Mobile Router Testing with Diverse RF Communications Links

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David Brooks	*Infinite Global Infrastructures*
Doug Hoder	*NASA Glenn Research Center*
Ryan Wilkins	*Infinite Global Infrastructures*

This is a short report on demonstrations using Mobile IP and several diverse physical communications links to connect a mobile network to a fixed IPv4 Internet.

The first section is a description of the equipment used, followed by descriptions of the tests, the theoretical results, and finally, conclusions and the actual data.

Background:

Future aeronautical communications systems require a network framework that can support several diverse physical communications links. IP (Internet Protocol) is the defacto standard for most communications today. There are many issues regarding the use of IP in a mobile environment, however. Mobile IP tries to relieve some of these problems by maintaining a fixed IP address for a mobile host, even when its mobile network transverses several different networks. These tests were an attempt to demonstrate the feasibility and functionality of Mobile IP over several diverse physical links: Ku-band satcom (through a geosynchronous satellite), L-band satcom (through low earth orbiting satellites), VHF line-of-sight and a commercial 802.11b wireless LAN systems were all used individually (as a baseline) and in mixed configurations.

We have attempted to demonstrate the feasibility and utility of using Mobile IP and Mobile Router in an aeronautical application. The AC/ATM Aero/Mobile Communications Van (Figure 1) was used as a mobile platform to simulate a host attached to an aircraft.

A description of the hardware, network is presented, along with test results.

Mobile IP and Mobile Router [1]

Mobile IP, as defined in standard RFC 3344[2], provides the architecture that enables the Mobile Router to connect back to its home network. Mobile IP allows a device to roam while appearing to a user to be at its home network. Such a device is called a mobile node. A Mobile Node is a node—for example, a personal digital assistant, a laptop computer, or a data-ready cellular phone—that can change its point of attachment from one network or subnet to another. This Mobile Node can travel from link to link and maintain ongoing communications while using the same IP address. There is no need for any changes to applications because the solution is at the network layer, which provides the transparent network mobility.

The Mobile Router functions similarly to the mobile node with one key difference—the Mobile Router allows entire networks to roam. For example, an airplane with a Mobile Router can fly around the world while passengers stay connected to the Internet. This communication is accomplished by Mobile IP aware routers tunneling packets, which are destined to hosts on the mobile networks, to the location where the Mobile Router is visiting. The Mobile Router then forwards the packets to the destination device. These destination devices can be mobile nodes running mobile IP client software or nodes without the software. The Mobile Router eliminates

the need for a mobile IP client. In fact, the nodes on the mobile network are not aware of any IP mobility at all. The Mobile Router "hides" the IP roaming from the local IP nodes so that the local nodes appear to be directly attached to the home network.

A Home Agent (HA) is a router on the home network of the Mobile Router that provides the anchoring point for the mobile networks. The Home Agent maintains an association between the home IP address of the Mobile Router and its care-of address, which is the current location of the Mobile Router on a foreign or visited network. The Home Agent is responsible for keeping track of where the Mobile Router roams and tunneling packets to the current location of the mobile network. The Home Agent also injects the mobile networks into its forwarding table.

A Foreign Agent is a router on a foreign network that assists the Mobile Router in informing its Home Agent of its current care-of address. It functions as the point of attachment to the Mobile Router, delivering packets from the Home Agent to the Mobile Router. The Foreign Agent is a fixed router with a direct logical connection to the Mobile Router. The Mobile Router and Foreign Agent need not be connected directly by a physical wireless link. For example, if the Mobile Router is roaming, the connection between the Foreign Agent and Mobile Router occurs on interfaces that are not on the same subnet. This feature does not add any new functionality to the Foreign Agent component.

Deployed on a mobile platform (such as a car, plane, train, or emergency medical services vehicle), the Mobile Router functions as a roaming router that provides connectivity for its mobile network. A device connected to the Mobile Router need not be a mobile node because the Mobile Router is providing the roaming capabilities.

Equipment Descriptions:

Ku Satcom System

The satcom subsystem of the mobile satcom/VHF terminal uses commercial Ku-band satellites and provided full duplex connectivity with a fixed station (located at NASA Glenn). The airborne (or mobile) hosts (computers) were connected into the Glenn network, and appear as local machines.

The aeronautical terminal design was based around earlier fixed and shipboard reflector antenna terminals built at NASA Glenn, but incorporated a set of electronically-steered phased-array antennas (receive and transmit). These were purchased from the Boeing Company.

The phased-array antennas are configured for frequency, polarization and longitude of the satellite to be used. The antenna control system takes the position data and platform attitude data and calculates the correct pointing angle for both the transmit and receive arrays. The platform position and attitude data are derived from an ARINC 429 interface from the laser gyro/GPS system on the van, or directly from an aircraft INS (*inertial navigation system*) system (on a ARINC 429-equipped aircraft).

At the *mobile* side of the system (the aero-mobile van), the received downlink RF signal was downconverted and directed to a commercial satellite modem (Comstream CM701) for demodulation. The demodulated data stream was then routed to a Cisco router, which served as a gateway for hosts connected to the terminal.

Similarly, the uplink data stream from airborne hosts was routed through the Cisco router to a semi-custom spread spectrum modem (based on an L3 EB200 development system), into an upconverter and then through the transmit antenna.

The spread spectrum modulation was used on the airborne uplink to mitigate adjacent satellite interference due to the wide beamwidth of the transmit array.

The *fixed* (ground) side of the system consisted of a complimentary terminal located at NASA Glenn. With the fixed station's 8 m antenna and correspondingly narrow beamwidth, there was no need for the spread-spectrum modulation, and the roles of the two modems (the Comstream CM701 and the L3 EB200) were reversed, i.e., the data stream *from* the mobile station was received by the EB200, and the CM701 was used to source data *to* the mobile terminal.

The constituant electronics and their interconnections for the mobile and fixed terminals are presented in Figures 2 and 3, respectively.

