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Test Report of Land Mobile Radio Connectivity via Shared Satellite IP Networks and the Internet

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Additional information regarding any of the items contained within this report can be obtained from the National Law Enforcement and Corrections Technology Center–Northwest (NLECTC–NW).

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Abstract

The National Law Enforcement and Corrections Technology Center – Northwest's (NLECTC-NW) *Land Mobile Radio Connectivity via Shared Satellite IP Networks and the Internet Test and Evaluation Project* goals were to conduct limited, impartial, test and evaluation of commercial off-the-shelf equipment and affordable commercial satellite systems that might prove successful in linking remote public safety communications systems to larger urban, land-based, communications networks. Tests were conducted using commercially available Voice over Internet Protocol gateway equipment, satellite communications services, and network element equipment. The testing and evaluation focused on public safety land mobile radio communications links between urban areas and vastly remote Alaskan communities. The tests evaluated and demonstrated voice over Internet protocol interface units, voice-grade satellite communications (Satcom) services, as well as Satcom optimized virtual private network products. This test report describes a limited, impartial, test and evaluation of commercial off-the-shelf equipment that could potentially provide these links. Session test results indicate remote users of "rural" land mobile radio systems can be connected to users on the current mainland Alaska Land Mobile Radio system (and other similar systems) – with some caveats. Connections can utilize low-cost shared satellite Internet protocol (IP) connectivity and the Internet, given highly tailored network design and equipment choices. Although the tested technology implementation may not meet all federal agency security requirements without additional equipment, identified communications links provided a promising and adequately secure transport means for local, regional, and state and public safety agencies.

NLECTC-NW's *Land Mobile Radio Connectivity via Shared Satellite IP Networks and the Internet Test and Evaluation Project*, and its Test and Evaluation (T&E) sessions, addressed an issue that has plagued remote U.S. public safety communications, especially remote Alaskan communications; they all lack cost effective radio, telephonic, and data communications with urban centers. Due to their vast physical separation from the established telecommunications infrastructure, Alaska's rural communities and associated public safety offices have only one option for voice, video, and data communications – Satellite Communications (Satcom). Agencies throughout the US have similar challenges when they respond to critical incidents or disasters outside their normal radio coverage areas.

Project objectives were to test and evaluate commercially available Voice over Internet Protocol (VoIP) gateway equipment, Satcom services, and network equipment to determine if, and how well, they could support efficient, cost-effective, and secure voice and data communications between urban and rural locations. The testing and evaluation focused on public safety land mobile radio communications links between urban areas and vastly remote rural communities, and utilized the Alaska Land Mobile Radio System (ALMR). Project results indicate distant users of rural radio systems can be cost-effectively connected to subscribers on urban systems, including ALMR, Alaska's newest and largest LMR system.

Alaska Land Mobile Radio System: ALMR

The ALMR System is a new, state-of-the-art, "statewide," P-25 standards-based digital land mobile radio system. Unique in the United States, ALMR relies on shared infrastructure and shared federal/non-federal frequencies provided by the project participants: Local agencies, regional governments, state agencies, federal civilian agencies and the US Department of Defense. Statewide, the system began beneficial use in 2005. Beyond the "road system," where traditional telecommunications networks support the system, deployment has been delayed until resolution of the challenge presented by extending the network into areas where terrestrial communications are not available.

NLECTC-NW completed 30 days of testing sessions and determined the feasibility of interconnecting the mainland ALMR system with potential rural or "bush" land mobile radio sites scattered across the State of Alaska. Results are expected to be transferable to other LMR systems and remote locations, nationwide.

Testing indicates that users of rural analog or digital land mobile radio systems can cost-effectively connect to subscribers on core LMR systems. The sessions evaluated products and services having potential to provide practical, but not perfect, rural-to-urban VoIP connections. This potential does have some caveats that must be considered before deploying an operational system relying on this technology. For example; vendors do not consistently "certify" connectivity using Satcom as reliable enough for "mission critical" communications.

While it is unlikely these Satcom connections may ever be relied upon in a "shoot – don't shoot" scenario, as the typical deployment would be to interconnect an existing LMR system serving the day to day operations in a remote area to a larger or regional interoperable network, it is quite likely they would be relied upon to coordinate aid and response in disasters or provide voice communications where none existed before.

Security constraints also require clarification. While tested configurations will meet the security needs of nearly all local and State public safety agencies, they currently do not meet the end-to-end encryption needs of many federal agencies, without the addition of other security equipment. Many of the vendors participating in this evaluation indicated that they were addressing this issue in future products.

Testing did clearly demonstrate that VoIP links via lower-cost Satcom systems are viable today, yet they do require careful equipment choices and modest engineering efforts leading to a tailored interface network design. These include such engineering requirements as optimized voice-grade satellite Wide Area Network (WAN) circuits, as well as Local Area Network (LAN) systems optimized for recognizing and handling Quality of Service (QoS) based, and, potentially, encrypted data. Equipment selected must be capable of tolerating the delays caused by the satellite connection; for example, some popular networking equipment evaluated during this test was unable to tolerate the delays.

Testing also determined that, via two of the session's more robust and secure Satcom connections, other digital information could be simultaneously passed over the same satellite connection while LMR voice was being passed. During testing, a VoIP telephone connection, as well as Internet and email service, functioned while not significantly degrading the LMR voice communications. This indicates that, in addition to supporting LMR voice communications for rural areas, the satellite connection could serve this dual role, thus helping justify the expense of the service.

Lower bandwidth Satcom systems, such as those tested, are significantly less expensive when compared to traditionally available bandwidth being sold by legacy carriers. Capital outlay for IP Satcom equipment and projected network recurring costs appear to hover around ten to thirty percent of the comparable costs for traditional single channel per carrier (SCPC) Satcom transport, often referred to as a "dedicated circuit."

Based on the results of this evaluation, an agency's requirements, and expected levels of required remote telecommunications services, NLECTC-NW suggests comparing traditional telecommunications carriers' Satcom transport to the lower-cost shared satellite IP providers. Shared systems may well prove adequate at much lower capitol and recurring cost. Conscious of the issues raised in this report, many agencies may wish to consider today's affordable and basic VoIP and Satcom capabilities, especially in areas where none existed

Cost Comparison example:

Today, in a related NLECTC-NW project, St. Paul Island's internet access via a shared satellite IP network provider costs $205.00 per month. In contrast, traditional carriers' tariff costs on St. Paul, for equivalent bandwidth of 128 Kbps and 256 Kbps, are $2300.00 and $3250.00, per month, respectively.

Capitol costs for dedicated C-Band earth-station equipment are estimated at $80,000, compared to those of shared VSAT IP satellite systems of approximately $15,000.

Objectives

The objectives of this test and evaluation were to – test and evaluate commercially available VoIP gateway equipment, Satcom services, and network element equipment as they pertain to efficient, cost-effective, and secure voice and data communications between urban and rural locations.

Methodology

Throughout the four week session, significant setup time was devoted to engineering and determining which VoIP interface products, VPN devices, and Satcom services were capable of configuration to prove viable. The remaining test time focused on collection of adequate quantitative data to analyze. See **Figures 1, 2, and 3** for the standard configuration setups. These varied for each of the tested VoIP gateways, VPN devices, and Satcom service systems. Sets of data were collected by making repeatable Delivered Audio Quality (DAQ) measurements between the various VoIP gateway and VPN devices used to pass VoIP traffic over each of the three different satellite wide area network (WAN) circuits.[1] These WAN circuits were dictated by each satellite provider's transport network, as well as their connection to the Internet.

Project constraints limited the scope of testing of available Commercial Off-The-Shelf (COTS) products and satellite services. Available project peripherals, time, and funding, limited testing of equipment and services to those listed below. Satellite systems available for testing were determined by available coverage within Alaska, where the tests were conducted, and the advice of Microcom Communications, an experienced satellite engineering firm in Alaska. Compared to the contiguous U.S., where many additional satellite systems and services are available, Alaska has but a few. Results of testing on systems available in Alaska are expected to be repeatable with on those serving the contiguous states and those serving most areas, globally. Microcom provided a detailed report, *Satellites and Satellite IP Service Providers serving Alaska,* is included as appendix six of this report.

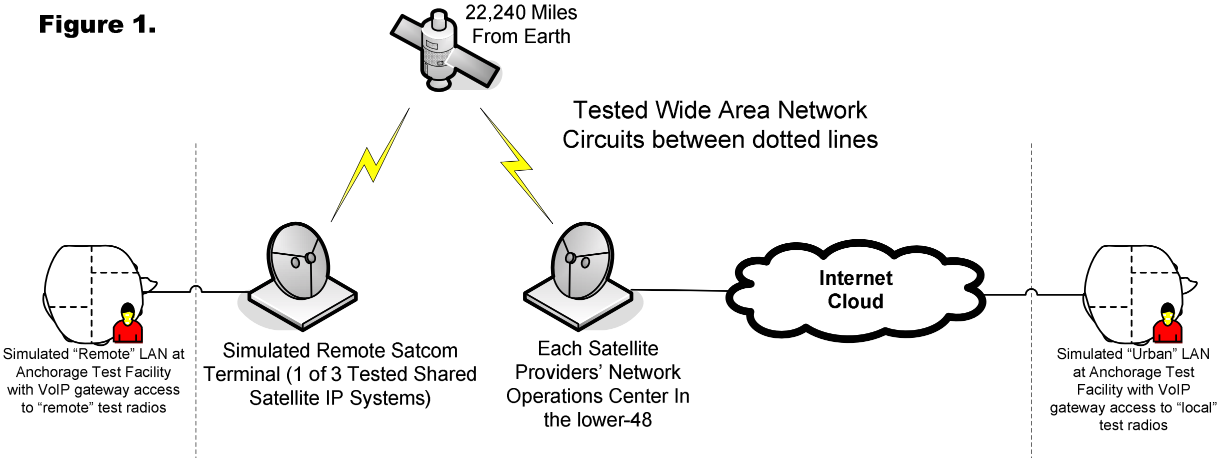
Delivered Audio	

Table A – Delivered Audio Quality Definitions

[1] DAQ measured by CTA Communications' Radio Coverage Evaluator (RaCE) test equipment and process. DAQ scores conform to TSB-88, a Telecommunications Systems Bulletin published by the Telecommunications Industry Association (TIA). DAQ level 3 is commonly specified as the minimum performance level for public safety systems.

Each Satcom provider terminated their Satcom circuit at their hub facilities, then routed all VoIP traffic, via the Internet, to our testing session's static IP addresses in Anchorage, Alaska, where testing was conducted. Refer to **Figure 1** for a simplified end-to-end network drawing of the tested configuration.

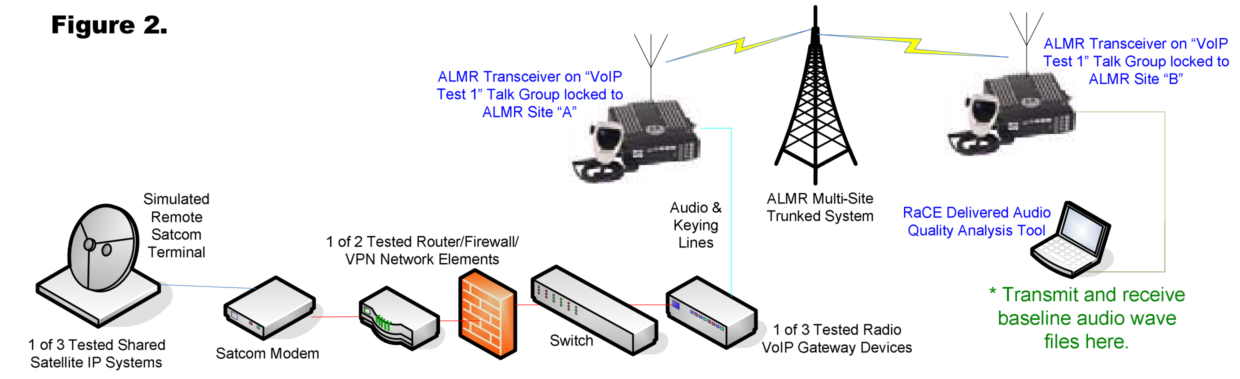
Figure 1.



Simple End-to-End Network Drawing

Figure 2 demonstrates the testing design used to simulate a rural or "bush" radio or VoIP gateway site, and represents a remote site with a local radio-to-radio connection to the mainland LMR system. Neither a VoIP telephone nor a computer connection is shown in this figure, but both could be connected through the multi-port switch.

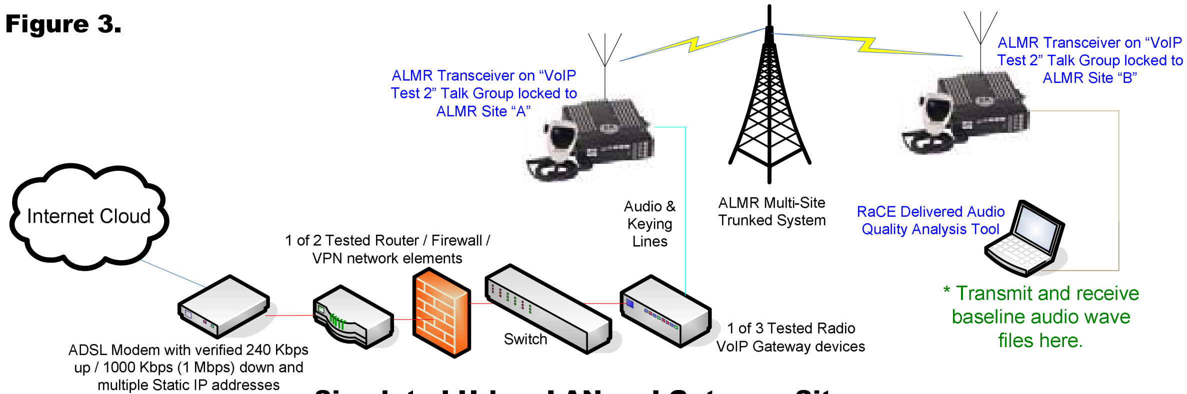
Figure 2.



Simulated Rural LAN and Gateway Site

Figure 3 details the simulated urban radio gateway configuration. As tested, this configuration allowed a single radio talk group (channel) from rural LRM system to fully integrate or communicate with the mainland LMR system.

Figure 3.



Simulated Urban LAN and Gateway Site

Developmental engineering and testing of VoIP, Satcom, and VPN equipment took place at the Municipality of Anchorage's Tudor Road microwave site. This facility was graciously offered to NLECTC-NW for project use, and offered a clear view to the sky for satellite shots, as well as available internet service, AC power, and ample space.

Satcom Systems

Testing and Evaluation of VoIP gateway equipment and VPN devices relied upon data transport via the available Satcom transport systems. Three distinct Satcom networks were tested.

Tested and evaluated Satcom systems:

- Network Innovation Associates (NIASat®) Network.
- LBiSat's Shared Hub/Network utilizing iDirect® technology.
- Starband's Small Office 484 with Turbomax® System.

Testing of the Starband Satcom network determined it was not compatible with any of our session equipment iterations. This was an expected outcome, as Starband specifically indicates that its system is not suitable for VoIP applications. However, because it was by far the most affordable, NLECTC-NW wished to determine if it engineering could prove it viable. The two remaining Satcom networks received extensive operational testing.

Comparison testing of the traditional, stalwart, and much more costly Single Channel per Carrier (SCPC) C-band satellite system with the shared satellite IP networks and their respective Ku-band Very Small Aperture Terminal (VSAT) systems would have presented an additional technical baseline – most likely favoring certain aspects of traditional satellite system transport due to its "dedicated circuit" qualities. Unfortunately, testing of a traditional C-band circuit was not possible, as the carrier was unable to provide a circuit during the session's testing period.

VoIP Gateways

Three VoIP gateways were testing during this evaluation. Each was provided by the manufacturer along with engineering expertise in their operation and configuration.

Tested and evaluated VoIP gateway equipment:

- Raytheon/JPS' ACU-T®.
- Motorola's MotoBridge®.
- Twisted Pair's WAVE®.

Given the relatively narrow bandwidths of tested Satcom systems, testing and evaluation was conducted using the VoIP gateways' lower bit-rate vocoders. A common low bit-rate vocoder was found between two of the three VoIP gateway units – the G.729 codec. The other tested vocoder (codec), the Global System for Mobile Communications (GSM) specification, was the nearest similar bandwidth codec. It was used for comparison purposes with G.729. Specifically, both Twisted Pair and Motorola's gateways were programmed for G.729 operation, which uses eight Kilobits per Second (Kbps) of bandwidth, while the Raytheon/JPS gateways were programmed for GSM (13 Kbps).[2]

Firewall/VPN Devices

Utilization of open networks for carrying sensitive information, such as public safety voice communications, mandates security measures are in place. Yet, all security measures have an impact on data throughput and can adversely impact data transmission through narrow bandwidth connections. NLECTC-NW personnel and project engineers wished to evaluate the impact of securing data flowing across the WAN circuit.

A limited number of recommended COTS solutions were tested. Two VPN systems met our requirements and were evaluated. The equipment configurations determined to work with some reliability and quality (without a VPN tunnel), were tested a second and third time – through the different VPN systems. Adjustments to these VPN systems were made to optimize VoIP transmissions, where possible.

Tested and evaluated Router/Firewall/VPN equipment:

- Cisco Pix® 506 Firewalls with VPN capability [this series recently unsupported by Cisco in May, 2005]
- End II End Communications™ Satcom optimized VPN devices.

Common Gateway Radio Platform

The common VoIP interface radio equipment consisted of four Motorola ASTRO™ Digital Spectra® Plus radios. P25 VHF mobiles were loaned by the State of Alaska for testing, and were internally configured to make use of the rear accessory connector that provided push-to-talk keying information, transmit and receive audio. For the duration of the session, two mobile radios were wired to each

[2] Communications Test Report, page - 29 -

vendor's VoIP interface devices – acting as the wireless access radios in the remote and urban systems. The two remaining radios acted as the subscribers communicating between one another across the Satcom/Internet link.

Audio analysis was performed by CTA Communications using their Radio Coverage Evaluator (RaCE) tool. Delivered Audio Quality (DAQ) tests were conducted while accessing the ALMR's P25 common air interface. Through the interfacing of end subscribers' radios, CTA utilized powerful laptop computers which transmitted and received baseline audio wave files to and from one another. CTA summarized recorded session results, and presented representative audio and visual samples of collected measurements. From this data, CTA was able to present findings regarding P25 conventional, P25 trunking, and Satcom-linked P25 trunked system subscribers' transmission delays, voice quality, as well as audio waveform analysis and general reliability.

Microcom Communications facilitated the session evaluation as Satcom subject matter experts, installing and coordinating satellite communications with Satcom vendors, as well as integrating the various vendors' VoIP interface and VPN and firewall products with the separate LANs.

Developmental Engineering and Other Issues Encountered

The first three weeks of testing identified a common problem observed with each vendor's VoIP transmissions on the available Satcom systems – the loss of the first 300 milliseconds to 1 second of message audio. This early audio data loss was diagnosed and corrected late in testing by implementing a small eight or twelve Kbps Committed Information Rate (CIR) to our VSAT terminal connections. In effect, this served to keep our satellite session "alive" and avoided the required set-up time normally experienced in data transfer on shared IP satellite connections. The addition of a small CIR rate to our Satcom services virtually eliminated the initial remote site transmitted audio loss. Any initial early loss identified after CIR implementation was determined to be inconsequential to voice quality.

Radio frequency interference attributed to the four VHF band mobile radios and associated antennas operating together in a confined, almost near-field, environment initially hampered testing. Mobile receiver desensitization and intermodution interference were subsequently minimized by differing antenna polarizations, maximizing antenna vertical and horizontal placement distances, and taking advantage of metal building shielding techniques; to include the insertion of coaxial line attenuators. Post session data analysis determined only one specific local trunking channel (of many available at the sites) was interfered with, so the data collected from our random use of that channel was subsequently removed from CTA Communications' final analysis.

General Results

The session's most revealing and helpful technical solution was the implementation of the small Committed Information Rate (CIR) of eight or twelve Kbps on the Satcom networks. This CIR feature virtually eliminated any initial transmitted VoIP audio loss, and appears to be an essential feature for future two-way radio transmissions transported via shared satellite IP systems. In essence, the CIR ensured “burstable” bandwidth, such as the immediate need for bandwidth generated by a two-way radio. It should be noted, a satellite connection configured with a CIR appears to add additional cost, as it may likely be considered a premium feature on a shared satellite IP system.

Each of the VoIP gateway devices provided radio linking capability. However, each gateway product is unique and presents characteristics suitable for different application suites. With few exceptions, VoIP gateway devices were not a limiting factor in this test and evaluation project.

Satcom system transport capabilities are important when considering VoIP data passage. Specifically, viable Satcom systems carrying radio related VoIP traffic must first be designed to efficiently carry general VoIP traffic. For example, Starband, a consumer-grade shared satellite IP network, was not capable of passing session voice traffic of any kind. While this network clearly stated that it would not support normal VoIP traffic, its potential was tested because of its low cost and wide-spread use throughout Alaska.

Satcom bandwidth evaluations revealed a narrower uplink width of 64 Kbps passed the tested VoIP radio traffic successfully. With at least one VoIP device, the Motorola MotoBridge®, larger bandwidth requirements like 128 Kbps or 256 Kbps (or higher) may be necessary in order to establish the multiple session initiation protocol (SIP) links for this system’s configuration. In a future shared, multiple site, satellite network design, these identified narrow bandwidth capabilities may offer efficiencies and management options as a limited bandwidth Satcom network grows with users. These narrower bandwidth requirements may lower the operating costs of any future shared satellite IP network system design, and may place a shared network design within the financial reach of more rural public safety organizations.

Evaluation of VPN devices readily demonstrated differences between devices designed for terrestrial networks and those optimized for transport over high latency and jitter prone Satcom networks. Through its transparency, the End II End Communications™ Satcom optimized VPN solution proved itself in testing, while an older Cisco Pix® 506 Firewall/VPN system did not pass VoIP traffic over the Satcom networks tested, in spite of extensive engineering efforts.

Communications Reliability

Consumers of terrestrial based LMR systems normally require a minimum reliability guarantee, or certification from their vendors, that the system will reliably pass communications to a certain percentage, sometimes as high as 99.999% or 5-9s reliability. At least one vendor currently will not certify their VoIP product for rigorous public safety use, due to the less-than-perfect communications via satellite transport mechanisms. The manufacturer indicated its VoIP system’s capability over these shared satellite Internet Protocol (IP) networks should only be used for “administrative use.” Other Voice over Internet Protocol (VoIP) interface vendors have not made this statement, and do indicate their solutions can be relied upon for public safety purposes.

Agencies should consider and weigh their requirement for communications reliability against their need to establish basic communications with remote locations where none ever existed. This has sometimes been referred to as Better than Nothing (BTN) technology.

Testing demonstrated that with proper configuration and provisioning, and robust ground based networks, barring a failure of critical equipment such as earth stations or networking equipment, systems should prove reliable.

Security Considerations

The tested configurations will meet the security requirements of the majority local and State public safety agencies. Each configuration ensured that all wireless and wire line transmissions leaving physically secure sites were encrypted with high strength measures – 128-bit or higher Advanced Encryption Standard (AES) on P25 common air interface (wireless) transmissions, and end-to-end 256-bit AES via Satcom and Internet transport. Federal security requirements, those that govern secure military systems, for example, are more stringent; tested configurations will not meet their requirements without the addition of bulk encryption devices between radio systems and the VoIP gateways.

As tested, and mandated by limitations of the VoIP gateways evaluated, the network configurations discussed in this report break out encoded transmissions at two intermediate points – each gateway location. Most public safety agencies will contain their radio and network communications equipment within a secure setting, such as a police station or other government facility. The fact that the tested configurations have points at which the network is subject to unencrypted data transmission is likely to be viewed as a manageable risk, when weighed against the cost of bulk encryption devices.

Federally secure systems require end-to-end encryption – without cipher coded data being broken down into uuencoded or "plain text" at any point along the transmission path, or between communications endpoints. Bulk encryption devices are being used to provide this additional level of security on secure systems relied upon by military and federal enforcement agencies. Advances in equipment and adoption of in interim Inter Sub-System Interface (ISSI) Standard for P-25 systems may well provide a solution to this issue in the near future.

Test results indicate users of rural analog and digital land mobile radio systems can be cost-effectively and securely connected to subscribers on traditional LMR networks. Today's COTS VoIP interface products, Satcom services, and public safety grade network security products can allow for a wealth of voice and data traffic to be passed efficiently, securely, and cost effectively to most remote places within North America, and, potentially, globally. In effect, communications professionals should no longer consider their systems in remote locations isolated due to the lack of Public Switched Telephone Network (PSTN) or microwave systems to urban or regional systems. The potential exists today, with even greater future potential, to create effective satellite-linked voice and data IP networks.

Summarized session findings:

- Substantial planning, engineering, testing, and troubleshooting are required to implement a reliable, stable, and economical Satcom connectivity solution.
- Capable Satcom IP services are available for voice and data transmissions in Alaska.[3]

[3] Appendix 6, *Satellites and Satellite IP Service Providers Serving Alaska.*

- The public Internet can be used to pass secure and practical VoIP and data traffic, and can be utilized as part of a secure WAN solution linking widely disparate locations.
- VPN solutions exist today that can secure public safety networks utilizing Satcom and the Internet.
- Voice land mobile radio traffic over Satcom can take place with little voice quality degradation.

Based on the positive results of this testing project, it is hoped that public safety practitioners find value, direction, and purpose in NLECTC-NW's project.

The very nature of IP lends itself well to the passage of a host of telecommunications services. IP voice and data over existing and upcoming satellite providers' communications networks offers communications capabilities seldom seen in areas were no PSTN connectivity exists, or where it is disabled or destroyed – such as remote parts of Alaska or in hard-hit, inhospitable, disaster areas like the Gulf Coast region after Hurricane Katrina.

Recent developments regarding the implementation of the P25 Inter Sub-System Interface (ISSI) standard, as well as our positive findings regarding two-way radio VoIP via Satcom and the Internet, offer a means for public safety and communications industry managers and engineers to review, compare, test, and evaluate how these IP technologies may facilitate effective VoIP and related IP data communications. NLECTC-NW would like to support further investigations regarding this unique and potentially far-reaching communication transport capability.

This project only scratched the surface regarding effective and secure IP over satellite communications systems. Project constraints limited the scope of engineering, testing, and evaluation that could be conducted. The project's narrow focus did allow involved parties to conduct a certain amount of developmental engineering – leading to some successes. Newer satellite IP providers' networks and packet based systems should be evaluated for their support of VoIP radio traffic. Future testing with alternative Satcom networks and interface devices will expand our knowledge and experience.

An actual application of this technology:

Alaska Land Mobile Radio project managers, based on the preliminary results of the NLECTC-NW test, have begun discussions with the US Air Force unit managing the Early Warning radar sites along the Aleutian Chain, and the northern and western coasts of Alaska. These sites could provide substantially enhanced coverage for the ALMR network in these areas, extending coverage to small communities otherwise unable to afford to participate in the new statewide system.

