IP Telephony for Interplanetary Exploration[1,2]

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NAS Technical Report NAS-04-011
September 2004

Abstract—Voice over IP (VoIP), using techniques developed for telephony, is a natural method for providing voice services for planetary explorers. Providing the ability to make telephone calls over the Internet, VoIP can replace radio frequency communications in remote environments that are not serviced by a conventional telephone system. VoIP can provide better quality voice than either analog radio or conventional phone. As another benefit, VoIP enables the integration of voice and data applications, thus eliminating the need for separate frequency management and antenna systems.

This paper will provide an overview of IP telephony and wireless LAN concepts and examine VoIP applicability for planetary exploration. The use of VoIP at the Mars Desert Research Station (MDRS) will be evaluated. Benefits will be highlighted and additional features that would be desirable to incorporate with VoIP will be discussed. The paper will conclude with a discussion of VoIP studies that will be conducted by the NREN group in the future.

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INTRODUCTION

The astronaut and her robot assistant make their way across the rocky field in the direction of the red mesa. The robot follows, positioning its antenna where it provides the best wireless Ethernet coverage back to the ship. It comes close to her side to provide sample bags for the rubies she picks up as well as for the fossils.

She looks up through her visor and says, "Telephone exobio." The phone is answered on the first ring. Several people are on the line, but one answers. "Peter here. How can I help, Marjory?"

"There is a rather large creature with very big teeth coming off the mesa toward me. What do you make of it?" With that she raises her arm, and like the archetype Shinjuko teenager, shoots a picture with her wrist cell phone. Several people see the image on their phone sets and start to skim through a book. "I found it!" says Julia. "Page 172." They all know which book.

Peter says, "Don't worry, it is not a carnivore, but it eats hydrocarbons sometimes . . . Like clear plastic…LIKE YOUR HELMET . . . RUN!"

The above is fiction but the telephone technology described is not. You may well have a phone in your pocket with many of the features highlighted above. In late March and early April of this year, the NASA Research and Education Network (NREN) team from NASA Ames Research Center (ARC) supported NASA exploration technology development and field science teams in an expedition to the Mars Society Desert Research Station (MDRS) near Hanksville, Utah. The MDRS has a "Habitat" structure in a rugged extreme environment (simulating Mars) supporting up to six astronauts during two-week mission simulations.

Bill Clancey and Rick Alena from ARC were co-Principal Investigators (PIs) for the "Mobile Agents" experiments. The Mobile Agents project, funded by the NASA Intelligent Systems Program, uses models of human work practice to drive automation of planetary exploration activities. These experiments provide support for simulated planetary extra-vehicular activity (EVA) using mobile intelligent software

[2] IEEEAC paper 1547, Version 2, Updated December 9, 2003
[3] Work supported by the NASA Advanced Supercomputing Division under Task Order A61812D (ITOP Contract DTTS59-D-00437/TO #A61812D) with Advanced Management Technology Incorporated (AMTI).
[4] Work supported by the National Aeronautics and Space Administration under Cooperative Agreement NCC 2-1426 with the Universities Space Research Association (USRA).

agents. The Mobile Agents experiment uses voice recognition software to command the Brahms software that supports astronauts in the field. The official charter for Mobile Agents from the Web site (http://is.arc.nasa.gov/HCC/tasks/MblAgt.html) is:

Manned planetary exploration will require on-site coordination of astronauts, robotic vehicles, scientific instruments and intelligent software agents. This task will develop a distributed architecture for simulation and coordination of human-robotic EVA teams, including model-based control of life support, communications, and spoken-language interfaces to rovers. Field data and work practice analysis from the Haughton-Mars Project (www.marsonearth.org) will guide development.

Aerial View of Habitat

The cast of characters included several groups from ARC, a robot- (ERA- Extra Vehicular Activity Robotic Assistant) wielding group from NASA Johnson Space Center (JSC), and of course, the NREN Transportable Earth Station (TES) satellite support folks from NASA Glenn Research Center (GRC). During these experiments we jointly prototyped the use of Internet-based phones for field studies. Geosynchronous communications satellites, with a quarter-second round trip time, are usually anathema for voice communications due to the high latency. We wanted to hear the new generation of IP-based telephone systems over the satellite and judge performance in the field for ourselves. There was also a field operations support role, since there was no telephone service, not even cellular to that remote part of Utah.

IP telephony has matured of late. It is no longer just a way to use a PC to make a cheap phone call at the expense of quality or a competing mass of standards and pieces that don't quite fit together. Prices are now competitive with POTS (Plain Old Telephone Service), and features are becoming inviting.

NREN management agreed to support the Mobile Agent experiments and to supply connectivity via the TES mobile satellite system. The TES consists of a trailer with a Ku-band satellite system and a van to pull it and to house equipment for Internet connectivity and support. The satellite station at GRC in Ohio routes the data from the TES to and from the Internet. The trailer and van are connected via a 100-Mbps microwave link when deployed. The trailer is kept well away from the experiments because of the noise of the generator needed to run it. Figure A illustrates the topology of the network built for the Mobile Agents Experiment.

Transportable Earth Station (TES) in field

The remoteness of the Mobile Agent field experiments made this a good testbed for communications prototyping. Voice over Internet Protocol (VoIP) was one of the emerging technologies that NREN chose to bring to the desert.

The 2003 Mobile Agents simulations did not take into account the effect of delays caused by light speed. For exploration of Mars, the 20-minute delay each way will be an obstacle for interaction between people on the Martian surface and people monitoring the mission on Earth. There will also be a habitat on the Martian surface, and reference mission concepts will use it as the primary point of mission control because the habitat can communicate with the field party in real-time.

THE SPEED OF LIGHT—IT'S THE LAW

It is well known that the speed of light will not allow for astronauts on Europa or Mars to carry on voice calls to friends and family on Earth. However, VoIP technology can be used for proximity communications between parties on a remote planetary surface, and on orbiters these technologies can be extended to interplanetary capability by voice mail technology and other non real-time but standard commercial offerings.

