WIRELESS ROTOR DATA ACQUISITION SYSTEM

Elias Kpodzo Ph.D., Marc DiLemmo, Wearn-Juhn Wang Ph.D.
L-3 Communications, Telemetry East
1515 Grundy's Lane
Bristol, PA 19007

ABSTRACT

Flight test data acquisition systems have been widely deployed in helicopter certification programs for a few decades. A data acquisition system uses a series of strategically placed sensors to provide instantaneous status condition of the helicopter's components and structure. However, until recently, it has been difficult to collect flight test data from helicopter rotors in motion. Traditional rotor solutions have used slip rings to electrically connect fixed and rotating mechanical elements; but slip rings are inconvenient to use, prone to wear, and notoriously unreliable.

KEY WORDS

Wireless Rotor, Slip Rings, Data Acquisition System, Mesh MANET Radio, Multicast Network, GPS, AirDAS System.

INTRODUCTION

A ***Wireless Rotor Data Acquisition System*** (WR-DAS), which has been developed by L-3 Communications Telemetry East (L-3 TE), provides a novel solution to deal with the drawbacks of slip rings and delivers convenient, reliable and full-featured data collection capability. WR-DAS consists of three separate functional subsystems: the Data Acquisition System (DAS), Mobile Ad-Hoc Network (MANET) Radio and Battery Power Supply (BPS) subsystems. It may be used in a stand-alone configuration with built-in solid state recording capability, or fully integrated and synchronized with the rotorcraft's main data acquisition system.

Using wireless techniques to transport sensor data from helicopter rotors allows instrumentation designers to avoid the major drawbacks associated with slip-ring designs. Slip ring installation and maintenance costs are significant. The physical constraints of adding large, mechanical, devices to rotor shafts adds to installation complexity and may affect flight test results. The potential for electrical noise, that can corrupt the transmission of rotor telemetry, results in increased costs due to loss of data.

The WR-DAS employs revolutionary Mesh MANET wireless technology that solves many of the problems associated with the traditional wireless technologies, such as Wi-Fi and Bluetooth, when subjected to multicast network data and motion. The MANET subsystem operates as a seamless layer 2 device allowing for true plug and play capability while bridging devices and networks. Data throughput of up to 30 Mbps provides the ability to transmit high speed data including full motion video. The rotor installation can also include its own GPS time source, allowing precise time synchronization with data collected elsewhere in the aircraft.

This paper describes the system architecture of the WR-DAS used in two different configurations: a full network based solution where all Data Acquisition Units (DAUs) produce time tagged data packets and a traditional PCM configuration.

WIRELESS DAS ARCHITECTURE OPTIONS

Bluetooth, Mesh MANET and Wi-Fi are potential wireless technologies that can replace slip rings for collecting telemetry from rotors. All three are electrical solutions using RF/Analog and digital circuits (transceivers) and have low maintenance costs compared to the traditional slip ring solution. The comparison between Bluetooth, MANET and Wi-Fi is summarized in Table 1 which shows that the MANET radios used in the WR-DAS solution have superior transmit power, transmission range, network infrastructure and network security characteristics over the competing technologies.

The Mesh MANET technology provides a low cost solution, and has the longest expected range of transmission. The communication routes are updated quickly and accurately. The resulting network is self-forming, self-maintained, and self-healing providing significant flexibility with no need for maintaining a fixed infrastructure. Maintaining MANET radios is significantly less expensive than replacing or maintaining slip ring assemblies or slip ring brushes. Bluetooth and Wi-Fi have only very short range applications, and in addition Wi-Fi is a point-to-point system that requires fixed infrastructure and/or line-of-sight (LOS). The feasibility of Mobile Ad-hoc routing over Bluetooth has been researched in [2]. The capability of Bluetooth technology is for one-to-one links only and not for broadcasting as in the case of Mesh MANET. Before one Bluetooth device can connect to another Bluetooth device, both devices need to be paired first; which is a major drawback that makes dynamic infrastructure building very slow and may require more complex routing algorithms.