Figure 1: Aero/Mobile Van

MDSS L-band Satcom

The Medium Data-rate Satellite System (MDSS) platform is essentially sixteen separate satellite phones combined. Each "phone" places a separate call, called a channel, through the Globalstar satellite constellation. The data-rate for each channel is 7 kb/sec. A system with all sixteen channels operational yields an aggregate data-rate of 112 kb/sec.

Globalstar operates an L-band satellite constellation of 48 individual Low Earth Orbit (LEO)

satellites, which provide seamless voice and data communications coverage throughout most of the world. The entire system uses Code Division Multiple Access (CDMA) modulation and a single wide hemispherical beam antenna for both transmit and receive. The hemispherical beam antenna and combined with CDMA modulation eliminates the need for a satellite tracking antenna system common to other mobile satellite technologies.

Internet connectivity is achieved by connecting to the MDSS Ethernet Port. Data riding over the Globalstar network traverses through one of several regional gateways which are connected to the global Internet where traffic is routed to its destination.

Mobile Router (MR) traffic originating from the MDSS is transmitted to the satellites, through a regional gateway, and routed to NASA Glenn's External Services Network (ESN). The ESN is kept separate from the Internal Glenn network, similar to a Demilitarized Zone . A router acting as a Mobile Networks Home Agent is placed on the ESN to handle any tunnels required for successful Mobile Networking operation. Packets originating from the MDSS may also be routed through a Foreign Agent (FA) which acts as a tunneling agent to allow traffic to flow between foreign networks. Traffic originating from the NASA Glenn end usually connects directly to the MDSS and not through a Foreign Agent, but in some cases through a pre-established tunnel running through an FA.

VHF System

The VHF subsystem consisted of a pair of commercial VHF packet modems (Teledesign TS4000 VHF data radio).

The Teledesign system was configured for full-duplex operation. Each side of the system consisted of two radios; one used as a receiver (demodulator) with the other used as a transmitter (modulator). On the mobile side, the modem RF ports were connected to a TX/RX Systems duplexer, and from there to a Comtelco VHF antenna mounted on the roof of the AATT aero-mobile communications van. The fixed side utilized the same system design with the exception that the duplexer was connected to an omnidirectional antenna at a height of about 9 m. Transmit power levels on both sides were set at 34 dBm. RF Data rates *were set to 19.2 kb/s.*

The mobile and fixed stations each had a single Cisco 3640 router. The two routers were connected via independent satcom and VHF data paths. The routers function was to route packets from the source host onto the selected data path to the destination host. The data path was selected based on weighted routing tables. The primary data path was the route with the lowest cost.

802.11b System

The 802.11b subsystem uses Cisco Aironet 340 access points configured in bridged mode. The bridges are connected to external 2.4 GHz bidirectional amplifiers. Connected to the amplifiers are 8 dBi gain omnidirectional antennas. The amplifier outputs a 20 dBm signal into the antenna.

Network connectivity is achieved via Ethernet directly connected to a Cisco 3640 router. While mobile, the bridge comes in contact with other bridges along the route and establishes a new path. The Mobile Router registers each new path in its table of relationships as they become available, while removing relationships that no longer exist. In the case of multiple bridges being heard from any one location, the bridge keeps it's association with it's current neighbor, if any, or it picks the stronger of the available signals to associate with.