Site surveys and system designs for these sites are currently underway, as this report is completed.

Areas that require further testing and evaluation include:

- Evaluation of packet-based satellite networks for support of VoIP radio transmissions
- Evaluation of Satcom networks supporting the contiguous US for suitability in supporting VoIP radio networks
- The passage of ISSI and related P25 IP transport standards via geosynchronous satellite systems.
- Subscriber encrypted digital transmissions via Satcom without dropping to base-band audio within the circuit (related to ISSI passage and new system and equipment deployments).

Communications Test Report

By

INTRODUCTION:

This report has been prepared by CTA Communications with a significant contribution from Microcom. The testing was conducted jointly by CTA and Microcom personnel in conjunction with representatives of the equipment suppliers. All of the satellite system and internet connectivity was arranged for and/or provided by Microcom. Microcom remained in charge of the frequent adjustments that were needed to addressing and IP equipment configuration throughout the test process. CTA provided the test equipment utilized for the objective evaluation of the audio quality delivered by the radios at each end of the circuits. CTA also handled the radio interface to the test equipment and had the overall responsibility for the collection and evaluation of the test results.

Questions concerning these areas of responsibility should be addressed to:

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EXECUTIVE SUMMARY:

The various users of the Alaska Land Mobile Radio System (ALMR) have identified the need to connect rural portions of public safety trunked radio networks to major dispatch centers in the Wasilla and Fairbanks areas. As most long haul telecommunications services in rural Alaska are provided over some type of satellite network, the ALMR system manager needed information on the feasibility and practicality of linking distant land mobile radio (LMR) systems via different types of satellite networks. The purpose of the test program conducted by the Northwest Law Enforcement and Technology Center was to determine if LMR equipment that cannot practically be connected over traditional landline means, can be linked in a reliable and useful manner over satellite.

Testing was performed using the existing Alaska Land Mobile Radio System as the test bed. During the project, various ALMR radios were interconnected using several satellite link configurations. Analog audio from the trunked radio network was converted to digital using standard vocoders used for VOIP and then transmitted over the public internet to satellite service uplink center. From that point it was sent via the satellite network to a remote VSAT and was converted back to analog audio for handoff to the trunked radio network. Several predefined vendors of Radio Internet Protocol (IP) gateways, satellite networks, and security enhancing Virtual Private Networks (VPNs) were tested in an attempt to determine which configurations should be pursued further.

During the course of the project, several areas of system link performance were investigated. These include link transmission delays, voice quality, and general reliability. Link delays were determined for the LMR and link portions of the system. Notes on reliability and ease of equipment setup are also included in this report.

CTA's Radio Coverage Evaluator (RaCE) tool set was used for determination of voice quality. RaCE evaluates human speech in terms of Delivered Audio Quality (DAQ) on a standard scale from 1 to 5.

Summary Results:

- With training, it is practical to carry on a conversation over a satellite-linked LMR radio system. Total call delay is in the neighborhood of 2.5 to 3 seconds. The IP/satellite link contributes roughly 2 seconds. The LMR equipment adds another 0.5 to 1 second depending on the configuration.
- Despite the complex linking path, voice quality is generally very good, measured in the DAQ 4 range.
- VPN equipment is highly recommended for system security, ease of system setup, and for improved system reliability.
- Satellite IP services that provide sufficient quality of service to support Voice over Internet Protocol (VoIP) telephony to the PSTN, can support trunked radio gateways. An initial bandwidth allocation mechanism, such as a Committed Information Rate (CIR) is required to avoid clipped speech.
- VPN solutions do exist that can be employed over public shared satellite IP networks to provide an end to end security solution without degrading the satellite network performance or voice quality. However, they must be specifically tailored for use on satellite networks since the high latency of these networks greatly limits most VPN performance.

- The minimum bandwidth needed to support a radio channel with or without a VPN tunnel over a shared satellite IP network is 64 Kbps (assuming use of a CIR).
- The public internet can practically serve as part of the network to provide a connection between two trunked radio networks without affecting network performance or voice quality.

PURPOSE AND DESCRIPTION OF THE TEST:

This report describes the test results of Voice over Internet Protocol (VoIP) transported over satellite communications links. The tests performed are those called for under Phase 2, Functional Testing in the test plan “Draft Test Plan for TCP/IP Transport through Satcom Facilities”, Revision 3.

The primary objective was to functionally test and evaluate commercially available Satcom providers and VoIP interface devices in an operational environment. Testing involved several vendors of VoIP gateway equipment, satellite service providers, and the public Internet to connect geographically separated radio systems allowing distant users to communicate with each other.

While the ultimate goal is to link distant radio sites via satellite, two local sites on the Alaska Land Mobile Radio (ALMR) System are used in this test exercise to facilitate easy access to both ends of the test setup. System diagrams illustrating eight test configurations are shown in Appendix 1.

A second objective was to explore the possible enhancements available to obtain the most reliable and stable operation of any link established. A third objective was to explore the possibility of operating through a Virtual Private Network (VPN) in order to provide additional security as well as a potentially more robust system.

TEST METHODS:

Each vendor of VoIP gateway equipment was encouraged to carefully optimize their equipment for the highest quality voice reproduction they could achieve over the available links. Assistance was provided by CTA and Microcom personnel whenever needed in setting levels and establishing Internet Protocol (IP) connections. The link consisting of the VoIP gateways, the satellite hop, the internet and the two radio sites were then tested to determine the Delivered Audio Quality (DAQ) as measured by the RaCE (Radio Coverage Evaluator) test equipment supplied by CTA Communications. The audio testing was accomplished by passing a known sample of speech in one direction through all of the series connected equipment and then evaluating the arriving signal at the destination to determine what changes in the voice quality had occurred. The system would then automatically test the return path in the same manner. The normal testing method was to initiate the RaCE mobile audio sequence into the satellite terminal end of the network and evaluate that call as it arrived via the internet end of the network using the RaCE stationary equipment. The return path started with the RaCE stationary unit connected to the internet end of the network and terminated at the mobile end connected to the satellite terminal where the second audio analysis was accomplished. The preliminary test results were displayed on the test computers for all participants to view. An additional test consisted of timing measurements of all the principle events occurring during the testing. The 8 tracks of data measured were the Push to Talk, Transmit Power, Transmit Audio Envelope and the Receive Audio Envelope as seen at the test radios at each end of the paths. The timing measurements were accomplished under multiple modes of system operation in order to see the effect of changing from one mode to another. A good knowledge of the timing results will assist users in understanding the special requirements for operating their systems over satellite links.

TEST RESULTS:

A very large number of results have been recorded and a few significant findings are displayed here. The WINDAQ Browser Software is included on the accompanying disk that will allow the exploration of the timing results.

The latest version of that software is available from HTTP://WWW.WINDAQ.COM on the internet. Waveforms of audio files (.wav files) can be viewed using a freeware program available from HTTP://WWW.AUDACITY.SOURCEFORGE.NET on the internet.

It should be noted that the entire team involved in this testing felt a great deal of disappointment in the observed results during the first phases of the test program. The results always seemed to fall short of what is required for reliable communications.

The calls initiated on the satellite end of the links tested were plagued by a persistent loss of the first portion of the message which included a necessary preamble that triggers the recording and analysis of the audio. Radio Frequency Interference (RFI) was a constant issue in the internet terminal to satellite terminal direction. No amount of repositioning antennas, adding attenuators or other means at our disposal completely eliminated the issue. Eventually it was determined that the RFI was associated with only one particular channel assignment. The effects at this point became easily recognizable and the offending results were removed in the post processing. There are notes in each of the resultant spreadsheets where this was necessary.

Towards the end of the scheduled testing, a solution was discovered that alleviated virtually the entire data loss problem at the start of the test messages. This solution which called for the satellite service provider to include a Committed Information Rate (CIR) of 8 KB allowed the radio originated messages to proceed without the necessity of negotiating a changed data rate in the satellite system. This solution is responsible, more than any other factor, for considering the test program a success.

During the testing we accumulated over 2.3 GB of data in more than 29,000 files. Many of these are only appropriate for the internal needs of the RaCE analysis software. A large number were generated during the setup and alignment phases of the project and for that reason are not appropriate for inclusion here. A CD is included with the report containing files that are appropriate for anyone wishing to delve further into the results. Included also on the CD, are page-size views of the timing records that are presented in the next section.

TIMING EVENTS

In this section we present the timing involved in the following types of calls:

- Direct radio to radio call in digital mode
- Radio to radio call in digital mode via a trunking site
- Digital call via Satcom link

The timing examples presented are a representative sample of the measurements collected, and serve to familiarize the reader with the mechanics of link operation. Building on this background, we then move into discussion on the performance characteristics of the various vendor and equipment configurations.

TIMING EVENTS FOR A DIRECT RADIO TO RADIO CALL IN DIGITAL MODE:

The direct radio to radio case allows us to observe the timing characteristics of communication between two digital radios. There is no satellite link or radio site infrastructure between the two radios. Mobile refers to radio #1 and stationary refers to radio #2.

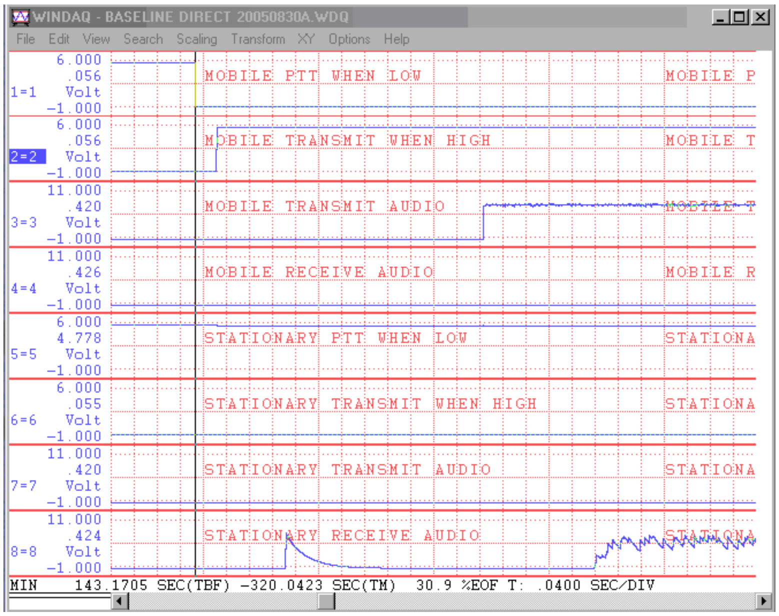


Figure 1 DIRECT PTT START.GIF

In Figure 1, the cursor is located at the start of the PTT operation. For our timing analysis, this is considered as TIME 0 (143.1705 seconds into the record).

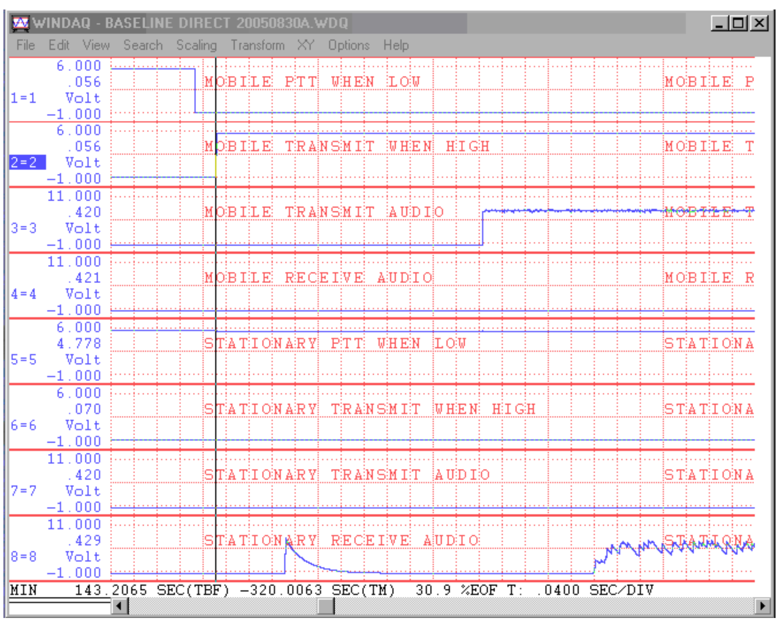


Figure 2 DIRECT TX START.GIF

In Figure 2, mobile transmit is shown occurring 143.2065 seconds into the record. This indicates that the mobile synthesizer and power amplifier required approximately 36 milliseconds to respond.

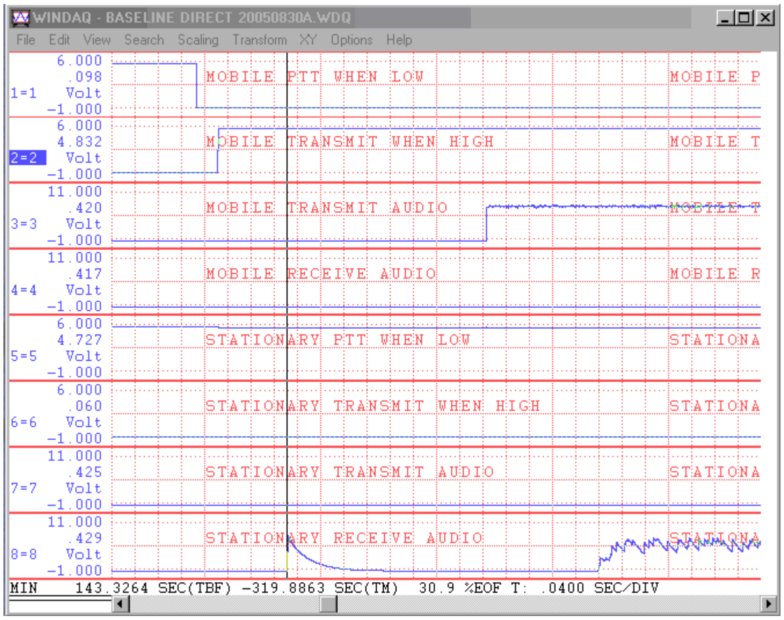


Figure 3 DIRECT RX UNSQUELCH.GIF

In Figure 3, RF presence and valid digital modulation have been detected. The receiving radio has responded by connecting its audio circuitry to the speaker and all of the audio circuits have not quite settled into equilibrium yet. The short pulse seen in trace 8 is usually not audible to the user.

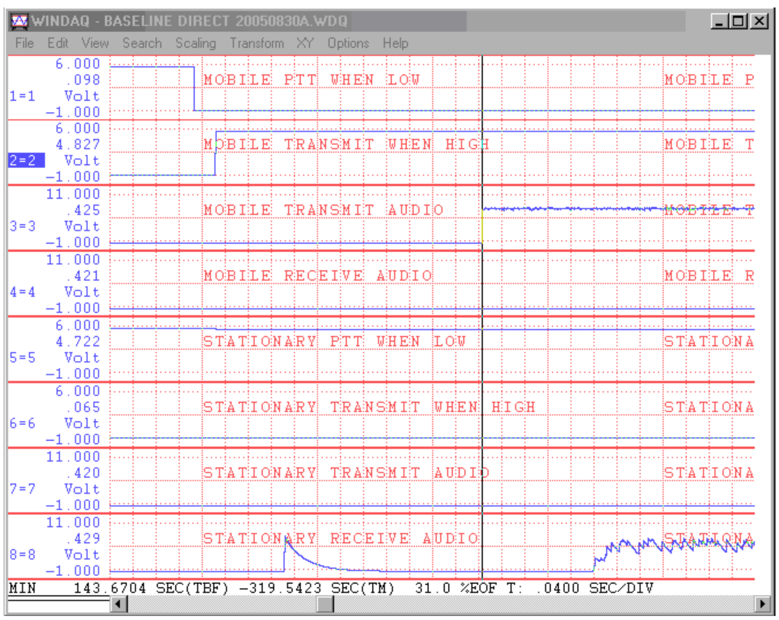


Figure 4 DIRECT PREAMBLE TX START.GIF

In Figure 4, the cursor is positioned at 143.6704 seconds into the record. RaCE waits until this point in time before starting to send audio. A deliberate delay of approximately 500 milliseconds is provided to insure that all audio circuits have settled into equilibrium. This preamble is detected by the destination radio as the trigger point for starting the recording of the receive audio to be analyzed.

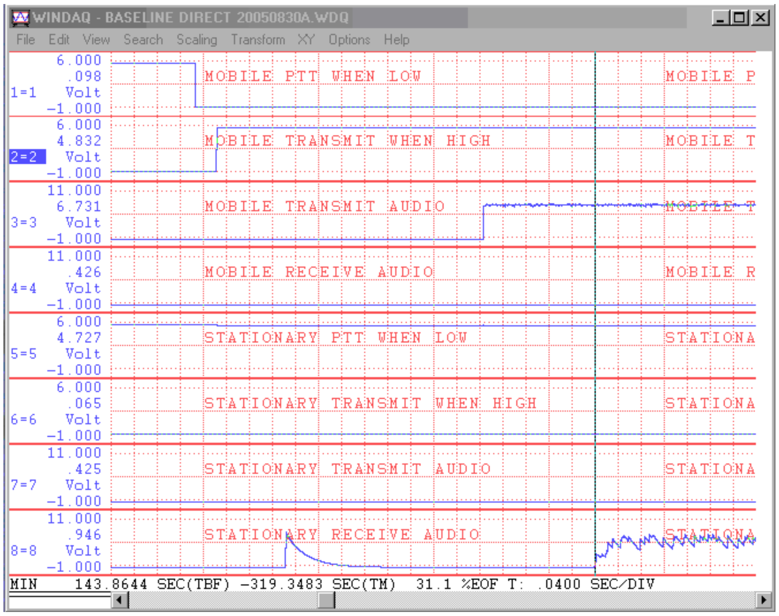


Figure 5 DIRECT PREAMBLE RX START.GIF

In Figure 5, the cursor now positioned at 143.8644 seconds, marks the point of valid receive audio. It took approximately 194 milliseconds for the transmitting radio to process the first packet of audio into a digital signal and for the receiving radio to decode it.

This value of 194 milliseconds is the typical latency contribution of a pair of radios within a digital system. This short latency period is not noticed by users under normal radio use conditions.

TIMING EVENTS FOR A RADIO TO RADIO CALL IN DIGITAL MODE VIA A TRUNKING SITE:

Processing a call through a trunking site and its associated control components always adds processing time. A study of the timing compared to that of the direct radio to radio call will provide a good approximation of the overhead imposed by the system. As with the direct radio to radio call, the delays and latency indicated are not normally noticed by, or of concern, to the users of the system. In no way is this information meant to be used to compare one trunking system to another; it is presented here as background for understanding trunked site timing before adding the satellite link into the equation.

It should be noted that there are some significant differences in the timing events when you compare a direct call to a trunking call. In the trunked scenario, there is an initial call made on the control channel followed by a change to an assigned working channel as well as the system storage and forwarding of the voice packets.

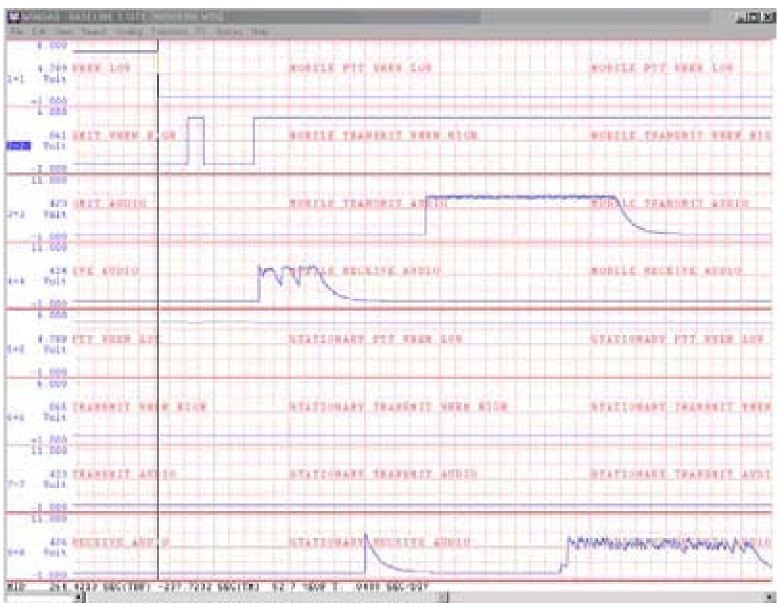


Figure 6 1 SITE PTT START.GIF

In Figure 6 the cursor is shown at the start of the mobile radio PTT operation. The time within the record for this event is 264.4213 seconds but is still considered as TIME 0 for this set of sequenced operations.

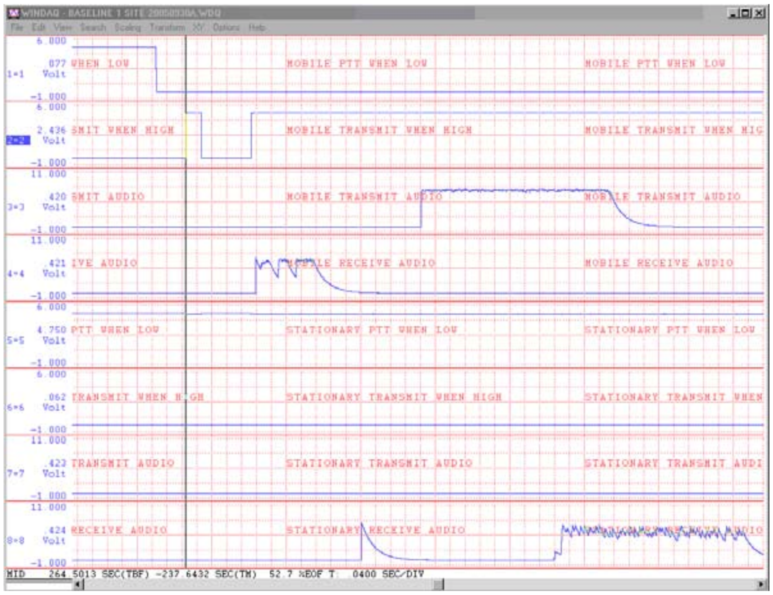


Figure 7 1 SITE CC TX START.GIF

In Figure 7, the cursor is now located at the record time of 264.5013 seconds which is approximately 80 milliseconds after the beginning of the PTT. This mobile transmission lasts about 40 milliseconds and is aligned in time with designated slots assigned by the radio site control channel transmitter. During this period the calling radio identifies itself and requests the type of call to be made. During the idle time following this transmit pulse, the control channel responds to the calling radio and the called radio(s) with a channel assignment. All of the radios involved in the call then leave the control channel and change to the assigned working channel.

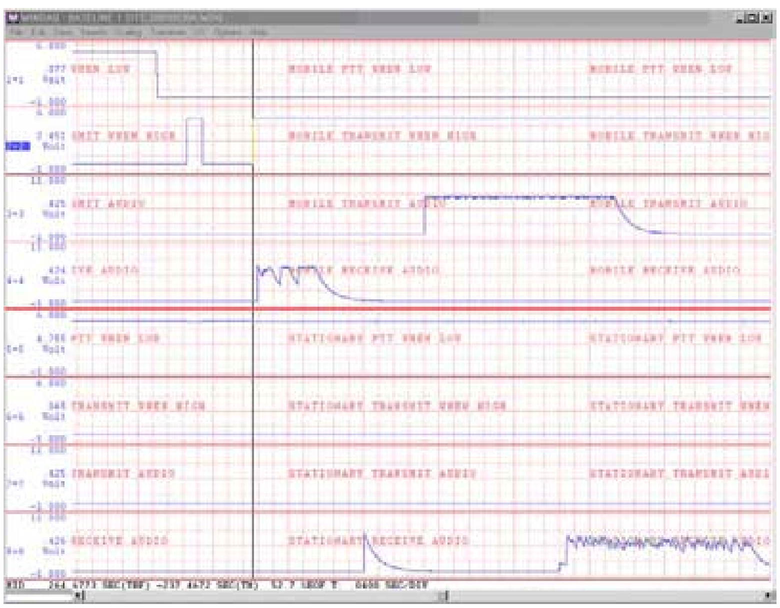


Figure 8 1 SITE WC TX START.GIF

In Figure 8, the transmitting mobile has begun its second transmission at the record time of 264.6773 seconds or approximately 256 milliseconds after the PTT start but is now operating on the working channel. Within a few milliseconds, the transmitting radio produces a “Grant Tone Sequence” in the local speaker indicating to the operator that it is now OK to begin talking. The local microphone is connected to the transmitter modulation circuits immediately after the end of the grant tone.

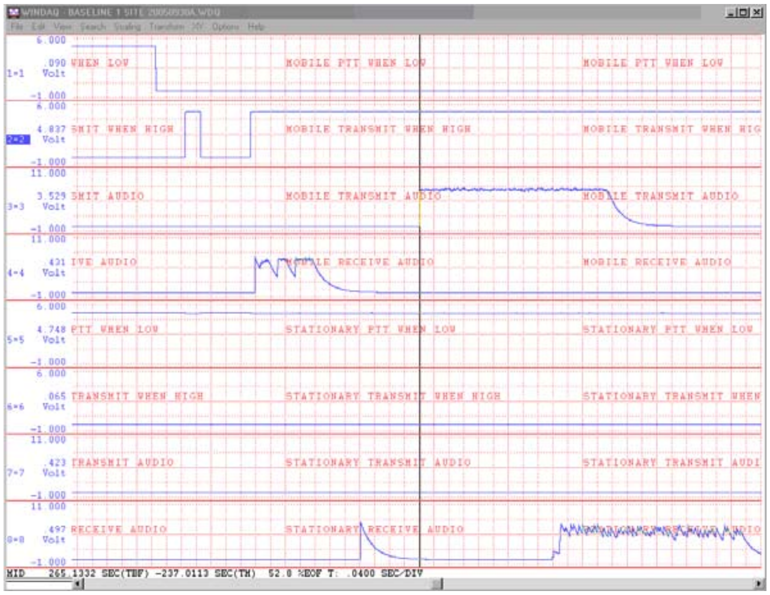


Figure 9 1 SITE PREAMBLE TX START.GIF

In Figure 9, the cursor at the record time of 265.1332 seconds marks the point where RaCE begins the transmission of the preamble. This point which is controlled by RaCE is well after the time when the audio circuits are energized and expected to carry normal user audio. At this point we are approximately 712 milliseconds into the call as referenced from the PTT.