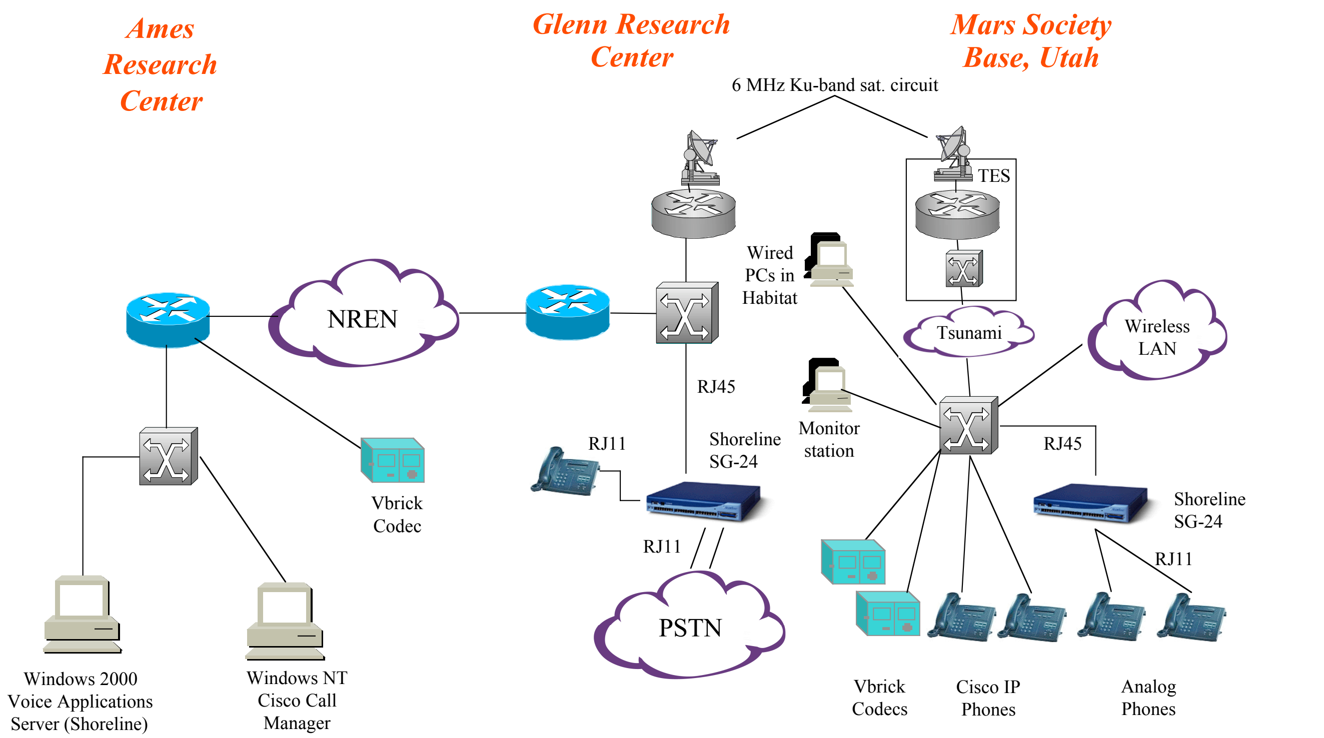

Figure A: Mobile Agents Support Network, Hanksville, Utah

WHAT IS VOIP?

VoIP is a collection of technologies that use Internet Protocols (IP) and techniques to interact with the telephone network. It includes using PCs as phones, using IP to communicate between phone switches and replacing voice PBX (private branch exchange) with "soft" IP-based PBX.

The worldwide telephone network is almost completely digital (except for the link from home phone sets to central offices). The technologies used for analog-to-digital compression and switching, however, were developed in the 1960s and are getting long of tooth.

Using newer voice compression methods saves bandwidth. Packet-switched voice makes more sense than circuit switched voice where phone calls reserve bandwidth for the whole call even when no talking is going on. Now, PBXs and other phone switches are being replaced by PC-based systems. This not only allows for voice compression that uses less bandwidth and gives better fidelity, but also enables use over a single wide area network. It also allows for common equipment and support for both data and voice. IP features, such as multicast and Quality of Service (QoS), can be used to optimize feature sets.

In the present phone network, new voice features (call forwarding, number portability, caller ID, etc.) usually requires new hardware upgrades for phone switches and training for technicians. IP switches can implement features with just software changes. "IP phones" are now available. Instead of an analog connection, these phones have Ethernet connectors on them. They connect to IP call managers that have the same functions as an old PBX. This allows for a single wiring system for a building, which could result in large savings. Even more important, these IP phones can connect to wireless LANs (WLANs). Wireless, high-speed 802.11-type LANs are becoming ubiquitous, and there is talk that this technology may augment or overtake cell phone technology.

NREN VOICE SYSTEMS AT THE MDRS

NASA is interested in evaluating and using a variety of commercial products that can fill certain operational roles in NASA missions including voice communications. NREN borrowed an entire voice system from Shoreline Communications in Sunnyvale, CA (www.goshoreline.com). The system consisted of two 24-port switches, the software for voice mail, and configuration management that ran on a NASA-supplied Windows computer.

This system supports both IP phones (which attach anywhere on the network via Ethernet) and regular analog phones. Analog phones attach to the ShoreGear voice switches with telephone cable and RJ11 connectors. ShoreGear voice switches run a real-time operating system and provide all call management (PBX) features. The decision to use the Shoreline gear was made late in the planning and was a way for NREN to learn about deploying IP telephony. We did not obtain any Shoreline-compatible IP phones for the mission, and as a matter of fact, took several old cheap phone sets augmented with some bargain phones that cost up to $10 each.

