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EVA Radio DRATS 2011 Report

Aaron J. Swank and Casey J. Bakula
Glenn Research Center, Cleveland, Ohio

August 2012

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Aaron J. Swank and Casey J. Bakula
Glenn Research Center, Cleveland, Ohio

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

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Extravehicular Activity (EVA) Technology Development Power, Avionics, and Software (PAS) EVA Radio Team:
Neil Adams, Casey Bakula, Larry Foore, Dave Pleva, Aaron J. Swank, and Dan Zeleznikar.

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Abstract

In the Fall of 2011, National Aeronautics and Space Administration (NASA) Glenn Research Center (GRC) participated in the Desert Research and Technology Studies (DRATS) field experiments held near Flagstaff, Arizona. The objective of the DRATS outing is to provide analog mission testing of candidate technologies for space exploration, especially those technologies applicable to human exploration of extra-terrestrial rocky bodies. These activities are performed at locations with similarities to extra-terrestrial conditions.

This report describes the Extravehicular Activity (EVA) Dual-Band Radio Communication System which was demonstrated during the 2011 outing. The EVA radio system is designed to transport both voice and telemetry data through a mobile ad hoc wireless network and employs a dual-band radio configuration. Some key characteristics of this system include: 1. Dual-band radio configuration. 2. Intelligent switching between two different capability wireless networks. 3. Self-healing network. 4. Simultaneous data and voice communication.

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1 Executive Summary

In the Fall of 2011, NASA GRC participated in the Desert Research and Technology Studies (DRATS) field experiments held near Flagstaff, Arizona. The objective of the DRATS outing is to provide analog mission testing of candidate technologies for space exploration, especially those technologies applicable to human exploration of extra-terrestrial rocky bodies. These activities are performed at locations with similarities to extra-terrestrial conditions.

This report describes the Extravehicular Activity (EVA) Dual-Band Radio Communication System which was demonstrated during the 2011 outing. The EVA radio system is designed to transport both voice and telemetry data through a mobile ad hoc wireless network and employs a dual-band radio configuration. Some key characteristics of this system include:

- **Dual-band radio configuration.** One 2.4 GHz radio is used for high data rate communication and a 900 MHz radio is used for contingencies to provide improved coverage and extended operational range.
- **Intelligent switching between two different capability wireless networks.** The switching algorithm utilizes the probability of a successful packet transfer (expected transmission count) for the wireless links in order to select the appropriate wireless network.
- **Self-healing network.** Alternative data paths are determined either within the same network, or by transitioning to an alternative independent wireless network with different capabilities and characteristics.
- **Simultaneous data and voice communication.** The wireless communication system uses Media Access Control (MAC) layer traffic control and open source Speex-based Voice over Internet Protocol (VoIP) technology.

2 Introduction

Due to the often conflicting requirements of high data rates and reliable radio coverage, a dual-band radio architecture is proposed for future EVA suit systems. This system uses a wideband, high data rate Radio Frequency (RF) interface with enough throughput to handle simultaneous voice, telemetry, and video flows, as well as a lower data rate RF interface that can carry mission essential voice and telemetry. The wideband interface is used amongst all radios while they are in range of each other, and since the link range of wideband networks is relatively short, the low-rate interface is used when the wideband interface fails. Low-priority data flows originating from the suit are queued up locally on

Figure 1. Test subjects with EVA Radio backpacks at DRATS 2011.

the suit and transmitted when the wideband network is available. This concept allows for each of the two interfaces to be designed separately according to each set of requirements for both coverage and high data rates.

In order for a dual-band radio system to work reliably, the switching between the two interfaces must be done gracefully to avoid dropouts and loss of data. This is not a trivial problem, as it involves an accurate assessment of the wideband link quality at all times. When the radio perceives that the wideband link is about to fail, it must propagate this information throughout the network so that all other radios can switch over to the low-rate interface before any data loss can occur. All of the nodes in the mesh must utilize the same network to avoid asymmetries in throughput and to ensure all of the nodes are receiving the same information. When the network is using the low-rate interface, all radios must evaluate the link quality for each wideband link within the network. Once all of the wideband links are established and stable, the radio network then switches back to using the wideband interface.

The EVA Radio prototypes tested at DRATS 2011 (Figure 1), are designed to implement the features described above using Commercial Off-The-Shelf (COTS) radio interfaces and open-source networking software. The system consists of three backpacks replicating EVA suits, with two being for crew members and the third as a backup. An additional base station node simulates a stationary relay communications terminal to an earth-based ground station. The DRATS test scenarios adhere to a typical EVA sortie featuring two crew members venturing away from a base station. The objectives of these tests are to:

- Evaluate the performance of the RF interface switching logic
- Gather the crew members' feedback about the concept of a dual-band radio and the current implementation
- Evaluate the performance of the COTS radios in an environment that more closely matches a lunar/Near-Earth Asteroid (NEA) setting
- Evaluate the performance of the open-source routing software

3 Radio Testbed

3.1 Hardware Description

In order to demonstrate the concept of a dual-band switching radio system, a testbed was constructed. The testbed consists of two mobile nodes representing EVA crew members and a fixed-node base station connected to a ground station terminal, hereafter referred to as XCOMM. The two mobile nodes and the single fixed node are constructed with the same functional hardware components and utilize the same software builds.

The components of the nodes are primarily COTS hardware, which includes an i686-based General Purpose Processor (GPP), a 900 MHz Orthogonal Frequency-Division Multiplexing (OFDM) radio, a 2.4 GHz Wireless Fidelity (Wi-Fi) radio, an Internet Protocol (IP) video camera, a pair of speakers, a microphone, and a Global Positioning System (GPS) receiver. A functional sketch of the dual-band radio testbed is depicted in Figure 2. The GPP runs the entire networking stack, handles the interfaces for all of the other hardware components and processes all incoming and outgoing data. An i686-based GPP is chosen specifically to run a full Debian Linux distribution. Linux is used to aid in rapid prototyping by leveraging the inherent software and hardware driver support that comes with using an established operating system. An outdoor, Access Point (AP)-class 900 MHz OFDM radio is selected as the contingency interface because of the favorable propagation characteristics and the fact that it can be configured for high bandwidth at lower data rates, which improves coverage by minimizing inter-symbol interference. The 2.4 GHz Wi-Fi radio is selected to evaluate the performance of 802.11 in an EVA sortie scenario, as well as the fact that an 802.11n AP is under consideration for the International Space Station (ISS).[1] Both the 900 MHz and 2.4 GHz radios are equipped with dipole antennas.

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[1] The ISS External Wireless System described in Boeing's draft document [1] proposes two COTS BelAir 802.11n APs to be installed inside the ISS with the antennas mounted outside. Coverage would be available to payloads mounted at several of the Express Logistics Carrier sites.

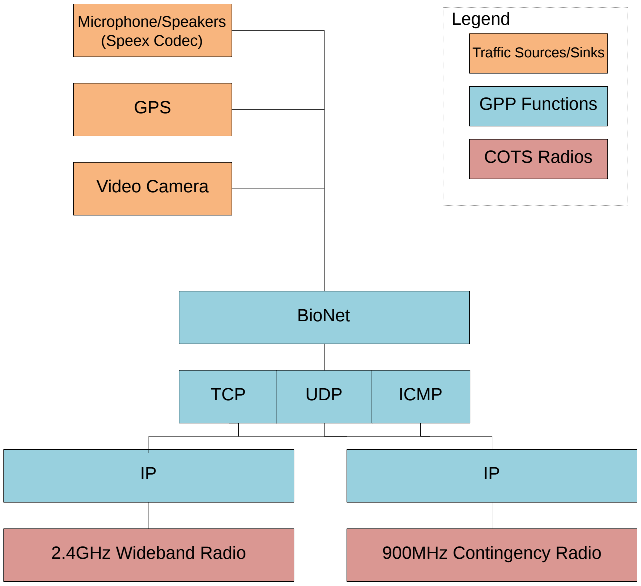
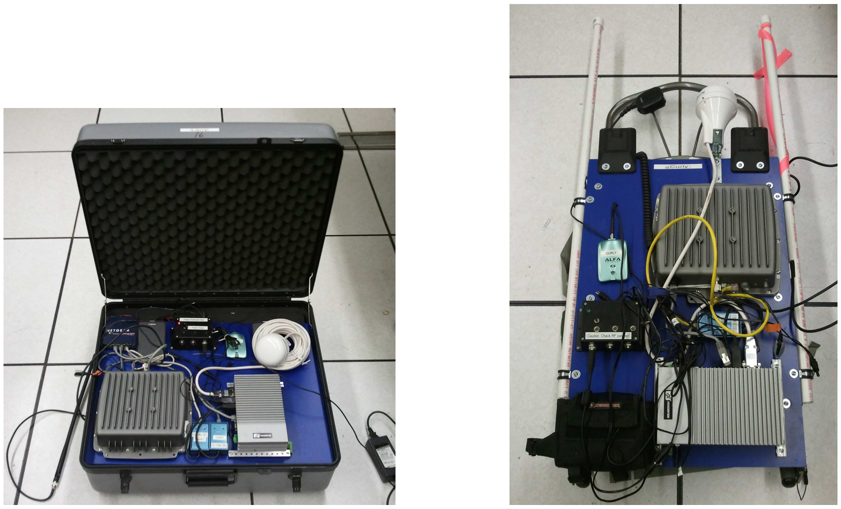


Figure 2. EVA Node Functional Diagram

Data is generated by the nodes via VoIP voice, video, GPS telemetry, and network/radio messaging. Each node contains a push-to-talk microphone connected to a line-level audio input on the GPP. Audio data is encoded, packetized and transmitted over the active RF interface. Incoming audio is decoded and output to a pair of speakers mounted near the crew member's head. The IP video camera, mounted over the shoulder of the crew member, generates an IP packet stream of video data over a gigabit Ethernet interface to the GPP, which then routes the video data to XCOMM if the Wi-Fi interface is available. If only the 900 MHz interface is available, the video data is stored locally until the Wi-Fi interface is re-established. The GPS unit, connected via serial port to the GPP, generates position information once per second. The location is transmitted over the active RF interface back to XCOMM. The routing protocol, described in further detail in Section 3.3.1, also generates its own network traffic for the purpose of evaluating link quality and establishing routing tables. Finally, the radios themselves generate MAC messages that are used to establish and maintain the wireless networks.

All of the hardware components are fixed to a plastic backing plate, and for the mobile nodes, the plate is securely mounted to a rigid external-frame backpack via aluminum struts. Plastic masts for the radio antennas are also fixed to the plate so that the antennas can be mounted safely above the crew member's head. Figure 3 shows the constructed dual-band radio testbed hardware.



(a) EVA Base Station (b) EVA Testbed Backpack

Figure 3. EVA Testbed Nodes

3.2 Radio Configuration

Both 900 MHz and 2.4 GHz COTS radios used in the EVA radio system are 802.11-based, although the system profiles are quite different. The configuration of each radio is described in the following sections.

3.2.1 2.4 GHz Wi-Fi Radio Configuration

The high data-rate radio is configured as an 802.11b/g radio. Refer to Table 1 for a summary of the configuration settings. The radio is configured in ad hoc mode, as the system is intended to operate in an environment where there is no pre-established infrastructure. Request To Send (RTS)/Clear To Send (CTS) is enabled to mitigate the effects of the classic hidden node problem, which was deliberately tested during the outing. RTS/CTS is an optional handshaking protocol that ensures a receiver is ready to receive a data frame before it is transmitted. A fragmentation threshold is also used so that large file transfers (i.e., stored video) will not occupy the wireless channel for long periods of time, preventing time-sensitive date from being transmitted during periods of high congestion. All data frames that are larger than the fragmentation threshold will be fragmented into smaller frames before transmission. This is desirable in certain networks, since radios on the network must wait for relatively long periods of time while large data frames are being transmitted. A fragmentation threshold also improves performance in the presence of RF interference. The 802.11 channel/frequency is chosen to minimize interference with other transmitters observed in the spectrum, as identified during initial test site location evaluation.