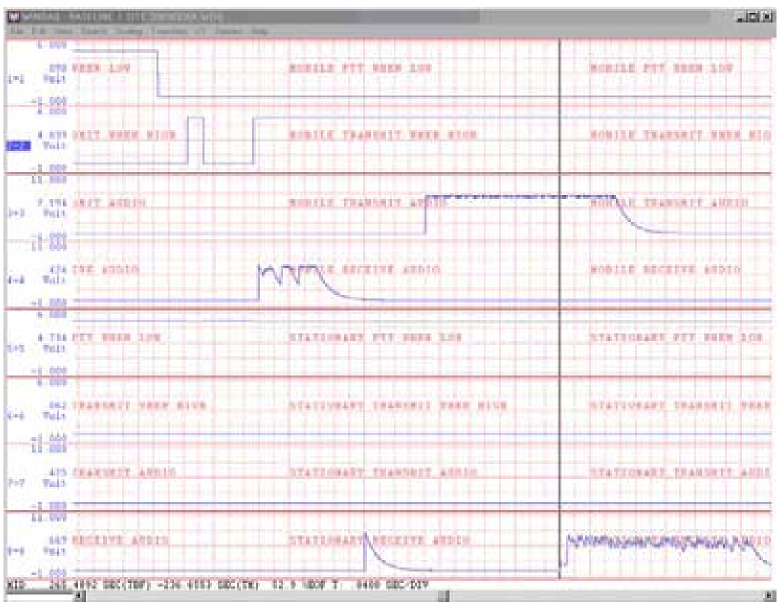


Figure 10 1 SITE PREAMBLE RX START.GIF

In Figure 10, the cursor is at a record time of 265.4892 seconds showing where the stationary radio has started to send the preamble audio to the speaker. Approximately 356 milliseconds have elapsed since audio was applied to the sending radio. This time represents the latency between two radios in a single site trunking system. Latency was 194 milliseconds between two radios operating directly, so the difference of 162 milliseconds is the overhead imposed by the trunking system. These times should be considered approximate as they would require a large number of measurements to determine an accurate average.

TIMING EVENTS FOR A DIGITAL CALL VIA SATCOM LINK:

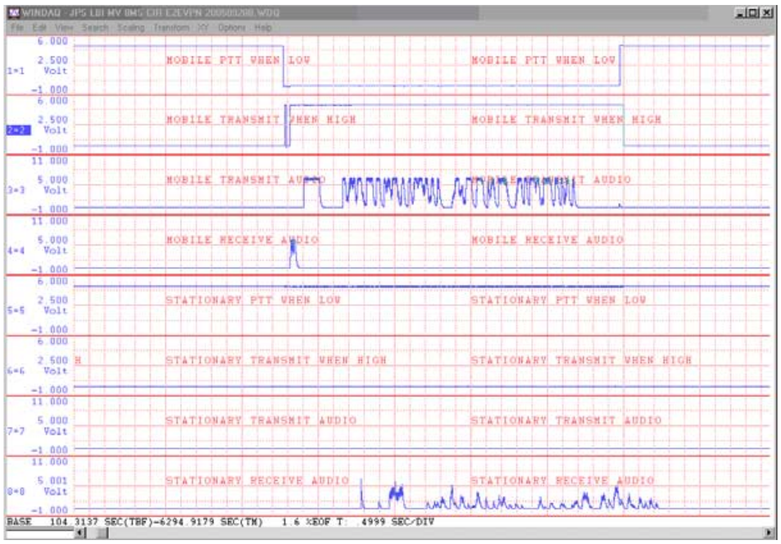


Figure 11 TYPICAL SAT TERMINAL ORIGINATED CALL.GIF

Figure 11 illustrates the timing sequence of a digital call between two radios, one on each of the trunked sites linked via Satcom. In this case, the test call originated on the satellite terminal end of the link and was received at the internet terminal end. The timing scale is 0.5 seconds per horizontal division.

Trace 1 shows the PTT signal of the originating radio. Trace 2 shows the actual transmit times for the originating radio including the short control channel burst. Trace 3 is the compressed envelope of the audio applied to the originating radio. Note the start point of the preamble, the first activity on trace 3. Trace 4 shows the grant tone on the speaker line of the originating radio. Trace 8 is the envelope of the received audio at the destination radio located on the internet terminal end of the link. Note that the preamble start time is about 5.6 divisions after the start in trace 3 representing a total link latency of 2.8 seconds in this direction. Subtracting the trunking latency for two sites (.356 X 2 = .712 seconds), the actual IP/satellite link latency is 2.088 seconds (2.8 - .712 = 2.088). This latency time includes not only the satellite transit time but also delays in all of the routers, bridges, IP gateways and VPNs in the entire route traversed by the test message.

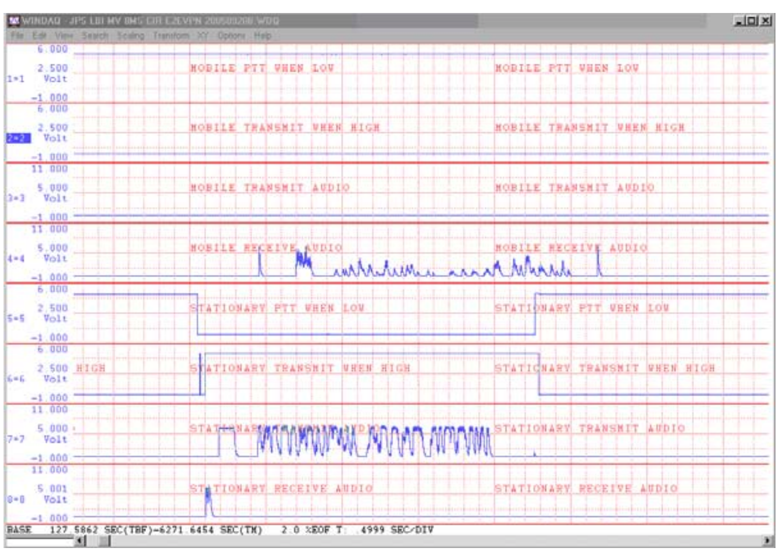


Figure 12 TYPICAL INTERNET TERMINAL ORIGINATED CALL.GIF

Figure 12 illustrates the call sequence in the opposite direction. This test call originated on the internet terminal (stationary radio) end of the link and was received at the satellite terminal end (mobile radio).

The originating radio PTT and actual transmit times are shown in traces 5 and 6. Trace 7 shows the originating compressed audio envelope. Trace 8 is the originating radio grant tone burst which is not a significant part of this measurement. Comparing events on trace 7 to events on trace 4 shows total system latency in this direction of 2.525 seconds. Subtracting the latency of the two trunking systems, 0.712 seconds, this equates to an IP/satellite link latency of 1.813 seconds. In practice, considerable call timing variation due to variable routing delays in the internet portion of this call path could be expected.

AUDIO PATTERN ANALYSIS

This section describes the audio patterns used during testing.

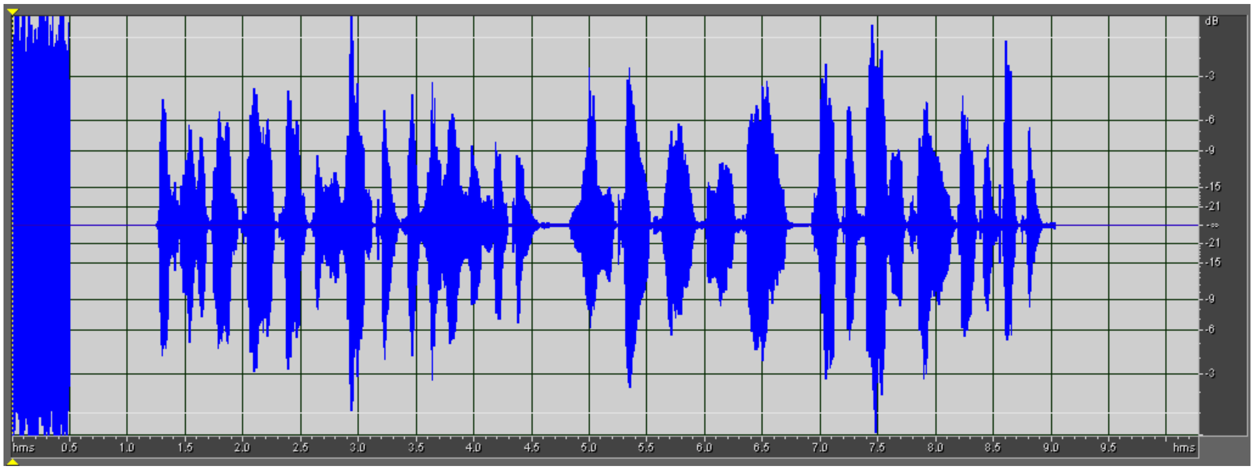


Figure 13 TX AUDIO WAVEFORM.GIF

In Figure 13, the waveform of the transmitting radio test audio is shown with a time scale of 0.5 seconds per division. This particular waveform portrays a message recorded with a male voice. There are four major elements to the test message. The first 500 ms is a burst of white noise that has been filtered to remain within the 300 Hz to 3000 Hz range. This is known as the Preamble and is used by RaCE to reliably detect the start of the message. It has been found that pure tones do not pass well through many types of vocoders but the noise sequence shown seems to be compatible with vocoders tested to date. The second element is a 750 ms period of silence. RaCE begins recording the receive audio during the silence period. The third element is the message body containing the actual human voice test phrase. Recording time is set for one second longer than the message body. Recording ends during the final message element, a 1.25 second silence period. This final period of silence helps insure the final squelch burst is not captured in the recording, adding unwanted noise degradation.

If at least 250 milliseconds of continuous preamble is detected and there is no preceding long burst of noise, RaCE will start the recording in the first silent period and end within the final silent period. It is not necessary to have a precise start trigger point because the algorithm used for determining the quality of the received voice is capable of shifting the waveform in time to align it for comparison. The test phrase utilized for this testing was: “This is a test of the Alaska Digital Radio System, one, two, three, four, five, alpha, bravo, charlie, delta, echo.” This test phrase does not present all of the possible English language sound combinations but it does contain a sufficient variety to properly test a vocoder based system. The overall test call length using this test phrase is about 10.3 seconds.

The following three figures show some typical audio waveforms as received by the RaCE equipment. Two of the figures represent the audio that should be expected with a properly configured system, and the third figure shows an example of the audio loss that occurs in the presence of heavy interference. Audio files resulting from this heavy interference, which was due to the close proximity of too many radio transmitters along with a non optimum system channel assignment, are not considered to be a valid test result and are not included in the voice quality analysis.

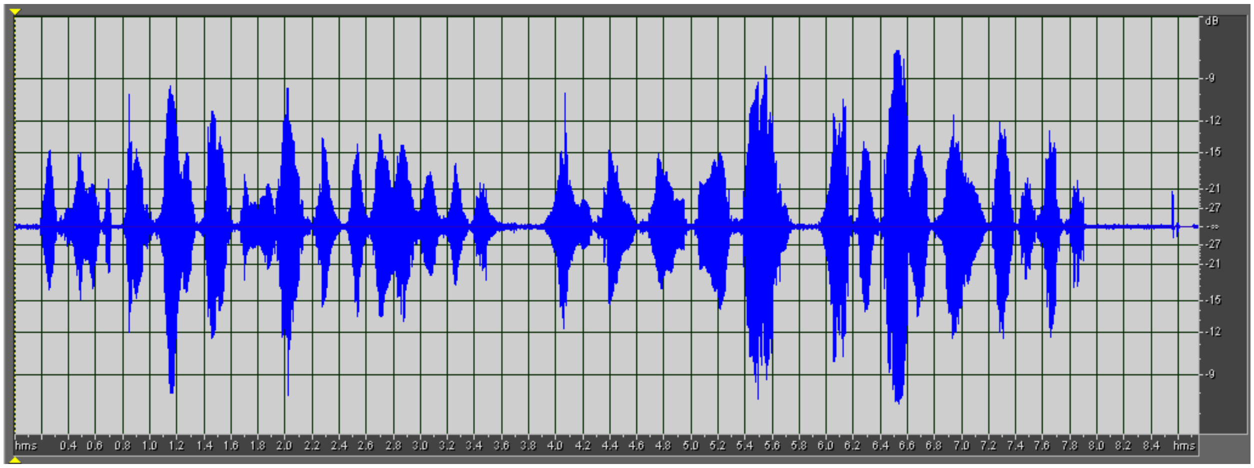


Figure 14 TYPICAL STATIONARY RECEIVED AUDIO.GIF

Figure 14 shows audio seen by the stationary RaCE unit during a call from the satellite terminal end to the internet terminal end.

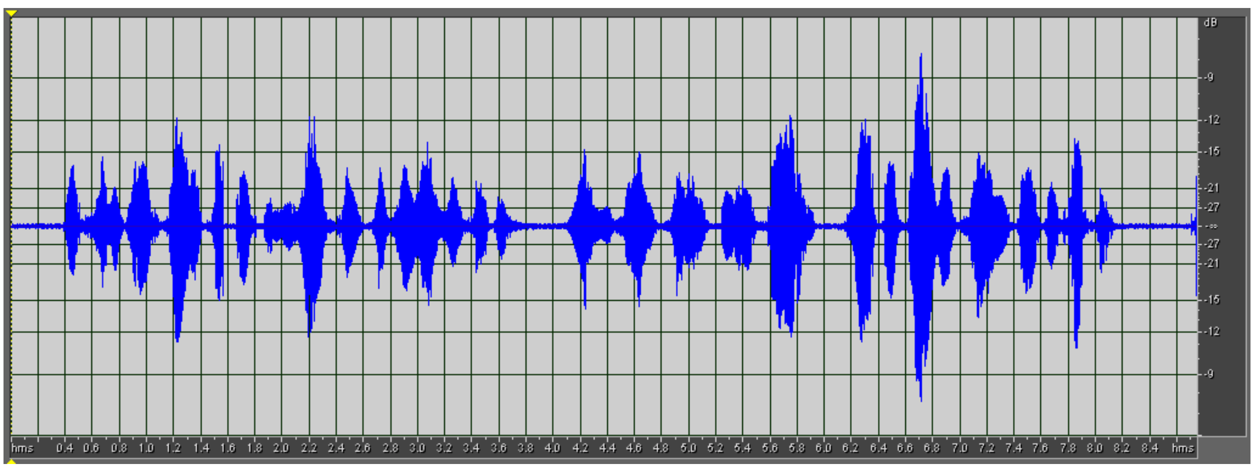


Figure 15 TYPICAL MOBILE RECEIVED AUDIO.GIF

Figure 15 shows audio seen by the mobile RaCE unit during a call from the internet terminal end to the satellite terminal end of the link.

Both Figures 14 and 15 show some modification to the audio compared to the signal that was sent in Figure 13. The noise level has also increased by a significant amount. Some of the changes that are visually apparent are due to the passage of the audio through 3 sets of vocoders, one in each pair of radios, and one in the pair of VoIP gateways. Despite this, the recovered audio quality was still very useable. In Figure 14 there is one apparent loss of a speech packet at approximately 0.75 seconds into the recording. In Figure 15 there is an apparent loss of one speech packet at approximately 1.6 seconds into the recording.

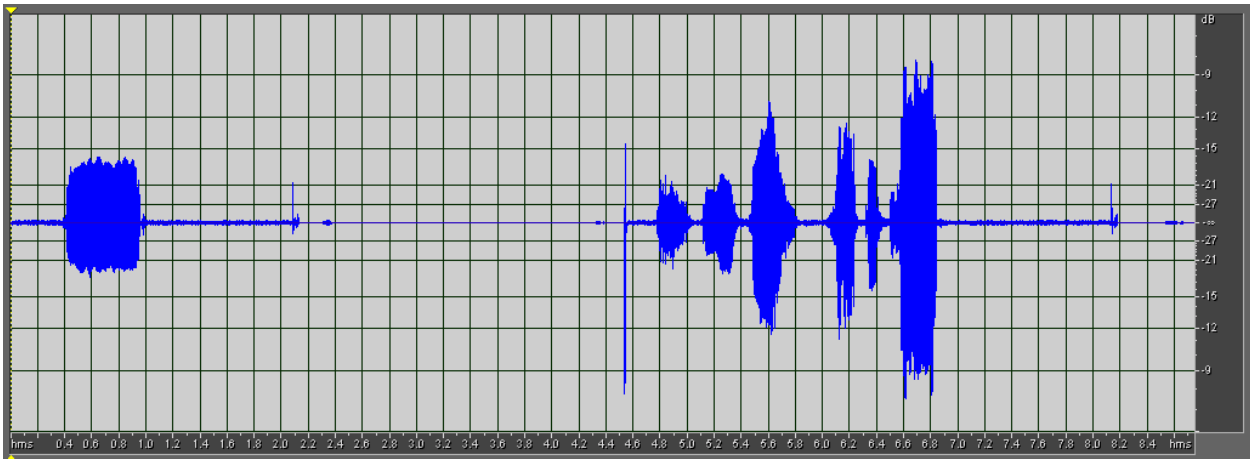


Figure 16 TYPICAL INTERFERENCE LIMITED AUDIO.GIF

Figure 16 shows a significant loss of speech packets as well as the introduction of a great deal of noise. This was not caused by the IP/satellite link, the path under scrutiny for this test. Instead, the loss was caused by localized RF conditions at the test site.

Results such as this, which are due to conditions outside the control of the test conductors as well as outside the intended analysis area, are being eliminated from the data used to produce the final result tables.

TABULAR RESULTS AND COMMENTS:

Link testing results are presented using various combinations of IP gateway and satellite provider as called for in the test plan. Each of the summary tables in this section contains information that was extracted from Microsoft Excel files produced during testing. DAQ scores are averages representing the received message analysis. These files are included on the data CD that accompanies this report.

At the time of the tests we noted the following information related to the vocoders used in the gateway equipment:

SUPPLIER	TYPE	DATA RATE
Twisted Pair	G729	8K
JPS	GSM	13K
Motorola	G729	8K

TEST SERIAL NO.	**20050914B**
IP GATEWAY	TWISTED PAIR
SATELLITE	LBI
VOICE TEST	MALE
DATA RATE	128K
8K CIR ENABLED	NO
VPN	NO
OTHER PRE LOADING	NONE
MOBILE DAQ AT INTERNET END	3.133
STATIONARY DAQ AT SATELLITE END	4.793
RECOMMENDED CONFIGURATION?	NO

In test 20050914B, there were a high number of timeouts on the satellite to internet path due to the loss of the preamble. The normal configuration for testing was to have the mobile connected to the satellite end of the circuit. In this test the mobile was connected to the internet end and the stationary was connected to the satellite end. The later tests are in the normal configuration. Even though the total configuration is not recommended, the Twisted Pair equipment showed a great deal of promise and appears to be fully capable of meeting the system needs for an IP gateway. The addition of an appropriately sized CIR should make this an attractive combination. A failure in one of the supplied cards caused a substantial loss in the measured speech quality which was evident in both listening tests as well as the RaCE Mobile DAQ scores. We recommend further consideration of the Twisted Pair product.

TEST SERIAL NO.	20050914C
IP GATEWAY	TWISTED PAIR
SATELLITE	STARBAND
VOICE TEST	MALE
DATA RATE	128K
8K CIR ENABLED	NO
VPN	NO
OTHER PRE LOADING	NONE
MOBILE DAQ AT SATELLITE END	BELOW 1.1
STATIONARY DAQ AT INTERNET END	NONE
RECOMMENDED CONFIGURATION?	NO

Test 20050914C used the Starband satellite link. The Starband link is not designed or marketed for use with voice over internet protocol. This fact was verified in the test trials, and as a result, Starband should not be considered as a viable satellite link provider for VOIP at this time. A reconfiguration of their internal protocols could modify their capability to carry VOIP in the future.

TEST SERIAL NO.	20050916A
IP GATEWAY	JPS
SATELLITE	LBI
VOICE TEST	MALE
DATA RATE	128K
8K CIR ENABLED	NO
VPN	NONE
OTHER PRE LOADING	NONE
MOBILE DAQ AT SATELLITE END	4.719
STATIONARY DAQ AT INTERNET END	3.348
RECOMMENDED CONFIGURATION?	NO

In test 20050916A, there were numerous timeouts in the satellite to internet direction due to the loss of the preamble. Some messages were almost entirely lost due to data allocation issues on the satellite link. The actual DAQ values are probably worse than indicated due to the automatic rejection of non correlated results in the analysis software. More clues may be gained by reviewing the timing record to see the effect of the lost preamble in messages as well as the general loss of data.

TEST SERIAL NO.	20050919A
IP GATEWAY	JPS
SATELLITE	LBI
VOICE TEST	MALE
DATA RATE	128K
8K CIR ENABLED	NO
VPN	NONE
OTHER PRE LOADING	IP PHONE
MOBILE DAQ AT SATELLITE END	4.533
STATIONARY DAQ AT INTERNET END	4.212
RECOMMENDED CONFIGURATION?	PARTIAL SEE NOTES

Greatly improved results were seen in test 20050919A compared to earlier tests. The improvement was due to artificially adding loading to the satellite circuit by operating an IP phone on the same circuit. This seems to indicate that this type of satellite circuit could be added directly to a satellite termination point that is already in continuous use providing other traffic on the same dedicated path.

If continuous traffic is not present, it may still be necessary to arrange for an appropriate CIR. Note that this configuration requires the addition of some type of circuit pre-loading such as a CIR. IP phone loading is not a practical solution.

TEST SERIAL NO.	20050919B
IP GATEWAY	JPS
SATELLITE	NIASAT
VOICE TEST	MALE
DATA RATE	128K
8K CIR ENABLED	NO
VPN	NONE
OTHER PRE LOADING	NONE
MOBILE DAQ AT SATELLITE END	3.604
STATIONARY DAQ AT INTERNET END	3.288
RECOMMENDED CONFIGURATION?	NO

The configuration shown in test 20050919B would probably work well if pre-loading or a CIR was utilized. There were two timeouts in each direction resulting from no useable RX data. Many aberrations are visible in the timing chart associated with this test. See the *.WDQ file in the 20050919B subdirectory on the accompanying disk.

TEST SERIAL NO.	20050919C
IP GATEWAY	JPS
SATELLITE	LBI
VOICE TEST	MALE
DATA RATE	128K
8K CIR ENABLED	NO
VPN	NONE
OTHER PRE LOADING	IP PHONE
MOBILE DAQ AT SATELLITE END	4.459
STATIONARY DAQ AT INTERNET END	4.585
RECOMMENDED CONFIGURATION?	PARTIAL SEE NOTES

The configuration shown in test 20050919C is judged as partial because a CIR is probably the best permanent solution to make this a fully recommended solution. This combination worked with excellent results.

TEST SERIAL NO.	20050919D
IP GATEWAY	MOTOROLA
SATELLITE	LBI
VOICE TEST	MALE
DATA RATE	128K
8K CIR ENABLED	NO
VPN	NONE
OTHER PRE LOADING	IP PHONE
MOBILE DAQ AT SATELLITE END	4.042
STATIONARY DAQ AT INTERNET END	3.746
RECOMMENDED CONFIGURATION?	PARTIAL SEE NOTES

The configuration shown in test 20050919D is judged as partial because a CIR is probably the best permanent solution to make this a fully recommended solution. This combination worked with excellent results.

TEST SERIAL NO.	20050920A
IP GATEWAY	JPS
SATELLITE	LBI
VOICE TEST	MALE
DATA RATE	128K
8K CIR ENABLED	YES
VPN	NONE
OTHER PRE LOADING	NONE
MOBILE DAQ AT SATELLITE END	3.800
STATIONARY DAQ AT INTERNET END	4.203
RECOMMENDED CONFIGURATION?	YES

In test 20050920A, the combination produced excellent results but did not include a VPN that could enhance security and make addressing easier.

TEST SERIAL NO.	20050920B
IP GATEWAY	JPS
SATELLITE	LBI
VOICE TEST	MALE
DATA RATE	128K
8K CIR ENABLED	YES
VPN	END TO END
OTHER PRE LOADING	NONE
MOBILE DAQ AT SATELLITE END	4.253
STATIONARY DAQ AT INTERNET END	4.387
RECOMMENDED CONFIGURATION?	YES

This combination in test 20050920B brings together all of the most desirable components for an operational system with the degree of security required for Public Safety.

TEST SERIAL NO.	20050920C
IP GATEWAY	MOTOROLA
SATELLITE	LBI
VOICE TEST	MALE
DATA RATE	128K
8K CIR ENABLED	YES
VPN	END TO END
OTHER PRE LOADING	NONE
MOBILE DAQ AT SATELLITE END	3.214
STATIONARY DAQ AT INTERNET END	3.778
RECOMMENDED CONFIGURATION?	YES

This combination in test 20050920C brings together all of the most desirable components for an operational system with the degree of security required for Public Safety. The DAQ scores were lower than some of the similar tests. This is believed to have been caused by the use of experimental software in the Motorola equipment that was not used during the other tests.

TEST SERIAL NO.	20050921A
IP GATEWAY	MOTOROLA
SATELLITE	LBI
VOICE TEST	MALE
DATA RATE	64K
8K CIR ENABLED	YES
VPN	NONE
OTHER PRE LOADING	NONE
MOBILE DAQ AT SATELLITE END	4.15
STATIONARY DAQ AT INTERNET END	4.285
RECOMMENDED CONFIGURATION?	YES WITH LIMITS

In test 20050921A, the combination worked well with the benefit of reduced bandwidth on the satellite circuit. It did not include the VPN which could have been added without any penalty to the operation. The VPN is highly recommended but missing in this test. There may be persistent bit errors at this data rate. Accordingly, this solution is judged as a limited solution.

TEST SERIAL NO.	20050921B
IP GATEWAY	JPS
SATELLITE	LBI
VOICE TEST	MALE
DATA RATE	64K
8K CIR ENABLED	YES
VPN	END TO END
OTHER PRE LOADING	NONE
MOBILE DAQ AT SATELLITE END	4.425
STATIONARY DAQ AT INTERNET END	4.485
RECOMMENDED CONFIGURATION?	YES

The combination in test 20050921B worked well with the benefit of reduced bandwidth on the satellite circuit. It did include the VPN which seemed to impose no penalty on the operation.

OTHER POSSIBLE VARIATIONS IN THE INTERCONNECTION OF RADIO SYSTEMS:

This test was accomplished by simulating two separate trunking systems of the same manufacturer. The IP/satellite link should be able to accommodate different combinations of systems such as the following.

- Motorola Trunking to Other Manufacturers Trunking
- Motorola Trunking to a Conventional Base Station
- Other Manufacturers Trunking to a Conventional Base Station
- Conventional Base Station to a remotely located Conventional Base Station
- Any type Conventional or Trunking System to a remote Phone Patch

SYSTEM IMPLEMENTATION RECOMMENDATIONS:

There were a number of difficulties noted during the testing. It is recommended that systems such as this be installed only by properly trained and skilled personnel. Specifically, the knowledge requirements include an exceptional knowledge of IP addressing, satellite antenna installation, audio level setting in Digital Land Mobile Radio Systems as well as good theoretical knowledge and practical experience in Land Mobile Radio. It is also recommend that all systems planned for installation in remote locations be pre-installed or staged at a prime location where all the needed technical expertise is located. The knowledge that a system worked once is highly valuable when troubleshooting in the field.

VENDOR SPECIFIC COMMENTS:

Satellite Vendors

LBiSat. Support by the LBISat Network Operations Center was excellent throughout the test. Their systems engineers were very quick to propose the 8 Kbps CIR as a means to correct the initial loss of audio due to delay in bandwidth allocation.

NIASat. Support from the NIASat Network Operations Center was excellent during the test.

Network Vendors

Alaska Communications System (ACS) DSL. The ACS DSL service provided 240 Kbps upstream service and 1 mbps downstream. This worked reliably throughout the test.