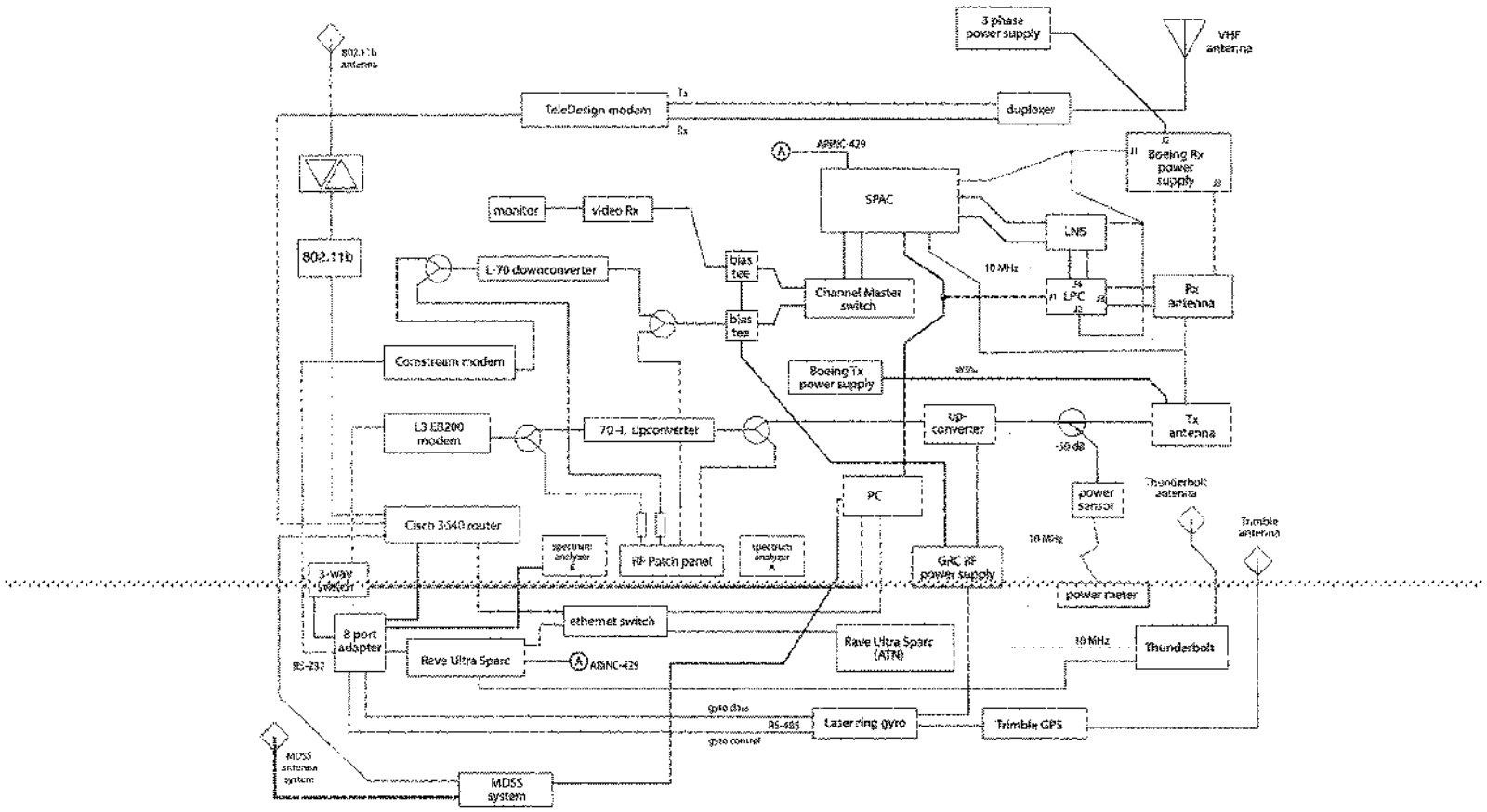

Figure 2: Aero/Mobile Van Electronics

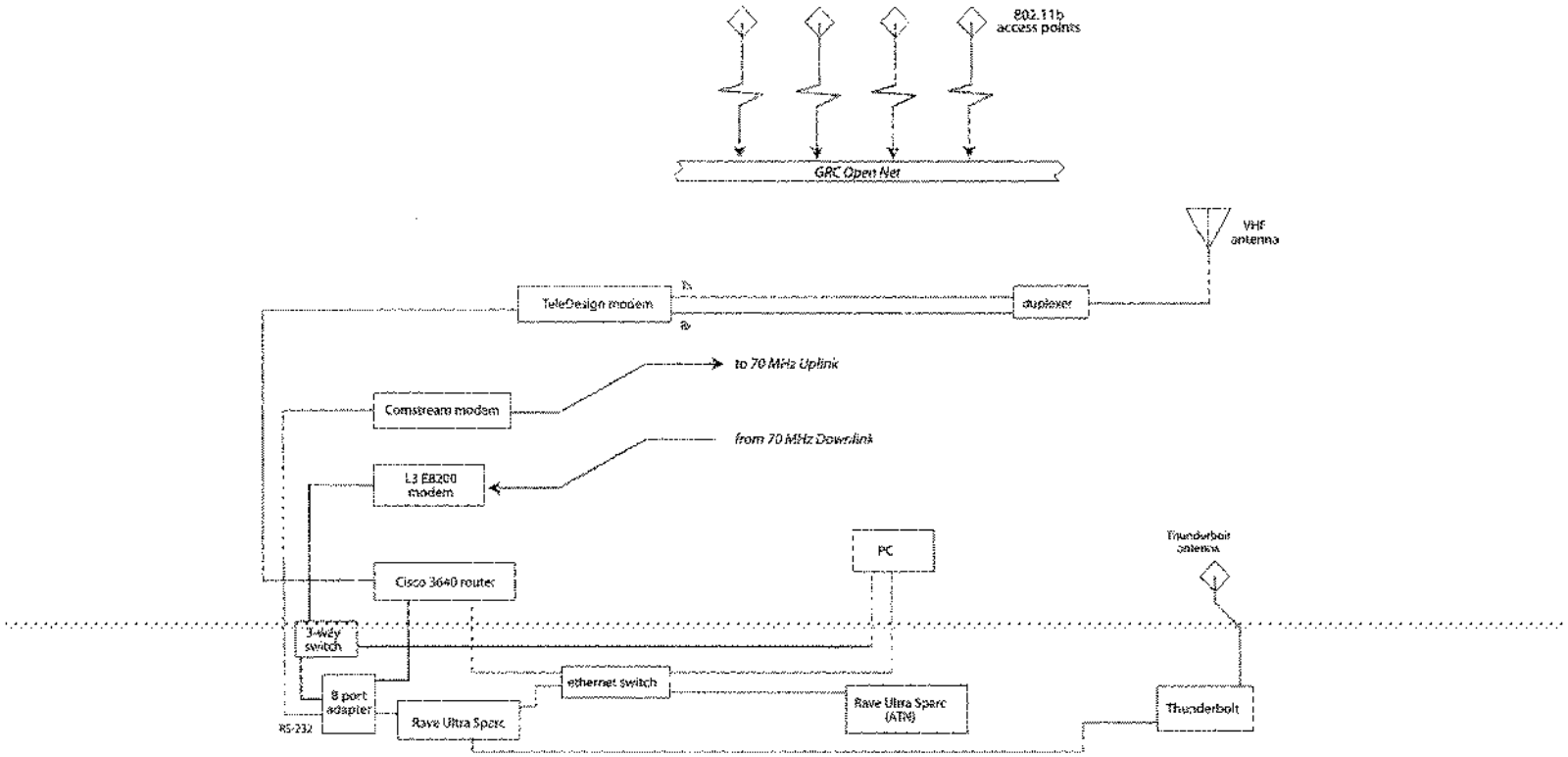

Figure 3: Ground-Side Electronics

Description of Network and Addressing

Mobile Network

On the mobile side, this network consists of four physical network interfaces, all connected to a Cisco 3640 router running IOS 12.3 code. The Cisco Aironet 802.11b bridge is connected, via 100 Mb/s full-duplex Ethernet, directly to a port on the 4-port ethernet card. The bridge was set to run at 5.5 Mb/s or 2 Mb/s over the RF link for topology reasons. When running at 11 Mb/s, we noticed premature connection disassociation when driving away from a fixed bridge, and extended association times while trying to acquire the next bridge.

The Ku-Band Satcom system is connected to the Cisco Router, via RS-449.

The Medium Data-rate Satellite System (MDSS) is connected directly to a port on the 4-port ethernet card in the Router.

The VHF system is connected to the router via an Asynchronous Serial Cable. The modulation scheme is Gaussian Mean Shift Key (GMSK). The radios are configured so as to not provide any buffering functions.