Technology	Max Power	Expected Range	Data Rate	Application	Security
Bluetooth Class 1	20 dBm	300 ft	2.1 Mbps	Point-to-Point, replacement for short data cables	Authentication and Encryption
MANET	28 dBm	105 miles	30 Mbps	Temporary networks with no need for infrastructure, infrastructure is built on the fly as required	Intrusion detection, link layer security, routing security, AES-256 capability & key management
Wi-Fi	20 dBm	300 ft	54/108/125 Mbps	Point-to-Point, replacement for Ethernet cables	Secure Methods and Protocols

Table 1: Comparison of Bluetooth, Mesh MANET and Wi-Fi Technologies

WIRELESS SYSTEM ARCHITECTURE DESCRIPTION

The WR-DAS solution builds upon a network based data acquisition architecture to solve the many issues encountered with mechanical slip rings. A MANET replaces the slip rings and provides an Ethernet network for bi-directional communications between the test article rotors, fuselage, DAS support hardware and even ground stations. The key requirement for successful deployment of a MANET within a DAS is having sensor data tagged with high resolution time stamps. Additionally, to facilitate data correlation during post test analysis, synchronized DAU's remove the need to interpolate data points to achieve time alignment between multiple sensors.

The MANET that is incorporated into the WR-DAS solution utilizes low cost radios. These radios operate at both licensed and license free frequency bands of 700 MHz, 900 MHz, 2.3 - 2.5 GHz, 3.5 GHz, 4.9 GHz, and 5.0 – 5.8 GHz using a proprietary protocol. IEEE 802.11a/b/g standard protocols are also supported. The range for the Mesh MANET Radio is up to 105 miles at an RF transmit output power level of 600mW (+28dBm) with data rates of up to 30Mbit/sec. The MANET, as implemented in the WR-DAS, is a collection of radio transceivers that form a self-configuring network. It is designed to maintain both peer-to-peer routes and connectivity to a data acquisition network. The system detects changes in connectivity and, using a revolutionary routing protocol, elegantly adjusts the pathways in order to maintain the most efficient route between endpoints. The transport network for this solution is based on IP (Internet Protocol) resulting in a plug and play system.

Considering the variable latency over any network and additional latencies when using a wireless network, time tagging sensor data at the source is the best way to facilitate correlation between multiple wireless and hard-wired DAU's. Adding GPS receivers to each segment of the MANET provides a means of producing time stamps for data and network packets. Additionally, the GPS timing signals can be used to synchronize the DAU encoders to a common time base. Synchronizing the DAU's and using Simultaneous Sample and Hold (SS&H) capability results in sensor signal samples that occur at the same time removing the need to interpolate data points during post test analysis.

Figure 1 illustrates a full network based solution where all DAU's are synchronized to GPS time and produce time tagged data packets which are subsequently sent to the Vehicle NETwork (vNET). The vNET consists of a hardwired network within the fuselage and the MANET is used to extend the vNET to each rotor hub allowing the rotor DAU's to publish packet data for use anywhere on the vNET. The MANET appears transparent to the individual DAU's and automatically routes packets to the desired destination even when point to point communications are disrupted.