IP Gateway Vendors

Motorola MotoBridge. The test configuration provided by Motorola used software that was still in development, and consequently was not fully documented. As time was spent with the product, a much better understanding of how the various software applications, logical and physical devices (Administrators Control Panel (ACP), OMC Server, work station and gateway unit) worked together. A more intuitive interface and complete documentation with a theory of operation would make this a more usable product. The ACP would seem to provide a network manager a good overall picture of the operational network, but it was unclear what tool would be used by dispatch personnel to dynamically make and break patches between sites. Specific training would be needed by network management personnel to ensure the operational integrity of the system.

Twisted Pair. The system consisted of two devices at the remote location and the hub. The first was a Cisco router with IP voice cards installed and the other was a Windows 2003 Media Server. This is a complicated but very capable system that seems to require a considerable amount of computer skill for proper setup. Once setup, the system seemed to remain stable and reliable during the short period we were able to test it.

Raytheon/JPS ACU1000. JPS excels at ease of setup; two of the test personnel with no specific training on the product were able to read the on line documentation and have it set up and operating in less than 10 minutes. Also noteworthy, was the simplicity of this application. It is not clear what other equipment and software is required to manage a large network of these devices. This device would be easy to support in remote Alaska due to its simplicity.

VPN Vendors

End II End Communications Network Security Suite. The suite of software implemented on a server running a hardened LINUX OS provided an IPSEC virtual network tunnel between the two radio gateways. The system used a 256 bit AES encryption algorithm and allowed the operation of both gateways inside private IP networks. This system performed flawlessly and had no measurable impact on network performance over the satellite IP network except that associated with the processing delay through the respective devices.

End II End preconfigured all the hardware so that set up was simple and fast. Only the VPN capability of the End II End security solution was used.

AREAS FOR FUTURE EXPLORATION:

All of the interfaces within this test were at the speaker and microphone audio points or their equivalent. This meant that three vocoder processes were always present and operating in series. We recommend that a system be eventually employed that allows for the direct digital connection of systems or stations to the VoIP gateways. This would contribute significantly to the quality of the voice passed through the system. It may even be practical in the future to connect the stations and/or systems directly to the VPN equipment which would bypass the need for the VoIP gateways. To accomplish this, either the VPN or the connected equipment would need to be equipped with voice store and forward to enable the required delays for control operations.

Software and hardware vendors should be encouraged to find ways to reduce the latency when operating over satellite circuits. A baseline test of IP telephones with one phone on the satellite terminal end and the other phone located on the internet end of the circuit produced a latency of approximately 575 milliseconds. This is considerably less than the latency figures for two radio systems over a similar link. While some of the extra latency cannot be eliminated due to the timing delays necessary to accommodate LMR trunking systems, it seems probable that a future reduction is feasible. This would certainly make satellite based radio communications much easier and intuitive to use.

CONCLUSIONS:

Testing performed during this exercise indicates that systems using VoIP gateways and satellite links are both possible and practical. Several specific equipment configurations that can practically be implemented are contained within this report. Below are several general conclusions.

Delay or latency is part of the reality with satellite links. Expect total system latency in the range of 2.5 to 3 seconds. The IP/satellite link contributes roughly 2 seconds. The LMR equipment adds another 0.5 to 1 second depending on the configuration. While future satellite systems may reduce link latency, it is possible to carry on a useful conversation with a little practice over IP/satellite linked systems.

Voice quality in the total system is very good, generally measured in the DAQ 4 range. This assumes operation in a LMR environment that would produce a DAQ 5 rating without any satellite link. The slight degradation in the linked environment is primarily due to the serial connection of three vocoders. The human ear cannot generally detect the difference between DAQ 5 and DAQ 4.

We recommend that implementations include VPN equipment such as the End II End equipment that was part of this test exercise. VPNs make addressing setup easier, more reliable, and provide the necessary encryption on the internet/satellite portions of the link.

Shared IP satellite IP services that provide sufficient quality of service to support VoIP telephone to the PSTN can support trunked radio gateways. A mechanism such as a CIR is required to overcome the delay of initial bandwidth allocation. If such a mechanism is not used, audio loss at the beginning of the conversation becomes unacceptable.

IPSEC VPN solutions exist that can be employed over public shared satellite IP networks to provide an end-to-end security solution without degrading the satellite network performance or voice quality. However, they must be specifically tailored for use on satellite networks since the high latency of these networks greatly limits most VPN performance. For example, we tested an IPSEC VPN implemented on CISCO Pix® Firewalls, and there was significant loss of packets when the VPN was up and stable. At times the VPN was not stable enough to support any communications through the tunnel.

The minimum bandwidth needed to support a radio channel with or without a VPN tunnel over a shared satellite IP network is 64 Kbps.

The public internet can be used in combination with a shared satellite IP network to provide a connection between two trunked radio networks without affecting network performance or voice quality, and this can be secured using an IPSEC VPN.

ALMR	Alaska Land Mobile Radio
CIR	Committed Information Rate
COTS	Commercial off-the-shelf systems or equipment
DAQ	Delivered Audio Quality measured on a scale of 1 to 5 with 3.0 considered acceptable for most communications
IP	Internet Protocol
IPSEC	Internet Protocol Security
LAN	Local Area Network
OoS	Quality of Service. High reliability provisioning of a circuit.
PTT	Push to Talk
RaCE	Radio Coverage Evaluator, an automated DAQ measurement system developed by CTA Communications of Lynchburg, VA.
Remote VSAT	Very Small Aperture Terminal: Remote site satellite transceiver equipment
Satcom	Satellite Communications
T&E	Test and Evaluation
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network
WAN	Wide Area Network

1. System Test Configuration Diagrams
2. Photos of the Test Operation
3. Enlarged views of screen capture figures
4. Satellite Network Configuration and Performance
5. Vendor Web Site List
6. Satellites and Satellite IP Service Providers serving Alaska

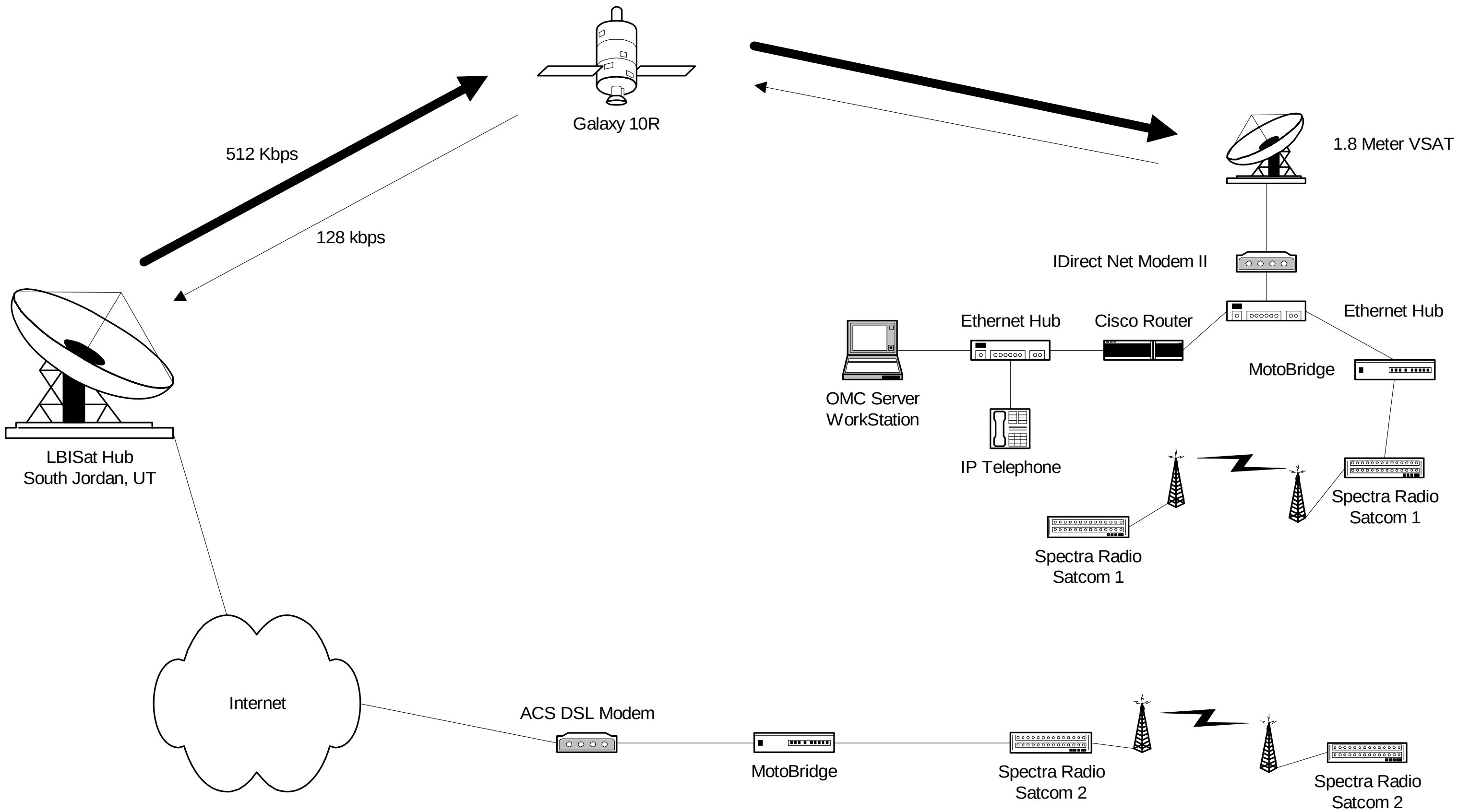
APPENDIX 1 – DRAWINGS

These drawings were prepared by Microcom of Anchorage, Alaska.

The CTA RaCE equipment is not shown on these drawings. The RaCE Mobile equipment was connected to the Spectra Radio assigned to Satcom 1 closest to the center of the drawings. The RaCE Stationary equipment was connected to the Spectra Radio assigned to Satcom 2 at the lower right of the drawings.

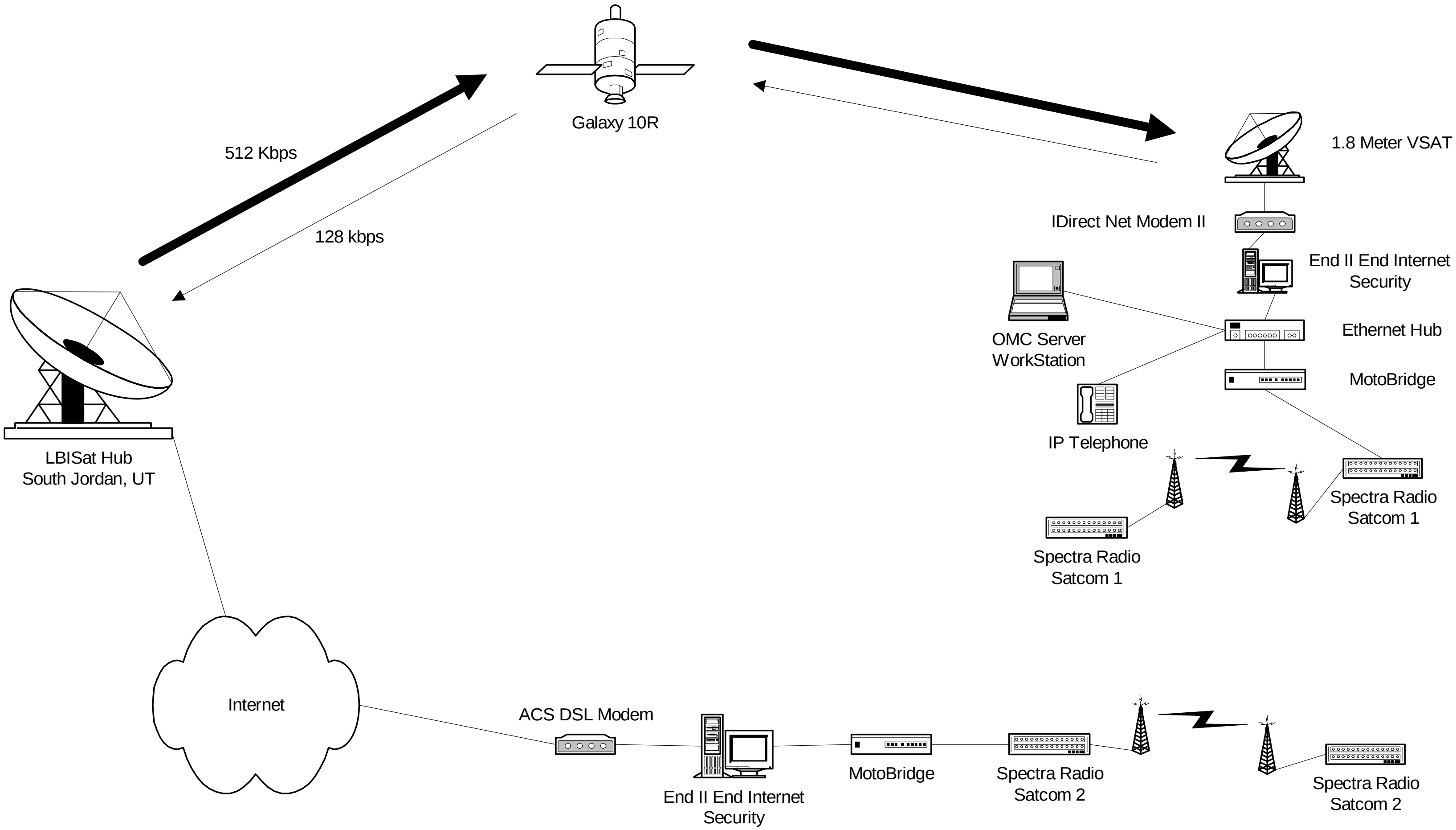
Network Drawings:

Test Configuration 1: LBISat, MotoBridge, No VPN



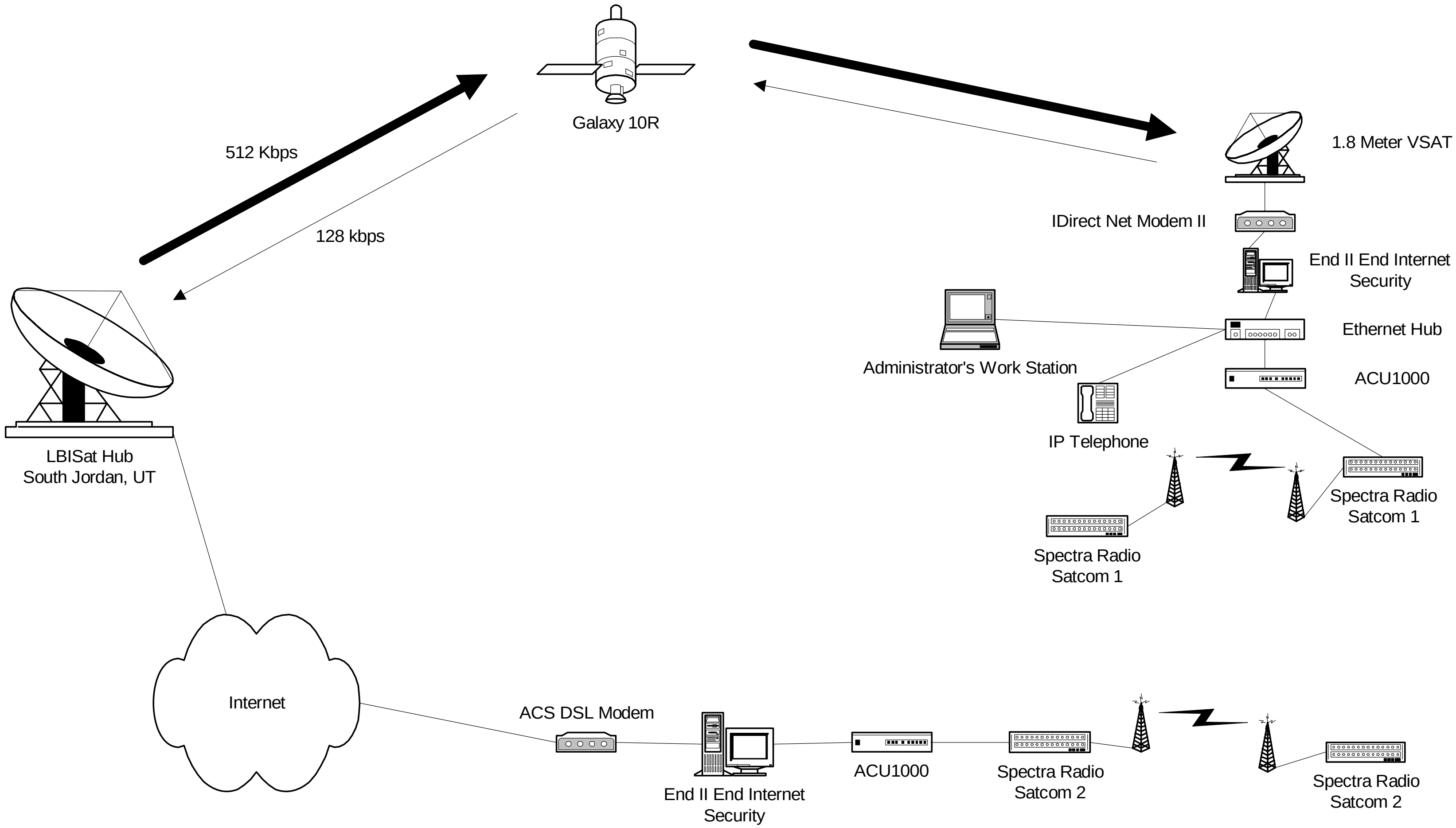
Test Configuration 1
LBISat and Motobridge
No VPN

Test Configuration 2: LBISat, MotoBridge, End II End Internet Security Gateway



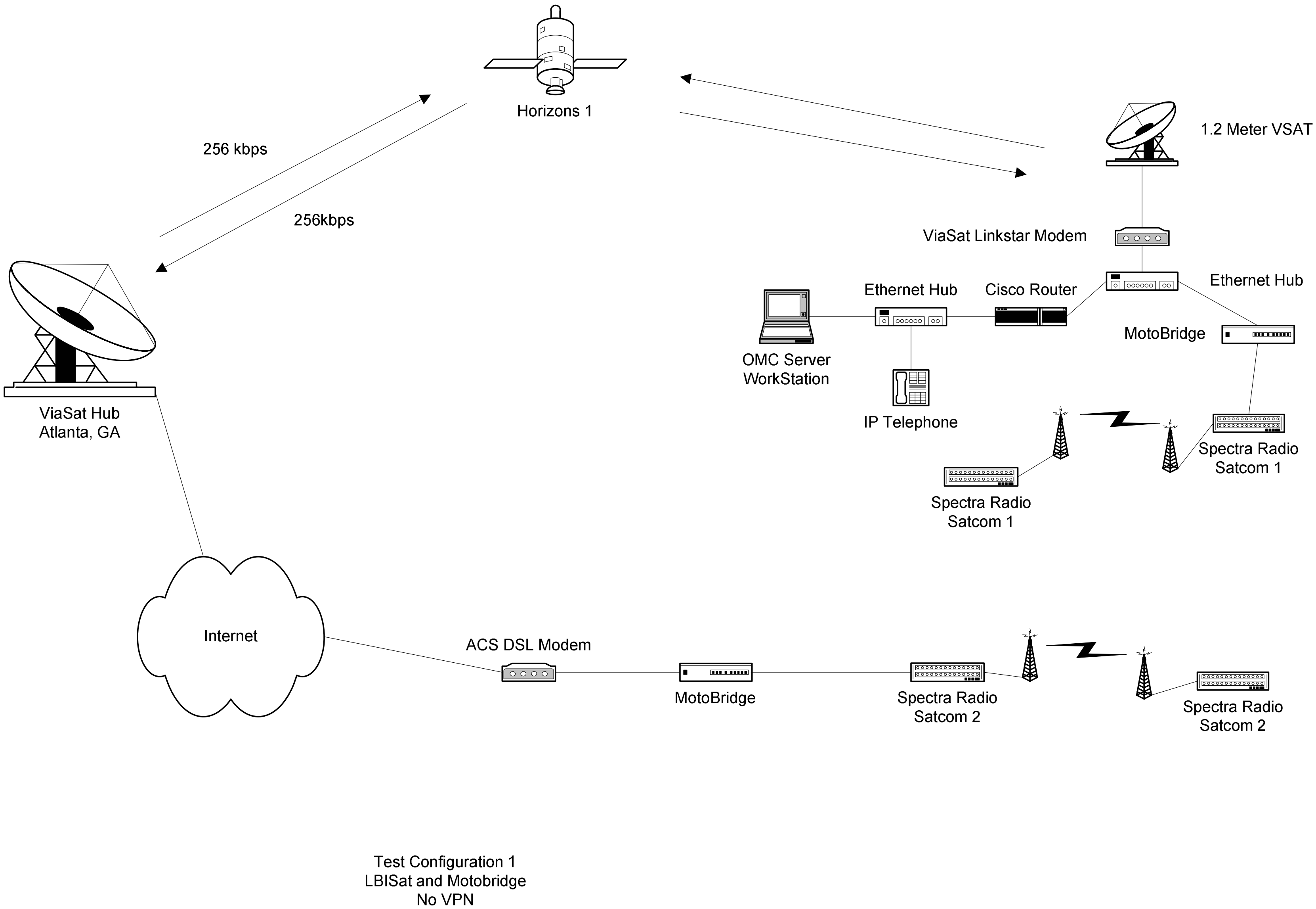
Test Configuration 2
LBISat and Motobridge
End to End Internet
Security Product

Test Configuration 3: LBISat, JPS ACU1000, End II End Internet Security Gateway

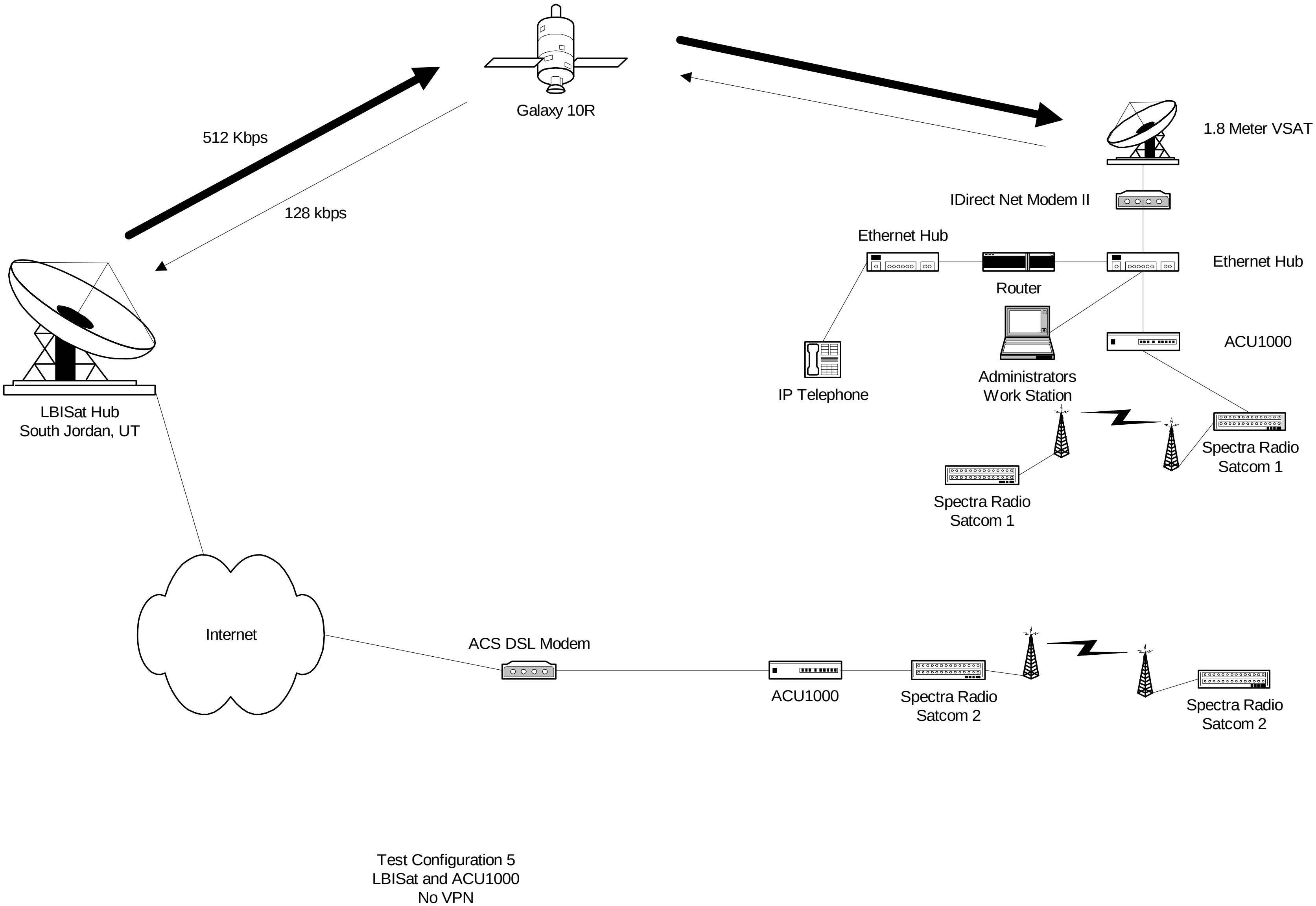


Test Configuration 3
LBISat and JPS ACU1000
End to End Internet
Security Product

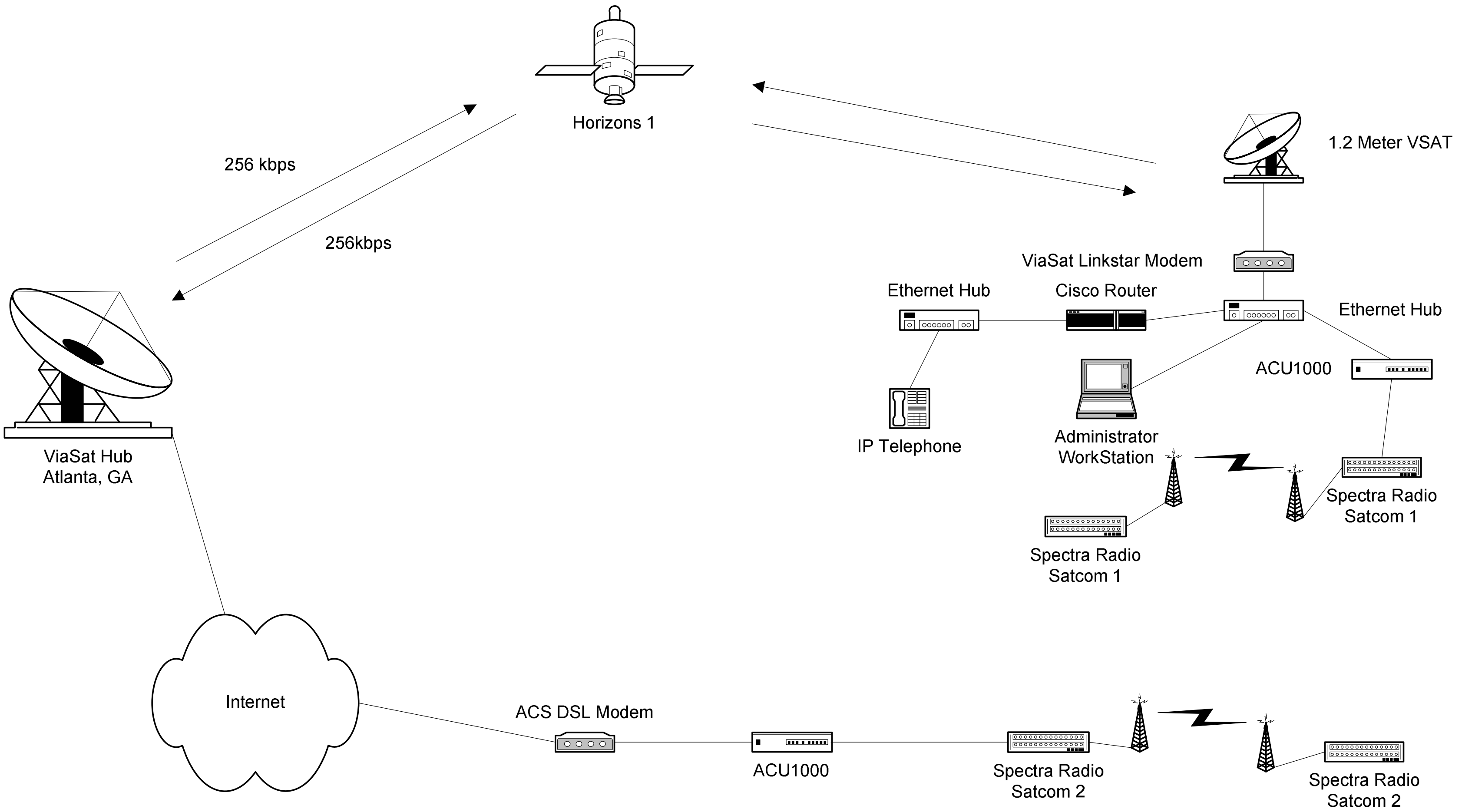
Test Configuration 4: NIASat, MotoBridge, No VPN