ShoreGear Voice Switches

Our system was laid out differently than the usual IP phone topology where a switch connects to an Ethernet and/or telephone sets on one side and phone lines on the other. There is no phone service anywhere near the MDRS and electric power is by generator, so we required a distributed architecture. One ShoreGear voice switch was installed in the Habitat at the MDRS with several voice phones attached. That switch was attached via Ethernet to a router through a wireless link and then to the satellite system. The satellite system was down-linked at GRC where a second switch was installed. That switch had one phone and two analog phone lines that attached to the phone network in Cleveland. Figure B shows the Shoreline network infrastructure.

The team set up and configured the switches and server at ARC. The most difficult part was setting up the Windows computer in a secure manner. The Shoreline system proved to be simple to configure, even for a crew that was not well-versed in telephony.

Astronaut Poses with Shoreline Phone

Astronaut in the Field

We wired the phones into the Shoreline switch in Utah and waited until the satellite link came up and the configuration would be uploaded from the server at ARC. Incredibly the switch and phone network came up and worked immediately after the link went active. We soon called the NREN team back at ARC and asked for some configuration changes including the ability to add more phones. The changes were made and the new phone lines were activated before we hung up. The Shoreline system provided all the function of a PBX; all of the phones were extensions that could dial one another with four digits. This included calling from the switch at the MDRS to the switch at GRC using four digits without having to go out over the phone network.

Voice quality over the satellite was our first concern. The Shoreline system voice quality was outstanding—no echo, no clipping and full tonality. It was hard to remember that one was talking over a satellite link, and therefore conversations were overrun on occasion. The digital signal processing of modern VoIP phone systems eliminates distortion and echoes caused by the delay times associated with talking over satellite links.

In addition to the Shoreline gear we also brought two Cisco IP phones to the expedition. These were borrowed from the Local Network support organization at ARC who also assisted in the configuration of their call manager hardware and router back at ARC. The Cisco gear had been obtained several years ago. Much work needed to be done to upgrade the software to support the telephony, and configuration was difficult. We were never able to interface the equipment with the phone network to make calls from the MDRS. We were able to configure the IP phones as intercoms to allow dialing between the two phones in Utah and the phone at ARC. Quality on the Cisco phones was good but not as good as the Shoreline system. A faint echo could be heard on the Cisco IP phones. Figure C shows the Cisco Network Infrastructure.