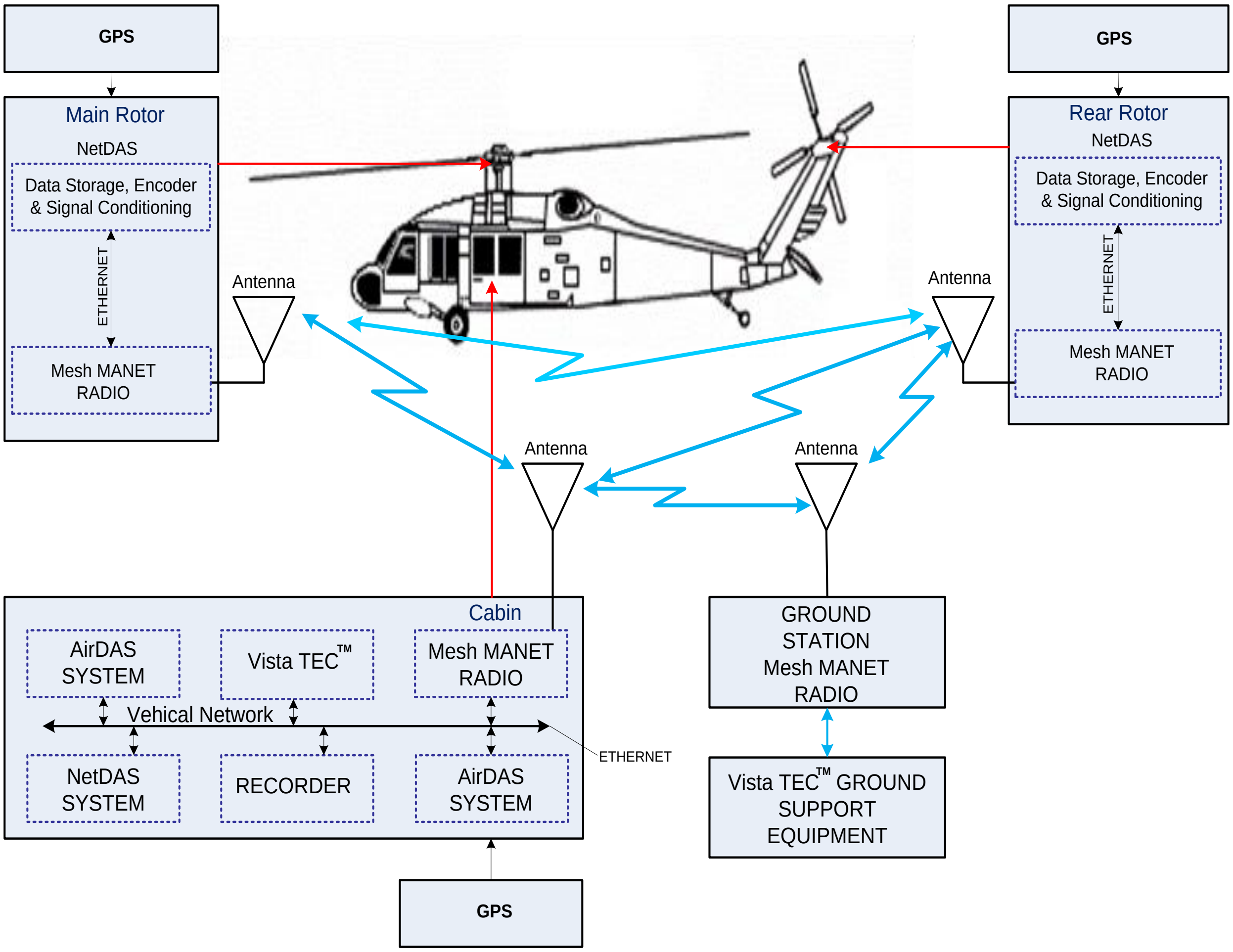

Figure 1: Wireless Rotor Data Acquisition System (Network Solution)

The requirement for a fully network based DAS is sometimes difficult to achieve due to the high cost to replace or retrofit existing assets. When adding a WR-DAS to a traditional PCM based DAS, specifically to solve mechanical slip ring issues, the network latencies need to be considered and data correlation requirements must be accounted for. Traditional PCM based DAU's can be augmented with network interfaces which packetize one or more PCM frames that are subsequently transported to the vNET over the MANET.

There are two common approaches used to integrate the rotor packet data with the main PCM stream generated by the test article DAS: Network packet capture with payload extraction and PCM regeneration followed by PCM merging.

Regardless of the approach used to reintegrate rotor data, the latencies produced by the network prohibit direct data correlation between rotor PCM frames and main DAS PCM frames. GPS can be used in this traditional PCM based solution, in the same manner as a full network solution, to synchronize the PCM schedules and SS&H events.

Figure 2 illustrates the WR-DAS with a traditional PCM configuration that uses the PCM regeneration technique to merge rotor data into the main PCM stream. A Network to PCM converter is used to acquire network packets, extract the payload data (which is one or more minor frames of PCM data) and regenerate the PCM stream. It is important to note that the regenerated PCM frames will be delayed relative to the main DAS PCM frames. However, all contained data samples were synchronously sampled. To accommodate the delayed nature of the rotor PCM frames, the time of the start of minor frame or SS&H event should be embedded into each frame. During post test analysis, the rotor data can then be easily aligned with main DAS data.