Test Configuration 5: LBISat, JPS ACU1000, No VPN

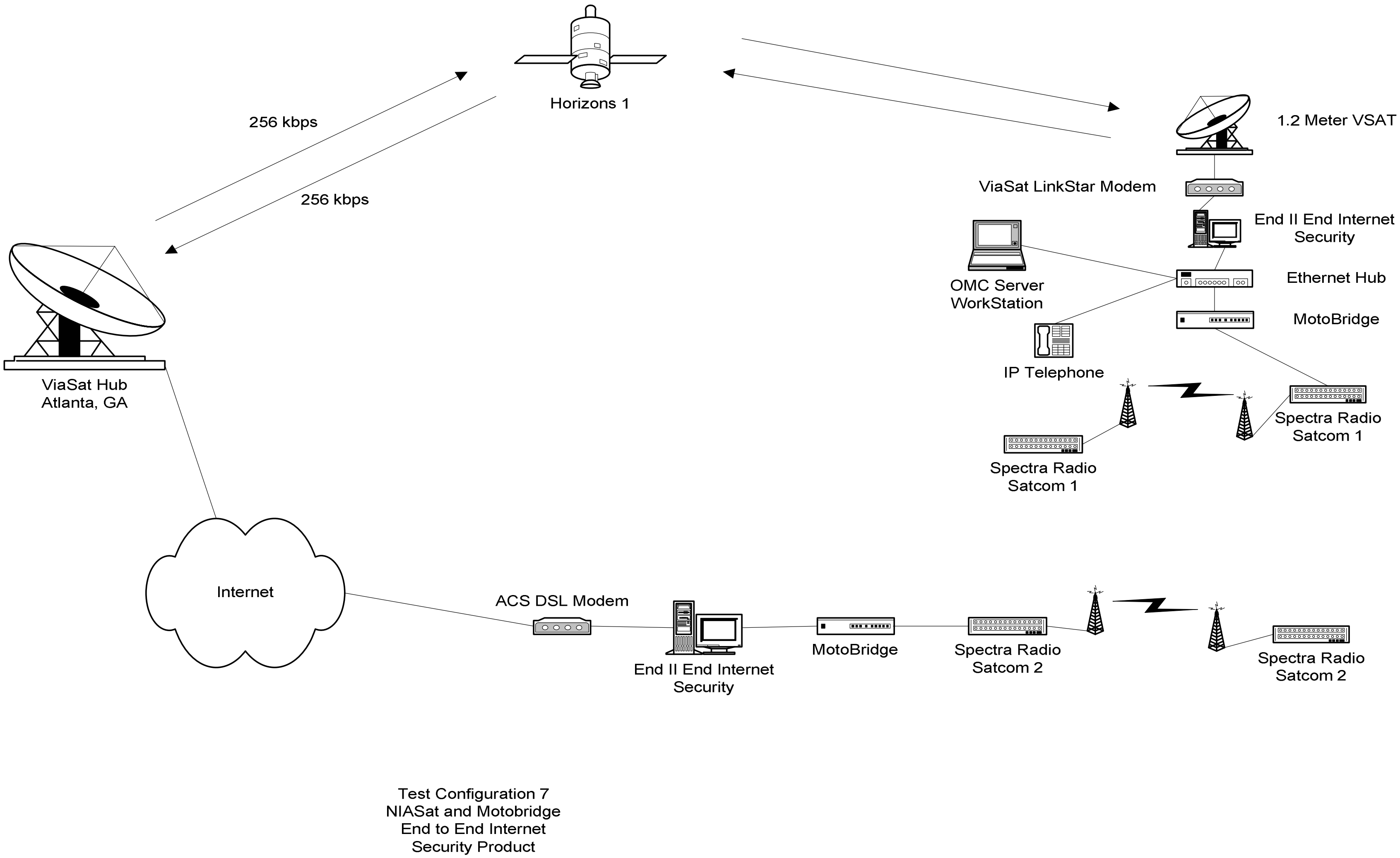


Test Configuration 6: NIASat, JPS ACU1000, No VPN

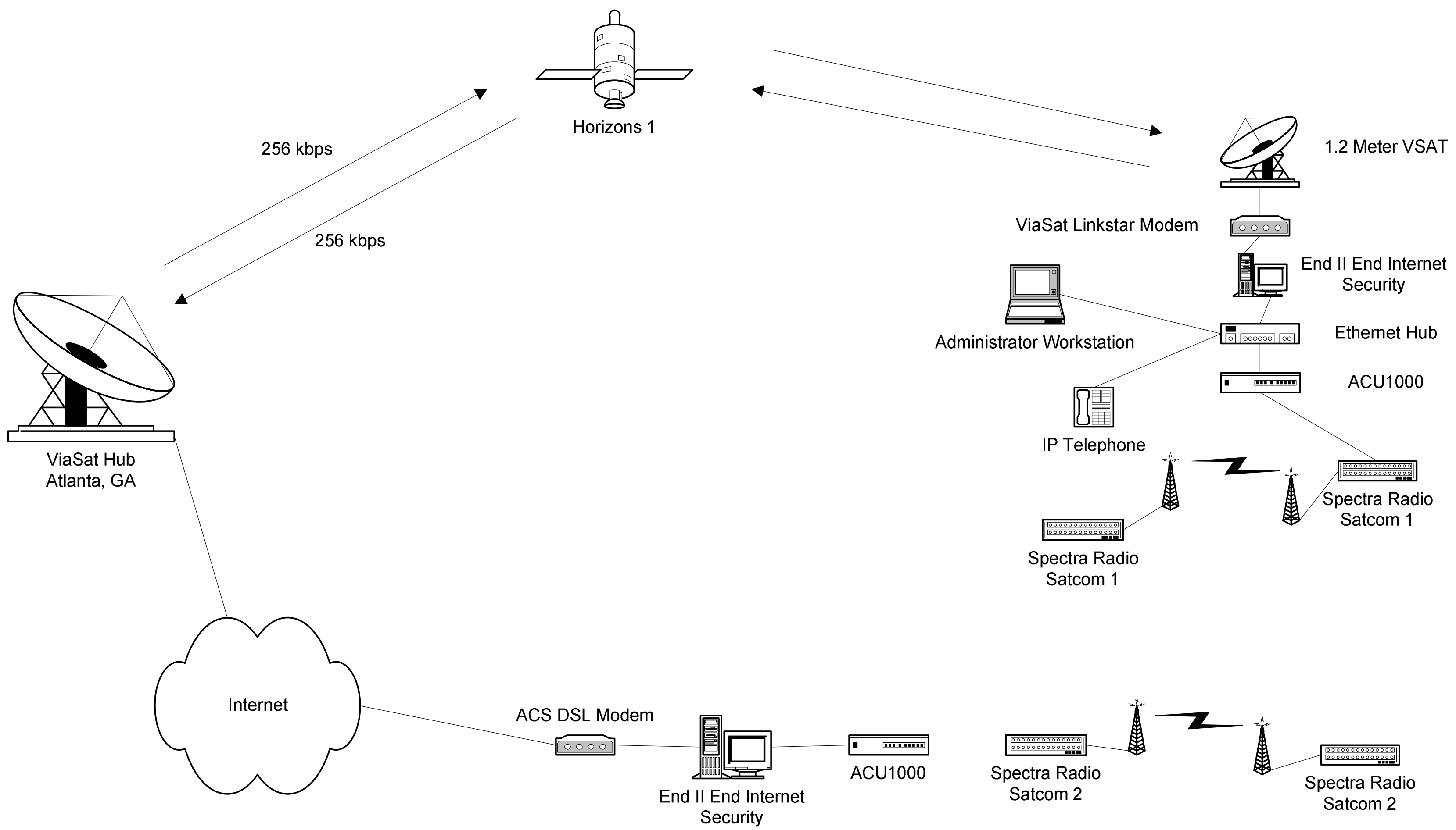


Test Configuration 6
NIASat and ACU1000
No VPN

Test Configuration 7: NIASat, MotoBridge, End II End Internet Security Gateway



Test Configuration 8: NIASat, JPS ACU1000, End II End Internet Security Gateway



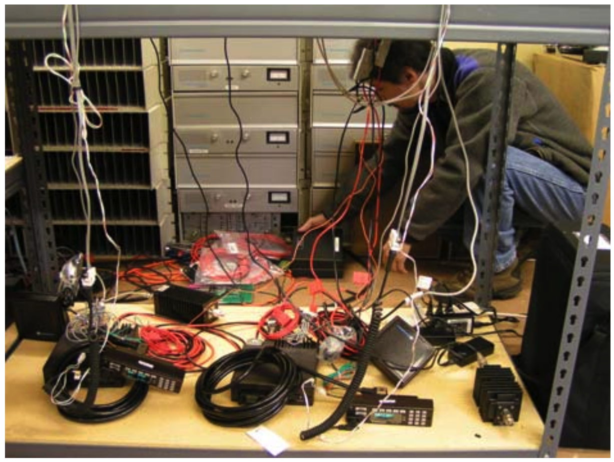
Test Configuration 8
NIASat and ACU1000
End to End Internet
Security Product

APPENDIX 2 – PHOTOS OF THE TEST OPERATION

A pair of satellite connections could be made at any one time.

Front view of the RaCE automatic DAQ measurement equipment.

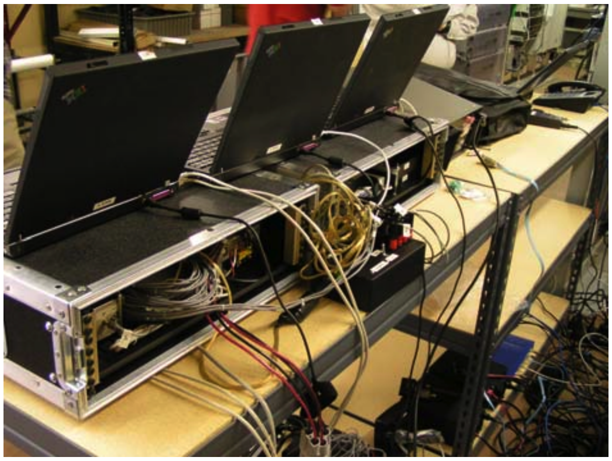
The JPS Raytheon equipment.



An obviously temporary interface to the test radios.

Test facility loaned by the City of Anchorage.

Setup in progress.



Rear view of the RaCE equipment showing the timing interface box.

An early version of the JPS equipment.

An early test in progress.

Motorola Motobridge equipment.

Another view during setup.

A test in progress. The operation was very computer intensive. Additional photos are available on the accompanying data disk.

APPENDIX 3 – ENLARGED VIEWS OF THE SCREEN CAPTURE FIGURES

These images are also available electronically on the data disk.

Software is included on the data disk to allow detailed exploration of the records that these screen capture images were derived from.