Configuration	**Setting**
Mode	ad hoc
Transmit Power	30 dBm (1 W)
Frequency	2.412 GHz (802.11 Channel 1)
Bandwidth	20 MHz
Modulation	variable
Data Rate	variable, 1-54 Mbps (802.11 b/g)
Fragmentation Threshold	512 Bytes
RTS/CTS	enabled

Table 1. Wideband Radio Configuration Settings

3.2.2 900 MHz Contingency Radio Configuration

Since the main design objective of the contingency radio is reliable coverage, the radio's 802.11 system profile is configured as such. It is important to note here that this radio is not a true 802.11 radio, since it operates outside of the 2.4 GHz Industrial, Science and Medical (ISM) band. The manufacturer intended this radio to be as close as possible to an 802.11 radio operating in the 900 MHz ISM band. To maximize range and minimize the Bit Error Rate (BER), Binary Phase Shift Keying (BPSK) modulation is used. High data rates are not needed for this interface, so the use of a higher order modulation scheme is unnecessary. To further mitigate the effects of multipath and inter-symbol interference, OFDM is used with a 20 MHz bandwidth. Since the signal is spread out over a large bandwidth, it is less susceptible to narrowband fading. Configuration settings for the contingency radio are summarized in Table 2.

Configuration	**Setting**
Mode	ad hoc
Transmit Power	30 dBm
Frequency	915 MHz
Bandwidth	20 MHz
Modulation	BPSK w/ OFDM
Data Rate	6 Mbps
Fragmentation Threshold	512 Bytes
RTS/CTS	disabled

Table 2. 900 MHz Contingency Radio Configuration Settings

3.3 Software Implementation

Where possible, existing software projects are utilized and the development effort made extensive use of open source software. For newly-developed software, each core software capability is contained as a separate software program or library. The core software capabilities for the EVA radio system fall into the following primary functional categories:

- Wireless Mesh Routing
- Wireless Network Health Sensing and Network Switching
- Speech Acquisition/Encoding for VoIP
- Sensor Acquisition and Distribution (Telemetry)

Each core software capability is described in the upcoming sections. All of the system software are developed and deployed on the testbed using a version control system. Additional information on the software development methodology and the software version control system is found in Appendix A.

3.3.1 Wireless Mesh Routing

The Wi-Fi radio hardware is configured to operate in an ad hoc mode as opposed to a traditional infrastructure mode. An ad hoc wireless network handles changes in the network topology in a distributed fashion, as there is no central AP or pre-established infrastructure. The ad hoc mode is primarily designed for peer-to-peer communication and the network topology must be discovered by each of the nodes. Often a peer-to-peer network is used to allow communication between nodes which are within range of each other without the need for an AP. An ad hoc wireless mesh network may also implement a routing protocol which utilizes other nodes in the network to route and forward data. If the destination node is not within direct range of the source node, the data is relayed over other members within the network. A disadvantage of such a network topology is that the data transmissions are susceptible to potentially large network delays. The user does not necessarily have control over the path that data takes to reach the intended destination. As a result, the information may not route through the most optimal or efficient path to the end point. In order to intelligently manage the routing of data throughout the wireless mesh on the Wi-Fi network, the EVA radio system adopted the Optimal Link State Routing (OLSR) ad hoc wireless mesh routing protocol [2]. Specifically, the open source OLSR implementation from `olsr.org` was utilized [3], [4].

The use of OLSR in the network also allows a node to establish a communication link to hidden nodes or to nodes which are unable to maintain a reliable direct path connection. All members in the wireless mesh may communicate either via a direct link or a multi-hop route depending on the optimal path as determined by OLSR. In order to determine the network routes, OLSR sends out `HELLO` and Topology Control (`TC`) messages at regular fixed intervals. These messages determine the network topology and distribute the information to all of the network nodes. Specifically, the `HELLO` messages are used to identify the neighbors visible to a node and the quality of the corresponding link. The `TC` messages are used to distribute the complete topology information to the entire mesh. The interval of these control messages is important, as the system must properly capture the mesh topology without consuming potentially limited bandwidth with redundant or unnecessary traffic. The default settings for OLSR is intended for large wireless mesh networks with nodes that are typically fixed in location. In the EVA radio system, OLSR is applied to a dynamic wireless mesh with mobile nodes. The complete system is comprised of only a few nodes, with only one stationary member. Therefore, for the EVA radio system, the default values for the `HELLO` and `TC` packet interval and corresponding validity times are reduced. While this results in a more frequent transmission of packets, it allows for the network routing and health metrics to be more rapidly determined for the system, which is necessary to properly react to the system dynamics. In the EVA radio system, the motion of a walking human presents changes in the system. The network packets used to determine mesh metrics must be generated more frequently than topology changes resulting from human motion. As a result, a modest value of 0.5 sec or 2 Hz for the `HELLO` packets is selected, as test results indicated walking speeds on the order of 2 m/s.

The essential OLSR configuration settings for the EVA radio system are found in Table 3. Further information on the OLSR configuration parameters can be found in the olsrd.conf manual page [5]. Note that the table lists the OLSR configuration for both the wideband and the low data-rate networks. Although OLSR is not required for routing data on the narrowband wireless network, the software protocol was used for analysis purposes to characterize the health of the network, as will be further discussed in Section 3.3.2. The implementation of OLSR on each network for the EVA radio system is independent and is not intended to allow packet routing between the two networks. The use of OLSR further provides an added redundancy, allowing for multi-hop data routing through the low data-rate network if direct connectivity is lost from the base station.

3.3.2 Wireless Network Health Sensing & Network Switching

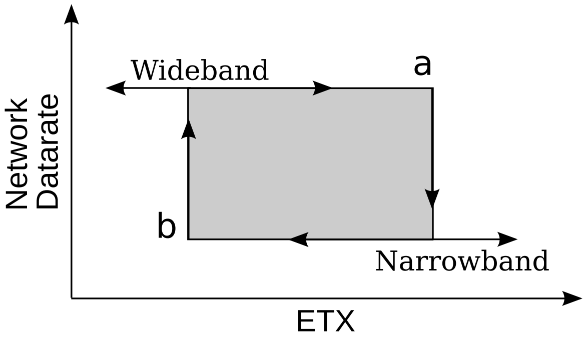
A core component of the EVA radio system is the capability to perform intelligent switching between two different wireless networks to reach the same destination node. If one wireless network is not available or exhibits a poor link quality, an alternative network will be used entirely by the system. In order to perform the intelligent switching, information pertaining to the health of each wireless network must be

OLSR Configuration	**Setting**
Hello Interval	
Wideband:	0.5 sec
Narrowband:	2.0 sec
Hello Validity Time	
Wideband:	5.0 sec
Narrowband:	20.0 sec
TC Interval	5.0 sec
Topology Validity Time	300.0 sec
TC Redundancy	All Neighbors
Link Quality Level	ETX enabled
Link Hysteresis	disabled

Table 3. EVA Radio OLSR Configuration Settings

known to the switching algorithm. To generate the necessary wireless link quality information, the EVA radio extracts information collected by the OLSR software. The particular version of OLSR implemented by the EVA radio system utilizes the link quality extension enhancement described by De Couto [6], [7]. The original RFC-compliant OLSR protocol controls the ad hoc mesh routing by minimizing the total number of hops between the source and destination nodes. One issue with the simple hop-minimization scheme is that a single direct link with a poor health may actually be preferred over a two-hop link with perfect link quality. The enhancement to OLSR proposed by De Couto overcomes this limitation and optimally routes network traffic through the wireless mesh by utilizing the *Expected Transmission Count* (ETX) metric. The ETX metric is the “expected total number of packet transmissions (including retransmissions) required to successfully deliver a packet along that path” [6]. In mathematical terms, the ETX value is one over the probability of a successful data transmission along the path. Therefore, the ETX metric indicates the *quality* of the connection between two nodes in a wireless network. The OLSR protocol utilizes this link quality information for optimally routing packets in the mesh. Furthermore, the OLSR protocol also provides distribution of the network topology to all of the nodes.

At each node the network topology *and* the corresponding quality of the link is known. Therefore, the ETX information can be further exploited to provide “sensor” input information to the intelligent network-switching algorithm. By knowing the probability of a successful transmission across the entire network, the primary network used for data distribution may be switched. For the EVA radio testbed, the network link switching is performed using a custom algorithm, with a hysteresis-based limit line, as shown in Figure 4. As the highest quality Wi-Fi link



Switch Point	ETX Threshold
a) Wideband to Narrowband	2.4
b) Narrowband to Wideband	1.8

Figure 4. EVA Radio Switch Points

metric to any of the required destination nodes in the network degrades below a pre-set value, the switching algorithm triggers a switch to the low data-rate network. Since OLSR distributes the topology and health metrics throughout the mesh, all of the nodes sense the degradation and perform the switch.

The switching parameters for the EVA radio system are setup to allow degradation of the network health to a level where a multi-hop situation will occur on the Wi-Fi network before a switch to the lower bandwidth network. When OLSR routes data across the mobile ad hoc Wi-Fi network, either a direct link or a multi-hop connection may be used. In the EVA radio system, multiple hops across the various Wi-Fi nodes often provides a higher throughput than utilizing the alternative low data-rate link. Although the Ultra High Frequency (UHF) link has a higher probability of maintaining the data flow, it is not adequate at delivering the required bandwidth. In the EVA radio system, the high data-rate video data is not transmitted when the system is operating on the low data-rate link. The video data is buffered and re-transmitted when the high data-rate network becomes available. Maintaining the Wi-Fi network link is therefore more desirable than allowing the system to switch to the low data-rate network. When a higher quality direct-link connection on the Wi-Fi network becomes available, the OLSR protocol will automatically update the routes to transition from the multi-hop route to the direct link. This allows the system to maintain the data flow on the Wi-Fi network as long as possible before switching to the low data-rate network.

OLSR is fully capable of utilizing mixed bandwidth links comprising one complete wireless mesh. The ETX metric will result in OLSR automatically preferring routes with the most efficient data transfer characteristics. As a result, one could utilize OLSR to route data across both the low data-rate and Wi-Fi network interfaces. Yet, allowing OLSR to fully handle the switching between the low data-rate and the Wi-Fi network is not desirable for the EVA radio system. By allowing OLSR to manage both the UHF and the Wi-Fi links as one contiguous network, the setup would allow a low data-rate link to be utilized as a portion of the multi-hop route. This potentially allows high bandwidth data to be sent over a much lower bandwidth network link, resulting in a bottleneck for critical data that must be received in near real-time. In the EVA radio system, one would rather utilize a store and forward approach for the non-critical data and provide high priority or sole usage of the low bandwidth communications link for voice and mission critical data components. As a result, for the EVA radio testbed, OLSR was not allowed to span the two different networks. The OLSR open source code was slightly modified to allow multiple instances of the software daemon to run concurrently and independently on the same host.

3.3.3 Speech Acquisition & Encoding

For voice transmissions, the EVA radio system utilizes VoIP technology. Although analog and non-IP digital voice radio systems are commonly used in practice, the use of VoIP technology is becoming more frequent. Digital voice transmission via VoIP offers a number of appealing advantages. For example, a digital VoIP audio system shares the same network as all of the other data flows, eliminating the need for a separate network and/or wireless channel devoted strictly to audio. Compared to a purely analog system, a wireless VoIP system may also provide a better quality audio signal with increased clarity during periods of signal fading or marginal reception. By utilizing a digital encoded speech format, the audio signal is less susceptible to noise on the wireless channel, since phase and magnitude distortions cannot directly affect the audio. A disadvantage of digital voice systems is the sensitivity to network latency and jitter. Voice packets can be delayed on a congested network or even dropped. VoIP protocols have built-in mechanisms for handling these issues, but the parameters of these mechanisms often need to be optimized for a specific network to maximize the performance of the system. These parameters are discussed in detail in this section.