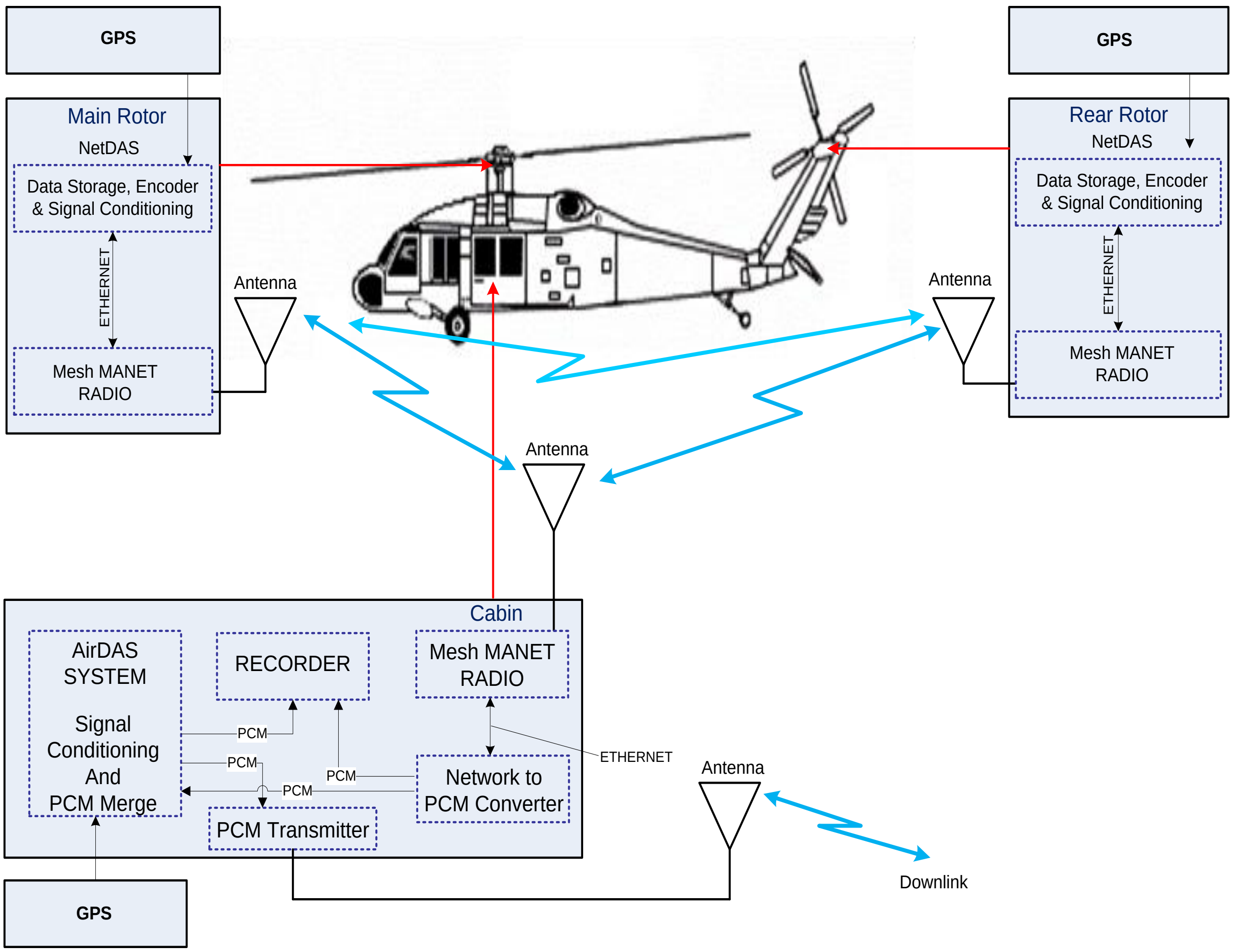

Figure 2: Wireless Rotor Data Acquisition System (PCM with Merge Solution)

If existing DAS assets can be augmented with an Ethernet monitor device, then passive network monitoring would be the most convenient way to reintegrate rotor data into the main DAS. Figure 3 illustrates the WR-DAS with a traditional PCM configuration that uses network packet capture to merge rotor data into the main PCM stream. The same synchronization and time stamping techniques are required for post test alignment of rotor data with main DAS data.