The Cisco router is a 3640 model with a four port ethernet card and a four port low speed serial

card in it. It is also equipped with a Voice-Over-IP (VoIP) module for interconnection to a phone. The router learns which physical links are suitable for data-transfer via Internet Router Discovery Protocol (IRDP) messages which are sent from the ground routers over all configured RF links. The IRDP messages simply announce that the Home Agent (HA) or Foreign Agent(s) (FA) are available to connect. The router will choose a link to use based on a priority list established in the router. If no priority list exists, it will choose the link on a first-come first-served basis.

Encryption was a requirement for interconnection to the Glenn network. Encryption services were provided by a Cisco PIX 501 standalone firewall. When a computer on the mobile network wanted to connect to the outside world, it would make its request to the PIX which in turn would set up an encrypted tunnel between itself and another PIX 501 connected to the Home Agent. Only the payload of each IP frame is encrypted.

Figure 4 illustrates the mobile network and interfaces.

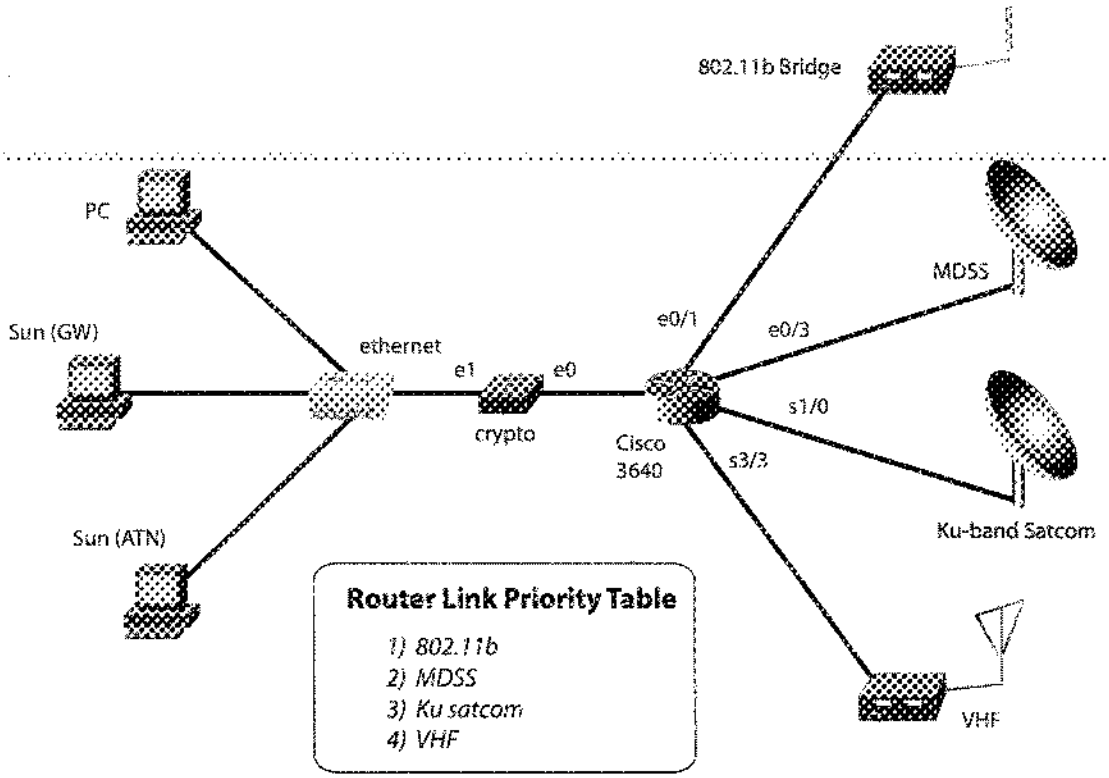

Figure 4: Mobile Network

Mobile Router: Ground Network Description

The ground network consisted of a variety of routers and RF equipment located at various diverse locations around Glenn. The Home Agent is the gateway for the addressable IPv4 network that all outside IPv4 hosts use to reach the Mobile IP network. The Home Agent was a Cisco 7513

router. The ground network was divided into three sections: Internet, External, and Internal. The Internet portion is the network connection to the rest of the Public Internet. The Internet portion is separated from the External and Internal networks by a Firewall. The External network is often called a "De-militarized Zone" (DMZ) where the Home Agent was located. The functionality allows for less restrictive access to network components without a full security plan of the Internal network. The Internal network has heavily restricted access to and from external networks.

A tunnel for the MDSS system comes from GlobalStar gateways through the public Internet. GlobalStar operates a number of regional gateways, which the GlobalStar satellites use to communicate with the ground. These gateways handle Voice and Data traffic which are forwarded to their appropriate destinations. IRDP messages are broadcast from a Foreign Agent, through the established tunnel, and out over the GlobalStar satellite constellation. These broadcasts were only sent while the tunnel is established to the mobile network.

The Home Agent and multiple 802.11b Bridges are on the External network in various buildings. The Home Agent manages the entire mobile networking process from setup to tear-down. The Foreign Agent only assists the HA by announcing IRDP messages over configured interfaces, and it provides a connection proxy to help establish a tunnel to the Home Agent from a network that the mobile network would not normally be able to communicate over. The IRDP messages announce a point-of-presence, which the Mobile Router (MR) can use to establish a tunnel to the HA.

The Glenn Internal network has a Foreign Agent in Building 7 announcing a 802.11b Bridge and two FAs in Building 311 announcing the VHF and Ku-Band satcom links. These FAs are configured to create a bridge for Mobile IP traffic to the Home Agent. Special (IP security) firewall rules were not needed as an internal network device is allowed to connect to the External network without issue. The reverse is not true.

Figure 5 depicts the ground network and interfaces.