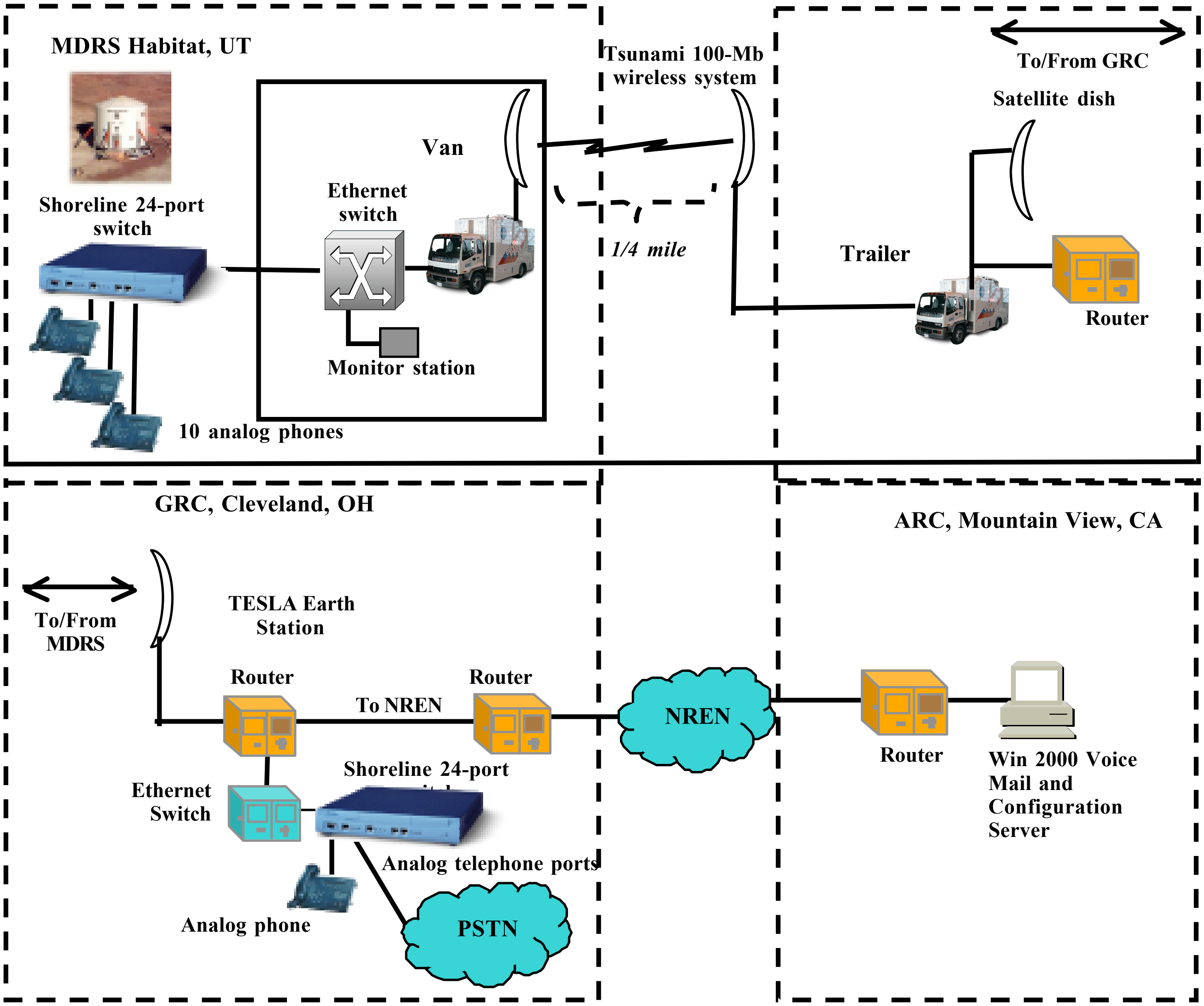

Figure B: Shoreline Network Infrastructure

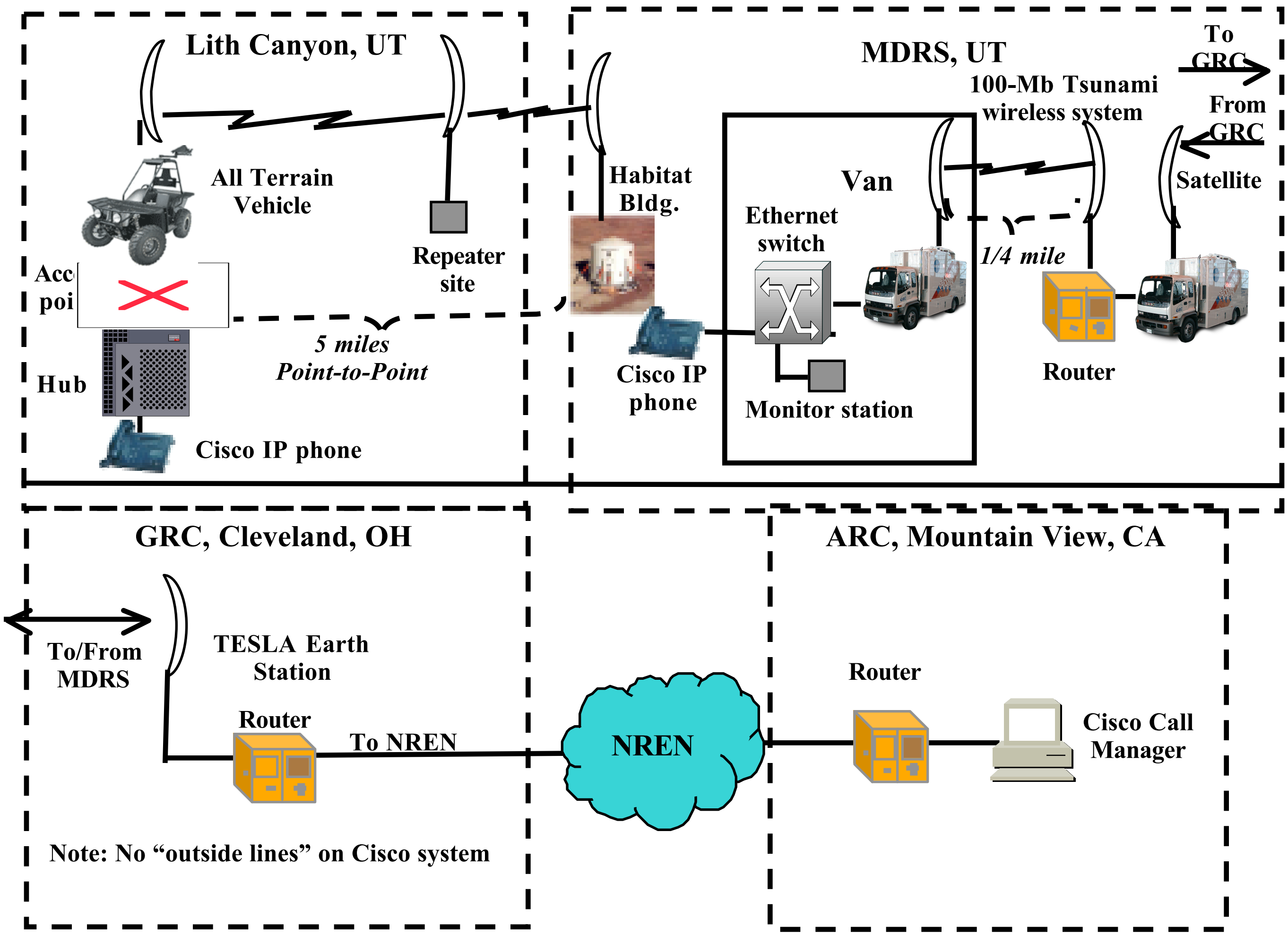

Figure C: Cisco Network Infrastructure

The Mobile Exploration System (MEX) field team, supporting the Mobile Agents simulations, had wired some All Terrain Vehicles (ATVs) with WiFi wireless connections and a computer system. These ATVs acted as repeaters for the experiments in the field. We thought that trying to include the Cisco IP phones onto the ATV would be an interesting experiment. When the Mobile Agents field management decided that the definitive test of the mission would take place over five miles away beyond many hills, it was quickly determined that the tests would take place out of walkie-talkie radio range. Up to that time audio radio communication was used to coordinate testing between the remote site and the Habitat. The IP phones, one mounted on an ATV and one connected via a hub in the Habitat, were “volunteered” to replace radio communications. At this point we were not sure if the Cisco IP phones would even work over the wireless LAN or how they would interact with the network data since we did not apply any QoS (Quality of Service) to the WLAN.

Local School Children at Habitat with Shoreline IP Phone

We were rewarded in our faith in IP-based communications when the phone link between the remote ATV and the Habitat worked flawlessly. Voice quality was clear and no drops occurred—all this over two repeater hops in some of the most hostile environments on the planet. This was a challenge since the wireless network backbone could produce variable latencies similar to geo-synchronous satellite links.

As previously mentioned, an important dimension of the Mobile Agent experiments was voice recognition. The better the fidelity of the voice, the easier it is for the software to get the words correct. On an audio radio circuit the software performs poorly. Telephone lines compress 3 kHz of bandwidth into 64 kb/sec using the standard PCM (Pulse Code Modulation). In contrast, MP-3 stereo audio (I love my MP-3) also takes 128-256 kb/sec but gives CD-quality stereo fidelity. IP telephones compress voice ranging from 8-128 kb/sec, and some systems allow you to choose the compression methods. There will also be packet header overhead.