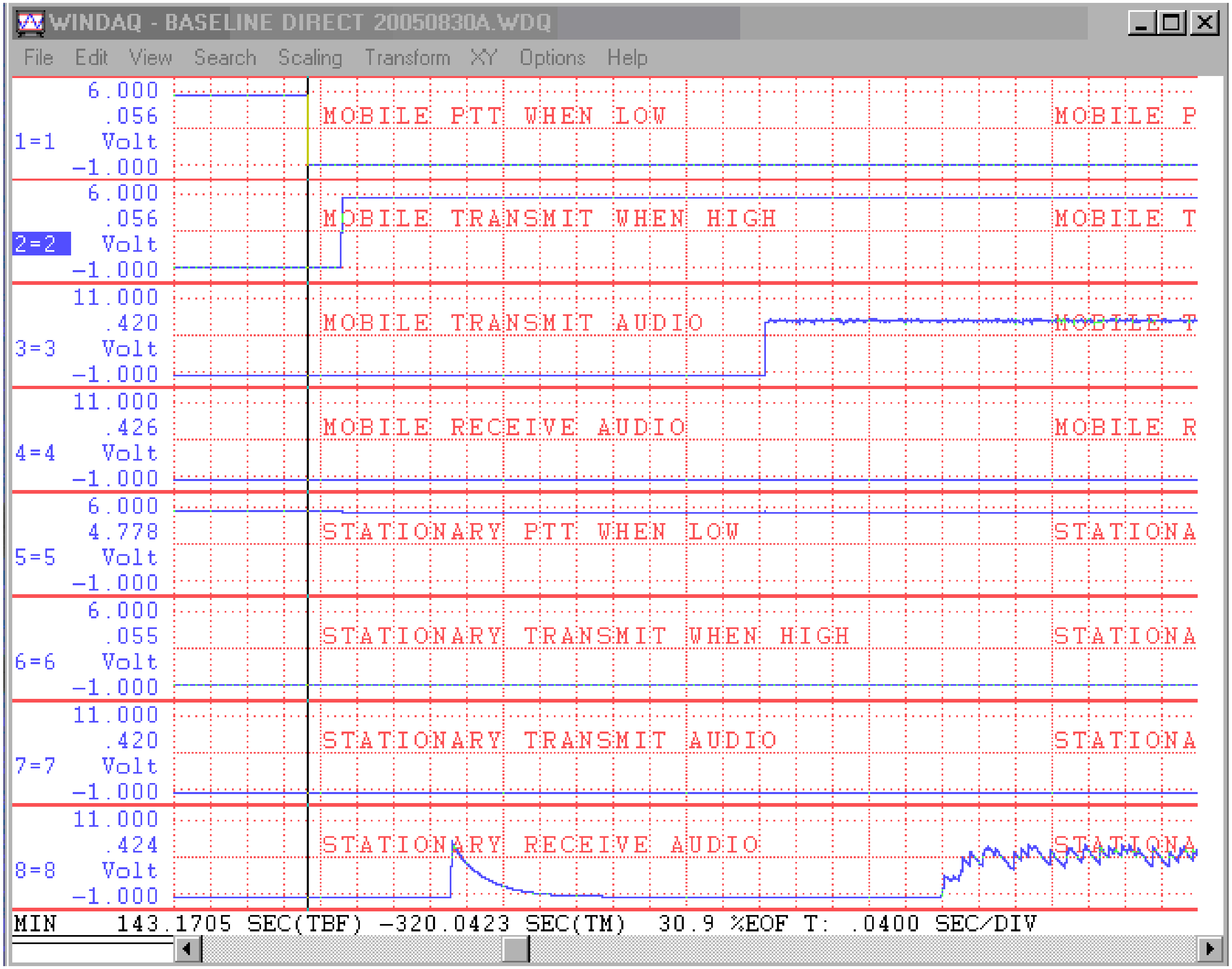


FIGURE 1 DIRECT PTT START.GIF

COMMUNICATIONS

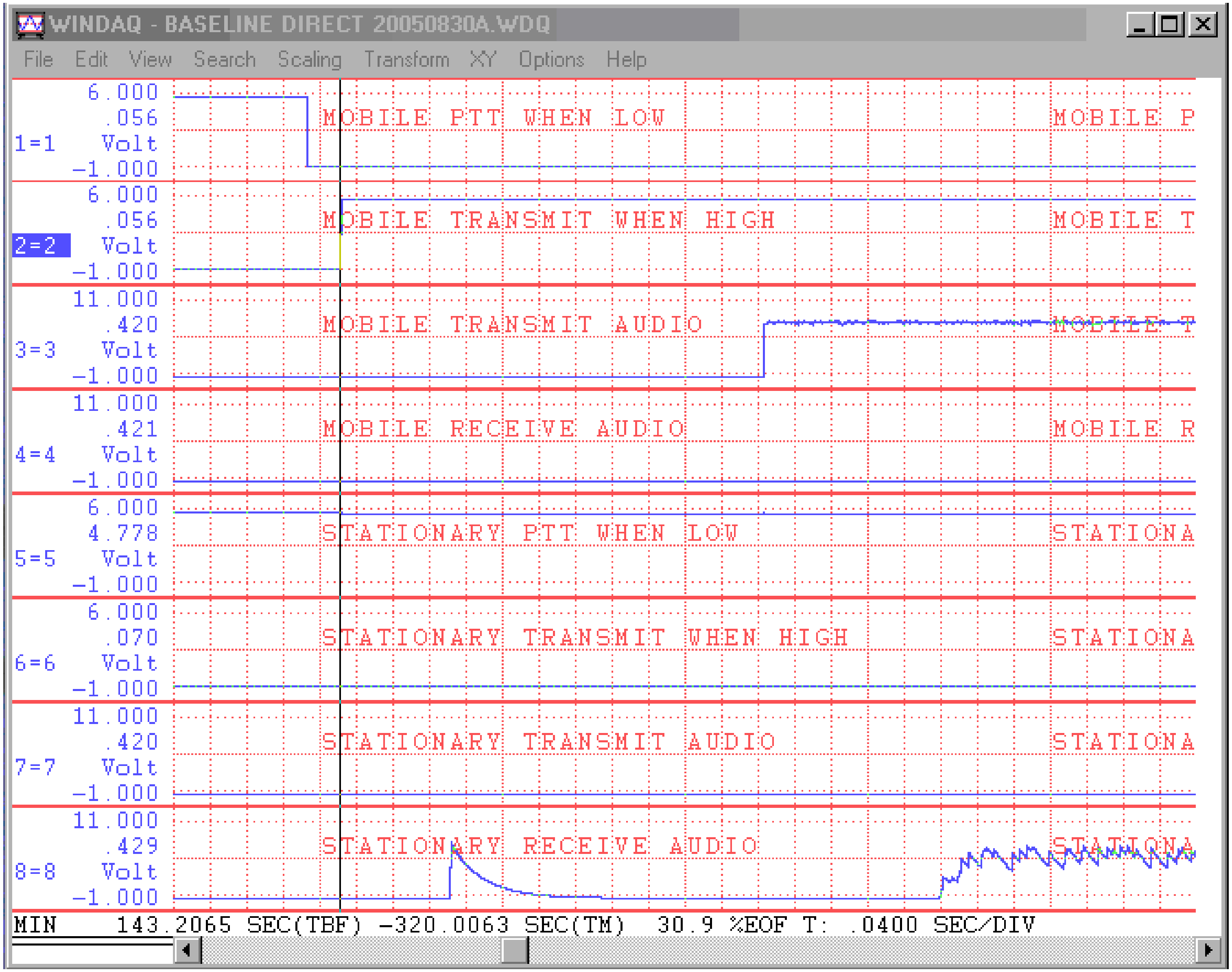


FIGURE 2 DIRECT TX START .GIF

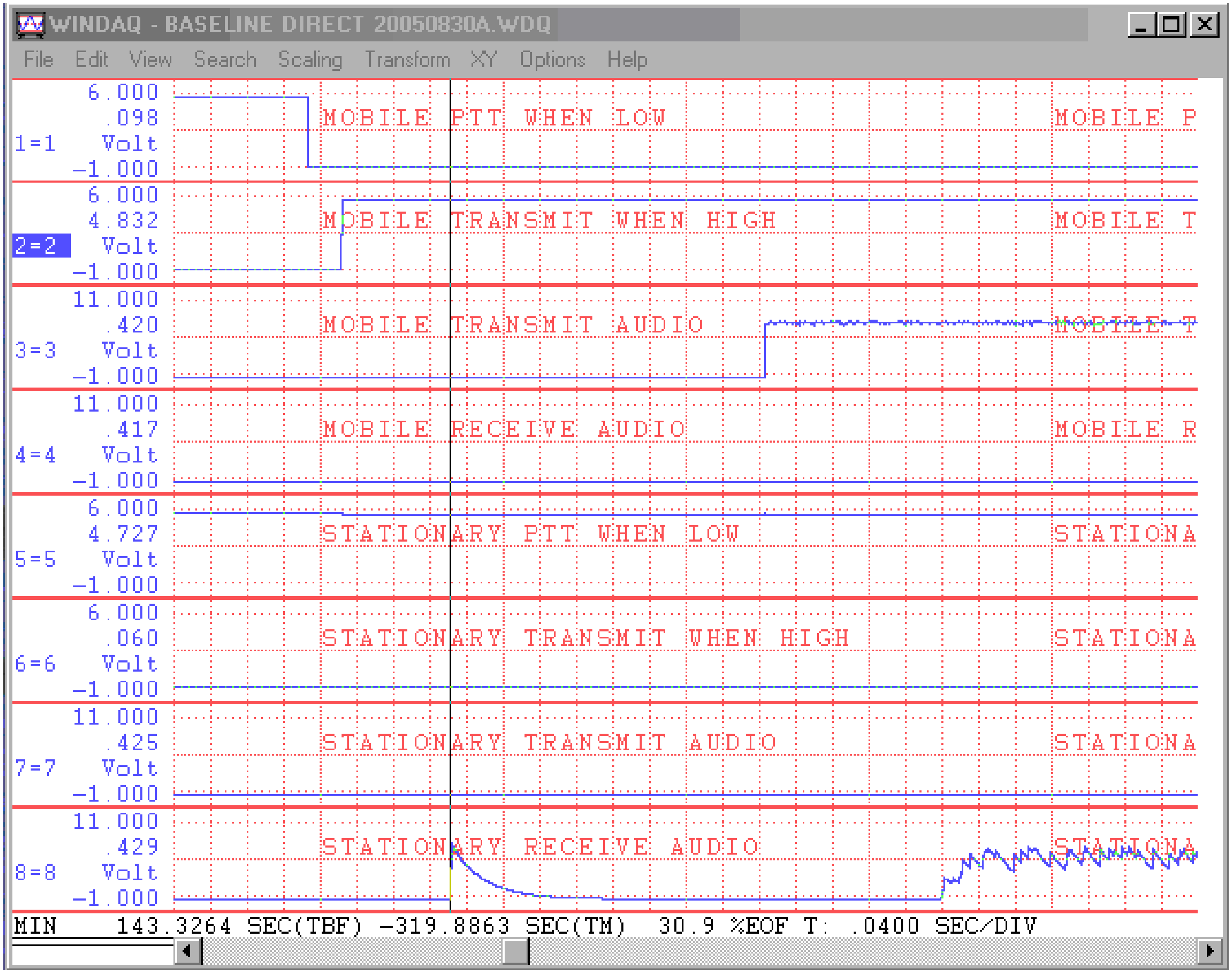


FIGURE 3 DIRECT RX UNSQUELCH.GIF

COMMUNICATIONS

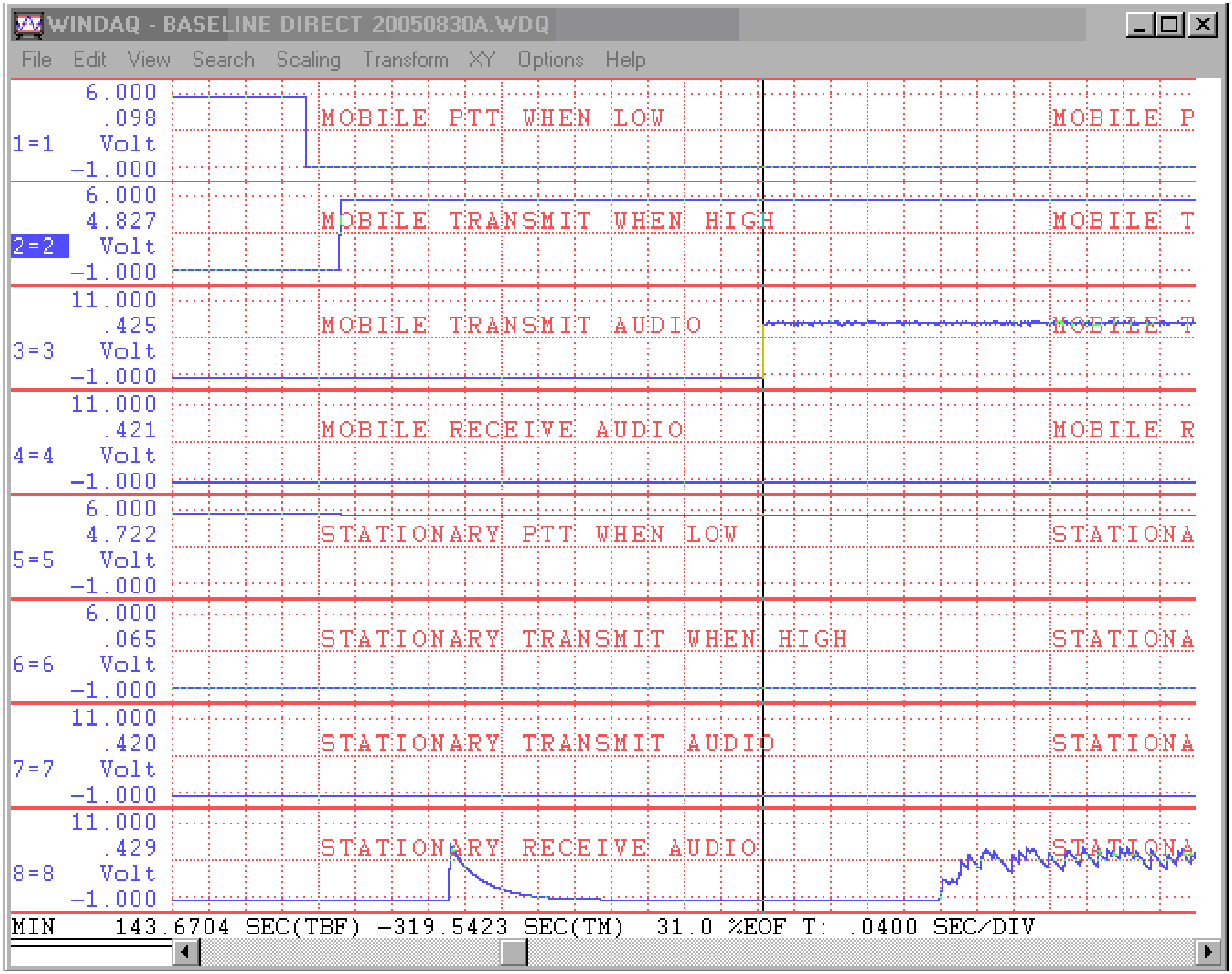


FIGURE 4 DIRECT PREAMBLE TX START.GIF

COMMUNICATIONS

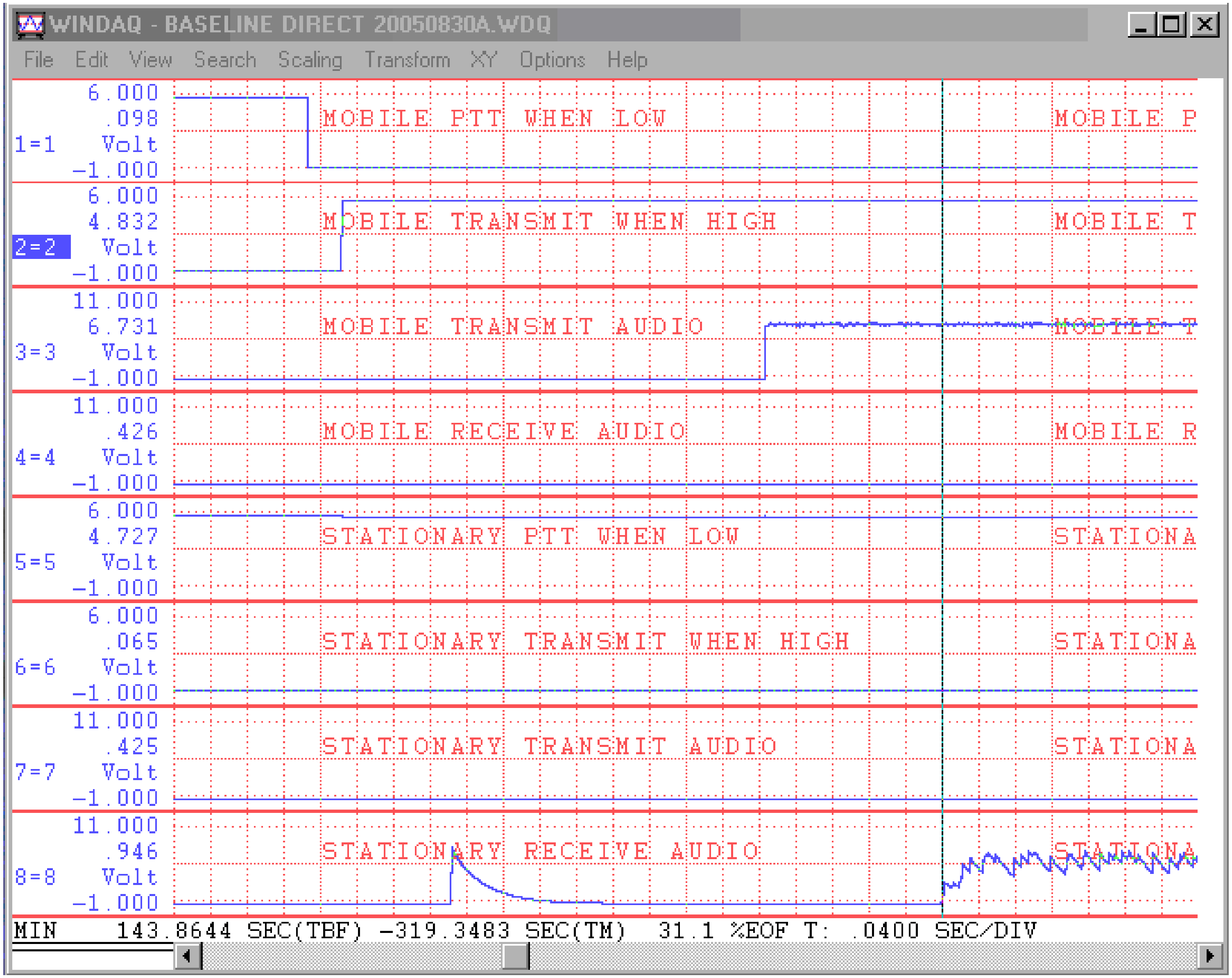


FIGURE 5 DIRECT PREAMBLE RX START.GIF

COMMUNICATIONS

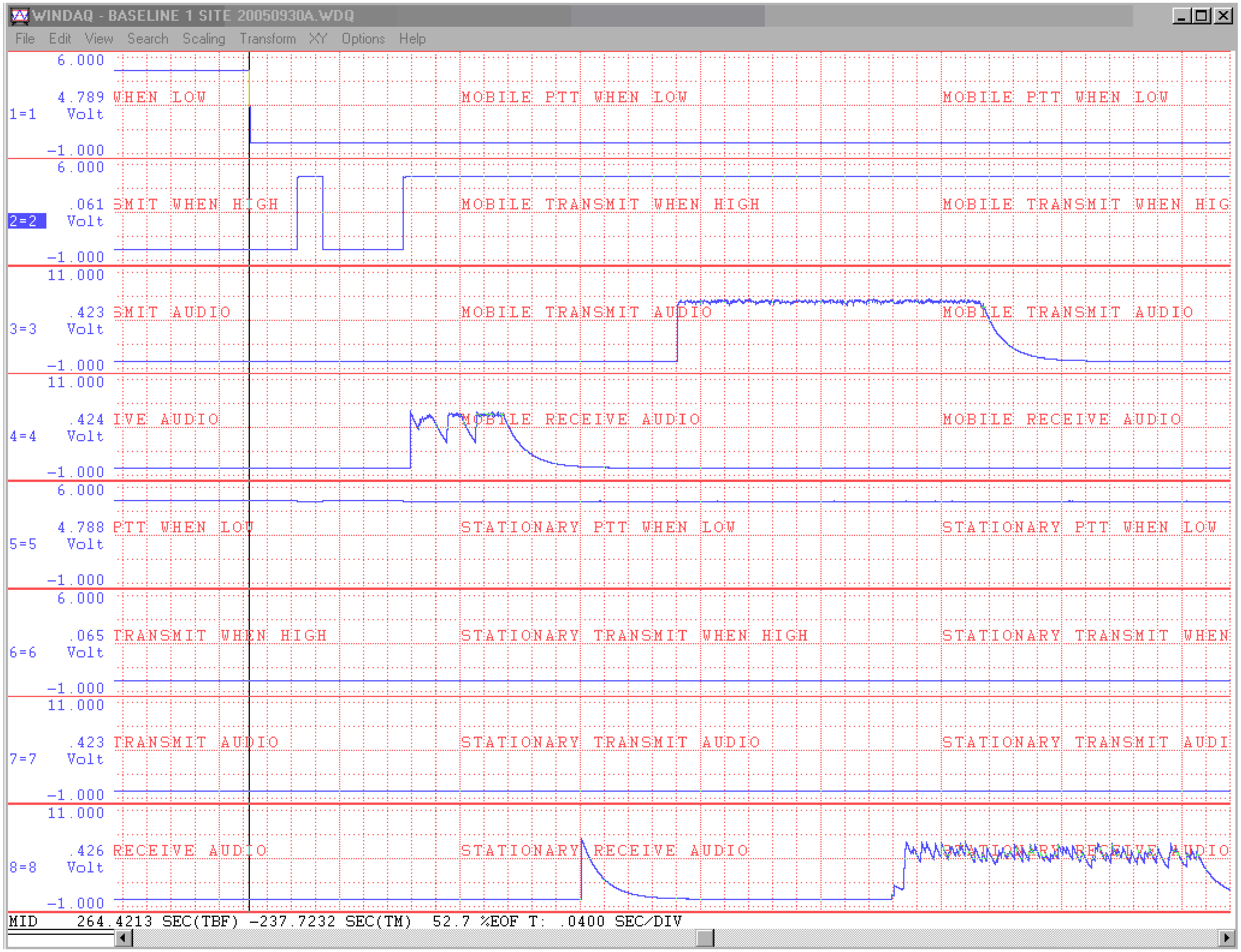


FIGURE 6 1 SITE PTT START.GIF

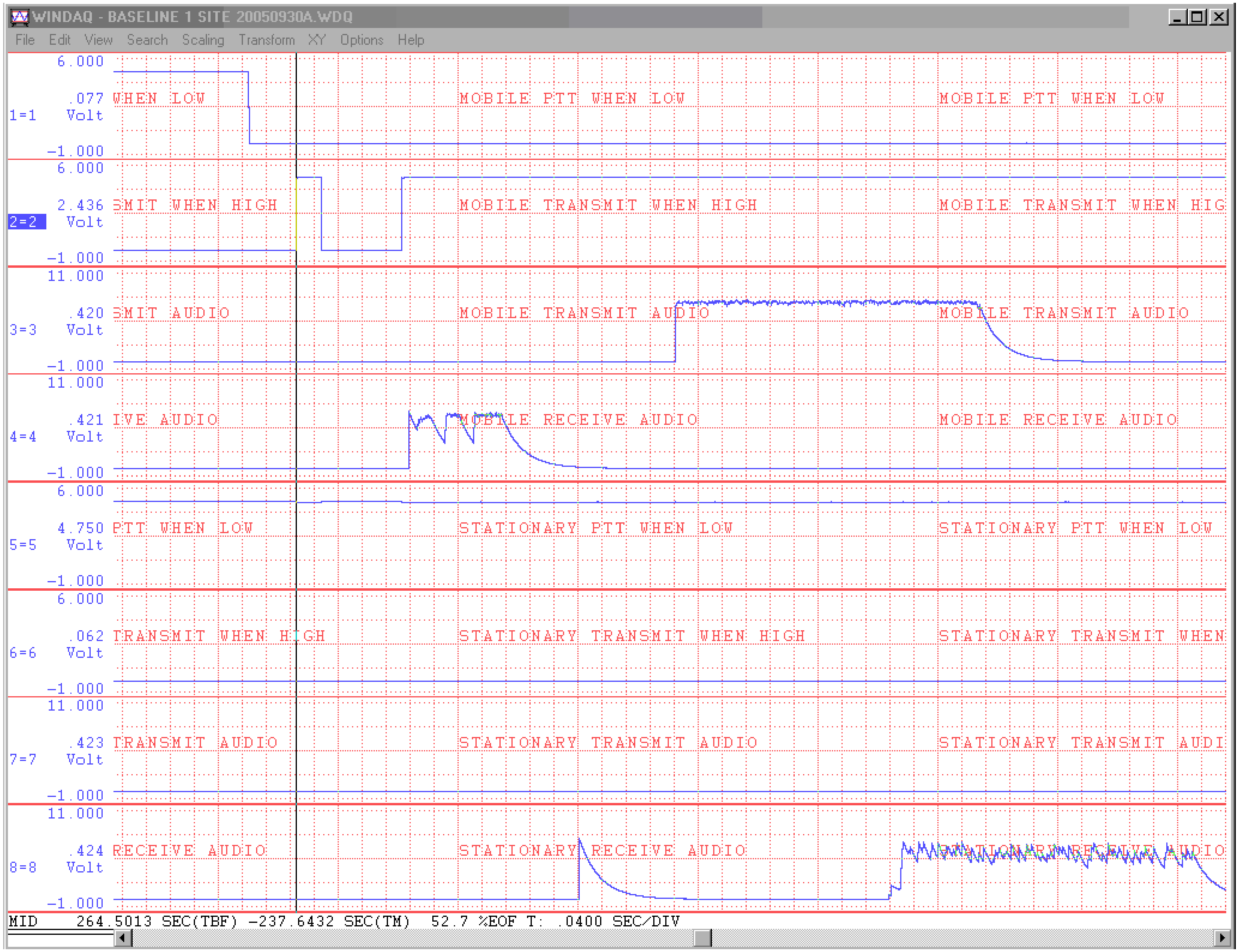


FIGURE 7 1 SITE CC TX START.GIF

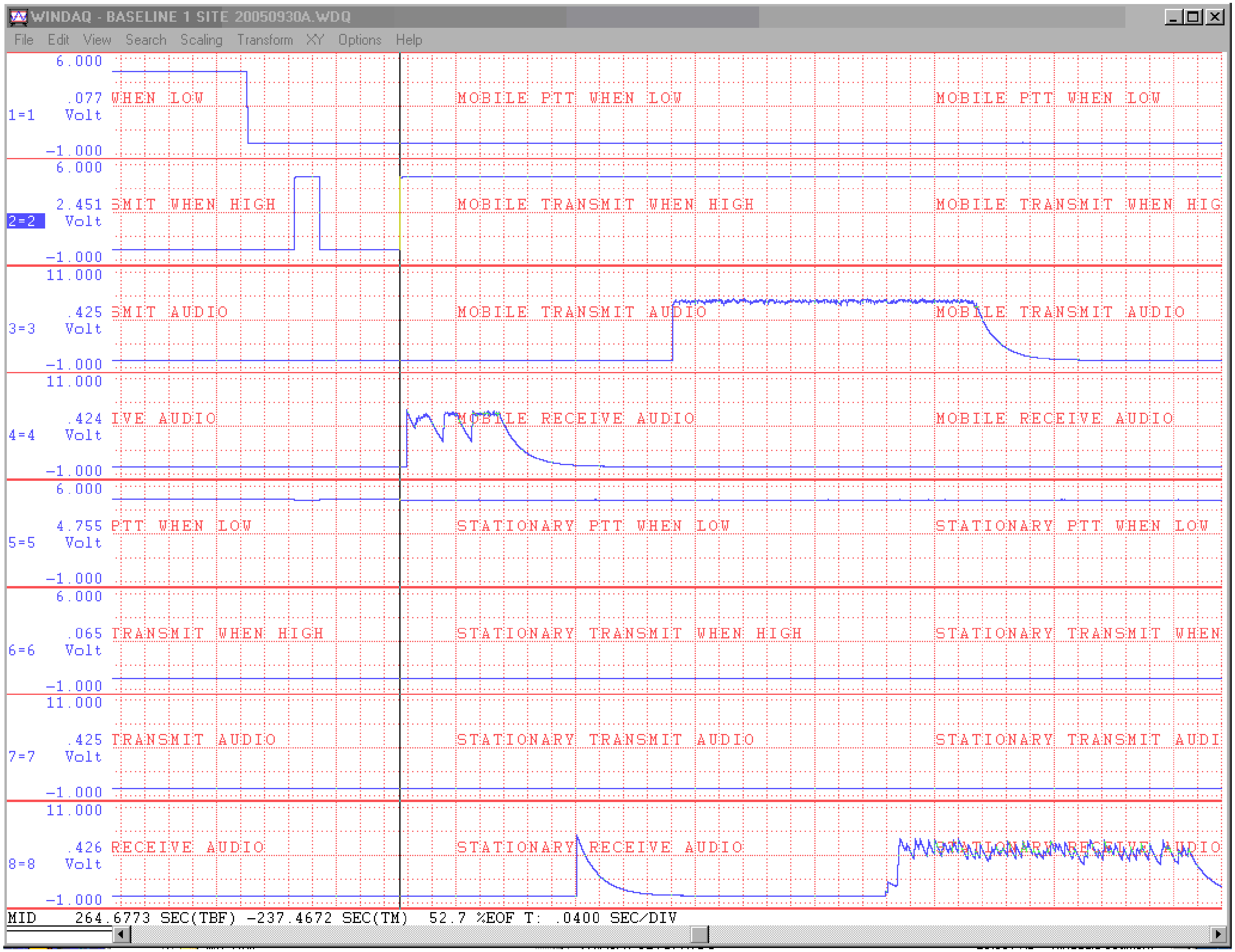


FIGURE 8 1 SITE WC TX START.GIF

CTA COMMUNICATIONS

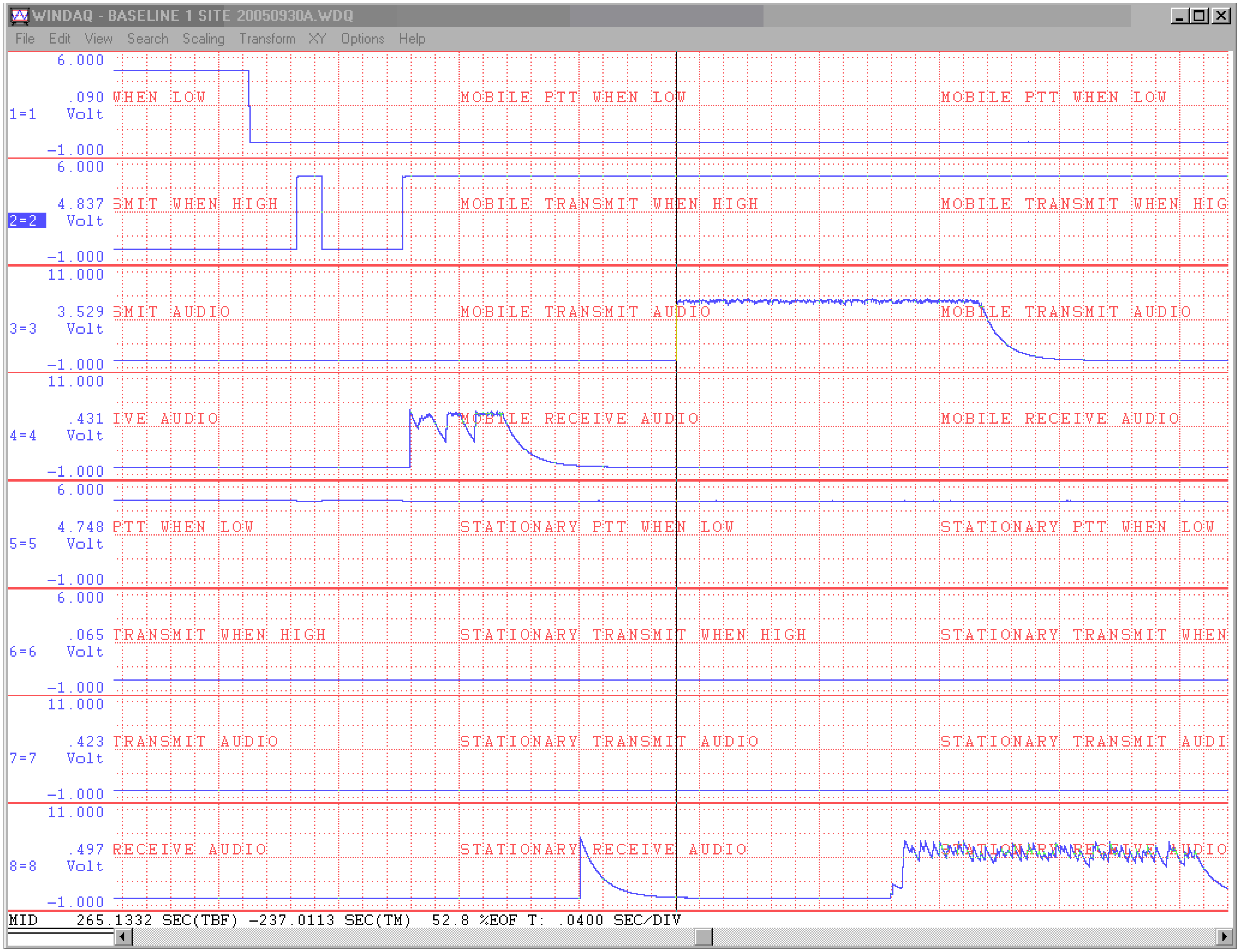


FIGURE 9 1 SITE PREAMBLE TX START.GIF

COMMUNICATIONS

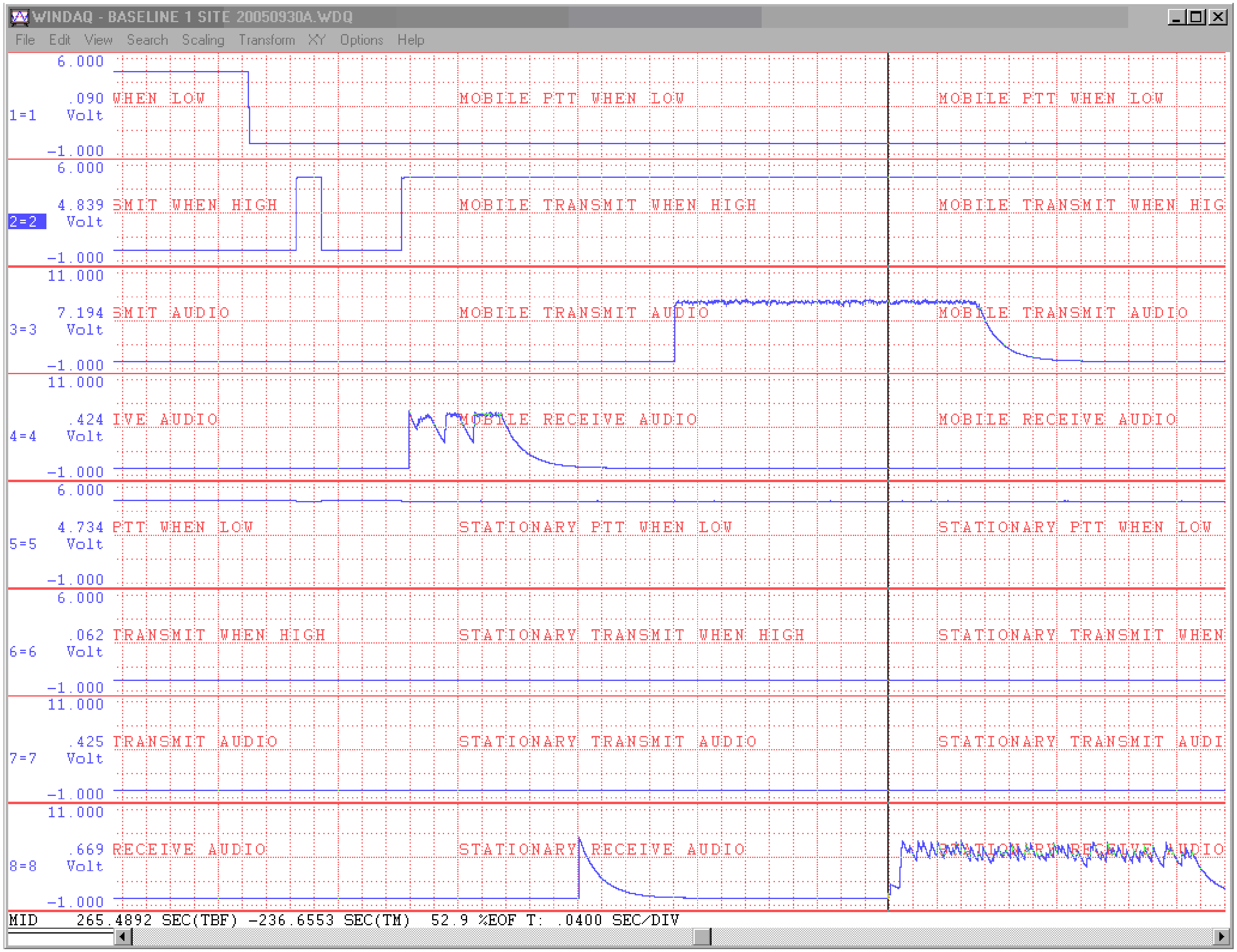


FIGURE 10 1 SITE PREAMBLE RX START.GIF

COMMUNICATIONS

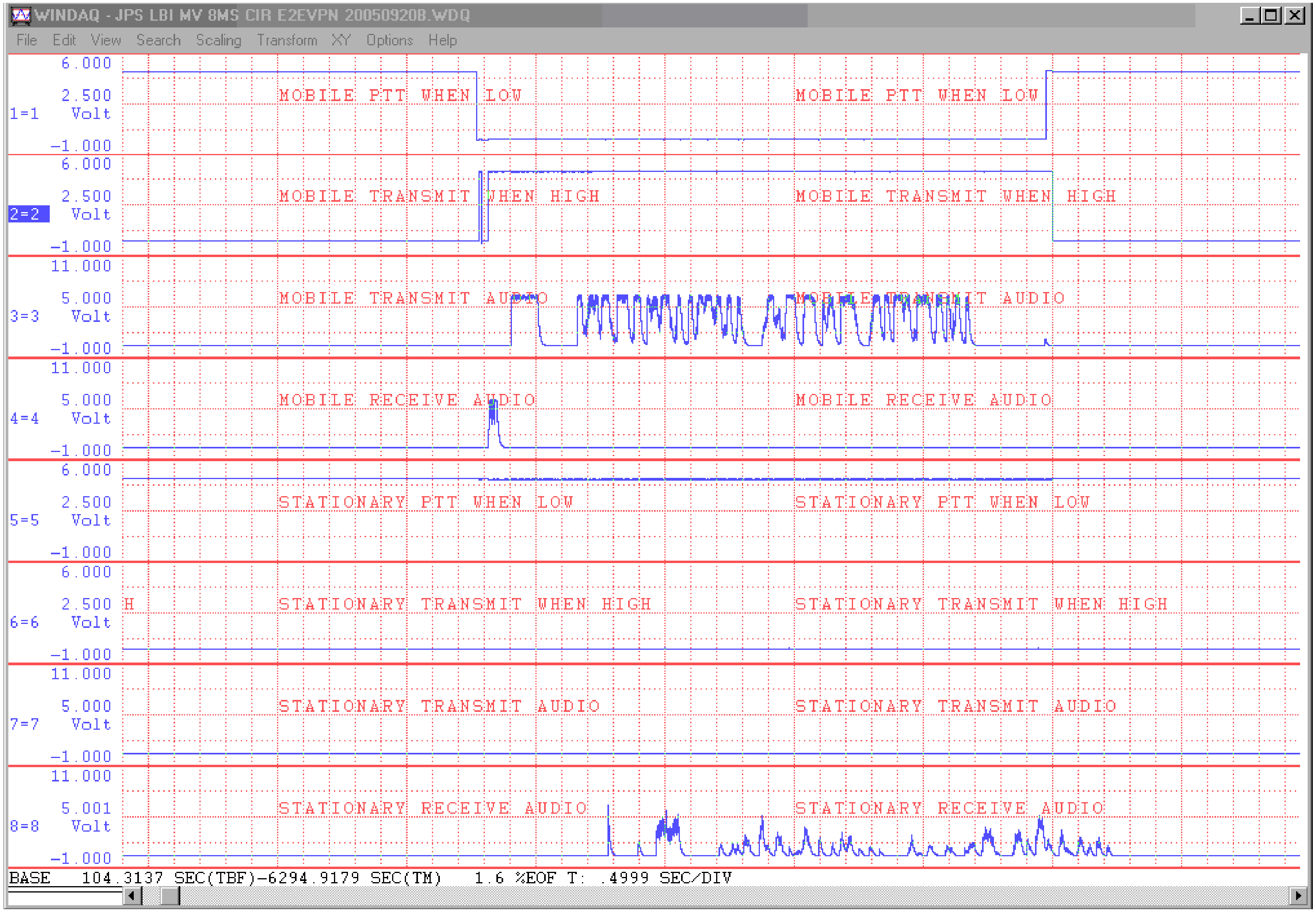


FIGURE 11 TYPICAL SAT TERMINAL ORIGINATED CALL.GIF

COMMUNICATIONS

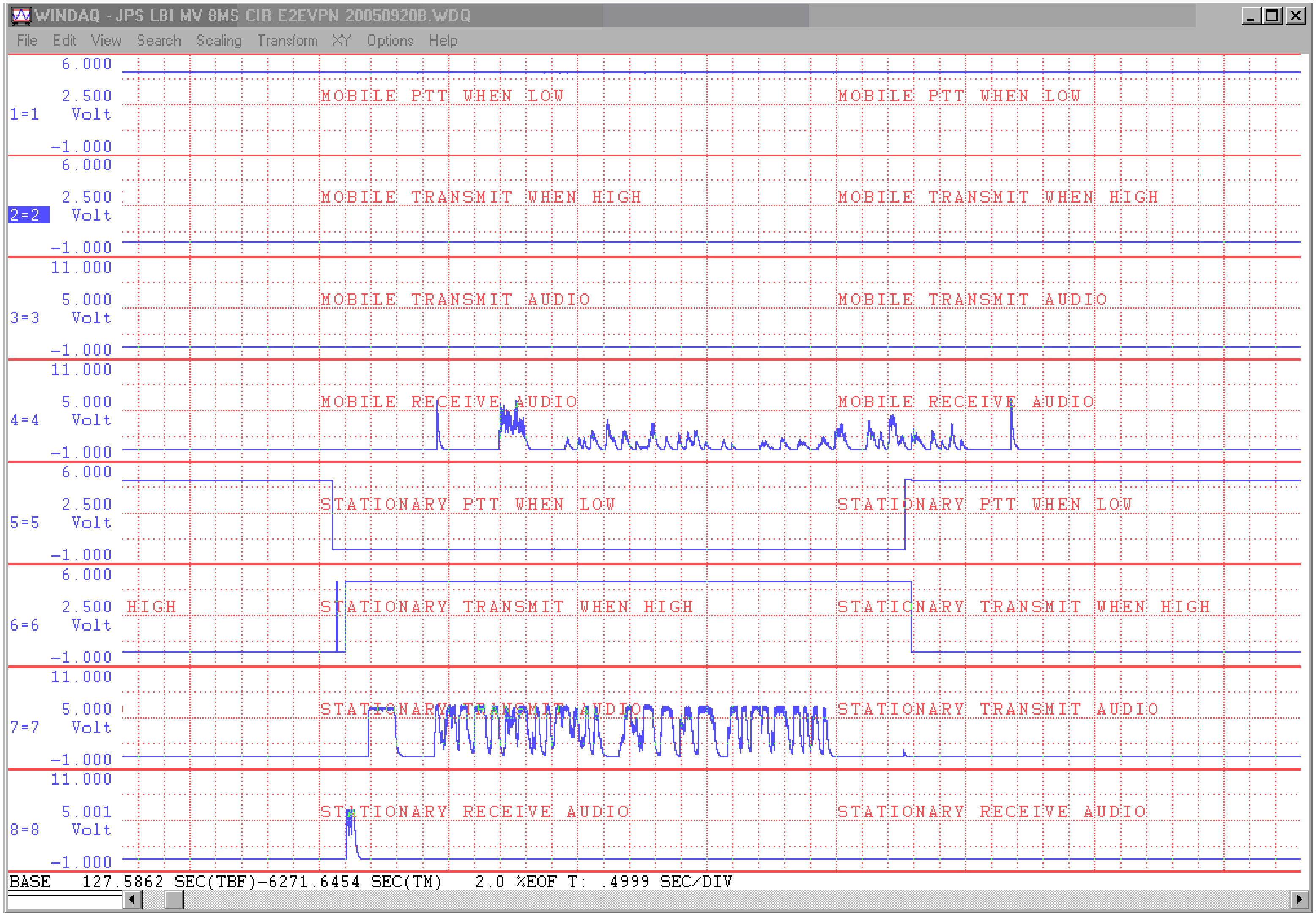


FIGURE 12 TYPICAL INTERNET TERMINAL ORIGINATED CALL.GIF

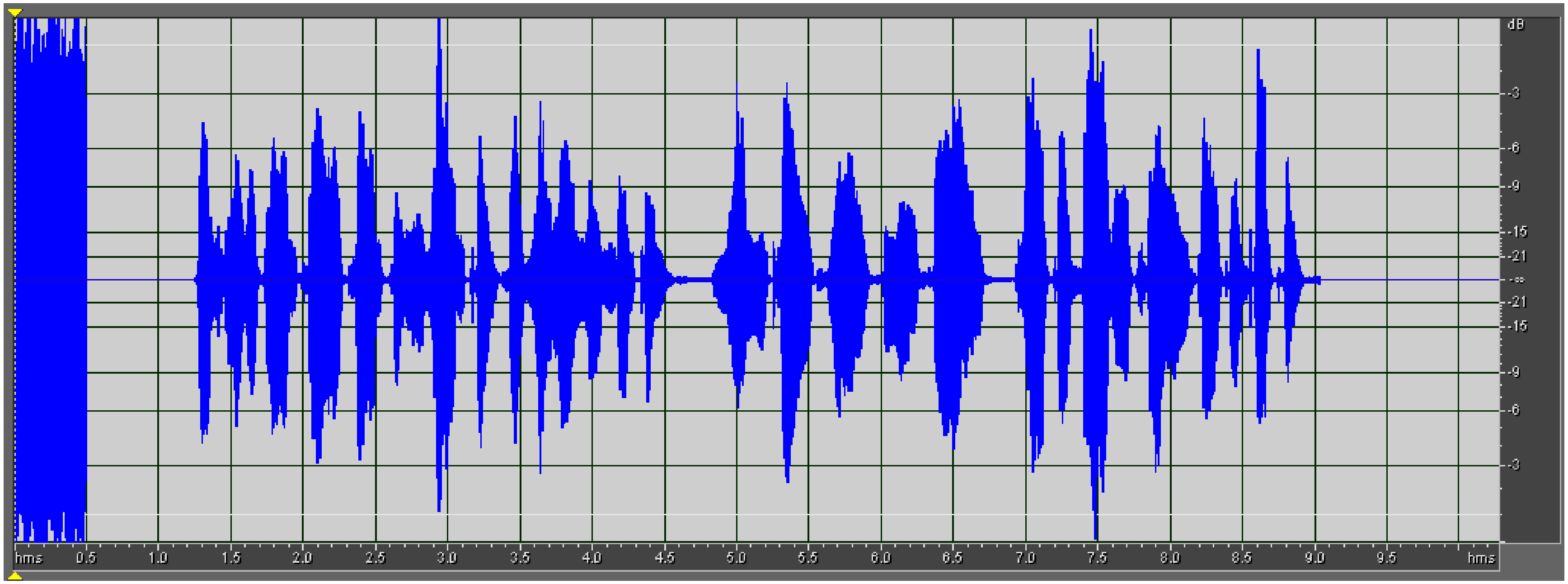


FIGURE 13 TX AUDIO WAVEFORM.GIF

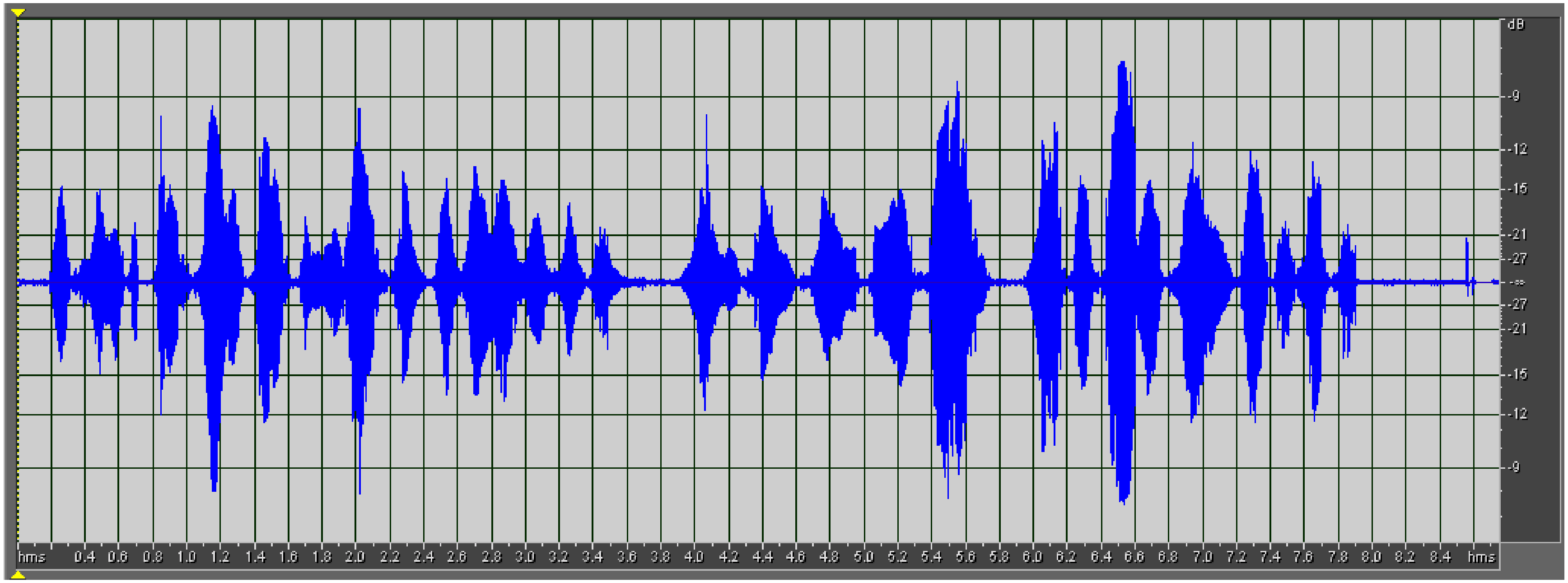


FIGURE 14 TYPICAL STATIONARY RECEIVED AUDIO.GIF

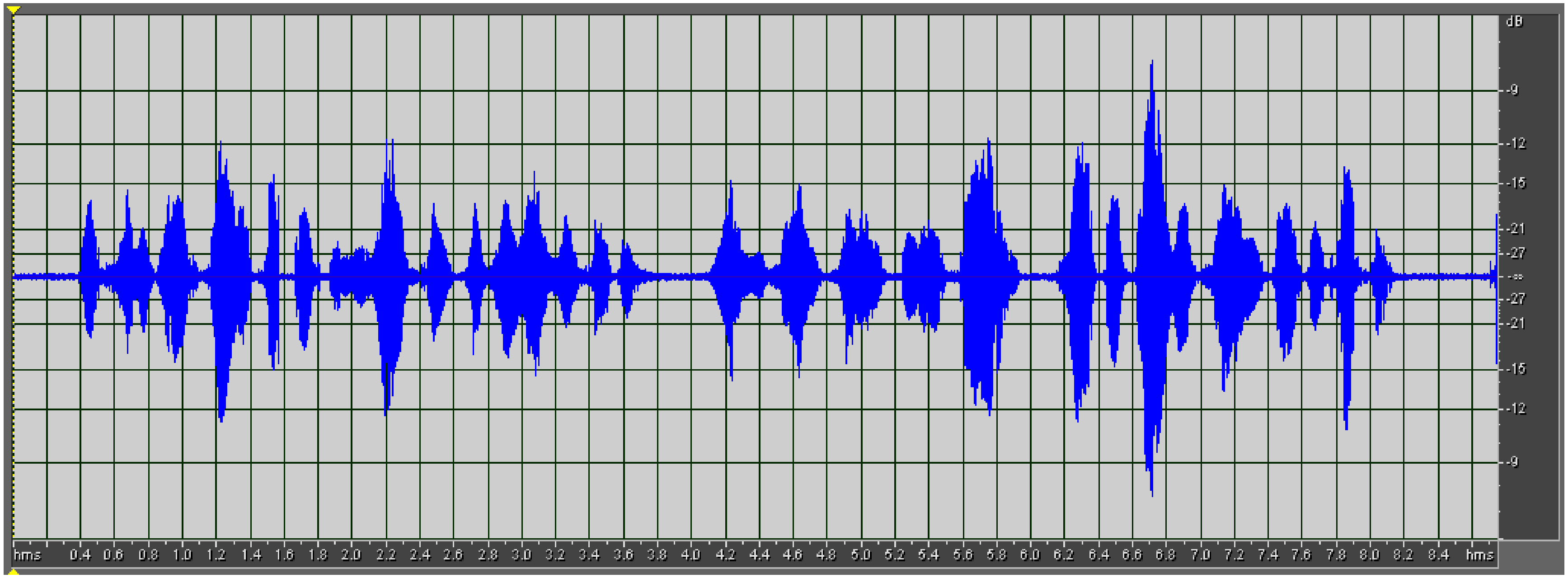


FIGURE 15 TYPICAL MOBILE RECEIVED AUDIO.GIF

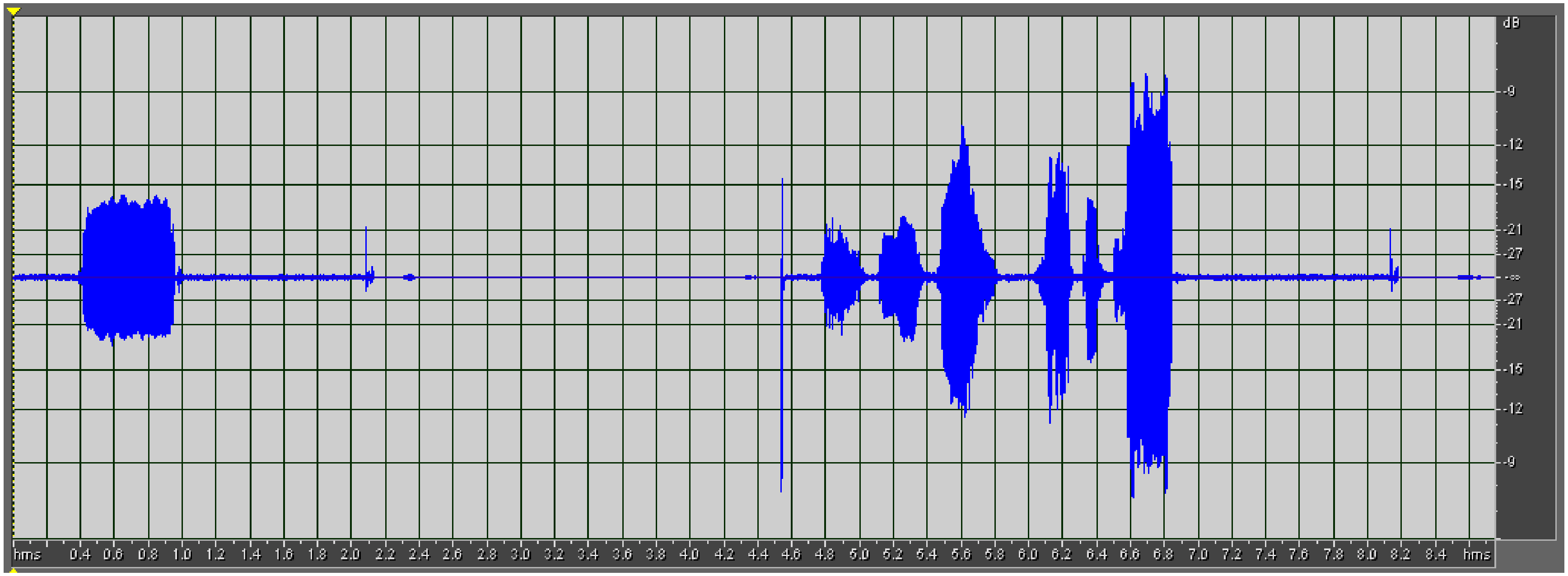


FIGURE 16 TYPICAL INTERFERENCE LIMITED AUDIO.GIF

APPENDIX 4

SATELLITE NETWORK CONFIGURATION AND PERFORMANCE

LBiSat Configuration and Performance

Anchorage, AK VSAT:	1.8 meter antenna 2 watt Ku band block up-converter Norsat 4506A Ku band low noise block down-converter iDirect NetModem II Galaxy 10R (123 degrees W) Horizontal transmit polarity 128 kbps (upload), 512 kbps (download) 8 kbps committed information rate (CIR) Average latency[1]: 693 ms Jitter[2]: 90ms
South Jordan, UT Hub:	6.1 Meter antenna iDirect TDMA Hub

Overall Summary: LBISat performance throughout the test period was excellent. One outage less than 5 minutes in duration was noted due to extremely heavy rain. At the end of the test, the link speed was turned down to 64 kbps for both upload and downloads to determine if the radio gateways could operate effectively at a lower bandwidth. The system was able to support both tested radio gateways at the 64 kbps speed.

NIASat Configuration and Performance

Anchorage, AK VSAT:	1.2 meter antenna 2 watt Ku band block up-converter ViaSat DRO Ku band low noise block down-converter ViaSat LinkStar Modem Horizons 1 (127 degrees W) Vertical transmit polarity Symmetrical 256 kbps (upload and download) Average latency[1]: 708ms Jitter[2]: 11ms
Atlanta, GA Hub:	7.2 Meter antenna ViaSat DVB/RCS Hub

Overall Summary: NIASat performance throughout the test period was excellent. One outage of less than 3 minutes in duration was noted due to extremely heavy rain.

[1] Round trip time between the remote VSAT and the LBISat DNS server.
[2] Standard deviation of 1000 roundtrip time measurements.

APPENDIX 5

VENDOR WEB SITE LIST

Satellite Networks:

NIASat (www.getnia.com)
LBISat (www.lbisat.com)
Starband (www.starband.com)

Radio Gateways

Motobridge (www.motorola.com)
JPS ACU1000 (www.jps.com)
Twisted Pair (www.twistpair.com)

VPN Solutions

Cisco Pix 506 Firewall (www.cisco.com)
End II End Gateway Security and Optimization Solution (www.eiiecomm.com)

APPENDIX 6

Satellites and Satellite IP Service Providers

Serving Alaska

Abstract: *This paper was prepared as part of a contract to support the National Law Enforcement and Corrections Technology Center—Northwest and Chenega Technology Services Corporation in their effort to test and evaluate voice over Internet protocol (VoIP) trunked radio services transiting a satellite IP network. The paper identifies basic satellite technologies in use today, the spectrums where they operate, characteristics of IP services over satellite, and listing of satellite IP service providers who potentially could offer service solutions in the Alaska Land Mobile Radio network.*

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Purchase Order No. 4000.39-05-Microcom-001

Satellites and IP Satellite Networks Serving Alaska

I. Executive Summary

Since a large portion of rural Alaska is exclusively dependent on some form of satellite service for communications, the ability to build a state wide land mobile radio network that includes rural Alaska is dependent on successfully using satellite systems to control the remote radio sites and pass the voice and data services. In the last 4 years multiple satellite broadband IP networks have been deployed in North American service that are operated both by telecommunications carriers based in Alaska and elsewhere in North America. Many of these carriers have implemented shared bandwidth services and are offering services at a much lower price than dedicated satellite services. In addition, they are using software and hardware that is optimized for provided IP services over a high latency satellite link.