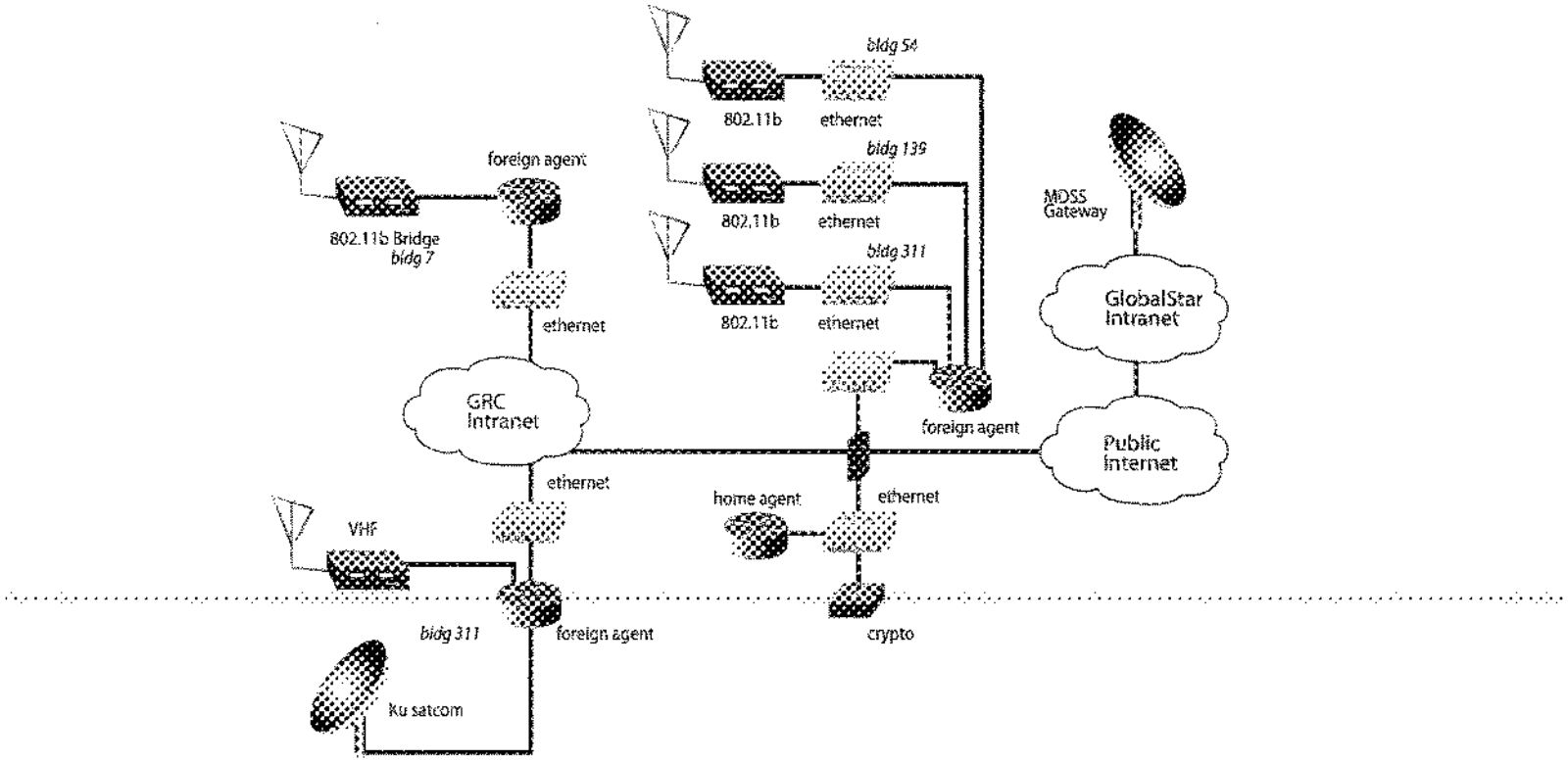

Figure 5: Fixed (ground) Network

Test Descriptions:

The tests were designed to demonstrate Internet services between mobile hosts on the Aero/Mobile Communications Van and hosts located on the NASA Glenn network and other outside internet hosts, and that connectivity could be maintained while the Van was in motion and supporting multiple communication paths. While moving between different mobile network attachment points, the Internet services can use fixed IP addresses to reach mobile IPv4 network hosts. This was accomplished using mobile IPv4 network that provides non-mobile hosts a connection to the mobile network using various "foreign" networks as "tunnels" to a fixed IPv4 addressable home network.

For each test, several physical links were set up and then the van was moved throughout the Glenn campus and used different Foreign Agents to connect back to its home network by various tunnels.

The different physical communication paths were selected by the on-board router using a prioritization scheme and the currently available paths. The prioritization scheme selects the links in the following order:

802.11b (highest priority),
MDSS,
Ku-band satcom,
VHF (lowest priority).

Test Goals

The goals of each test are summarized below:

1) Examine the behavior of the aero/mobile van's Mobile Router while driving around the NASA Glenn campus using the 802.11b (using two different access points) and VHF links. Record Mobile Router, UDP and TCP statistics as necessary.

2) Can the aero/mobile van's Ku-band system support a full duplex link between the Aerovan and Build 311 using the AMC-9 satellite?

3) Confirm a stationary aero/mobile van can switch between VHF, MDSS, Ku-band and 802.11b while links are powered off and on. The fixed van tests are for initial testing before driving the van around.

   Record Mobile Router, UDP and TCP statistics to support the above statement.

4) Try to understand why aero/mobile van sometimes cannot reach certain hosts inside the Glenn network.

5) Confirm the moving aero/mobile van can switch between VHF, MDSS, Ku-band and 802.11b while links become available and unavailable due to the location of the van. Record Mobile Router, UDP and TCP statistics to support the above statement.

6) Confirm Internet services (ftp and http) between the mobile hosts and non-mobile hosts while in motion.

Test Results and Comments:

1) Throughout the testing period we attempted to increase the system's capabilities in a progrssive fashion. We began with examining the behavior of the aero/mobile van's Mobile Router while driving around the Glenn campus using the 802.11b (Access points at B7 and B311) and VHF links, while recording Mobile Router, UDP and TCP statistics. We were able to maintain a 128 kb/s UDP stream between a fixed and mobile host using the 802.11b link and Mobile Router while in motion.

2) We then attempted to verify that the aero/mobile van's Ku-band antenna system can support a full duplex link a fixed and mobile host.