For the EVA radio testbed, the audio data is acquired from a push-to-talk microphone on each node and then digitally encoded using Speex. The Speex-encoded voice stream is encapsulated into a Real-time Transport Protocol (RTP) audio packet stream and then transmitted over the wireless network. Speex is an open source/free software patent-free audio compression format specifically designed for speech [8]. The open source aspect of the audio codec eliminated the need to acquire software licenses and therefore expedited software development. Speex is also available in a floating point and fixed-point version [9], although the

Speex Configuration	**Setting**
VAD	enabled
DTX	enabled
AEC	disabled
Sampling Rate	8 kHz, 20 ms/frame (Narrowband Mode)
Jitter Buffer Size	8 Speex Frames

Table 4. EVA Radio Speex Configuration Settings

fixed-point implementation was not necessary for the initial EVA radio proof of concept implementation. Speex is also well-suited for wireless applications, as the signal is purposely degraded to reduce the required bandwidth. A lossy format as such is quite appropriate for audio content containing normal conversational speech. In addition, Speex provides the capability to reduce the amount of data transmitted over the network based on the audio being encoded. For example, Speex may be configured to operate in a Voice Activity Detection (VAD) mode. The VAD mode is used to detect when the audio to be encoded contains actual speech content or is merely background noise/silence [9]. The detected non-speech periods may then be encoded with the minimal number of bits required to generate a comfort noise. Alternatively, a Discontinuous Transmission (DTX) mode for Speex may be enabled to eliminate the comfort noise completely. The DTX mode is an enhancement to the VAD mode, where the encoded audio is not transmitted during periods of non-speech detection [9]. In DTX mode, the RTP audio stream is maintained, yet only the minimum Ethernet packet size (46 bytes) is transmitted. Utilization of the Speex VAD and DTX mode reduces the total amount of network traffic for each node and thus allows for a more efficient utilization of the wireless link. In the EVA radio testbed, the DTX and VAD modes are enabled. A number of other configuration options are available for the Speex codec. Table 4 provides a summary of the Speex configuration options used for the EVA radio system.

A jitter buffer is used on the receiving end of a VoIP system to handle the variation in the RTP packet arrival times due to network delays. A trade-off must be made between the acceptable latency of the audio stream and the desired quality. Increasing the jitter buffer size results in an improvement of the audio quality, but is made at the expense of an increased latency of the audio stream. For real time operations, voice data that is significantly delayed is considered unsatisfactory to end users. The International Telecommunications Sector addresses the acceptable delays for voice applications. The International Telecommunication Union (ITU) recommended one-way delay should not exceed 400 ms and indicates that callers usually notice round-trip voice delays of 250 ms or more [10]. For VoIP applications, a delay requirement of less than 200 ms is typical [11]. The Speex library provides a jitter buffer, which is specifically designed for Speex. The Speex jitter buffer provides an adaptive trade-off between good quality audio stream and low latency by varying the size of the jitter buffer. If a large network delay is encountered in the system, then the Speex adaptive jitter buffer size will be increased to ensure good quality. The issue arises when streaming RTP packets across a wireless link, where the signal may often fade in and out. The unreliable wireless link will cause the adaptive jitter buffer to select a large size for increased audio quality, but may be at a level with a larger delay than what is acceptable. Although Speex provides some configuration parameters to set the desired maximum latency, for testing purposes in the EVA radio system, it was more desirable to have a fixed, deterministic maximum allowed delay in the voice stream. As a result, the Speex/VoIP implementation in the EVA radio system does not utilize the built-in Speex adaptive jitter buffer provided by the Speex software library. The EVA radio system uses a fixed jitter buffer size, which is more deterministic and provides better control over the observed maximum delay in the voice stream than the adaptive technique. The fixed buffer size is appropriate for the initial EVA radio test setup, but other techniques should be considered for future development. In addition, Reference [11] provides further insight into reducing the transmission delay for voice over *multi-hop* 802.11 wireless networks. Such techniques should also be considered for future development of the EVA radio system.

3.3.3.1 Voice Data Distribution

As already indicated, the voice data transmission builds upon VoIP technology. The encoded speech must be received by all the nodes, and is not simply a point-to-point VoIP stream. Each node in the wireless mesh must distribute the VoIP traffic to *all* of the other nodes on the mesh, as well as receive the VoIP traffic from the other nodes. In the EVA radio testbed, the VoIP audio stream is distributed using a multicast destination address. All nodes in the mesh are then able to subscribe to the audio stream if the multicast packet is received. In a non-OLSR-enabled network, only the nodes with a direct link to the node broadcasting the multicast information would be able to receive the information. In the OLSR-enabled network, an additional mechanism is necessary to distribute the multicast data through the mobile ad hoc mesh, including nodes which may not have a direct connection to the originating node or to nodes which may have a limited connectivity. To handle the multicast data distribution and routing issue, the EVA radio system uses the Basic Multicast Forwarding (BMF) OLSR plug-in. The BMF module is designed to forward IP-multicast and IP-local-broadcast traffic over the network. The multicast forwarding is achieved by encapsulating the original multicast packets and transporting them over a User Datagram Protocol (UDP) socket. The BMF module will relay and forward multicast packets as necessary throughout the network. It is important to note that although the voice data is originally distributed using a multicast address, the actual distribution throughout the network by OLSR and the BMF plug-in is achieved in a unicast fashion. The unicast distribution of the multicast data is important because the wideband radio is configured to implement a fragmentation of the Wi-Fi frames. An 802.11 source does not apply the fragmentation threshold setting to multicast or broadcast frames [12]. Thus, an additional advantage of utilizing the OLSR BMF plug-in is that all of the multicast traffic will also be subject to the fragmentation threshold setting since all of the multicast data is relayed using a unicast link.

3.3.4 Telemetry & Sensor Data Distribution

For distributing the sensor data throughout the network and for the internal Command and Data Handling (C&DH) subsystem on each node, the EVA radio system uses the BioNet framework [13]. BioNet is available as open-source code and provides plug-and-play operation of software/hardware. Control information and sensor data distribution is achieved through a publish and subscribe method with a service discovery protocol. BioNet can also provide a CCSDS compliant data delivery system by utilizing the Interplanetary Overlay Network (ION) software package, which is also an implementation of the Delay-Tolerant Networking (DTN) architecture [14], [15]. The BioNet framework provides a standardized interface to software applications, and can be configured to either enable or disable the DTN capabilities as necessary without a direct impact on the software interface.

For the EVA radio system, simulated telemetry data is collected from an on-board GPS unit. The positional telemetry is passed through the BioNet framework from each node on the EVA radio testbed to the base station node. In addition to the positional information, the simulated telemetry also includes sensor data from the switching algorithm and the OLSR ETX metrics from each node. The switching algorithm parameters, including the ETX metrics, are distributed via BioNet throughout the entire mesh in addition to the base station node. The real-time voice data, as already described in Section 3.3.3, is not handled by the BioNet framework in the EVA radio testbed. This design choice is necessary, as real-time voice data must be received with a minimal amount of latency. A DTN-enabled BioNet middleware could increase the data arrival latency by nature of the DTN store and forward architecture.

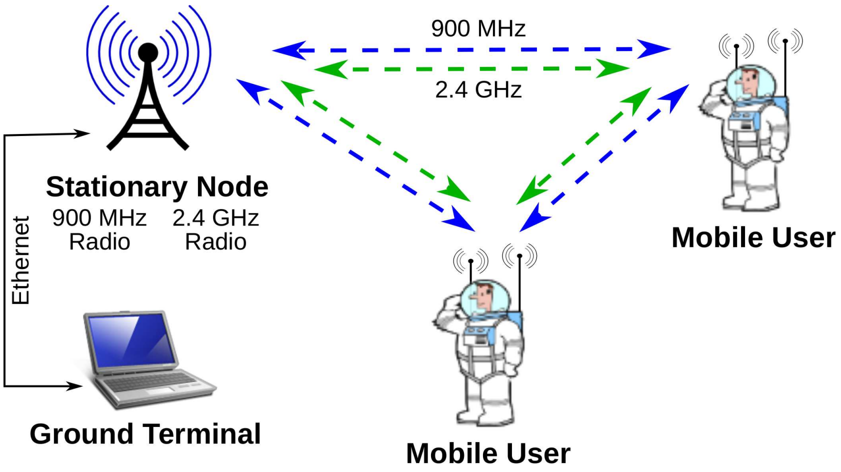


Figure 5. Test Setup for Simulated EVA Sortie.

4 Experiment Test Description

Performance testing of the EVA radio setup was performed in early September 2011 at the NASA DRATS outing. The tests were in the desert near Flagstaff, Arizona, which exhibits a terrain and environment similar to a potential extraterrestrial exploration activities on the martian or lunar surface. For the EVA radio system tests, a scenario representative of an EVA sortie is executed which is also specifically designed to test two conditions pertinent to the EVA radio communications system:

- Nominal Traverse
- Hidden Node

For the simulated EVA sortie, the test setup includes a remote ground station for visualization purposes, a stationary node and two remote mobile nodes. Figure 5 depicts the test configuration. The nominal traverse includes conditions with direct and non-direct line-of-site communication conditions on the high data-rate network to the base station via the stationary node. The traverse path is designed such that the high data-rate communications link is established, lost, and then re-established.

The classic hidden node condition is designed to generate a two-hop relay configuration for voice and data communications over the high data rate wireless network. One mobile node is positioned with a direct line-of-site communications link via the high-data rate wireless link to the base station and to the other mobile node. The other mobile nodes are positioned such that direct line-of-site data communication to the base station is not possible, yet a direct line-of-site link between the two mobile nodes is maintained. The scenario either requires communication via the 900 MHz contingency radio or for communication information to

(a) Rock Pile (Dest. No. 1)

(b) Rock Outcrop (Dest. No. 2)

Figure 6. Destinations for Walk Test

be relayed over the other remote node to the ground station. During the test, it is assumed that the contingency radio network is always accessible.

4.1 EVA Test Scenario

For the test scenario, two walking subjects representing EVA crew members are used for the mobile nodes. During the test, the subjects are to make notes and records of any interesting rock formations or sites of interest via video captures and audio transmissions. The test subjects are advised to maintain line-of-site distance to their companion walker and to conduct all conversations over the push-to-talk voice system, consistent with the characteristics of a normal EVA.

The test subjects are instructed to walk to two destinations of interest, simulating a geological science exploration EVA. Destination No. 1 is a volcanic rock pile near the base of SP Crater. Destination No. 2 consists of a volcanic rock outcropping near a dry creek bed. A photo of the two test destinations is depicted in Figure 6.

The actual traverse path taken by the walking crew members is not specifically marked. Yet, a large portion of the traverse route follows the dry creek bed, which passes by the base of SP Crater and connects to Destination No. 2. A topographical map of the testing area is depicted in Figure 7. The test destinations are indicated in the figure and a potential walking path is also depicted. During the walking test, the subjects are led by a field guide between the destinations to ensure consistency between test runs. The field guide also ensures the field operations are efficient and safe, as the guide is already familiar with the test objectives and intended traverse path. The route led by the field guide is designed to always maintain connectivity on the low data-rate network, as the test is designed to evaluate the radio switching performance characteristics and not the COTS radio hardware.

To begin the test, the test subjects depart the base station location by descending down a slight hill to the dry creek bed. The test subjects then traverse from the base station to the rock pile (Destination No. 1)

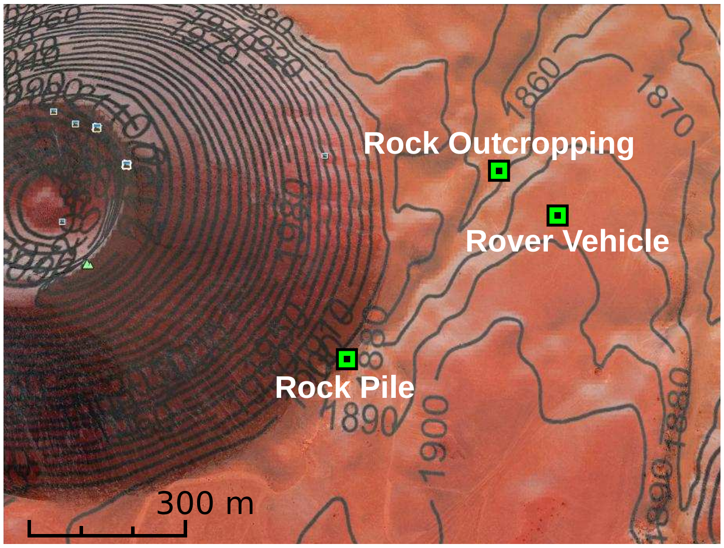


Figure 7. Topo Map with Walk Test Destinations Near SP Crater. A dry creek bed runs between the rock pile and the rock outcropping at the base of SP Crater.

by means of the dry creek bed. The route of the dry creek bed passes through locations where the direct line-of-site communication to the base station via the high data rate network is lost and then re-established. During this portion of the traverse, the EVA radio system will switch between the high data rate communications link and the contingency radio in order to maintain voice and data communications with the base station. Once at the first destination, one crew member moves to higher ground by carefully scaling the rock pile. This crew member maintains the high ground as the traverse is continued back along the dry creek bed. The crew members are instructed to always maintain line-of-site to each other during the traverse. The objective here is to generate a two-hop communications configuration for the EVA radio system. One crew member maintains direct line-of-site connectivity with the base station, while the other crew member following the dry creek bed. The path following the dry creek bed passes through regions where loss of direct connectivity occurs. At this point, the system may develop a two-hop data link configuration. If the health of the single direct link is not sufficient to maintain acceptable voice communications, the EVA radio system will switch to the contingency communications radio.