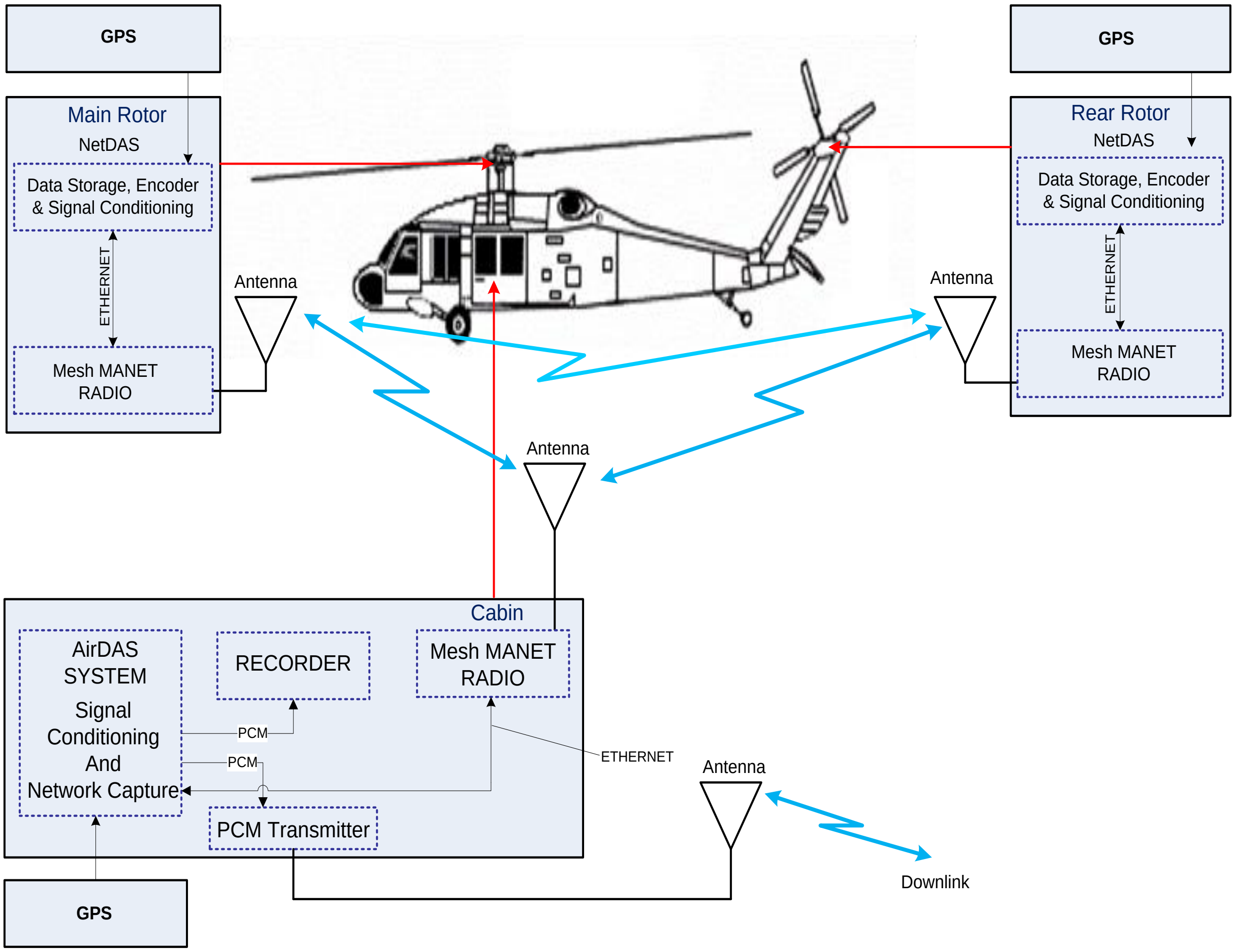

Figure 3: Wireless Rotor Data Acquisition System (PCM with Ethernet Capture Solution)