   A full duplex Ku satellite link was established between the fixed and mobile hosts, with the following link performance:

   fixed-to-mobile link: rate: 2 Mb/s, E_b/N_o = 10.3 dB, channel BER = 0
   mobile-to-fixed link: rate: 256 kb/s, E_b/N_o = 9.0 dB, channel BER = 0

3) We next attempted to confirm a stationary aero/mobile van can switch between VHF, MDSS, Ku-band and 802.11b while links are powered off and on. This was done to simulate the Mobile Router losing links and finding new ones. We then recorded Mobile Router, UDP and TCP statistics.

   We began with VHF, switching to the other links in the following sequence:

   VHF -> Ku satcom -> MDSS -> 802.11b -> MDSS -> Ku satcom -> VHF-> Ku satcom

   We were able to demonstrate correct switchover between the RF links and that the aero/mobile van's Mobile Router could maintain a TCP connection while the Mobile Router switched links. Several times, the TCP connection was lost due to TCP time-out.

   Also, we intentionally oversubscribed the VHF link at times since the capacity of the Ku satcom and 802.11 links (>1.5 Mb/s) was much higher than that of the VHF link (12 kb/s).

   All four links (802.11b using two different access points, VHF, MDSS and Ku satcom) were powered off and on in order to test Mobile Router switching in order of priority. Priority was 802.11b (highest)->MDSS->Ku satcom->VHF (lowest).

   The aero/mobile van's Mobile Router maintained a link across the four links, however the links that could not support the 240 kb/s dropped UDP packets as expected.

   Due to its lower data rate, switchovers from the VHF system oversubscription (low-rate link to high-rate link) required longer times for the router to empty its RS-232 buffers.

4) Finally, we tried to confirm the aero/mobile van Mobile Router can switch between VHF, MDSS, Ku-band and 802.11b while links in motion and links become available and unavailable.

   We drove around the Glenn campus, and outside the lab, within range of two different 802.11b access points, MDSS, VHF and Ku satcom links active, using a 12 kb/s stream between fixed and mobile hosts. All links were available with no links forced down. The Mobile Router switched correctly between the various communication links while in motion.

   We also transmitted web cam images using ftp to a fixed host at Glenn.

Selected Data Sets in Map and Graphical Form

In this section, we display graphical output of data from several test runs. The van's latitude/longitude position (updated every 1/10 second) is combined with the router's currently associated link (updated approximately every 2 seconds) into a map. The maps are devrived from two runs on March 2, 2004. These maps were created from several programs: miploggerd[3], insd[3], logger[3], parse[3], mipdebug2csv[3], openmap[4], tcpdump[5], and Iperf[6].

Graphs also display the number of received bytes of TCP segments and UDP messages at a computer's ethernet interface is plotted against time.

The map in Figure 6 map is a 20 minute subset of a 70 minute test to demonstrate switchover between all four physical links on the aero/mobile com van while under motion around Northeast Ohio. For this run, iperf was used to generate two TCP streams to simulate 8192 byte network writes between a ground workstation called aatt-temp2 and a van-based workstation called mobileb7-gw. Iperf used 18 kB TCP buffers on the mobile-to-fixed bulk data transfer direction and 150 kB TCP buffers on the fixed-to-mobile bulk data transfer direction. Simultaneously, the van's web camera transferred 16 KB pictures to aatt-temp2's webserver directory every minute using the ftp protocol. Two graphs of the number of bytes received at both workststations during this run is shown in Figure 7 for the mobile computer and Figure 8 for the fixed computer.