After leaving the rock pile, the crew members rejoin in the dry creek bed and proceed to the second destination. Destination No. 2 is designed to break the direct line-of-site communications link for both of the EVA crew members to the base station. At this point, the system should transition from the high data rate communications link to the contingency

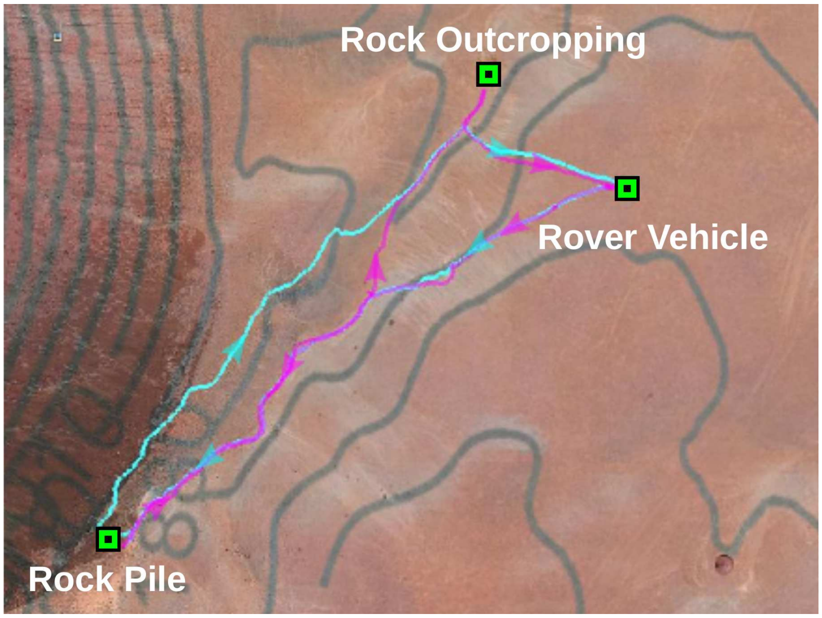


Figure 8. Example Traverse Path. The traverse path for EV1 and EV2 is depicted using cyan and magenta respectively. The base station tower is located at the Rover Vehicle.

radio. After operating for some time on the contingency radio link, the test subjects then return up the hill back to the base station. Eventually the EVA radio system will switch back to the high data rate network as the link becomes available and stable link health metrics are observed.

5 Early Assessment of Test Results

5.1 System Evaluation

The traverse path depicted in Figure 8 is representative of a route taken by the test subjects during the DRATS 2011 test experiments. The path demonstrates both the normal traverse and the hidden node (multi-hop) test conditions as described in Section 4. At the beginning of the traverse, both test subjects start from the Rover Vehicle and walk together to the rock pile. Once at the rock pile, one test subject, referred to here as EV1, ascends the rock pile to higher elevation. The other test subject, referred to here as EV2, stays within the confines of the dry creek bed and proceeds to the rock outcropping. Both EV1 and EV2 maintain line-of-site to each other and join back in the dry creek bed prior to reaching the rock outcropping. For this particular traverse, EV2 enters the rock outcropping, while EV1 stops short of the outcropping. After investigating the rock outcropping, both test subjects return to the Rover Vehicle.

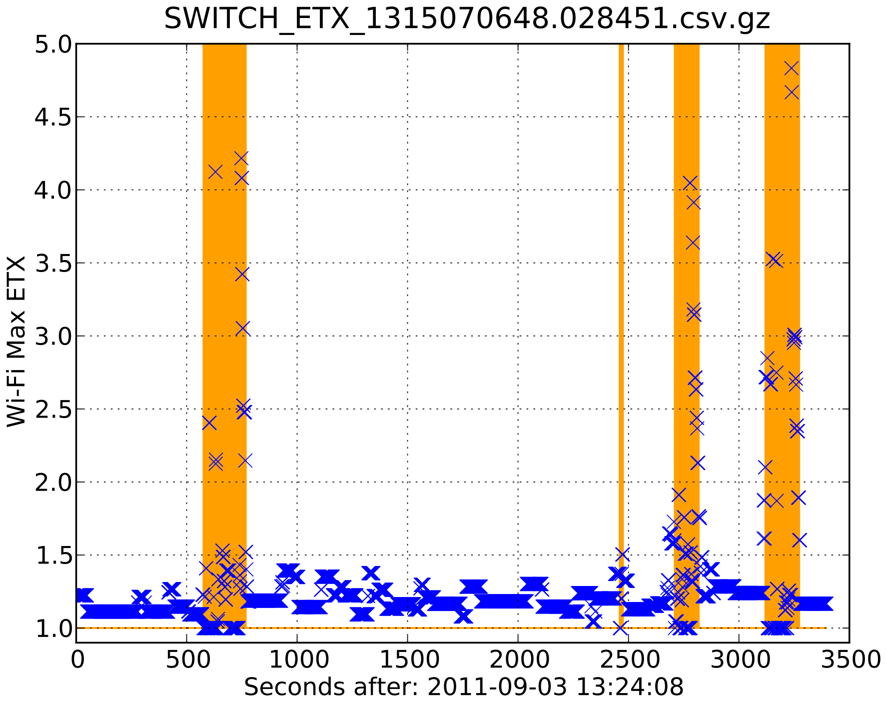


Figure 9. ETX vs Time with Radio Switch Status. Shaded regions indicate radio switch periods on the low data rate network. An ETX value of one indicates a node in the network is missing. The region centered around the elapsed time of 3000 seconds on the high data rate network is a multi-hop route configuration. At this portion of the experiment, data for one test subject is routed through the other test subject back to the base station.

5.1.1 Wireless Network Health Sensing & Network Switching

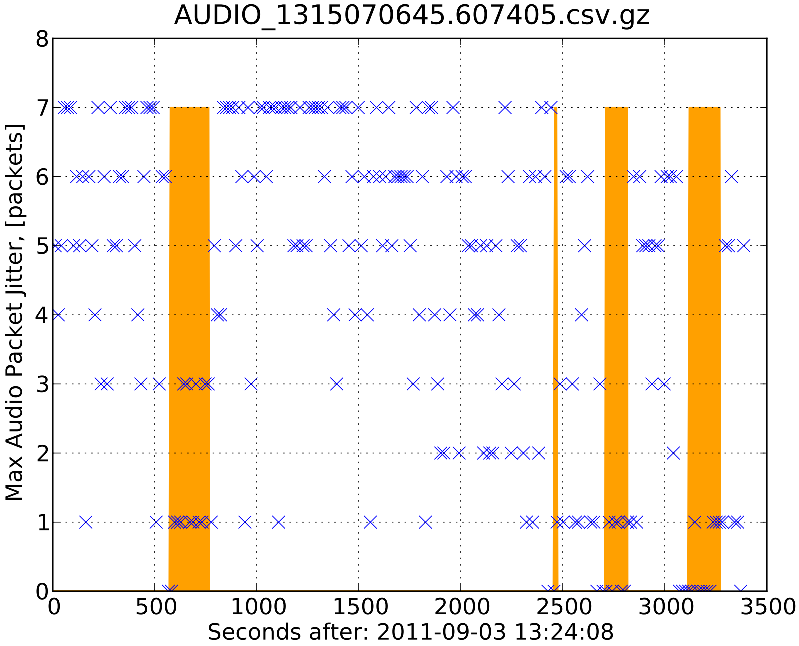
During the test, the ETX value for all of the links is monitored and recorded by the EVA radio system. As the system switches between the two networks, the timestamp of the switch is recorded. The maximum recorded ETX value for all of the 2.4 GHz radio links is used for driving the switching routines. Figure 9 shows the recorded ETX value and the system behavior corresponding to the traverse depicted in Figure 8. The shaded regions of the plot indicate time spans where the EVA radio is utilizing the low data rate network. During the first portion of the traverse, with both test subjects walking together, the system maintains the high data rate radio connection. After an elapsed time of approximately 550 seconds, the line-of-site connection to the base station is lost and the system switches to the low data rate network. This is observed in the plot by observing an ETX value of one. A number of ETX values above two are also observed, indicating an unreliable connection. The system then regains connectivity using the Wi-Fi radio and switches from the low data rate network around an elapsed time of approximately 750 seconds.

As the traverse continues, some fluctuation in the ETX metric is observed, yet connectivity via the high data rate network is maintained. During some portions of the traverse, as EV1 maintains higher elevation and EV2 walks the dry creek bed at lower elevation, the system momentarily sets up a multi-hop scenario as fading of the connections causes one link to be preferred over another. Yet, the multi-hop condition is not maintained for a substantial amount of time.

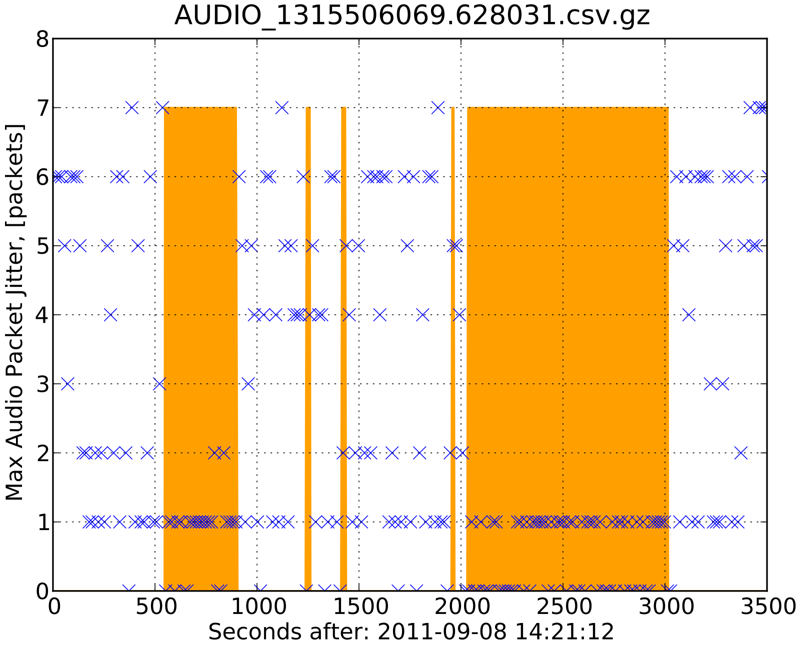
Near the end of the traverse with an elapsed time of approximately 2700 seconds, as the test subjects approach the rock outcropping, the EVA radio system again transitions to the low data rate network. The data depicted in Figure 9 indicates that one of the nodes is missing from the network. The loss of connectivity via the Wi-Fi radio is achieved as EV2 enters the rock outcropping, while EV1 stops short of the outcropping to perform a simulated science operation. At approximately an elapsed time of 2800 seconds, the system re-establishes a connection via the Wi-Fi radio. This region centered around 3000 seconds of elapsed time actually corresponds to a multi-hop condition over the 2.4 GHz network. The data for EV2 is relayed over EV1 to reach the base station.