MANET DATA LINK PERFORMANCE

The system configuration shown in Figure 2 is currently being used to determine WR-DAS performance. However, test data was not ready for incorporation into this paper. The test data is expected prior to the 2011 ITC and will be available during this papers presentation. For the purpose of characterizing WR-DAS performance, a data link between a helicopter and a ground station as shown in Figure 1 was used. By including a WR-DAS radio with the ground support hardware and/or ground station equipment, actual flight test data was collected. The ground data link configuration effectively demonstrated how multiple MANET nodes on the test article support dynamic routing using nodes that have the best link quality.

The above described flight test was used to quantify the RF link and Quality-of-Service (QOS) capability of the WR-DAS. A 6dBi omni-directional airborne antenna and a 27dBi tracking antenna were installed on a helicopter and the ground station respectively to support the two test cases shown in Table 2. The height of the ground station antenna was 20 feet. The output power for both the MANET radios was 600mW. A Cloud Cap EO/IR Gyro Tracking Camera and a

LinkTEK JPEG 2000 Video Encoder and Bandwidth Monitor were set up in the helicopter to transmit a live video stream to the ground station for monitoring.

Test Case	Asset	Antennas Installed	Radio Configuration
1	Helicopter	6dBi Omni	2.4GHz
	Ground Station	27dBi Tracker	2.4GHz
2	Helicopter	6dBi Omni	2.4GHz
	Ground Station	6dBi Omni	2.4GHz

Table 2: MANET Flight Test Configurations

During the configurations described above the helicopter flew to a maximum distance, which maintained the minimum bandwidth for a clear video image, on the LOS link at fixed altitudes. Figure 4 describes the flight patterns that the helicopter followed during the tests.

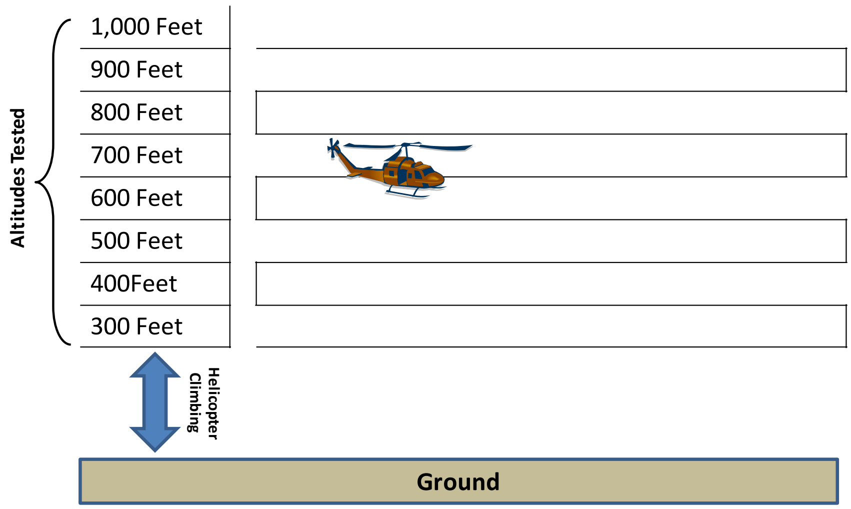

Figure 4: Helicopter Flight Pattern

During all tests, the Signal-to-Noise Ratio (SNR) and the video bandwidth were collected and logged every one mile according to the GPS positioning data. Figure 5 and Figure 6 show the SNR vs. distance and the video bandwidth vs. distance at the 1,000 foot altitude for test cases 1 and 2 respectively. Minimum video bandwidth for a clear image is about 2 Mbps which is approximately a 13dB SNR. A wave propagating model was created to simulate the receiving power at different distances and altitudes and compared with the measurements. The measured SNR (Red Line) is lying on top of the simulation curve (Blue Line) for both cases which imply a good correlation between the simulations and measurements. Fluctuation of the measurements was caused by the antenna angle on the helicopter and multipath fading due to rough terrain.