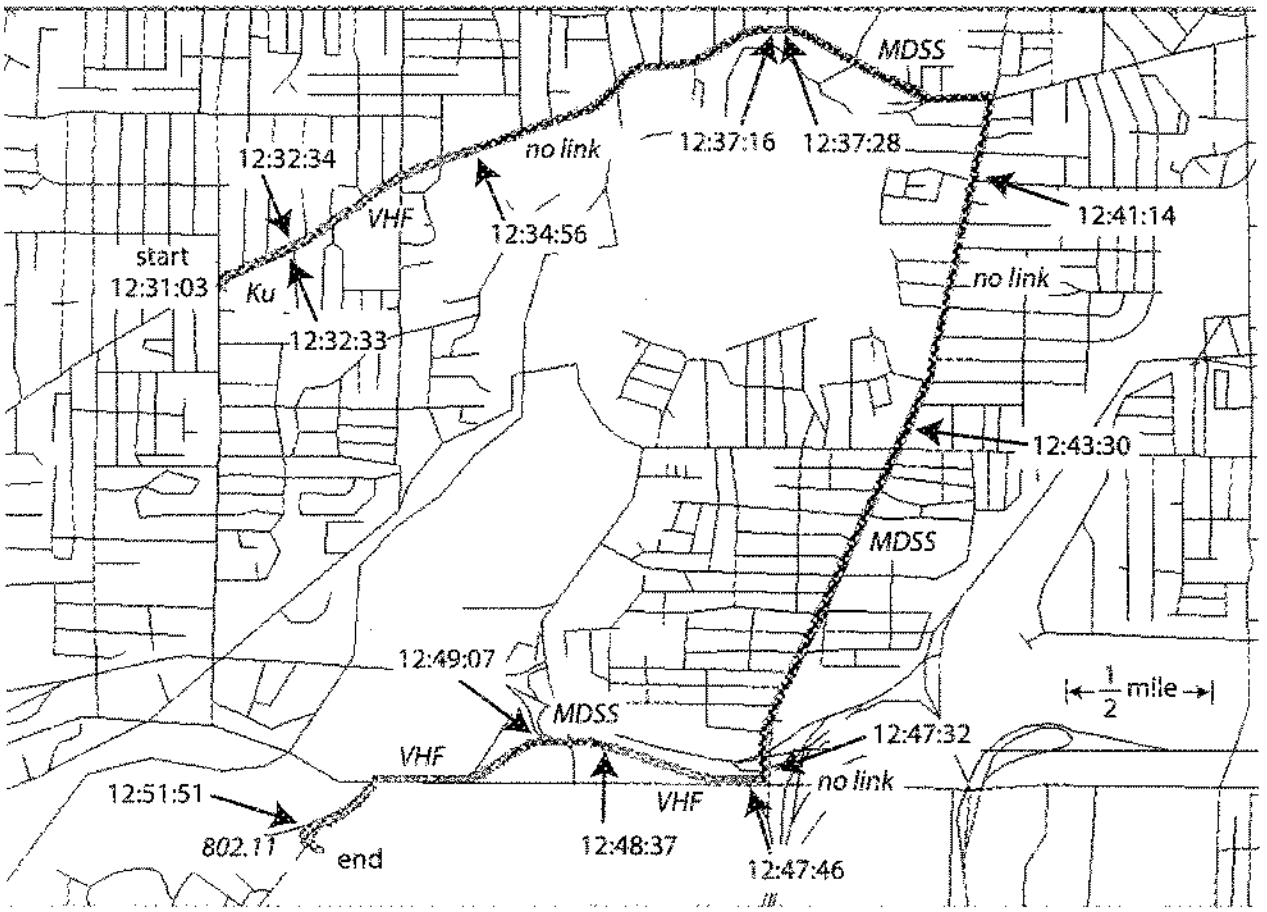

Figure 6: Position and associated physical link of aero/mobile com van around Northeast Ohio.

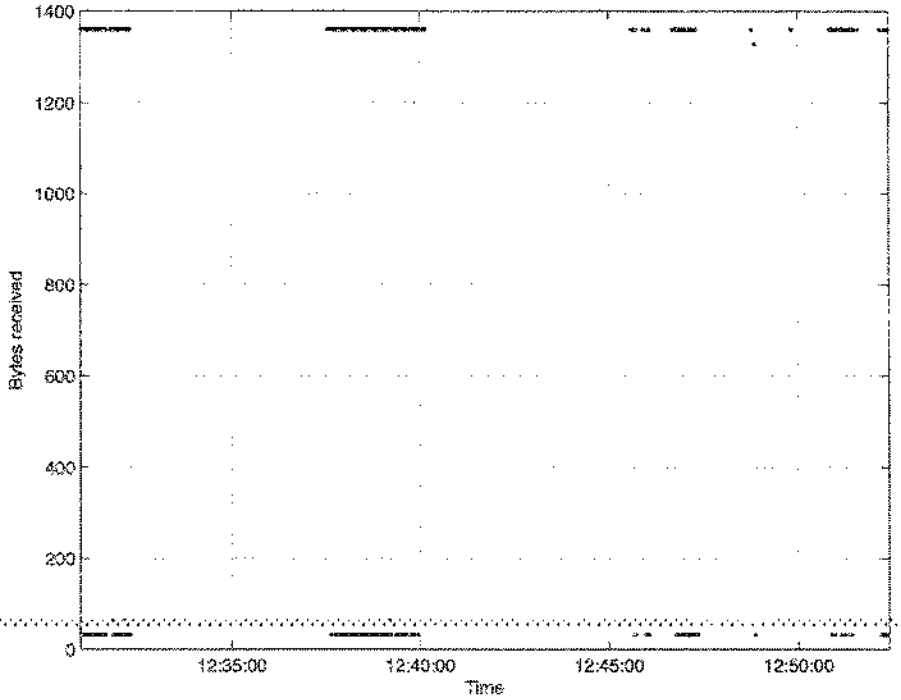

Figure 7: Received protocol data on mobileb7-gw's interface on 03/02/04

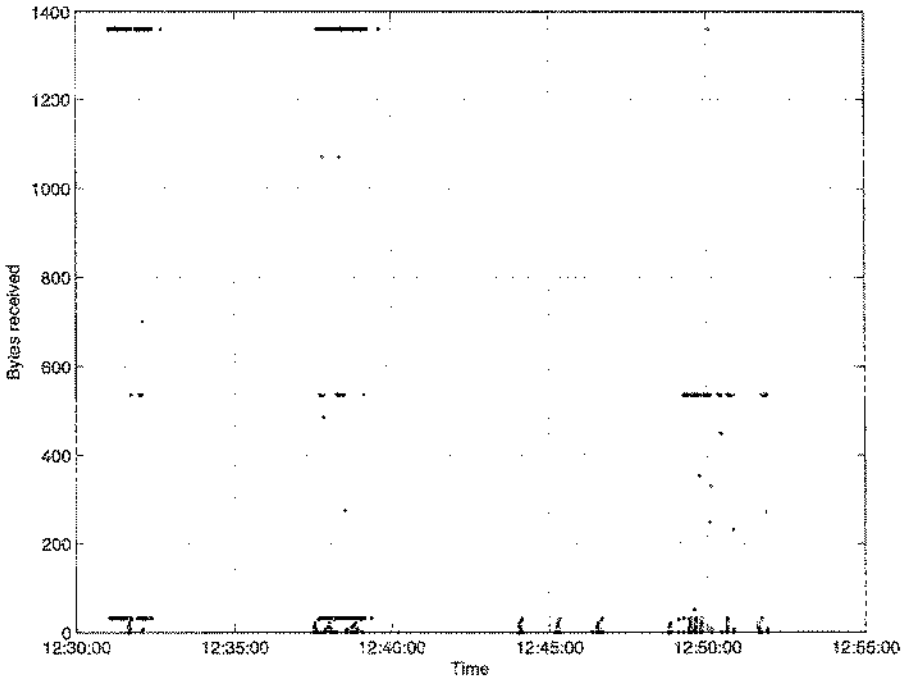

Figure 8: Received protocol data on aatt-temp2's interface on 03/02/04

The Figure 9 map is a 21 minute subset of a 25 minute excursion run again showing switchover between all four physical links on the aero/mobile com van while under motion around Northeast Ohio. For this run, iperf generated two TCP streams to simulate 8192 byte network writes between a fixed workstation called aatt-temp2 and a mobile workstation called mobileb7-gw. Iperf used 18 kB TCP buffers on the mobile-to-fixed bulk data transfer direction and 150 kB TCP buffers on the fixed-to-mobile bulk data transfer direction. Again, the van's web camera transferred 16 KB pictures to aatt-temp2's webserver directory every minute using the ftp protocol. A graph of the number of bytes received at the mobile workststation during this run is shown in Figure10.