Rick Alena on Cisco Phone at Lith Canyon (5 miles from Habitat)

We soon realized that using standard phone technologies for human exploration of space was a good idea. People are used to phones and their foibles and features. Radio communications with the “over and out,” strange buttons and channels are not natural for modern people. Cell phones, voice mail and conference calls are. In some ways, telephones are simply modern extensions of voice radio technology, adding full-duplex communication paths, eliminating complexity, and integrating with the communications infrastructure. The marriage of telephony with Internet technology is a great opportunity for space exploration.

IP Telephone Framework for Ground and Space

There are several applications for IP telephony at NASA besides the obvious use as a voice analog PBX replacement:

- For use in NASA’s distributed Spacecraft Operations Center Architecture

  At present, a separate network of voice lines is distributed to special (and expensive) switches that form “push to talk” voice conference groups of those involved in various aspects of monitoring and operating spacecraft (health and safety, payload operations, etc.). This is an area where IP telephony could have a big impact at NASA.

- For use at field studies

  For example, where investigators are at remote locations doing science and need to communicate among themselves, with a base camp, and with the rest of the world. Features of radio communications (much like the voice conference groups described above) need to be included in VoIP for this to succeed.

- For use in interplanetary exploration

All of the features that are needed for supporting nomadic networking and other NASA applications are available now (or are easily added) but not all in the same package from one vendor. NASA can exert some leverage and at least find a prototype for this communication.

In fact, NASA has already incorporated one form of modern VoIP equipment aboard the International Space Station. A VoIP phone is set up from Station to Mission Control in Houston allowing the astronauts aboard Station to phone home! This system was a simple modification of a commercial (Cisco) product to account for the rather long time delays associated with NASA's Tracking and Data Relay Satellite (TDRS) system.

Here is a list of VoIP attributes that might be required for NASA field and interplanetary exploration and a brief discussion of each.

Wireless LAN phones

IP phones designed for operation over 802.11 (WiFi) wireless LANs are now being marketed. WiFi phones are optimal for field work. It was well and good to hook a wired IP phone to a WiFi repeater via a hub, but the freedom of a truly wireless phone (with a long battery life) is what is required away from infrastructure. When trying to match IP phones and VoIP systems, one finds that not all phones work with all systems even though each may support several VoIP standards. This maze of standards is one of the obstacles to widespread VoIP deployment. We will incorporate such a phone into the ATVs for routine field team-to-habitat communication in future missions.

VoIP Standards

It is unfortunate that there are still many competing standards for IP phones. Among them H.323, SIP (Session Initiation Protocol - RFC 3261 and others) and MGCP (Media Gateway Control Protocol - RFC 2705-3435 and others). It is important that a good VoIP system support all of them, and support should include all standard phone features, not just dialing and ringing. Some current VoIP switches also support standard voice phones connected via RJ11 connectors. This is a plus to hold costs down.

Security

We do not have to worry about our telephony system on Mars being hacked into and the Martians making long distance calls to relatives on Io, but we do need to worry about securing the terrestrial end of the link and securing any Earth-bound testing. For installations here on Earth, both the telephones and the central equipment need to be secured. Our experience is that the current crop of VoIP systems is not designed with security in mind. This is an area where NASA and other federal users can help provide requirements, road maps and access to technology.

Another aspect of the security problem is passing the VoIP information through firewalls. VoIP-distributed switches send information between each other continually, as well as sending the actual voice packets. The best way for allowing access through the firewall's rule set is to use standard interfaces such as SIP or MGCP that can use standard methods to allow traffic. Otherwise navigating between the firewalls of NASA Centers and of internal networks to pass voice traffic will be problematic.

Quality of Service (QoS)

Voice traffic requires that the network support traffic prioritization, as well as other QoS methodologies such as policing. It is important that IP Phones and VoIP equipment support the existing QoS standards. On the LAN (or WLAN) side, the ability to set the 802.1p (VLAN tag) bits is minimal. On the VoIP switch side, the ability to set the DiffServ codepoint (or at least the IP precedence bits) is a requirement. Of course this means that the access points, routers, switches and other exotica must also support the standards. The new WLAN QoS standard (802.11e) will help as will the interoperability standard (802.11f). Internet QoS will allow for VoIP traffic to traverse complex networks without the annoying artifacts such as clipping and echo. In the past, VoIP traffic was limited to small single domain networks. DiffServ will allow VoIP traffic to traverse today's complex networks.

Voicemail

There will be a need for voice communications between remote planetary explorers and Earth. Text messages are all well and good but there is nothing like voice for personal communications. Distances make direct conversation via phone difficult (we can get used to 1- to 2-second delays but not to 40-minute delays). This is similar to the communications problems of some companies where people are always away from their desks, or even in families where keeping track of members is problematic, especially when trying to plan an event such as dinner. The solution here on Earth has been voicemail. Although we profess to hate it, it has become a primary communications media. We are very used to leaving messages and checking for a reply. Voicemail is a good solution for long-delay situations (such as interplanetary missions) as it has been for cases where projects span multiple, distant time zones.

IP telephony allows for voicemail and e-mail to be interchangeable. Voicemail can be sent to e-mail accounts, and software exists to turn it into text. In the other direction, e-mail can be sent to wireless phones as either text messages or synthesized voice messages.

Just one more point about voicemail integration—there are standard Internet mail interfaces. VoIP systems should not be tied to a single mail package. It is important that mail integration is available on many platforms and that it support many users' preferences.

Push-to-talk and walkie-talkie features, conference bridges and all that

This topic is too big for this paper. A basic facet of NASA mission management is the use of voice loops, with many people able to listen in on a large conversation between many different people. Generally mission controllers monitor several voice loops (i.e., conversations) simultaneously. It takes some practice, but people can make sense of several different conversation tracks at once! The

Mobile Agent project requirement for replacing walkie-talkies in the field means users in an interest group all need to be able to communicate in ad-hoc conferences. In a conference call having many participants, there is a real need to manage who is speaking, therefore mute and push-to-talk features are a must for conference phones. Large conference bridges will also be needed for VoIP operations centers. IP multicast allows for this and more at a very attractive bandwidth cost. NASA is in a position to offer multicast expertise to VoIP vendors and to provide test facilities for features.