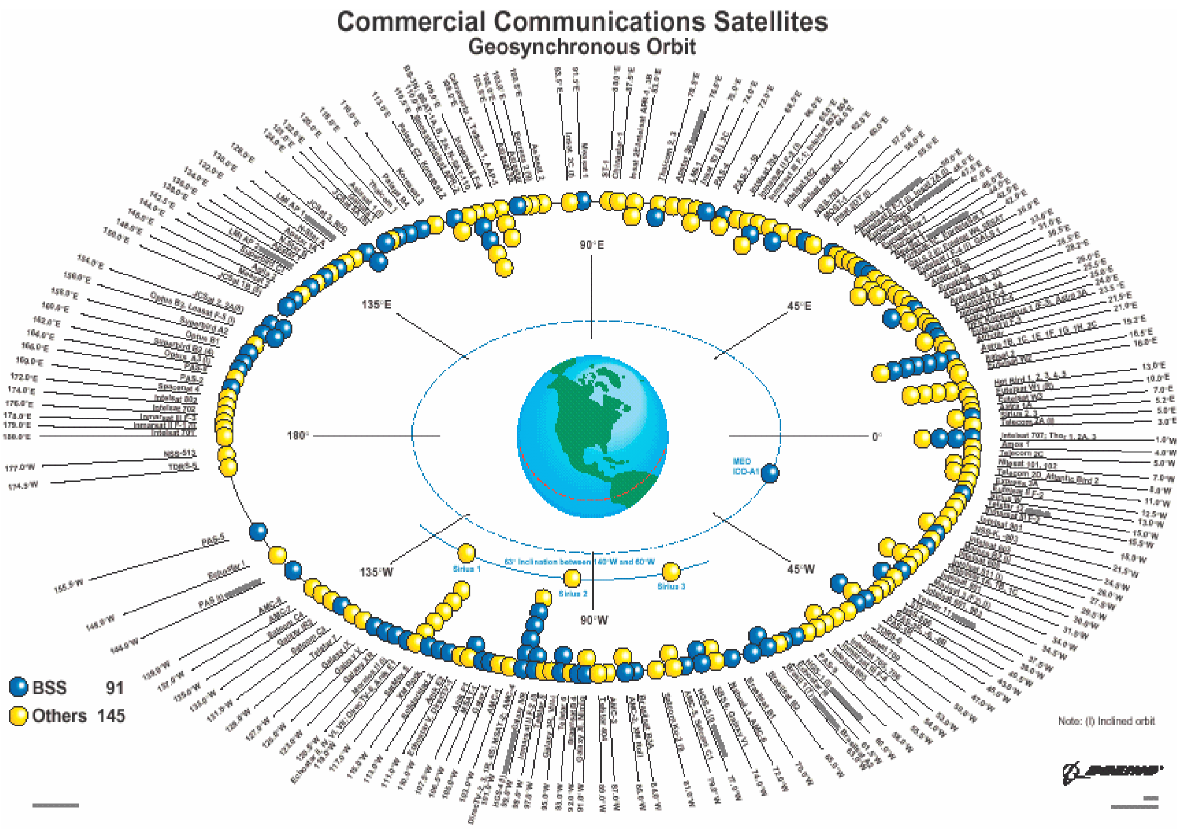
The satellites and satellite services in this paper use either C-band or Ku band satellite platforms. Both of these bands have a long term track record of providing reliable service throughout North America, the major difference being the size and cost of the equipment needed to use C-band is generally much greater than Ku-band. On the positive side, C-band does not experience the same degree of signal loss in heavy rain. From a network reliability perspective, properly designed satellite networks should have comparable reliability. The shared satellite IP services share both outbound bandwidth to the remotes and the return channels back from the remote to the hub. Sharing basically means that a given group of users shares bandwidth among themselves. In this environment, one user is not allowed to dominate all the bandwidth, but if there is no other demand for service, a single user will see performance close to that experienced on a dedicated circuit.

There are currently six satellites currently in orbit that significant service to at least mainland and Southeast Alaska (Galaxy 10R, Galaxy 13/Horizons 1, Intelsat Americas 7, and AMC-8). Four of these satellites provide coverage over all of Alaska (Galaxy 10R C-band, Galaxy 13 C-band, Intelsat Americas 7 C and Ku Band, and AMC-8 C-band). There is a scheduled launch of a satellite in November of this year (AMC-23) that will provide Ku-band coverage of all of Alaska. There are six service providers on these six satellites, one on C-band, one on C/Ku band, and 4 on Ku band only. Only 3 service providers cover the entire state (ATT, GCI, and Starband) and the others cover mainland and southeast Alaska (LBISAT, NIASAT, DirecWay).

Given the number of network operators, it should be possible to obtain competitive pricing for any network architecture ranging from dedicated point to point IP service, publicly shared IP services, or a private shared IP satellite service

II. Satellites and Spectrum

For purposes of this study, we are only concerned about geosynchronous satellites in commercial service. While there are non geostationary satellites in service providing digital voice services, e.g., Iridium and Globalstar, they are not considered suitable for satisfying the needs of the ALMR program.



The drawing above shows a representation of the satellites in service in the geosynchronous orbit. By definition this orbit is located approximately 22,500 miles above the equator. Because the majority of Alaska is located above 60 degrees north latitude, any geosynchronous satellite will be at a low elevation angle compared to most other regions of the world. For example in Anchorage, the satellite with the highest elevation angle is an EchoStar satellite at 148 degrees west longitude. Its elevation angle is 20.6 degrees. In order to realistically serve all of Alaska at a reasonable elevation angle (>5 degrees), a satellite would have to be located between 112 degrees west longitude and 172 degrees east longitude. To put that in perspective in the figure above, that would be approximately those satellites between clock positions 7 and 9. There is a discussion later in this paper of specific satellites that are of interest to Alaska.

The best way to conceptually view satellites is the same as active microwave repeaters. With very few exceptions, a satellite takes in signals on a specific frequency, amplifies them, and transmits them out on a different frequency. It does not process or in any way affect the data that transits the satellite. There are plans for some newer satellite constellations (Spaceway, www.spaceway.com, for example), to actually provide a switching matrix in the satellite to more efficiently route data between satellite terminals. This however, is not available today.

There are several portions of the radio frequency spectrum in use by commercial geosynchronous satellites ranging from 350 MHz (UHF) up to 30 GHz (Ka band). The discussion in this paper is limited to C-band (4/6 GHz) and Ku-band (12/14 GHz) as they are the only commercial satellite systems in general use today that provide IP services. Ka band services are just being deployed in the residential and small business market. None are on satellites that could provide any meaningful service in rural Alaska and to date the reliability of service using the Ka band is unknown.

