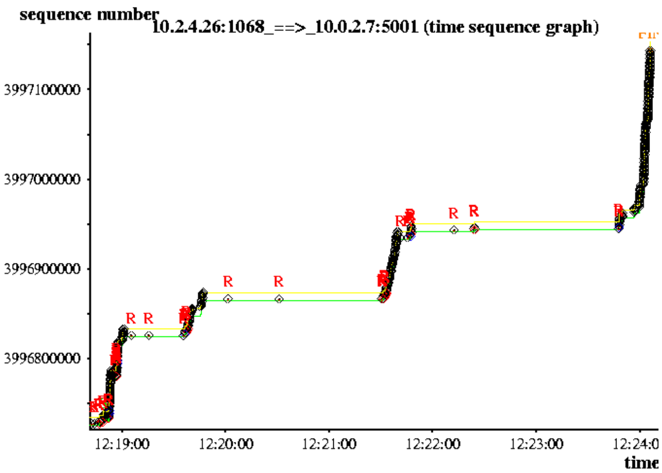

Figure 6. TCP transfer with Hold down Timer = 0

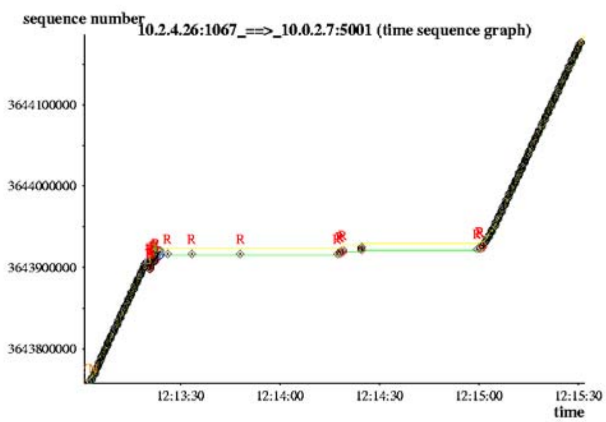

Figure 7. TCP transfer with Hold down Timer = 30 sec

7. TRANSPORT PROTOCOL PERFORMANCE

We have demonstrated the mobile router functionality with live demonstrations. These live demonstrations validated the general mobile routing algorithms, including the preferred path. The mobile router was able to perform with round trip time delays of up to 3 sec (1.5 sec in each link). Some of the applications we demonstrated included email transfers, Web browsing, voice over IP (VOIP), ftp file transfers, secure shell, and Telnet.

In order to access the system performance during handoff situations, a series of tests was developed to emulate two operational networks: a terrestrial wireless network and an aeronautical wireless network. The testbed shown in figure 3 was used. The bandwidth on the preferred path was 10 Mbps and the bandwidth on the nonpreferred path was 128 kbps. The only difference between the wireless terrestrial network and the aeronautical network was the delay settings of the Adtech SX/14. For the wireless network, we used 100 msec round-trip times, and for the aeronautical network, we used 700 msec round-trip times. We use 100 msec as a reasonable estimate of terrestrial network delays through a wireless Internet service provider (ISP). The 700-msec round-trip time includes 500 msec for single-hop geostationary satellite round-trip delays and 200 msec for terrestrial round-trip delays.

In order to isolate the handoff performance from other networking issues (congestion control, Quality-of-Service, etc.), data was taken for a single user emulation. The TCP implementations used were configured with fast retransmission, selective acknowledgement, and time-stamps options. The TCP performance tool, ttcp, was used. TCP receiver and transmitter buffer sizes were set for 11200 bytes, which is optimal for the bandwidth-delay product of the nonpreferred path at 700 msec delay. Packet size was 1400 bytes. The hold down timer was set for 30 sec. Tests were performed for both 100 and 700 msec delays while the mobile router transitioned between nonpreferred and preferred paths. Two ttcp sessions were running simultaneously. The first had the source on the mobile router LAN and the destination on a LAN connected to a foreign agent. The second had the source at the foreign agent LAN and the destination on the mobile router LAN.

Figures 8 and 9 show simultaneous TCP transmissions between a workstation on a foreign agent LAN and a workstation on a mobile router LAN. The delay in the nonpreferred, 128 kbps path was set to 100 msec. Data was taken at the source of the TCP transmission. The workstation clocks were not synchronized; therefore, there is a slight offset in the timing settings on the time-sequence plots. However, it is readily apparent that transmissions originating on the mobile router LAN and originating somewhere on the Internet have similar characteristics. During these transmissions, the van transitioned the network in the following manner:

- Nonpreferred path
- Preferred path
- Nonpreferred path
- Preferred path

Figure 10 is a blown-up section of figure 9 from time 15:30 to 15:32. Figure 10 shows the smooth handoff from the 128 kbps, 100-msec delay nonpreferred path to the 10-Mbps preferred path. Soon after utilizing the preferred path, we lost the preferred path link, as evidenced by the number of TCP retransmissions.