Compression options

Some IP phone systems have options to use various types of compression. This document is not the place to discuss these options but only to say that some newer compression modes offer better quality at lower bandwidth. The compression modes are options between switch nodes and not always between IP phone sets and associated switches. Some of these by default use 64-kb/sec ADPCM, and some use more frugal technology. It would be a boon to allow users to choose the compression method between IP phones and switches. This is especially true for WLAN communications where bandwidth can be at a premium.

Features and commodity PBXs

Aside from the great technology die off, the reason for the slow acceptance of VoIP was that conventional voice PBXs technology had driven down prices and added feature sets that were hard to surpass. Voice toll rates have also declined to where converting to Internet-based voice could not be justified on toll rates alone.

The feature sets on these later generation PBXs have evolved over the years to provide users with very sophisticated packages that VoIP solutions have only now been able to match. Some of these features include:

- *Simple interfaces for station adds moves and changes*
- *Networking ability to use voice trunks for traffic engineering*
- *Built-in voice mail*
- *Directory services*
- *The dreaded automatic voice response*
- *Public address systems with distributed speakers*
- *Phone sets with speaker phone, call waiting, transfer, limited conferencing, caller ID and more*

Early VoIP systems were built on PC Microsoft platforms that were not reliable and did not include many features. Newer systems are based on real-time O/S and distributed architectures.

Voice recognition for phone features, dialing and mobile agents

Four-year-old cell phones have voice recognition. The voice recognition and database are integrated with the tiny phone. One large addition to this feature for interplanetary applications is that there may need to be intermediary voice recognition software to segregate phone conversation from conversation with local mobile agents (e.g., “Take a voice note, I put the blue rock in bag number 182”).

Camera feature

Cell phones are now able to send snapshots over the network. Because of the limited bandwidth of even “3G” networks, the images are fuzzy and of low resolution. IP phones, even those on WLANs, have more bandwidth to work with, and there is no reason not to take advantage by allowing higher resolution pictures and even video to be sent using integrated cameras.

GPS locators

An important requirement for fieldwork in remote parts of this planet or others, is the ability to know one’s location and impart this information to those who might provide assistance in case of an emergency. The Inmarsat satellite constellation offers single-button distress calls to marine (shipboard) subscribers. Inmarsat uses satellite triangulation to locate the distress beacon and sends the location and identification to the nearest search and rescue organization. Cell phone companies are being asked by the FCC and state PUC to provide E-911 service. This will require every mobile phone to provide exact coordinates so the provider can connect to a nearby emergency service switchboard even if the user’s phone has an area code a continent away.

Locating a mobile phone can be done either by triangulation from cellular towers or by providing GPS capabilities to phones. Some mobile phones currently on the market include GPS (as part of a telephony-enabled handheld computer). It will be some time before IP telephony standards are mature enough to allow manufactures to build VoIP/mobile hybrid phones, but this is in some marketing plans already. When these combination phone sets are sold, they will also be required to impart location information. GPS locators are an option that should be included in today’s VoIP phones. The technology is available. Location is required for many field activities, and having an integrated GPS in an IP phone will mean one less item to carry.

Of course, GPS is a terrestrial system and would not be available on other planets. It could be posited however, that a positioning system of some type would be in orbit when humans are sent to explore a new world, and position reporting can be included in our ideal universal phone.

Standard test procedures and compatibility

VoIP is mature enough that test equipment and software is readily available, as long as equipment conforms to established standards. Equipment is available to simulate phone calls to ensure throughput on VoIP systems. Compatibility of equipment from different vendors is still a large problem. Phone systems are complex with many features and these features can come in many flavors. Although equipment may be advertised as supporting phones or other equipment, this support can be minimal and not provide the service levels expected. There does not seem to be an organization dedicated to testing compliance and interoperability of VoIP equipment as there is for WiFi.

STANDARDS AND IP PROTOCOL, THE TWO PILLARS OF VOIP FOR SPACE EXPLORATION

Standards: the bedrock

There are many standards that concern VoIP. Many specify the same functions in different, incompatible ways. Some are incomplete, subject to interpretation that can render "compliant" equipment actually proprietary. The industry needs to mature to see the benefits that interoperability can bring. Too much of the VoIP business comes from the telco industry rather than from the Internet community where this lesson was assimilated years ago.

IP Protocol: the common thread

The glue for seamless voice and data networking is the Internet Protocol family. IP provides all the hooks for communications so that voice, data, and video can use a single physical network. It is adaptable over many technologies. If one wants to convert from 802.11a, or 802.11b, or 802.11g, IP requires that only the physical network need be changed and no underlying software needs to be modified. Hybrid networks can be built using all three standards if need be.

It may be that in the deep space environment, major hardware changes are needed and devices designed for terrestrial use will not work or are not ideal for planetary exploration. TCP presupposes a return link with low errors and short roundtrip time. It may not be suitable for the long delays and intermittent nature of deep space, but UDP-based communication is proven in the space environment. The use of IP family protocols means that custom space-rated hardware can be developed and tested, and the software and features that are used by millions will still work in space.

It may be that instead of the 2.4 or 5 GHz bands, the Ka band, which will deliver very high bandwidth with very small antennas, is the best band for Mars communications. However, using IP means that the same telephone features available at the mall are available to astronauts on Mars with a few changes to the physical layer of devices. The most difficult and costly portion of system development is the definition of functions using standards and implementing the software to perform the desired functions. Special hardware suitable to extreme environments can be developed using the same system standards and software from commercial products resulting in optimal development costs.

FOR FURTHER INVESTIGATION

NREN is using network monitoring tools to look at VoIP performance in the field. Protocols and operations will be vetted to insure that distances will not be a problem for normal operations. Software loads and configuration changes will be watched to see if they can withstand the space environment of loss and long delay. NREN is also looking at QoS methodologies for mitigating any congestion issues on WLANs.