5.1.2 Voice Data Distribution

Although user feedback provides a good representation of the system performance for distributing voice data between the nodes, a number of metrics may also be evaluated. The Speex audio packet arrival jitter provides an indication of the system voice characteristics. Figure 10 shows the observed Speex packet arrival jitter, which are typical and representative of the DRATS test runs. In order to ensure a continuous play of RTP voice data, the received Speex packets are buffered and the maximum jitter that can be accommodated is equal to the buffering delay. As indicated in Section 3.3.3, an end-to-end delay requirement of less than 200 ms is typical for VoIP applications and users tend to notice delays greater than 250 ms [10], [11]. As configured for these tests (refer to Section 3.3.3, Table 4), the Speex packets contain 20 ms of voice data per Speex frame. A one-packet jitter therefore corresponds to an audio packet arrival time variation of 20 ms. As shown in Figure 10, the maximum observed audio packet jitter is less than seven packets, corresponding to 140 ms of delay. Although the metric does not include the decoding time, the observed value is below the desired levels for an acceptable two-way voice system. Further analysis of the total number of lost or late Speex packets indicates that the jitter buffer size could potentially be increased slightly to accommodate the observed jitter variation to improve voice quality during fade-outs in connectivity with a minimal impact on the end-to-end delay time. In addition, if the built-in Speex adaptive jitter buffer were utilized, the system would make use of the



(a)



(b)

Figure 10. Observed Maximum Audio Packet Jitter. Two representative data runs. Figure (a) corresponds to the traverse depicted in Figure 8. Figure (b) more clearly shows the difference in the observed jitter values between the two wireless networks during an extended period on the low data rate network. Shaded regions indicate radio switch periods on the low data rate network.

packets provided by the DTX option to catch up, by reducing the length between breaks in the voice data.

The recorded maximum audio packet jitter values also show a dependency on the underlying wireless network used. In Figure 10, the shaded regions indicate periods of time where the system is utilizing the 900 MHz communications radio. These timeframes exhibit a lower observed maximum audio packet jitter value than those periods when the 2.4 GHz radio is used. A number of factors could be attributed to this result. Indeed, slightly more data is being transmitted over the network when the wideband radio is in use, which could potentially generate an increased delay in packet delivery. However, the increased data while on the 2.4 GHz wireless network is primarily due to video snapshots, which are sent periodically in the form of file transfers. The jitter data does not exhibit these periodic variations, suggesting the increased data flow, although perhaps a contributor, is not the primary culprit for the increased jitter values on the wideband network. Instead, it is believed that the variation in the maximum jitter value between the two wireless networks is attributed to the underlying hardware and communications parameters. For example, both a variable modulation scheme and a variable data rate setting are enabled on the 2.4 GHz radio. The 900 MHz contingency radio is configured at a fixed data rate below the maximum data rate for the wideband radio. Yet, the lowest configurable data rate for the contingency radio is still above the lowest two data rates settings on the wideband radio when a variable modulation scheme is enabled. Thus, in areas with poor connectivity, the contingency radio had a higher data rate than the wideband radio. In addition, the 900 MHz contingency radio is more appropriately suited for the outdoor propagation environment than the wideband radio. The COTS 900 MHz contingency radio is designed to be an outdoor access point, while the wideband radio is an indoor radio designed for use in an office environment. The receive path design, especially the equalizer, is driven by the environment in which the radio will operate. Therefore, it is expected that the 900 MHz contingency radio will perform much better outdoors with regard to multipath effects.

5.1.2.1 Audio Packet Data Rate

The Speex implementation in the EVA radio system is configured to utilize the VAD and DTX features. The VAD and DTX settings are beneficial, as the settings reduce the total number of bytes transmitted over the wireless connection. This feature is especially desirable for low bandwidth applications. The results clearly show a variation in the total data rate when the VAD algorithms are enabled. Figure 11 shows the results for the accumulated total number of transmitted audio bytes during a test run. During an extended period of silence observed near an elapsed time of approximately 1200 seconds in Figure 11, a clear variation

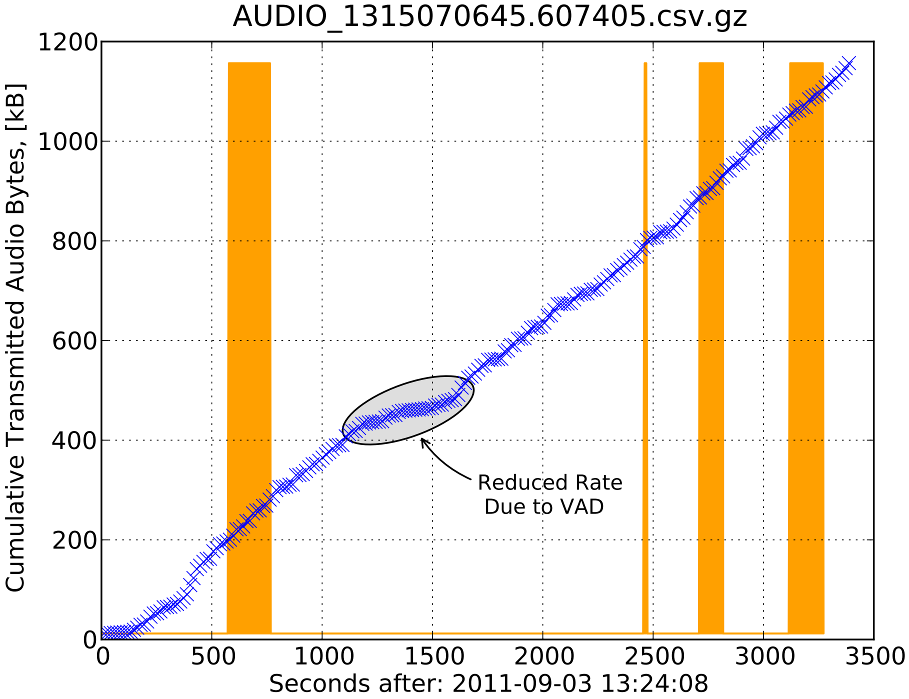


Figure 11. Cumulative Transmitted Audio Bytes. A reduction in the transmit rate results from the Speex Voice Activity Detection (VAD) and Discontinuous Transmission (DTX) mode. The effect is clearly seen for an extended period after an elapsed time of 1000 seconds. Shaded regions indicate radio switch periods on the low data rate network.

in the total data rate is observed. The results indicate a potential benefit to wireless speech applications, especially when the data throughput rate may be constrained or highly variable.

5.2 Test Subject Feedback

At the DRATS outing, a number of test subjects were used for evaluating the EVA radio technologies. The test subjects had a wide range of background experience including astronauts, flight controllers, scientists, engineers, and students. The test subjects provided subjective or personal perspectives on the EVA radio system and concept. These comments are summarized in the following sections.

5.2.1 Voice Quality

Overall the test subjects reported the voice transmissions were clear with excellent audio quality. One test subject indicated that the voice transmissions had a slight metallic sound which is believed to be attributed to the small, low quality speakers and mounting strategy. [2] Other users did not note of any other discernible difference in the audio quality. The user feedback indicates that the Speex codec as configured is sufficient for audio transmissions from a speech intelligibility aspect. In addition, the Speex codec was configured for narrowband mode (8 kHz sampling rate) indicating that a higher quality signal is not necessary for the EVA radio application.

During the DRATS experiment, a scenario was set up where one user did not have a direct link to the base station via the Wi-Fi link, but was able to receive voice communications over the Wi-Fi network using a multi-hop route. The users indicated that the data multi-hop setup on the Wi-Fi network worked well. The voice quality and throughput was maintained at an acceptable level. The users were quick to point out that a normal operational scenario would not utilize an astronaut for long periods to act as a "communications relay". Still, the users agreed that the multi-hop option is a good capability to have for short durations and could be used to extend the EVA operational range.

5.2.2 Switching Logic

The test subjects provided feedback on the switching of the system between the two wireless networks. In general, the switching between the two wireless networks was seamless and provided good voice quality without interruption. The comments regarding the characteristics of the EVA radio switching related to the viewpoint of either the direct end user (astronaut) or the remote user (mission control). The astronaut just wants the audio to work and doesn't care about the added capability that does not impact them directly. For instance, the astronaut is not going to be concerned if mission control is not receiving real-time high data rate video as long as the mission critical voice data flow is transmitted and the video eventually gets transmitted. As a result, the astronaut as an end user would prefer that the system switch immediately to the low data-rate communications link and be very slow to return to the more capable wideband network. The end user at mission control has the opposite desire, where they need as much remote data as possible and therefore would rather stay on the high data rate network as long as possible. Although some further tweaking of the switching algorithm is needed, it appears as though the current selected settings are reasonable.

A number of users also indicated that it would be nice to have a switching override capability for contingencies. It is believed that this user feedback may have been generated by the very nature of how the experiment was conducted. For example, the end user was provided with audible tones every time the radio switched between networks. These audible tones were utilized to help system designers verify system func-

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[2] The speakers were crudely mounted to the backpack frame by directly drilling through the speaker, which clearly modified the audio characteristics.

tionality and to critique the system. The tones were also intended to help the end user identify the network being used when evaluating the quality of the voice provided by the communications subsystem. Under nominal operations, these audible tones would not necessarily be generated and the switching between the networks would be transparent to the end user. These tones, however, made it immediately apparent as to the frequency of the switching between the networks, especially in an environment where a loss of or fading of the wireless communications link was common. Still, the capability to force the system to utilize one network or the other could be useful for a contingency scenario, provided that the manual override capability does not become a nominal operational procedure. As a result, both mission control and the astronaut should have control over the manual override capability. In addition, the end user needs some sort of feedback, either visual or audible, to indicate the manual override is engaged.

5.2.3 User Interface

The user displays or human interface to the communications system was not a target development effort or an intended evaluation criteria for the DRATS EVA radio experiment. Still, the test subjects provided feedback on a desired user interface to the system. The users indicated a need for the health metric parameter conveyed to the user for each network. This is consistent with common-day mobile communications devices which indicate the number of bars for the wireless signal. During the experiment, the ground station terminal did indeed have a continuous feed for the health status of the wireless network for system evaluation and diagnostics. The health of the wireless network was conveyed to the user over the voice loops as desired or needed. During nominal operations, it is not expected that the user would require a continuous update on the wireless network health status, but such information could be useful. For instance, real-time evaluation of the signal quality may allow the astronaut to select a different traverse path which would maintain better signal connectivity. The information may also be necessary in a contingency scenario. Regardless, the need for a health metric parameter indicator (i.e., number of bars for each of the wireless communications networks) generates a requirement for basic status information to be provided from the communications system to the informatics system.

6 Recommendations

6.1 Environment Implications

The DRATS experiment was performed in the Arizona desert and is a common test site for NASA analog studies. The location has historically been used due to the similarity in terrain and conditions that may be encountered at destinations beyond Earth. The landscape also has limited man-made structures and has applicable science to perform. In addition, for the EVA radio experiment, it presents a testing environment where the RF spectrum is relatively under-utilized compared to urban locations, with fewer concerns for interference with other spectrum users. Indeed this was case for the EVA radio team when conducting the experiment. There was only one other signal in the spectrum range of interest that needed to be avoided for possible interference.

There were, however, some difficulties encountered during the testing that are attributed to the terrain at the Arizona test site. Debugging and diagnostic work on the EVA radio testbed indicated symptoms of a very high multipath environment. During one experiment, the orientation of the dipole antenna on the backpack was altered such that it was positioned at 90 ° to the source signal antenna. In this configuration, the radio signal strength increased and the ETX metric improved. Such a response indicates the signal polarization had been altered or a reflected signal was stronger than the direct path signal. The test site landscape is free of man-made structures, which could be the source of large signal reflections and multipath effects as commonly encountered in an urban environment. The soil composition at the test site is primarily volcanic in nature and therefore contained a high iron concentration. This high iron concentration in the soil generated much higher multipath environment than anticipated. For the EVA radio testbed, the issue was handled by changing the radio configuration parameters. The UHF radio utilized an OFDM modulation technique, which could be adjusted to provide better multipath rejection. In order to help cope with the multipath environment, the UHF radio was configured to utilize a higher bandwidth at the same data rate. This in turn extended the symbol period to reduce the inter-symbol interference generated by the multipath environment. By extending the symbol period, without reducing data rate, inter-symbol interference in a multipath environment is reduced. Therefore, for further surface radio communication development efforts, consideration should be given to multipath effects in the radio design. There are a number of common solutions available for multipath mitigation and should therefore be considered for future design efforts. For example, spread spectrum techniques may be used to aid in rejecting multipath effects or utilization of a rake receiver would enable the system to identify and compensate for multipath signals.