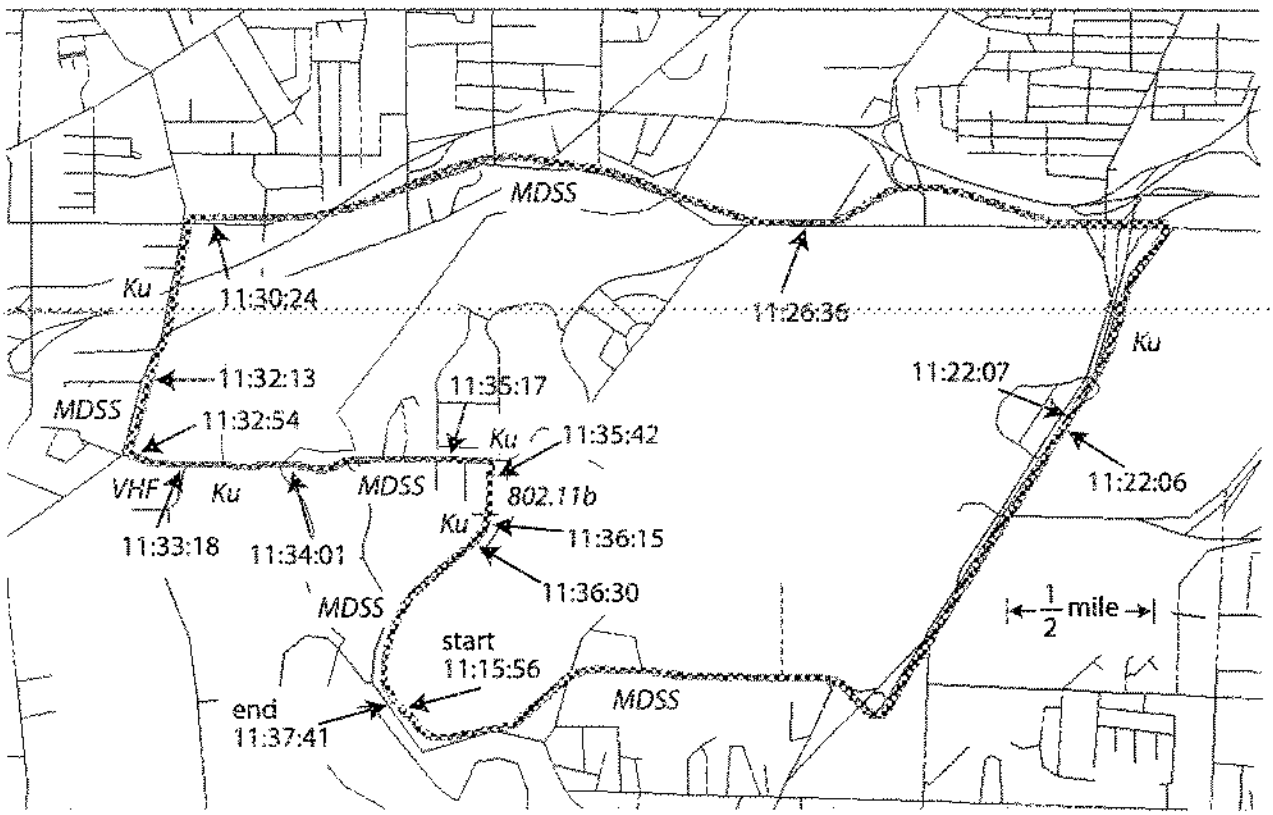

Figure 9: Position and associated physical link of aero/mobile com van outside Glenn campus

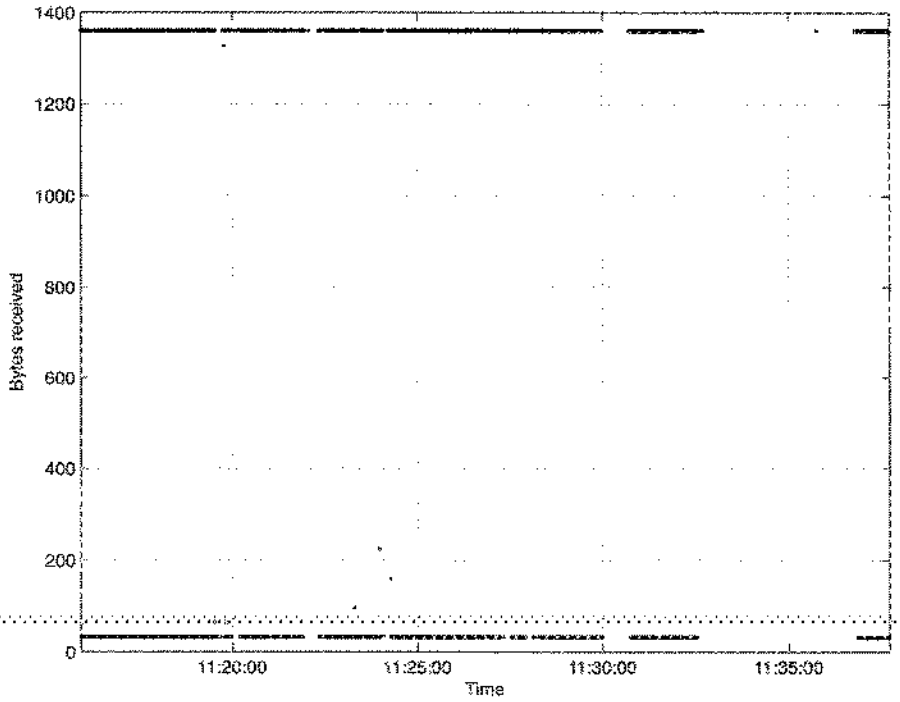

Figure 10: Received protocol data on Mobileb7-gw's interface on 03/02/04

Conclusions

We were successful in demonstrating the following:

1) using the AC/ATM Aero/Mobile Communications Van as a communications simulation testbed for an aircraft in motion

2) performance monitoring and data logging of all the communications equipment on the mobile platform

3) TCP and UDP transport to a mobile network in motion

4) integrating multiple communications systems into a testbed with a mobile platform (network) with fixed IP addresses using Mobile Router.

References

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