NREN has been looking in depth at traffic patterns from the Shoreline and Cisco IP telephony systems and plans to extend this analysis to other vendors' offerings some time in the future. We have found that each vendor's system has its own architecture and protocol suite, making comparisons difficult. However, the primary objective of our analysis has been to find common patterns that are important for facilities planning and traffic engineering.

NREN captured data from several field outings and laboratory settings using our PCMon data collection and reporting system. We have been looking at the protocol flows between devices and wide area and local area networks. We will be expanding that to look at WLAN traffic in the near future.

The first part of our analysis will be to outline the protocols used by the systems. Figure D shows the protocol flow for the Shoreline network, and Table A is a description of the several protocols needed to provide telephone service via the Shoreline offering.

The second part of the analysis will be to collect data and present it in tabular form. Figure E is an example of some the output from the PCMon software from the MDRS field-tests. Data has been collected for each device and socket pair on the network from several outings. This data can be used to answer questions about the bandwidth required for calls, usage patterns and overhead.

Table A: Protocols to Support Shoreline Offering

Protocol	Layers	Port	Purpose
RTP (Real Time Protocol)	UDP > RTP > G.711 or G.729a	Port 5004	Send digitized voice packets between IP phones and switches, and switches and the voice mail server. Streams at 2400 or 80,000 bits per second
FTP (File Transfer Protocol)	TCP > FTP	Ports 20, 21 and others	Send boot data to switches from the configuration server in case of corruption, and updates to software to IP phones from server
MGCP (Media Gateway Control Protocol)	UDP > MGCP	Ports 2427, 2727	Call control for IP phones
SIP (Session Initiation	UDP > SIP	Port 5441	Call control between Shoreline switches and Configuration

Protocol)			Manager, and between Shoreline switches
RPC Traffic (Remote Procedure Call)	TCP > RPC	Port 1024 and others	Applications services such as voice mail, tracking call activity, configuration of switches and logging events
http (Hyper Text Transport Protocol)	TCP > http	Port 80	User interface to Configuration Manager

The third part of the project will be to actually use the data to optimize VoIP deployment. Here are some of the areas that we expect our investigation to impact.

- The placement of hardware elements in a geographically diverse deployment can be optimized when the protocol requirements are known. For instance the Cisco Call Manager must be involved in each incoming and outgoing call; therefore it needs to be available to all phones and voice mail systems at all times, but its traffic load is small. The Shoreline Configuration Manager is most interactive at startup and not required to complete connections. The voice mail server is part of the same physical system and may be very bandwidth intensive in some situations, so this appliance also must be carefully located in the network.

- A major reason that advanced QoS technology has not been widely implemented is the difficulty with deriving policy. It is not so much a question of how to classify traffic and expected behavior for optimizing but of assigning bandwidth limits for the classes. Knowing the expected traffic load from the complex protocols used for VoIP can aid in setting policing limits and discard thresholds.

- Fieldwork almost invariably involves constrained links. Satellite connections and wireless connections, especially point-to-point wireless over long distances, are typical of remote activities (as are sensor nets and other low-speed but persistent emitters). Agile QoS techniques can provide functionality that allows for success in situations where bandwidth haggling could cause failure. Although we usually think of the RTP stream as the totality of IP telephony, some of the other protocols need to be given priority to allow for connections to be made and configurations completed.

- An example is when there are several phones used in a field test connected via a limited-bandwidth wireless connection. Before and after the actual field test, many phone calls may be needed to complete setup and to analyze results. During the test, however, phone activity may need to be limited. Service levels can be set up to activate policing to limit calls when other real time data traffic is active, and to "borrow" bandwidth for calls when the data sources are quiet. This all requires that traffic patterns are known for each source so that the circuit can be engineered to prevent congestion.

- If a link is over subscribed, then drastic measures such as using lower bandwidth voice digitization methods, RTP header compression or silence suppression can be implemented. These methods may add to the cost, complexity or packet delay of the system and may not be available on the fly. Understanding the requirements before implementation will allow for proper engineering.

- One of the most vexing problems with setting up IP telephony is devising proper firewall and router filter policy. Understanding of the protocol interactions and traffic flows can result in more secure networks and can aid in troubleshooting when IP phones do not work when used over a new network topology.