6.2 Network Configuration Drivers

6.2.1 Network Data Traffic Control

During the EVA radio testing, it was determined that there is clearly a need for data queue prioritization of different network data types. There are a number of drivers for the data queue prioritization necessity.

For example, some data types, such as voice transmissions, must be delivered with a low latency and in near real-time. Other data types, such as archived data, will have an increased allowable latency and does not necessarily need to be delivered in real-time. In addition, bandwidth-hungry network data, such as streaming high definition video, may swamp the entire allocated bandwidth. Thus, the network applications must be capable of providing Quality of Service (QoS) capability in order to provide different priority to different data flows.

For the EVA radio testbed, the need for a QoS capability was recognized during evaluation of the health metrics for the wireless network. If the network becomes swamped with an application utilizing a large portion of the total available bandwidth, the OLSR ETX metrics will become blocked or delayed and therefore will not accurately describe the health of the wireless links. Ideally, the ETX metric will represent the quality of a route, independent of any network traffic. Indeed, De Couto recognizes this limitation in the ETX implementation, indicating that "[ETX] is highly sensitive to load because of the effects of unfairness and interference on the probe broadcasts" [6]. A suggestion to solve the issue is to implement a MAC data communication protocol sub-layer, which supports priority traffic. The OLSR ETX messages can then be isolated from the contending network traffic.

Recognizing the need for QoS capabilities on wireless networks for multimedia applications, the IEEE 802.11 standard was amended in 2007 to provide such QoS enhancements to wireless networks [12], [16], [17]. Yet, hardware that supports the QoS enhancements are not readily available. As a result, an alternative method is implemented for the EVA radio testbed. The design uses the Linux traffic control [3] utilities for managing the transmission of packets [18]. Specifically, the EVA radio testbed uses `tc` commands to manage "traffic control". `Tc` is a binary command line tool and is part of the iproute2 suite of utilities [19]. The application is used to manipulate network configuration structures in the Linux Kernel. Among many other uses, `tc` may be used to limit total bandwidth, prefer latency sensitive traffic, or to simply prioritize the data being sent to the network interface. For the EVA radio testbed, the system is set up to generate Kernel traffic control parameters to handle packet prioritization, rate limits and latency parameters. Yet, only the capability for network data prioritization was enabled for the DRATS experiments. The data prioritization is performed by establishing a priority queue map. Priority levels are set as follows:

1. BioNet traffic
2. OLSR messages (control messages and BMF packets)
3. VoIP audio packets
4. All other network packets (not specifically prioritized)

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[3] Quality of Service (QoS) is often used as synonym for traffic control.

Prioritization of BioNet traffic ensures that the radio switching algorithm has all the necessary information in order to perform the switch between radio networks. The BioNet packets handle the sensor data distribution throughout the network. Prioritization of the OLSR messages ensures that the network health statistics collected, or ETX parameters, are representative of the underlying network. It is imperative that the OLSR broadcast messages are not delayed or blocked by other packets within the network. Finally, prioritization of the VoIP stream ensures that the voice traffic will always take precedence over any other traffic, especially resource-intensive traffic to help reduce the end-to-end latency. All other network traffic has a lower priority and is not specifically prioritized by the network configuration structures within the Linux Kernel.

6.2.2 Wireless Link Access Time

On the EVA radio system, the traffic originating from each node is prioritized to help ensure essential near real-time data is received in a timely manner. As discussed in Section 6.2.1, the network data QoS for the EVA radio testbed is regulated at each network device. Yet, fundamentally, 802.11 is an access-driven network and not a time-driven network access; the 802.11 standard does not provide a means for limiting the access time of network nodes [12]. Thus, despite the MAC layer data prioritization, the EVA radio system as designed with the 802.11-compliant COTS radios still has the issue where low priority data may be delivered from one node before high priority data of another. For example, if a large file is being transferred over the network, it may prevent other nodes from transmitting any data for an extended period. The fragmentation configuration threshold does help to create more opportunities when another node may slip in a RTS request, but the setup does not guarantee that one node will not utilize all the available transmit time. The issue is further compounded when there is backlogged data, which may be the case if all the nodes are attempting to transmit data simultaneously. Thus, for an 802.11 EVA radio system, one needs to be able to limit the link access time, or to provide a preemption method for interrupting an existing link. A possible solution may be the 2007 QoS enhancements to the IEEE 802.11 standard. Future development efforts should evaluate the QoS enhancements as applicable to the EVA radio design.

6.2.3 Network Packet Characterization

The OLSR algorithm determines the network topology and the expected transmission count in each direction of the link. For determining the probability of a packet being received at the destination, the OLSR ETX algorithm assumes constant packet sizes in the network. The ETX predictions may be adjusted to more appropriately reflect a particular

Packet Type	**Payload Size** [bytes]	**Notes**
Voice:		
Nominal	115	Speex VoIP data
VAD	46	“Silent Frames”
OLSR:		
`HELLO`	44 - 48	
`TC`	76 - 108	Variable.

Table 5. Packet Sizes for OLSR and Voice Data in the EVA Radio System. The OLSR `TC` messages will increase in size as the number of nodes in the mesh is increased. Note that an entire `TC` message also includes `HELLO` message information.

packet size [6], but does not necessarily represent network traffic consisting of widely different packet sizes. When OLSR determines the ETX metric, a different prediction error will be associated with different packet sizes [6].

For the EVA radio system, the goal of the OLSR ETX metric is to properly reflect the probability of voice data arriving at the destination. This information is used for the radio switching algorithm. Since the OLSR packets and the VoIP audio packets are similar in size, as shown in Table 5, the ETX metrics accurately reflect the probability of a successful audio packet transmission. Therefore, when using OLSR link metrics for estimating the probability of a successful data transmission, some consideration for the associated packet size should be given.

6.3 Delay Tolerant Networking Rationale

In the initial stages of the EVA radio design, it was assumed that some sort of DTN implementation would be necessary for communicating with the ground station. Yet it was quickly discovered that a DTN implementation of *all* the data flows was not necessary. DTN is designed for and excels well in communication links with long delays and with links having an approximate pre-determined range of expected transmission delay values. DTN is not designed for or intended to be used to handle communications links that are delayed due to the link fading in and out as opposed to just having a constant delay associated with the packet transmit time due to the distance between the transmitter and receiver. As a result, DTN need not necessarily be utilized for handling traffic flows between the nearly colocated nodes under nominal operations. For communications between space suits, the DTN implementation is not needed. To simplify the design, it would therefore make sense to implement DTN only on a relay station that would be handling the potentially long distance communications link to the ground station.

The initial implementation of the VoIP communication on the EVA radio testbed was delivered using the DTN Bundle Protocol (BP). The DTN BP is designed to be a store-and-forward overlay network. The BP design is to help cope with intermittent connectivity and can take advantage of scheduled, predicted connectivity [20]. It was found difficult to implement DTN with data packets associated with voice communication information, such as VoIP traffic, due to the total latency added to the signal by the protocol and associated overhead. It is essential that the voice communication information be transmitted and delivered to the other nodes in the network with as minimal delay as possible. For VoIP applications, a delay requirement of less than 200 ms is typical [11]. During initial testing on the EVA radio testbed using the BP, delays on the order of 250 ms could be achieved under ideal conditions, but it was not unusual to observe latencies on the order of a few seconds. In addition, if for some reason a disruption in the RF communication link occurs for a prolonged period of time, an individual typically would not want old voice data to be buffered up and transmitted. Instead, one would rather just drop the content. The newly generated or current near real-time voice communications data would take priority over any historical voice data. Historical voice communications data is therefore most likely only useful for individuals in the mission operations center for post-mission analysis. As a result, only certain nodes (primarily only the mission control station) have a need or a use for real-time essential data, which is deemed to be stale or has been buffered up for a long time.

Using a DTN implementation to transfer the VoIP traffic between all the nodes, especially between two space suits, is not practical. On the EVA radio system, the original BP implementation for the transfer of voice data was dropped in favor of a multicast UDP connection. As noted, a DTN implementation would be desirable for transferring the data to a remotely-located ground station, but such a capability need not necessarily be implemented on the space suit. For the ground station link, one could provide those missing voice time segments as data files, which can be downloaded/received at later times for post-mission review and analysis. For the space suit data transfer portion of the link, the proper solution is likely a simple intelligent buffering system to handle the fade in/out of the wireless signal.

7 Future Work

7.1 System Configuration

7.1.1 Switching Logic

Prior to the DRATS EVA radio experiment, no effort had been devoted to properly filtering the sensor data. The health metric for the

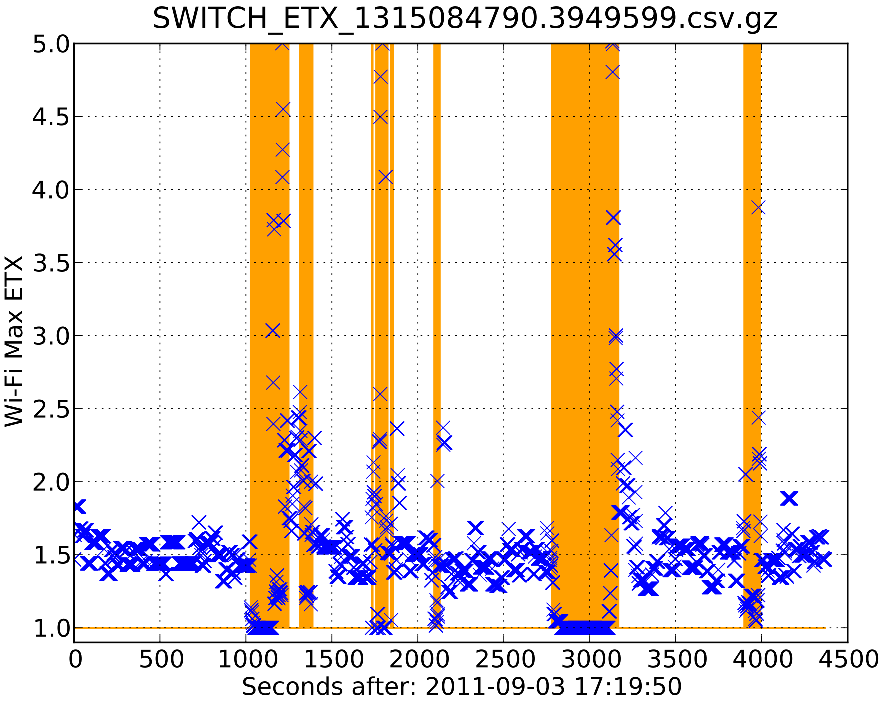

Figure 12. ETX Versus Time with Radio Switch Status, with Premature Switching. Shaded regions indicate radio switch periods on the low data rate network. Results indicate that filtering of the ETX values is needed.

wireless metric, the ETX value, is one such parameter that requires additional filtering. Some averaging of the ETX value is built into the OLSR software, but adjustment of the configuration parameters also affects the performance of the OLSR system. A second stage of filtering for use by the EVA radio switching logic is necessary to obtain the desired time-response characteristics. For system tuning of the EVA radio switching logic, some additional damping is desired.

As indicated in Figure 4, the ETX threshold for the switch from narrowband to the wideband radio is at a value of 1.8. In Figure 12, the shaded regions indicate that the EVA radio is utilizing the low data rate communications link. A few of the transitions, for example at around an elapsed time of 1250 seconds and 3200 seconds, indicate that the system returned to the wideband communications link prior to the system achieving a stable ETX value below the required threshold. After the transition, the ETX instability shows values well above the set threshold of 1.8. The system does indeed eventually stabilize at an acceptable level below the 1.8 threshold, but a simple filter on the ETX parameter for use in the switching logic would help to ensure the system does not prematurely switch to the wideband communications link. Future work should therefore include basic filtering of the network health metrics to reduce switchovers from transients.