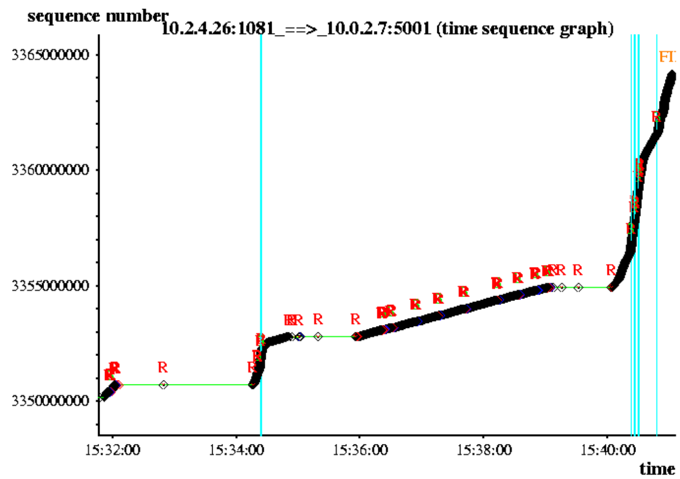

Figure 8. Source: Mobile Router LAN

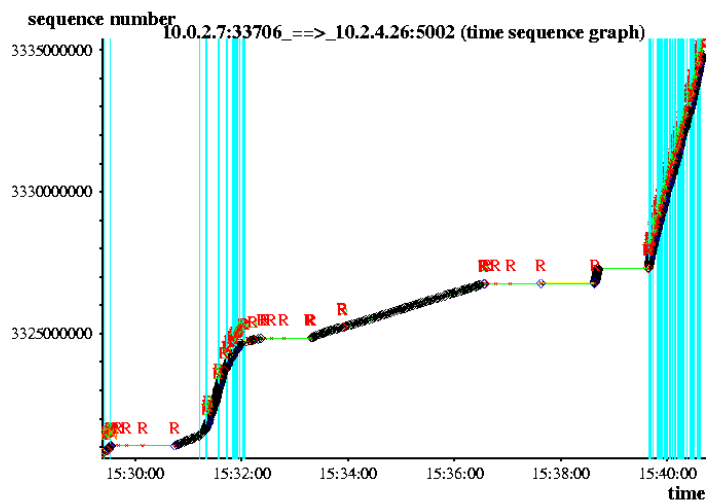

Figure 9. Destination: Mobile Router LAN

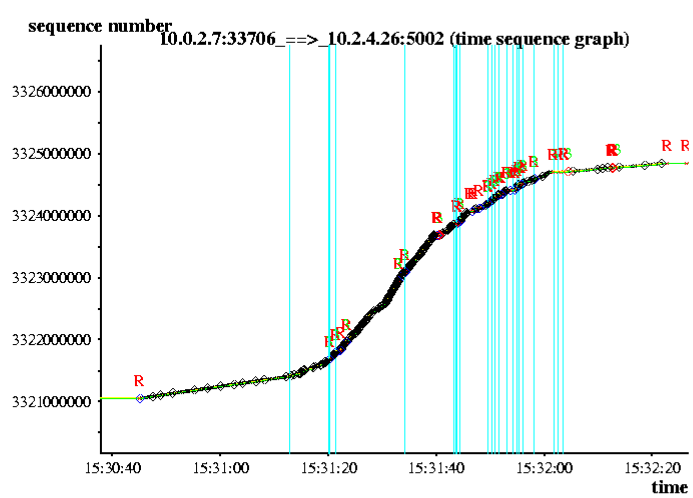

Figure 10. Smooth Handoff From NonPreferred to Preferred Path

6. SUMMARY

We have described the mobile routing protocol and operation, the mobile router and some key configuration parameters. In addition, we provided a detailed description of the test network and the performance of transport protocols in dynamic routing environments. The results indicate that the current version of the mobile router code operates well, and handoffs are smooth between nonpreferred and preferred paths. In addition, the features available to manage handoffs can greatly improve performance, but they must be utilized judiciously with optimal settings varying between individual networks or network types.

REFERENCES

[1] C. Perkins, RFC 2002 October 1996