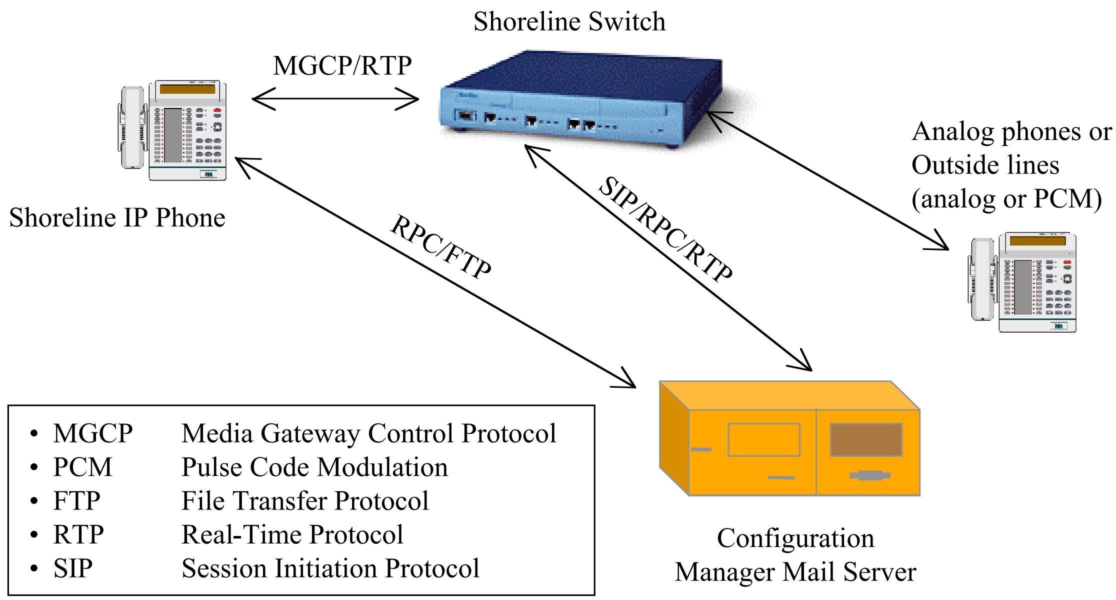

Figure D: Communications Between Shoreline IP Phone and Network

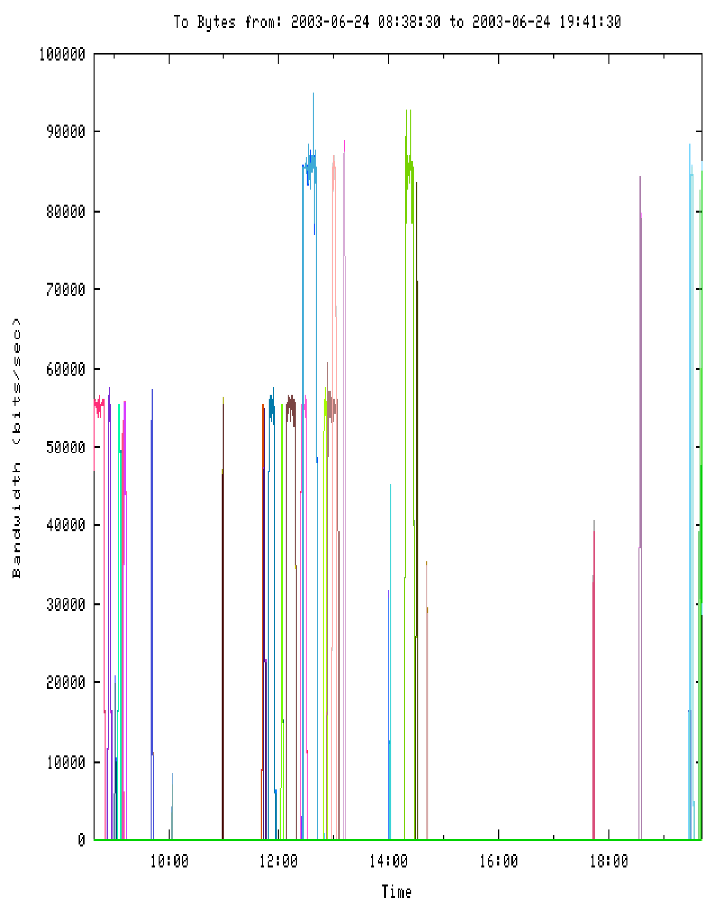

Figure E: RTP Traffic from MDRS to GRC 6/24/03

CONCLUSIONS

VoIP technology has many advantages for proximity (on the surface, or in orbit around a planet, or moon) voice communications. Voicemail bundling for interplanetary distances is practical and is used today for collaboration between far away time zones on Earth. Immediate NASA uses include conference voice loops for mission control and collaborative science teams.

ACKNOWLEDGEMENTS

The following people were instrumental in the VoIP effort for the Mobile Agents testing:

CSC (Computer Sciences Corporation), ARC

Nichole Boscia and Mark Foster set up and configured the Shoreline and Cisco voice system and provided support from ARC. Mark Foster also engineered the PCMon network monitoring system that provided traffic statistics. Thom Stone provided the overall project oversight and field support for the equipment.

NASA Civil Servants

Ken Freeman of ARC provided overall network oversight for the NREN effort.

Rick Alena of ARC provided Mobile Exploration System hardware support in the field as well as being a Mobile Agents co-investigator.

West Kurihara of ARC provided the Cisco VoIP system and technical support.

Mike Cauley of GRC, in addition to setting up the TES satellite link, helped with testing the features of the VoIP systems.

Vendors

We would like to thank Shoreline Systems, Inc., (www.goshoreline.com) for their technical support and for the loan of the equipment for the field activities.

BIOGRAPHIES

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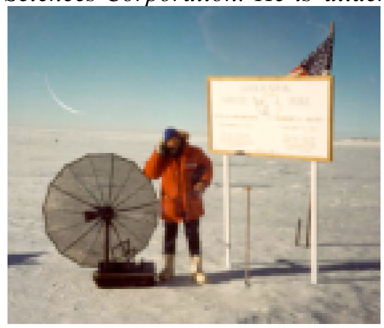

(NASA Research and Education Network) project at Ames Research Center (ARC). Stone has been at NASA ARC employed by various contractors since 1989. He was an engineer with the NASA Science Internet (NSI) project office where he led the project that bought reliable Internet connections to remote locations including US bases in Antarctica, McMurdo Station and Amundson Scott South Pole Station. He was principal engineer for communications for the NASA Search for Extraterrestrial Intelligence (SETI) project and was a senior engineer for the Space Station Biological Research Project (SSBRP). Before his involvement with NASA, Stone was employed in the computer and communications industry and taught telecommunications at the undergraduate level.

Dr. Marjory Johnson *is deputy manager for the NREN (NASA Research and Education Network) project at NASA Ames Research Center. During her twenty years with*

NASA she has been involved in several networking research projects, including local area networking for the International Space Station, development of standards for international space communications, the Bay Area Gigabit Network Testbed, and the NREN testbed project.

Richard Alena *is a computer engineer and the group lead for the Intelligent Mobile Technologies (IMT) Lab and the*

Mobile Exploration System (MEX) testbed at NASA Ames Research Center. The IMT team integrates mobile hardware and software components into unique systems capable of extending human performance aboard spacecraft during flight and payload operations. He was principal investigator for the Wireless Network Experiment flown aboard Shuttle and Mir, technology later adopted by the International Space Station Program. Alena spent four summers in the

Canadian Arctic developing mobile technologies for human planetary exploration. He is a co-investigator on the Mobile Agents project, which is conducting field simulations in the American southwest. He has a MSEE&CS from University of California, Berkeley.

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