7.1.2 OLSR Configuration

The ETX scheme of OLSR is not specifically intended to account for mobility of the underlying mesh nodes. In fact, Reference [6] questions if the ETX metric would perform well in a mobile network. For the EVA radio testbed, the motion is slow compared to the update interval of the `HELLO` and `TC` messages. Care was taken to ensure the topology control and `HELLO` messages are updated at a rate faster than the system dynamics. The motion of a person walking occurs at only modest speed of around 2 m/s, so it is possible to propagate the OLSR network metrics faster than the system dynamics. As a result, the ETX metric can be applied to the mobile mesh consisting of walking people. Still, the configuration values can be further modified to more accurately describe the underlying system. During the DRATS experiments, it was observed that the `TC` message interval most likely should have been modified. These observed characteristics may be an artifact of the environment due to the rate at which the radio signal is lost and re-established. To maintain consistency between the test runs, the parameters were kept at a fixed value throughout the DRATS experiments. Future tests should consider increasing the update rate of the `TC` messages and perhaps reducing the corresponding validity time. In addition, future work with OLSR-enabled mobile networks should consider inclusion of metrics provided by the 802.11 interface card, such as the number of retransmissions per packet [6]. During the EVA radio DRATS experiments, the number of retry transmissions was logged. Unfortunately, the COTS Wi-Fi device used in the testbed does not properly report the number of retransmissions and appears to be unsupported by the driver.

7.1.3 OLSR Multicast Configuration

The forwarding mechanism for the BMF plug-in may be set to use either a “Broadcast” or a “UnicastPromiscuous” mode. The configuration of the BMF plug-in defaults to a “Broadcast” forwarding mechanism. On the EVA radio testbed, the parameter was not specifically set, resulting in the default configuration. According to the BMF documentation, the parameter most likely should have been set to “UnicastPromiscuous” for the wireless network [21]:

> “In the ‘UnicastPromiscuous’ mode, packets are forwarded (unicast) to the best candidate neighbor; other neighbors listen promiscuously. IP-local broadcast is not used. This saves air time on 802.11 wireless networks, on which unicast packets are usually sent at a much higher bit rate than broadcast packets (which are sent at a basic bit rate).”

The retransmission of the received packet is handled by the forwarding mechanism configuration parameter. Thus, for the EVA radio testbed, retransmissions were sent in a broadcast fashion. The BMF plug-in does send the original messages encapsulated into a UDP packet and are therefore delivered using unicast. Thus, multi-hop links may benefit from the "UnicastPromiscuous" setting for the BMF module. Although the communications links during the EVA radio tests were primarily direct, some performance increase may be achieved with the alternative configuration and should therefore be evaluated.

7.1.4 Radio Configuration

The wireless packet fragmentation threshold configuration setting for the Wi-Fi radio should be revisited in future EVA radio efforts. When fragmentation is enabled, the source network interface device divides the 802.11 frames into smaller chunks or fragments. These fragments are sent separately to the destination, with each fragment receiving a separate acknowledgment. Fragmentation generates additional overhead and therefore decreases performance in an ideal environment. In a very noisy environment, the fragmentation threshold setting increases performance by allowing packets to get through interference bursts. The configuration value utilized on the EVA radio testbed was originally determined and verified in an urban environment. During the DRATS tests in the desert environment, verification of the fragmentation threshold value was not performed. Future work to determine an appropriate value for the expected environment should be performed. In addition, as already mentioned in Section 3.3.3, 802.11 does not apply fragmentation to multicast or broadcast frames [12]. Also, the OLSR implementation encapsulates multicast information into unicast packets. Further work is necessary to properly characterize how fragmentation affects the link performance and the associated added network overhead for multicast messages distributed by OLSR.

7.2 Localization

The use of OLSR may bring the additional benefit of localization information or supplement position information systems. Indeed, a number of individuals are attempting to use OLSR mesh connectivity information to determine position information using convex optimization methods [22], [23]. These works attempt to estimate the unknown node positions for dense mesh networks. For sparse networks, such as the few node network expected for space exploration, additional information is likely necessary. Range information or time difference of arrival, for example, may be used with trilateration methods to determine position. Some research works utilize OLSR to distribute the routing and position information for simultaneous routing and localization [24], [25], [26]. Future work should therefore consider the additional benefits OLSR may provide in terms of localization/position information.

If position or velocity information is available, there are additional modifications to the OLSR implementation that may benefit a mobile mesh. As discussed in Section 3.3.1, OLSR needs to exchange the topology control information and receive the `HELLO` messages faster than the change in the layout of the mobile nodes in the mesh. This update rate must be increased for a highly mobile mesh. Yet, knowledge of the motion and the corresponding velocity could potentially be used to adaptively change the rate at which messages are transmitted between the nodes. Nodes which are in motion could send/receive `HELLO` messages at a higher rate than those with a near stationary average velocity. An increased update rate for nodes that are in motion may improve the link characterization. Reducing the update rate for stationary nodes will also eliminate unnecessary packet transmissions and reduce the utilized bandwidth. Future work should evaluate the potential increase in performance achieved when positional information is used for variable OLSR packet update rates.

7.3 Operational Concepts

A number of operational concepts may be considered that are enabled by the multi-hop ad hoc mesh routing capabilities described in this work. These multi-hop scenarios may potentially extend the high data rate operational range. For example the “data mule” or remote relay concept could be envisioned. In one case, the multi-hop relay is achieved by a mobile node containing a store-and-forward capability. In the remote relay concept, a portable relay terminal or astronaut is used to relay both high data rate information and voice communications data. As already stated in Section 5.2.1, the use of an astronaut as a relay asset for extended periods is not likely. Yet, other operational concepts may be explored, such as for short durations or to “leap frog” across an area with limited connectivity. Furthermore, with the addition of portable communication terminals used for communications relay purposes, the fixed positional nature of these nodes could also aid the localization problem.

7.4 Data Analysis

During the DRATS EVA radio experiment, a number of parameters were collected for debugging, performance analysis and research purposes. Currently, only a preliminary data analysis has been performed on a small subset of the data collected during the experiment. Future efforts should be directed at a more complete data analysis. Refer to Appendix C for an explanation of the data collected during the experiment.

8 Concluding Remarks

The EVA Radio Team designed and built a radio testbed that allowed for extensive field testing in Flagstaff, Arizona during the month of September 2011. The primary goal of this testing was to exercise the performance of the dual-band radio design, while operating in a simulated manned exploration environment. There were no major malfunctions or events that prevented the team from fully completing the full battery of tests over the two-week period. Multiple simulated exploration sorties were performed by both the team itself and objective subjects, including actual crew members from the astronaut corps.

Each wireless interface comprising the EVA radio system individually worked well, even under these mobile test scenarios. External interference was never an issue, and the wireless coverage areas were consistent throughout the two-week period. The 802.11 ad hoc network protocol performed quite well, even under the highly dynamic test scenarios, which included many forced network dropouts and hidden node situations. The switching between the interfaces, guided by OLSR, generally worked well, but there were a few occasions when the hand-off between the interfaces produced a noticeable degradation in the voice quality just prior to a transition to the contingency radio. The team attributes this degradation to the switching algorithm, the OLSR configuration settings and the lack of filtering on the health metrics used for the switching algorithm. In general, the Speex audio quality was excellent, and several crew members commented that the voice quality was an upgrade to the existing ISS radio system.

The switching criteria used to trigger a jump of the EVA radio system from one interface to the other is the primary target for system improvement. The team used an appropriate set of OLSR link quality thresholds to trigger a switch, but several tests indicated these metrics were much more dynamic than originally expected. Several instances of "chattering" between the two interfaces were initially observed, which can be easily corrected by implementing standard sensor filtering techniques and by fine-tuning the OLSR configuration parameters. The data collected during the field tests will prove to be essential for establishing the system response characteristics for tuning these filters and for selecting additional switching criteria.

Although not an issue during the DRATS field tests, during system development efforts, the team had to experiment extensively with the 802.11 adapter software drivers. The software drivers are especially unpredictable when used in ad hoc mode. The team did generate a configuration suitable for the demonstrations, but this setup restricted the team's ability to operate the 802.11 radios in several different modes of interest. A solution is to generate a set of in-house communication radios, in which the developers have complete insight and control. The use of custom radios for future tests would not only alleviate the driver issues, but it would further allow incorporating physical network layer metrics into the link switching criteria. Incorporation of the physical layer metrics, which are not typically available when using COTS hardware, should improve the performance of the wireless interface link switcher algorithms. For example, physical layer hardware metrics may allow for a more accurate assessment of the link quality.

In summary, this work has demonstrated a dual-band radio with intelligent switching capabilities can effectively be used to achieve high data rates and extended operational range capabilities for mobile users. Simultaneous voice and data can be effectively transferred over the same limited bandwidth wireless connection and the OLSR ETX metrics can be used as a metric for intelligent switching between two different capability wireless mobile networks.

Appendix A

Configuration Management

Proper version control or configuration management is essential for any project utilizing software, regardless of the project size. Version control provides among many benefits a method for tracking and locking changes and greatly enhances parallel concurrent development. The EVA radio development has utilized a complete configuration management system from the initial source code development through the actual software deployment. In order to fully appreciate the software development and deployment system implemented, some background knowledge is necessary. The EVA radio configuration management system consists of the following core technologies:

- Version Control Server
- Debian Source and Binary Packages
- Debian Package Management System
- Advanced Packaging Tool
- Automated Builder

A version control server is a system that manages changes to files, maintains current and previous file revisions and allows collaborative modification of the same files by a team of developers. A version control system typically provides the ability to revert to previous revisions, compare differences between revisions and may also merge different versions between multiple developers. Typically, a version control system is used to handle software source code, but is also readily applied to configuration files and documentation. A number of open source systems exist. The EVA radio system utilized the Bazaar (BZR) distributed version control system.

To promote modular software code development, each software daemon, library or configuration parameters for the EVA radio system is distributed as a Debian package. A Debian *source* package is first created, from which a Debian *binary* package is then created for distribution to the desired hardware platform. A Debian binary package (.deb file) is simply a group of files, which is maintained as a single archive.[A1] The package contains both the package data and the package metadata and installation/removal information [27]. The binary Debian package may contain for example the software executable (typically a compiled binary) and any documentation or configuration files. A Debian source package contains all the information necessary to build a binary package.

[A1] The archive file within a Debian package contains two tarball (.tar) files compressed with GNU zip utility, one containing the data and the other the corresponding control and configuration information for the package.

The source package consists of the original software source files and the information required to build or compile the binary package. Although a binary package is the most typical and convenient to the majority of users, the source package format allows for a binary package to be created for a number of different operating system versions, architectures, or even compiled/linked against other different library versions. Thus, by starting first with a source package, the development method not only allows for complete flexibility and control over the deployed software, but additionally provides a further degree of version control and traceability, as the original software source used to create the binary package is also attached.

Once the Debian packages are generated, the Debian Package Management System, coupled with the Advanced Packaging Tool (APT), is used for distribution and installation of the software. The Debian Package Management System (`dpkg`) is a utility to install and remove software packages. The package management system automates the process of maintaining and installing software packages in a consistent manner. The system controls dependencies, conflicts and package versions. In addition, the system ensures proper installation and clean up from prior software package installations. APT provides a front-end to `dpkg` with further networking enhancements, including the retrieval and installation of multiple Debian packages from a networked software package repository. For example, to install a hypothetical package called `eva-example`, one would issue the command `apt-get install eva-example`. The command instructs APT to query the software repository and download the software package for automated installation by `dpkg`. In addition, APT also performs the retrieval of additional software packages from the networked software repository to satisfy package dependency requirements. During the installation process, if the package management system determines that additional software dependencies must also be installed, APT searches the software repository for the dependencies and downloads the software packages as necessary for installation. The complete system allows for a complex system of modular software packages to be installed, maintained and versioned in a robust fashion.