The test results indicate that the maximum distance for maintaining good QOS is about 37 miles by using the 27dBi tracking antenna and 13 miles by using the 6dBi omni-directional antenna at the Ground Station. The distance constraint for the 27dBi tracking antenna is due to the curvature of the Earth and objects in the link path. According to our simulation, the effective communication distance for this case can be extended to more than 60 miles if the antenna has sufficient height. The distance limitation for the 6dBi omni-directional antenna is due to insufficient receiving power. With an additional 6W power amplifier at the helicopter radio (i.e., 10dB more power gain), the effective communication distance could be extended to 27 miles (See Figure 7).

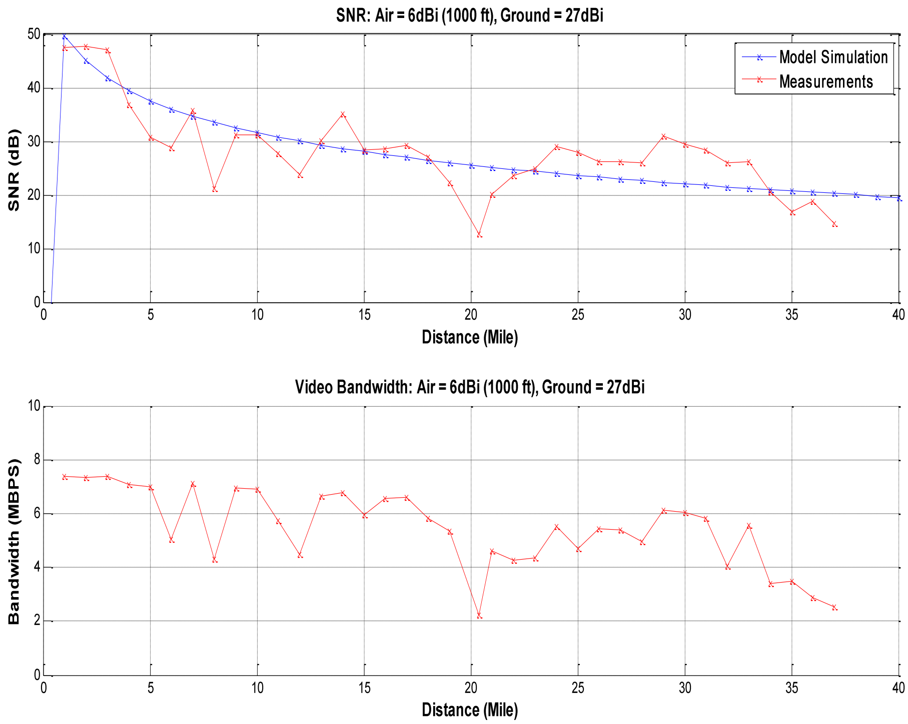

Figure 5: SNR and Video Bandwidth vs. Distance for the Test Case #1 at 1,000ft Altitude