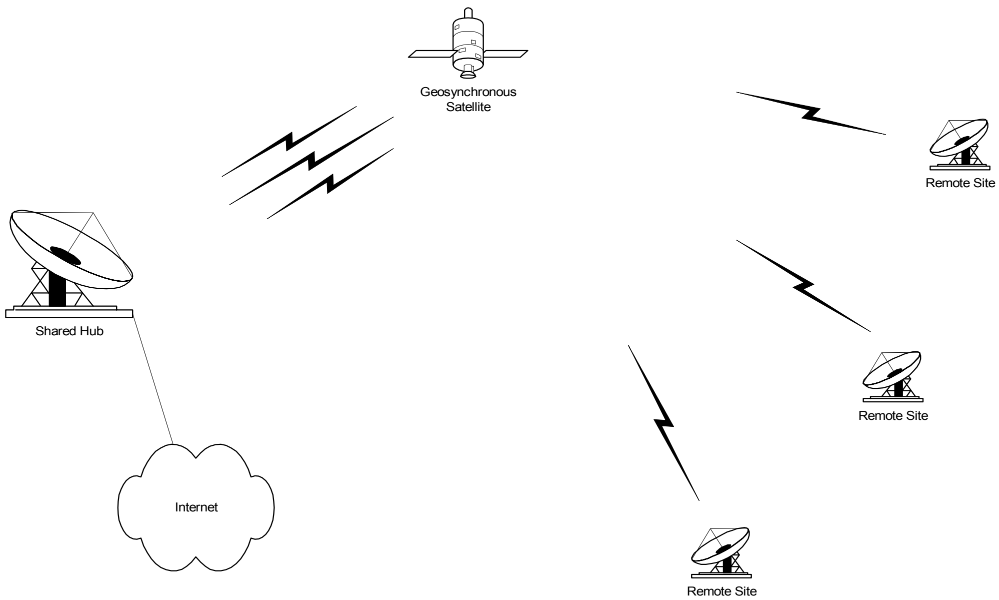
III. IP Services over Satellite

There are numerous ways to handle IP services over satellite networks, but most service providers generally have three areas where they implement specific hardware and software solutions to efficiently provide service. These areas are:

Managing and allocating satellite bandwidth
Grooming of IP for satellite Networks
Handling of IP Data at the hub earth station and remote VSATs

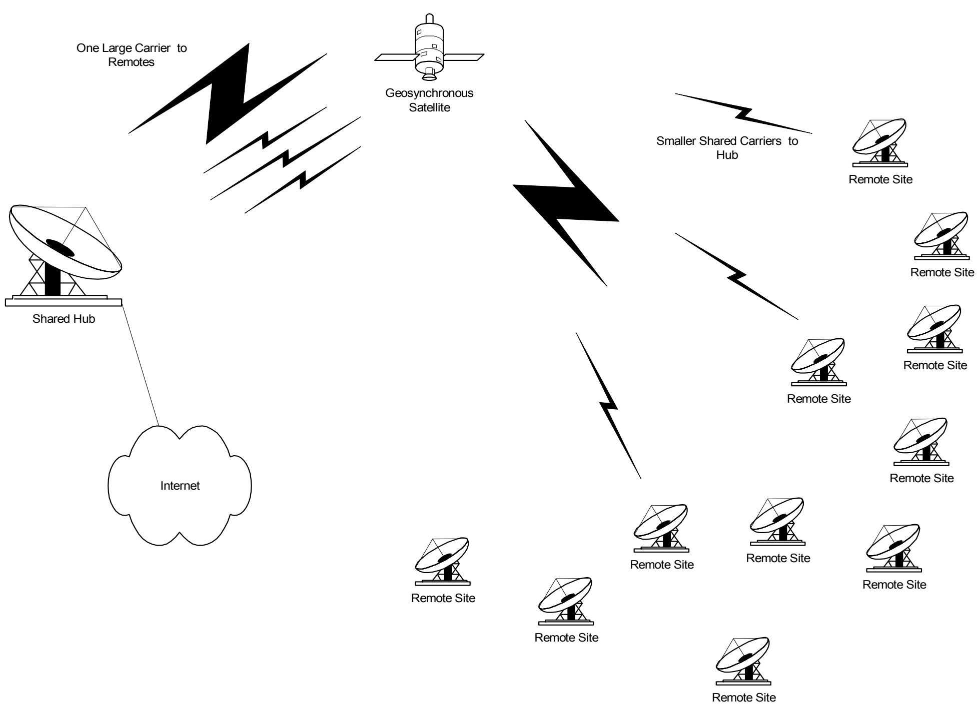
Managing and Allocating Satellite Bandwidth

In its most basic form, satellite bandwidth is allocated on the *single channel per carrier* (SCPC) model. In other words you buy the ability to transmit a given amount of data (also referred to as bandwidth) between two points. This is the most expensive way to manage satellite bandwidth in a network. On many of these SCPC networks, there is no special consideration given to grooming IP for transmission over a high latency network and the interface to the customer equipment uses no special standard other than that associated with digital data services. In other words, the customer has essentially leased a point to point data circuit and elected to place IP services on it. Due to the latency of the network there are some distinct physical limitations on this type of service when used for handling IP. The most significant of which is the maximum throughput regardless of the size of the transmitted carrier is limited to 400 kbps in a single session unless equipment is used on each end to groom the IP stream for a satellite network. The figure below shows an example of an SCPC satellite network.



SCPC Satellite Network

Most satellite IP providers today are using some form of network control system that allows them to more efficiently manage IP services among multiple network users in a classic star network. From their hub earth station they generally transmit, a large outbound carrier to remote VSATs and the remote transmits a much smaller carrier allocated to it based on time or traffic demand. The following figure depicts the basic structure of this type of network.



Shared Satellite Network

The two most prominent technologies used in shared satellite networks are:

TDMA—Time Division Multiple Access. In this technology, a remote terminal is assigned a time slot on a fixed carrier. For example, the carrier may be 192 kbps, meaning when the modem is sending data, it is transmitting at a line rate of 192 kbps. Based on network loading, you could be assigned multiple time slots to send data. The maximum throughput rate would be the line rate of 192 kbps. The only way to get more throughput is by transmitting a larger carrier.

SCPC DAMA—Single Channel per Carrier Demand Access Multiple Assignment. In this scenario, the carrier is not shared over time, but allocated to a specific remote terminal on demand. Once assigned, there is no division of the carrier into multiple time slots. You get the line rate of the carrier until it is released back to the DAMA pool. Some systems using SCPC DAMA increase throughput to the user by aggregating several smaller carriers together.

Handling IP Data in the Satellite Network

There are three competing technologies for handling data that are standards based (trying to set the standard) and vendor unique technologies that are imbedded in the satellite modem and hub equipment. Inherent in these data handling technologies is some type of processing of IP packets to allow faster speeds than 400 kbps in a single IP session. This IP acceleration is generally vendor specific and may take several forms and be implemented in hardware or software or both. IP acceleration can also be applied in SCPC IP services in the same manner. Below is a summary of the three data handling standards that are being proposed:

DOCSIS. As the name implies this is the same standard that is used in cable modems with some additions to handle satellite networks. The reason this standard is being used is it tends to lower the cost of terminal equipment as it uses existing chipsets. This is being used by satellite providers such as Wildblue and ViaSat in the US. (ViaSat is also the manufacturer of this type of shared satellite technology.)

DVB-RCS. This acronym stands for digital video broadcast—return channel satellite. DVB is the same standard used in direct broadcast satellite networks or digital cable networks. As an existing standard, it also has access to lower cost chipsets for terminal equipment. This is being used by EchoStar Data Networks and ViaSat in the US.

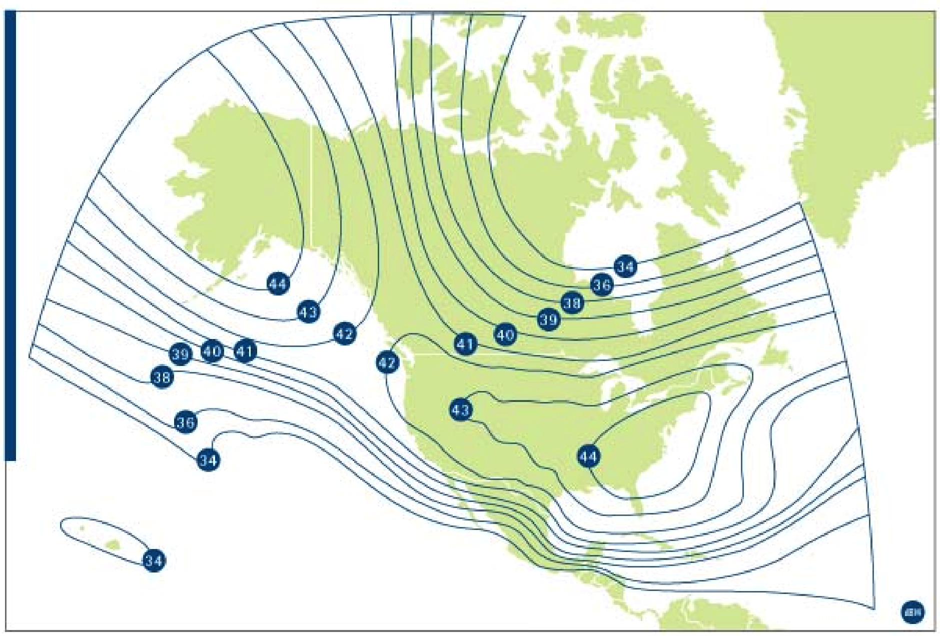
IPoS. This is a Hughes network developed standard other wise known as IP over Satellite and is used in the Hughes DirecWay network. No other service provider uses this standard but the size of the DirecWay customer base makes it a de facto standard.

However, most shared hub networks are using proprietary systems, the most prevalent of which is the IDirect hub manufactured by IDirect Technologies, www.idirect.net. Operators using the IDirect platform include Lyman Brothers, Tamsco, and GCI.

IV. Satellites of Interest to Alaska

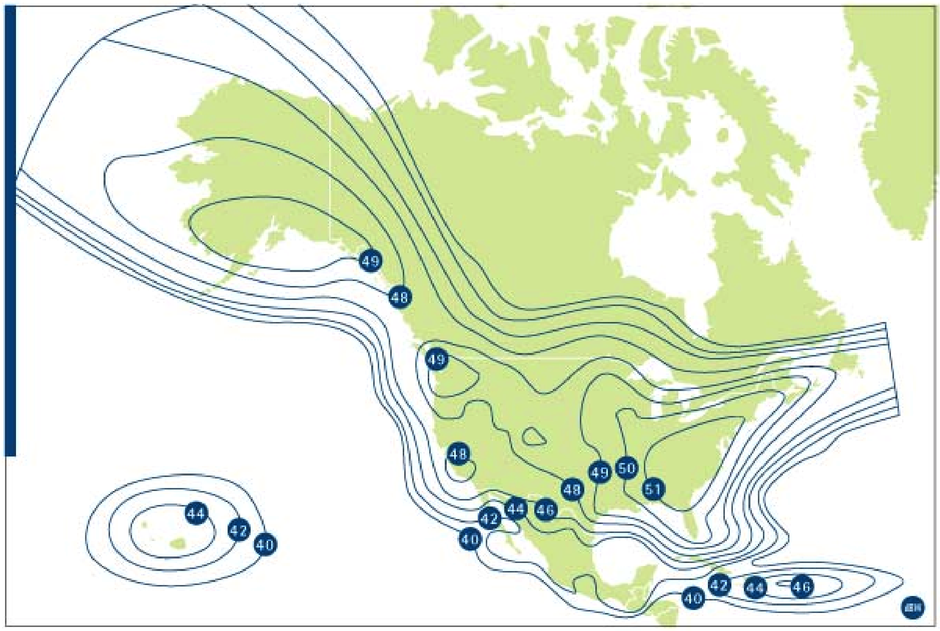
While many satellites can be used in portions of Alaska, very few satellites are capable of providing two way services over the entire state at a reasonable level of performance. A reasonable level of performance is defined as providing effective incident radiated power (EIRP) comparable to that provided to other regions of the country and G/T (a measure of the satellite's ability to receive transmissions from the ground) that does not require the use of unusually large transmitters. While this is a somewhat loose definition, it does effectively limit the number of satellites of interest to Alaska to the following:

a. Galaxy 10R, 123 degrees. A C/Ku band satellite with very good coverage of Alaska at C-band and coverage at Ku band limited to mainland Alaska. Some services have been deployed to St Paul Island and Dutch Harbor on the Ku band portion of Galaxy 10R, but they required the used of much larger antennas and satellite radios with significantly greater transmit power. The drawings below show Galaxy 10R coverage of Alaska.



HORIZONTAL BEAM
C-Band

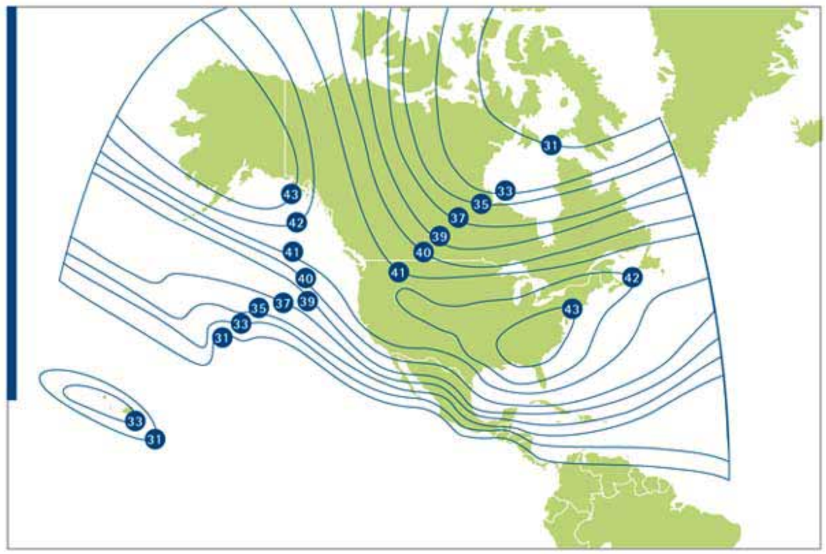
PanAmSat.



HORIZONTAL BEAM
Ku-Band

PanAmSat.

b. Galaxy 13/Horizons 1, 127 degrees. A C/Ku and satellite that provides essentially the same level of service to Alaska as Galaxy 10R. The Alaska coverage is shown in the drawings below.



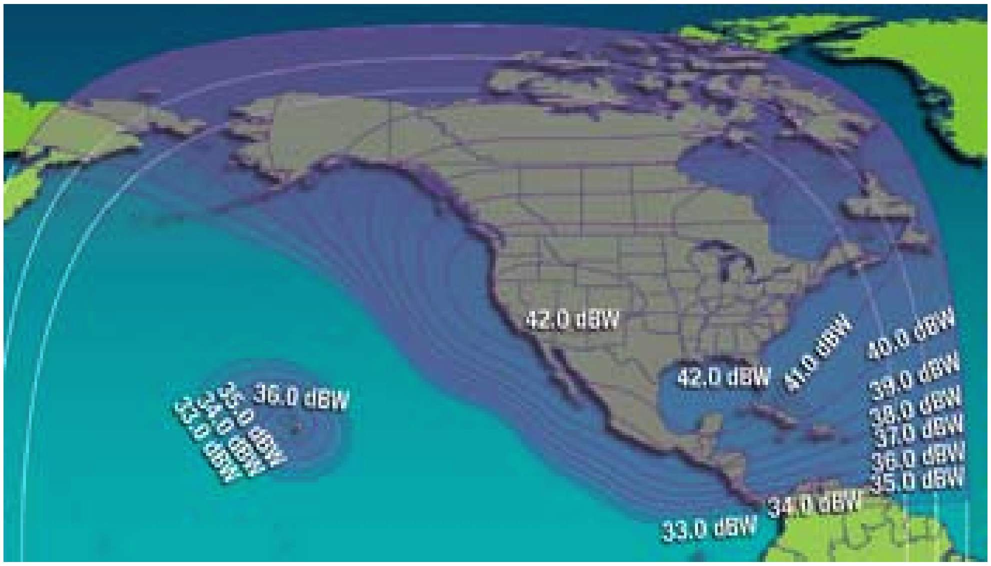
HORIZONTAL BEAM
C-Band

PanAmSat.

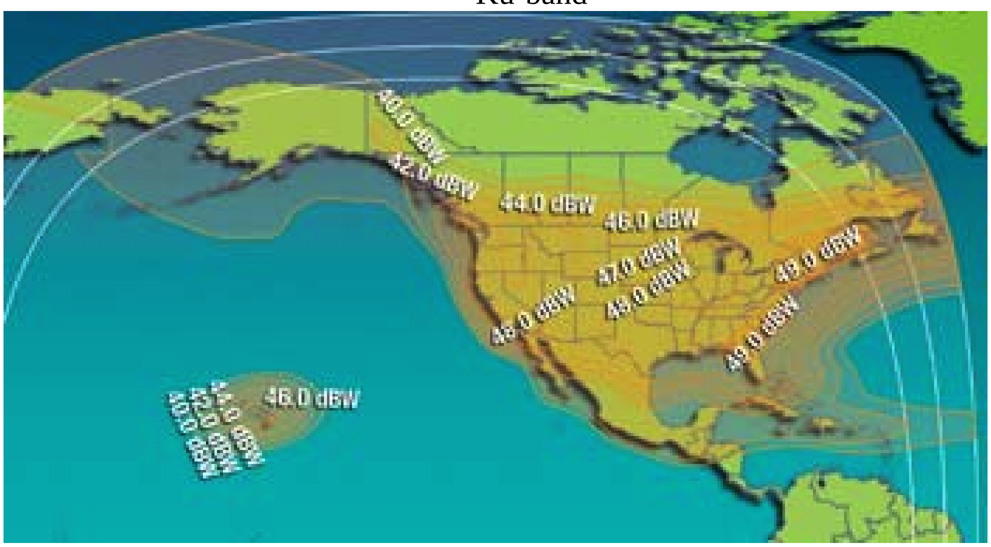
HORIZON 1 Horizontal Beam: Ku-Band
EIRP Levels

c. Intelsat Americas 7 (IA-7), 129 degrees. This satellite was originally named Telestar 7. It was the first satellite to provide Ku band coverage of all parts of Alaska including the Aleutians. In December 2004, the power system on this satellite suffered a major anomaly resulting in the loss of half of the transponder capacity. The long term prognosis on this satellite is unknown. No replacement has been announced. Alaska coverage of IA-7 is shown below.

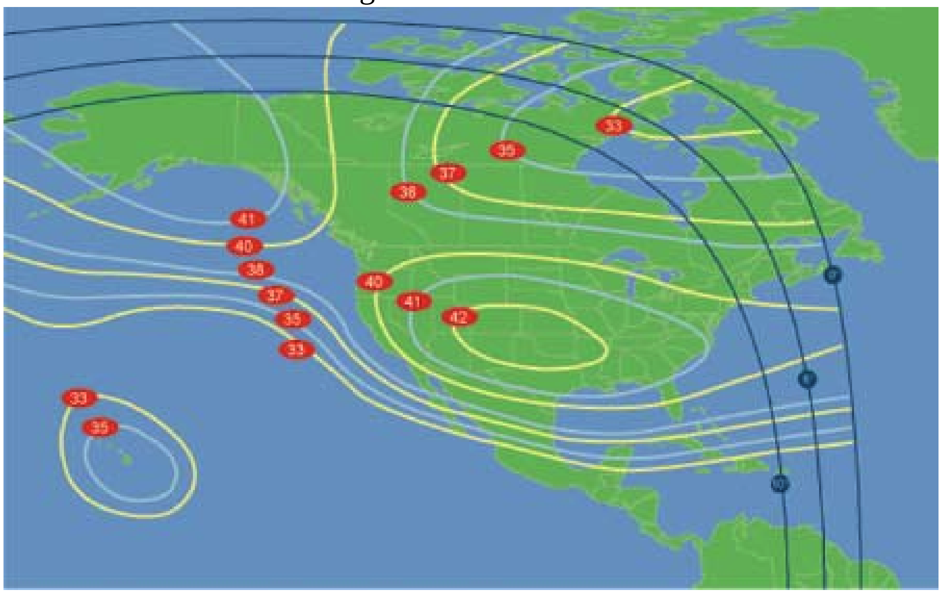
C-band



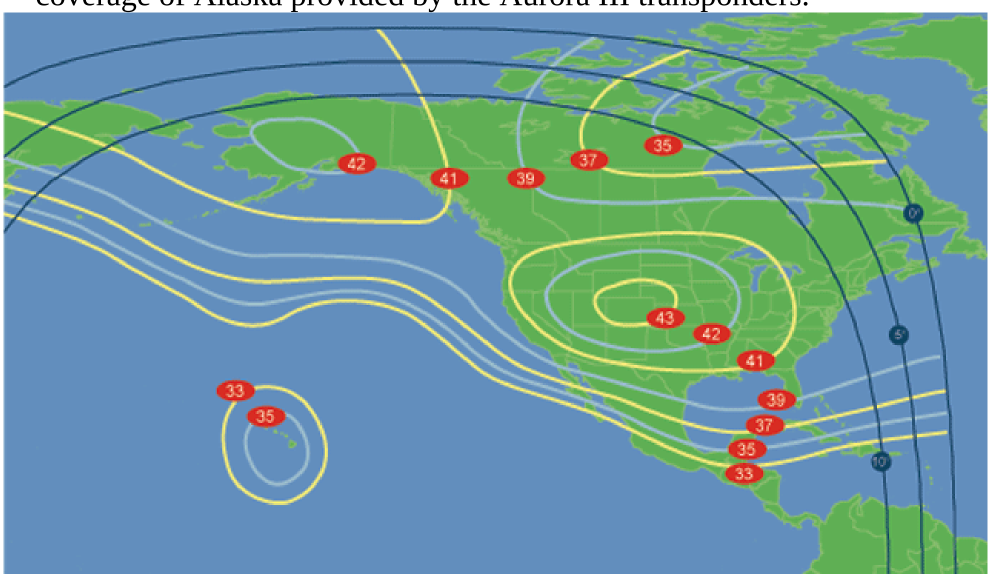
Ku-band



d. AMC-7, 137 degrees. This C-band satellite was designed as an “airborne” spare for AMC-8. It provides a reasonable amount of C-band service to the entire state. AMC-7 coverage of Alaska is shown below.



e. AMC-8/Aurora III, 139 degrees. This satellite jointly owned by SES and ATT was specifically designed to provide enhanced C-band service to Alaska. AMC-8 coverage of Alaska is shown below. This does not show the special coverage of Alaska provided by the Aurora III transponders.



f. AMC-23. 172 degrees east longitude. This satellite is scheduled to be launched in November 2005 specifically to provide service to Boeing Connexcion (www.boeingconnexcion.com). Boeing Connexcion offers broadband IP service to aircraft and ships in the Pacific Ocean Area. Ku band coverage of this satellite includes all of Alaska. SES Americom indicated that there would be available capacity on this satellite.

Of the twelve satellites in the geosynchronous orbital arc that could potentially provide service to Alaska (that portion of the arc west of 110 degrees west longtitude) only five can realistically do so based on their design. This limits access to network providers.

V. Service Providers on these Satellites

Service Provider	***Hardware Architecture***	***Satellite***	***Major Users***
LBISAT (Lyman Brothers) www.lbisat.com	IDirect Shared Hub TDMA, Proprietary data handling	Galaxy 10R (123 degrees)	Individual government and business subscribers, remote ISP's, small multi-site networks.
NIASAT www.getnia.com	ViaSat Link Star, Shared Hub TDMA, DVB RCS	Horizons 1 (127 degrees)	Individual business subscribers and small multi-site networks
Starband/SpaceNet www.starband.com	Gilat 484 Shared Hub TDMA, Proprietary data handling	Intelsat Americas 7 (129 degrees)	Residential and small businesses.
DirecWay (Ground Control) www.direcway.com	Hughes Networks Shared Hub TDMA, IPOS	Horizons 1 (127 Degrees)	Residential, small business, and enterprise customers in private networks.
ATT Alascom	Single Channel Per Carrier digital data service	Aurora III (139 degrees)	ISP's, schools, libraries, health care, and rural businesses.
General Communications Inc www.gci.com	SCPC DAMA Shared Hub TDMA, Proprietary data handling	Galaxy 10R (123 degrees), AMC-7 (137 degrees)	ISP's, schools, libraries, health care, and rural businesses.
Boeing Connexion www.boeingconnexcion.com	Unknown	AMC-23 (172 degrees east)	Aircraft and ships operation in the North Pacific ocean area.
Tamsco www.tamsco.com	Shared Hub TDMA, Propietary data handling	Galaxy 10R (123 degrees east)	Schools, libraries, and health care

VI. Comparative Network Analysis

It is very difficult to compare satellite IP networks based on cost and performance; however, there are some generalizations that can be drawn. The most costly satellite network when looking at day to day operating costs would use single channel per carrier (SCPC) technology such as that offered by ATT. The least costly network would be a shared network directed at consumers such as those offered by Starband and DirecWay. In the middle are those shared networks offered by LBISAT, NIASAT, and DirecWay's Enterprise service. The quality of service/performance is controllable by the network provider and the customer is charged accordingly. To put a dollar value on this, the range is from $49.99 per month for Starband consumer service to more than $13,000 per month for a dedicated 1.54mbps of IP service over an SCPC satellite channel. On the consumer service you can check your e-mail and surf web pages while on the dedicated service you can provide high levels of service for voice and video IP traffic. It cannot be over emphasized that the primary driver on quality is price and not necessarily the technology being deployed. The most import aspect is to match the network to the need. Shared networks are great if traffic loads vary over time and spike infrequently. As traffic loads go up, shared networks can be closely managed to insure a good quality of service. Interestingly, there have been no definitive studies of how scalable a shared network architecture can be in the face of increasing network traffic needs and what evolutionary path these networks will take over time to respond to those needs.

VII. Network Planning Considerations

One of the most important things to understand about any satellite IP network is the customizations, if any, the service provider has implemented to enhance performance of various types of IP traffic. Most satellite networks have enhancements that target TCP packets and in some cases specific IP ports such as port 80 used for world wide web traffic. In planning a satellite IP network of a single site or multiple sites, profiling the type of IP traffic that will transit the network and reaching an understanding with the network provider on how that traffic will be processed is extremely important. For example, operating any type of IPSEC virtual private network (VPN) or a satellite link has always been problematic. With that in mind, here is a laundry list of items to consider when looking for a satellite IP network:

- Type and volume of IP traffic
- Aggregation rate of the provider
- IP enhancements of the provider
    - TCP Acceleration
    - VPN Support
- QOS implementations
    - Voice
    - Video
- Criticality of service
    - 7x24 Network Operations Support

Emergency plans in event of satellite failure
Redundancy at gateway earth station
Remote site redundancy and sparing
Remote site maintenance
Network Security
Satellite Path Encryption

VIII. Conclusion

In the last five years the number of broadband satellite operators that provide service to Alaska has increased substantially. From two network providers, the state now has at least six. However, the number of satellites providing that service has for the most part remained the same. While Galaxy 13 represents a new satellite platform, the partial failure of Intelsat Americas 7 offsets that increase. The deployment of Ka band satellite services by Wildblue/Telesat Canada, Spaceway, and possibly EchoStar Data Networks will have an indirect impact on Alaska as they affect the fate of Starband and the DirecWay consumer service. Successful deployment of these Ka band consumer services (Wildblue/Telesat service is currently available and the other satellites have been launched) will probably mean the demise of Starband and DirecWay's consumer service, but will have the effect of making additional bandwidth available on Horizon's 1 and Intelsat Americas 7. The key to fielding a satellite IP network in support of the Alaska Land Mobile Radio project is the availability of satellite capacity of the right type and quality and a network operator. Those both seem to be available in the near term.