The final core technology utilized in the EVA radio software development flow is a networked automated builder. A networked software build server ensures that all deployed software packages are compiled against a consistent set of software libraries with a consistent set of development tools. Furthermore, an automated builder simplifies the build/test/deployment process as the entire procedure is extracted away from the software developer. The automated builder system may for example, auto-generate the Debian source package, compile the architecture-dependent binary Debian packages and then push the resulting packages to the APT repository. For the EVA radio development, the open software project “Buildbot” is used by the entire development team. Buildbot is an open source “continuous integration system designed to automate

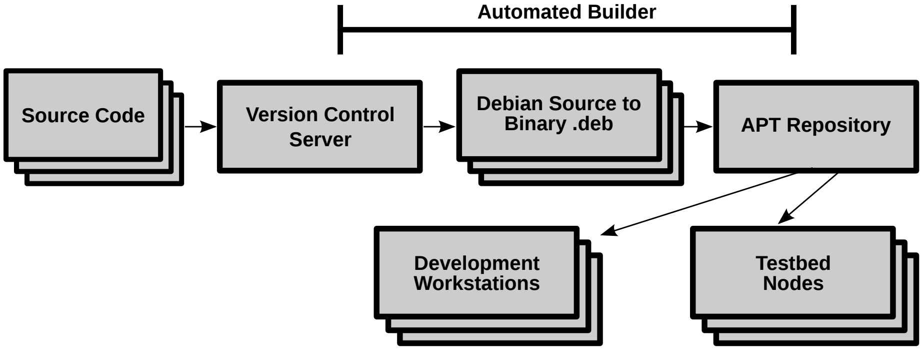

Figure A1. Software Development Flow

the build/test cycle" [28]. A master buildbot builder triggers from commits to the software version control system. Automated builds are then distributed to a set of slave builders (either virtual or physical) for the desired set of processor architectures and operating systems. For the EVA radio development efforts, automated slave builders were setup for the i686 and x86-64 platforms to accommodate flexibility in development workstation and testbed platform hardware.

The software development flow process for the EVA radio system is depicted in Figure A1. In the software development process, the developer first creates the desired software source files as is normally done with any software development effort. The software files are then submitted to a version control server for source code configuration management. The source project is then further modified by the developer to allow auto-generation of a Debian Source Package. In order to generate a Debian Source Package, a simple description file must be created, which describes the software package and necessary package build and run-time dependencies. In the Debian nomenclature, the package description information is contained within a "`debian/control`" file.

An example Debian Control file is shown in Listing 1. The first block describes the source package and the dependencies required to build the binary package. The second block describes the binary package generated from the source package. A Debian source package may be used to generate multiple binary packages. In the example, a single binary package is listed and the corresponding required packages necessary for run-time are also listed. Within the Debian Control file, a number of additional description fields may also be specified. The example provided only contains a minimal representative set of control fields. Further information on the Debian package structure and additional control fields is available in References [27], [29], [30].

```
Source: eva-example
Section: net
Priority: extra
Maintainer: Software Developer <nospam@NASA.gov>
Build-Depends: debhelper (>= 7), cdbs, g++, python
Standards-Version: 3.8.3

Package: eva-example
Architecture: any
Depends: ${shlibs:Depends}, ${misc:Depends},
         python (>=2.6), python-daemon, net-tools,
             speex
Description: Example software package for EVA.
 This is an example Debian software package for EVA.
 .
```

Listing 1. Example Debian Control File

Appendix B

Topographical Map Generation

The topographical maps used in the ground station visualization program are generated using Digital Elevation Map (DEM) information available from the United States Geological Survey (USGS) in GeoTIFF format. The topographical maps are only intended for visualization purposes and are not used for any portion of the algorithms implemented on the EVA radio testbed. Described here is the procedure used to generate the topographic map tiles used in the EVA radio visualization program.

First, data is obtained from the USGS. The National Elevation Dataset (NED) 1/3 arc second data is downloaded by using the USGS National Map Seamless Server Viewer at `http://seamless.usgs.gov`. The web interface allows NED information to be obtained for a rectangular area described by a set of latitude and longitude coordinates. To aid in automating the download process for multiple tiled regions, a custom C#.net utility was created. The utility program `GetUsgsDrats.exe` takes as input parameters the latitude and longitude, the number of tiles to download and the desired size for each tile. These parameters are then passed to the Seamless Viewer to download each desired tile.

Once the DEM information has been obtained, topographic contour lines and shading of the elevation levels is then generated into an image file. Post-processing of the DEM files is obtained by using the open source Mirone [31] software tool[B1], which is a front-end interface to the open source Geospatial Data Abstraction Library (GDAL). Using Mirone, the GeoTIFF files are used to generate contours for all of the

---

[B1] Mirone may be obtained from `http://w3.ualg.pt/~jluis/mirone` tiled images at regular-spaced intervals and to generate a color shading between the minimum and maximum elevation observed in the entire set of downloaded tiles. Using Mirone, a set of image files are generated which are representative of topographic information. The open source ImageMagick[B2] suite of utilities is then used to aid in cropping and resizing the resolution of the Mirone-generated image files.

B.1 Detailed Instructions

An abbreviated step-by-step set of instructions for generating the topographic tile images is presented as follows:

1. Download USGS DEM files using `GetUsgsDrats.exe`
    (a) Enter latitude/longitude, tile size and number of tiles.
    (b) Start the program and select *Download* to save `.zip` file.
    (c) Click *Next* to repeat the process.
2. Extract downloaded `.zip` files.
3. Start the Mirone software tool.
    (a) Open the extracted GeoTIFF files.
    (b) For each downloaded GeoTIFF file, note the maximum/minimum elevation to determine the limits for the given set of tiles. *Grid Tools — Contours — Contour Tool.*
    (c) Return to TIFF files, and for each:
        i. Select *Palette TB.* Enter the maximum/minimum elevation values for the set to make color gradients consistent throughout the entire set of tiles.
        ii. Select *Image — Illuminate — GMT GrdGradient.* Accept the default values.
        iii. Select *Grid Tools — Contours — Contour Tool.*
        iv. Select *Add Common Charting Intervals.* Add any other desired contour elevation value by typing in value in *Single* input form field.
        v. Select *Apply.*
        vi. Select *File — Export.* And save image as `.png` at the maximum available resolution.
    (d) Use ImageMagick to remove scale area from tiles:

    ```
    convert -crop 6935x7271+490+73 INPUT.png OUTPUT.PNG
    ```

    (e) Rename the images files to the format:
    `USGS_LAT_LON_LAT-SPAN_LONG-SPAN_.PNG`
    where the latitude and longitude are for the center of the tile.

[B2] ImageMagick is available from `http://www.imagemagick.org`

Note that the custom utility program `RenamePngs.exe` will aid in the file renaming process.

(f) Use ImageMagick to scale the image files to desired size:
`convert -scale 25% USGS_xxx.PNG USGS_yyy.PNG`

Appendix C

Experimental Data Description

During operation of the EVA radio testbed, a number of parameters and sensor data is collected to aid in system development and performance analysis. A brief description of the data collected and file formats is described here.

In general, file names are of format TYPE_timestamp.ext. The timestamp format is in POSIX time, or the number of elapsed seconds since epoch, 01 Jan. 1970. The timestamp is from the system time on the device which the data was recorded. The system time of all the nodes were synchronized at the start of the DRATS 2011 outing via network time protocol, but were left free-running without updates throughout the duration of all the tests. The offset in the system time can be determined from the GPS log files, where both the system time and the time derived from GPS is recorded. The file extension may be either `.bin` for raw binary, or representative of the contents such as `.csv` for comma separated values or `.mp4` for encoded video or `.spx` for Speex encoded audio. All text files contain a header to indicate the format of the data within the log file. All binary format files adhere to standardized formats.

Audio Data Files of type `AUDIO` contain Speex-encoded audio data as it was received at the destination node. Playback of these files allows a user to hear the audio as it was played to the test subject via the external speakers during the system test.

Configuration Files Any of the configuration files that may have been altered prior to a test are copied for documentation purposes. The configuration files help to confirm settings utilized on a particular run. The configuration files include parameters pertaining to the audio encoding, the link switcher settings, the OLSR configuration, and the network interface configuration.

Position Data Files of type `NMEA` contain the raw GPS data in NMEA format as transmitted by the GPS every second. Files of type `GPS` contain an extracted set of positional information which was distributed across the wireless network to the base station.

OLSR Data Files of type `OLSR_DOTx` has output from the OLSR daemon. This data is the raw OLSR output from a text plug-in and contains information on the network topology and the forward and neighbor link quality from which the ETX metrics are derived. The information in this file is parsed and then extracted to generate network health information to be used by the link switcher algorithm. Files of type `OLSR_SWITCH` contain the parsed OLSR information and is the information which is distributed throughout the network for use by the link switcher algorithm on each node.

Radio Connectivity Information A number of data file log types exist for determining the radio and network connectivity information. Logs pertaining to radio connectivity and health information are found in files of type: `IFCONFIG`, `IWCONFIG`, `SNMP_IFCONFIG` and `SNMP_RSSI`. The `IFCONFIG` and `IWCONFIG` file types pertain to the 2.4 GHz radio. These logs contain information as generated by the Unix `ifconfig` and `iwconfig` commands. The `SNMP_X` file types pertain to the 900 MHz radio. These logs contain information similar to that generated by the Unix `ifconfig` and `iwconfig` commands.

Raw Network Traffic Files of type `TCPDUMP` contain all of the raw network data which was sent over the network interface. The data files are generated with the `tcpdump` utility and may be read using `libpcap` capable utilities such as `wireshark`. The data files contain a `.bin` extension to indicate they are of a binary format.

Switching Algorithm Status Files of type `SWITCH` and `SWITCH_ETX` contain information from the switching algorithm. Each time a switch between the high data rate and low data rate networks is performed, a timestamp and status information is logged to the `SWITCH` file. The `SWITCH_ETX` file type contains the network ETX information which the switching algorithm uses on each cycle of the routine.

Video Files Files of type `VIDEO` are MPEG-4 video files as recorded on the mobile nodes. The video files are approximately 10-second snapshots.

Appendix D

Acronyms and Abbreviations

AP Access Point
APT Advanced Packaging Tool
AEC Acoustic Echo Cancellation
BER Bit Error Rate
BZR Bazaar
BMF Basic Multicast Forwarding
BP Bundle Protocol
BPSK Binary Phase Shift Keying
CCSDS Consultative Committee for Space Data Systems
COTS Commercial Off-The-Shelf
CTS Clear To Send
C&DH Command and Data Handling
DRATS Desert Research and Technology Studies
DTN Delay-Tolerant Networking
DTX Discontinuous Transmission
DEM Digital Elevation Map
ETX Expected Transmission Count
EVA Extravehicular Activity
GDAL Geospatial Data Abstraction Library
GPP General Purpose Processor
GPS Global Positioning System
GRC Glenn Research Center
IEEE Institute of Electrical and Electronics Engineers
ION Interplanetary Overlay Network
ISM Industrial, Science and Medical
ISS International Space Station
ITU International Telecommunication Union
IP Internet Protocol
MAC Media Access Control
NASA National Aeronautics and Space Administration
NEA Near-Earth Asteroid

NED National Elevation Dataset
NMEA National Marine Electronics Association
OLSR Optimal Link State Routing
OFDM Orthogonal Frequency-Division Multiplexing
PAS Power, Avionics, and Software
QoS Quality of Service
RF Radio Frequency
RTP Real-time Transport Protocol
RTS Request To Send
TC Topology Control
UDP User Datagram Protocol
UHF Ultra High Frequency
USGS United States Geological Survey
VAD Voice Activity Detection
VoIP Voice over Internet Protocol
Wi-Fi Wireless Fidelity (IEEE 802.11 wireless networking)

Appendix E

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14. ABSTRACT

In the Fall of 2011, National Aeronautics and Space Administration (NASA) Glenn Research Center (GRC) participated in the Desert Research and Technology Studies (DRATS) field experiments held near Flagstaff, Arizona. The objective of the DRATS outing is to provide analog mission testing of candidate technologies for space exploration, especially those technologies applicable to human exploration of extra- terrestrial rocky bodies. These activities are performed at locations with similarities to extra-terrestrial conditions. This report describes the Extravehicular Activity (EVA) Dual-Band Radio Communication System which was demonstrated during the 2011 outing. The EVA radio system is designed to transport both voice and telemetry data through a mobile ad hoc wireless network and employs a dual-band radio configuration. Some key characteristics of this system include: 1. Dual-band radio configuration. 2. Intelligent switching between two different capability wireless networks. 3. Self-healing network. 4. Simultaneous data and voice communication.

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