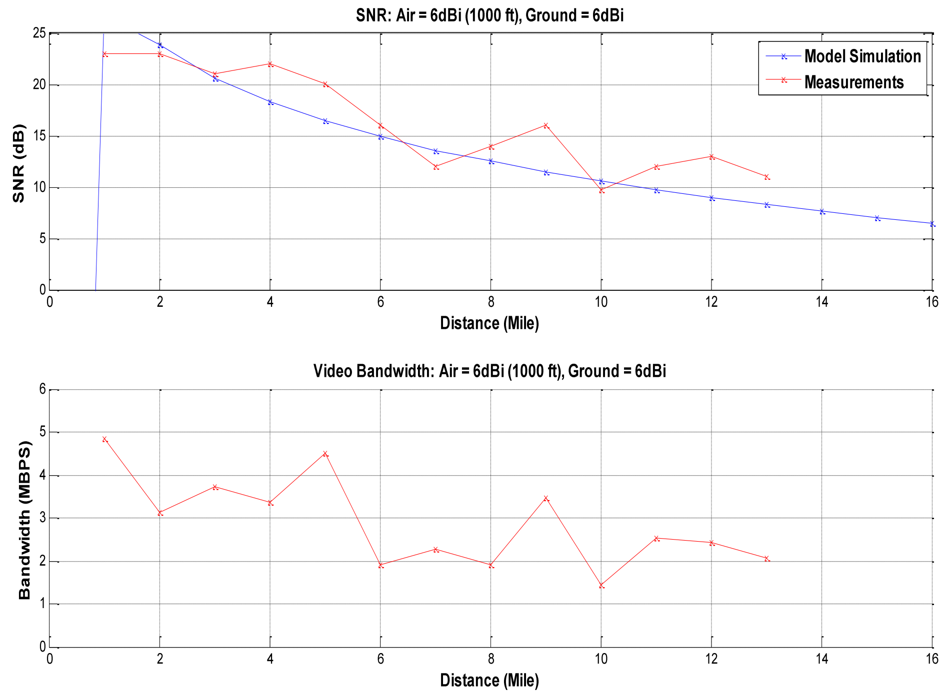

Figure 6: SNR and Video Bandwidth vs. Distance for the Test Case #2 at 1000ft Altitude

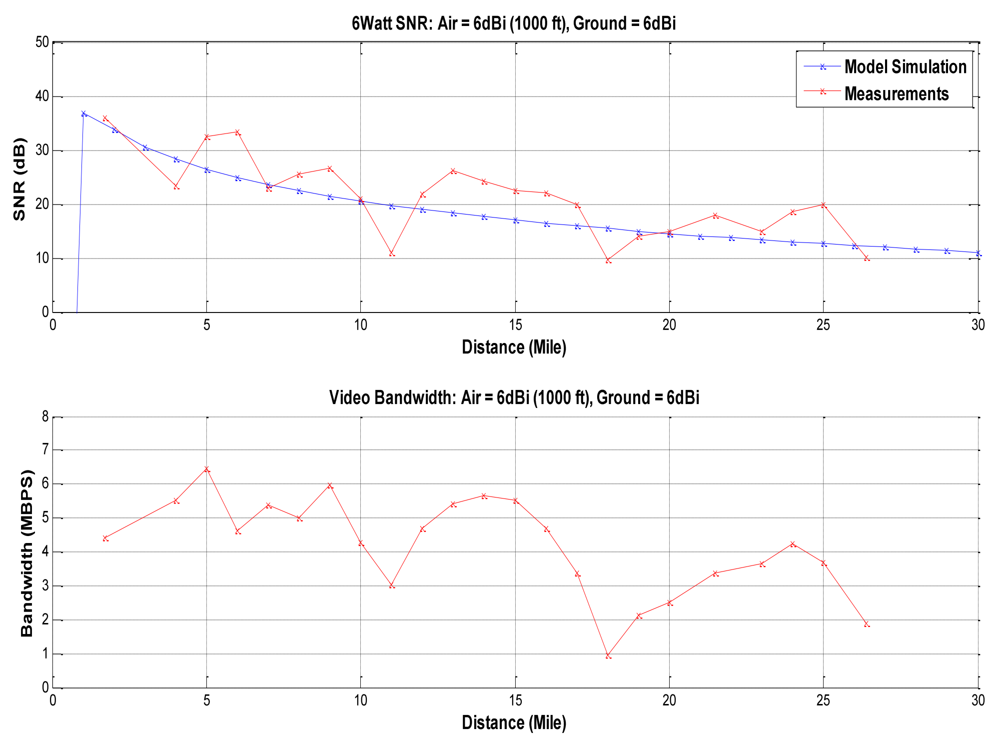

Figure 7: SNR and Video Bandwidth vs. Distance for the Test Case #2 with an additional 6W Power Amplifier at the Helicopter Radio at 1000ft Altitude

POWER SUPPLY SOLUTIONS

The required battery (22 to 30 VDC) under consideration for this application uses Lithium-Ion (Li-ion) technology and is custom designed for aerospace and defense applications such as aircraft, spacecraft, military, communication and scientific satellites, launch vehicle systems, unmanned aerial vehicles, etc. Lithium-ion batteries provide higher energy levels and longer cycle life at a lower weight and smaller size than lead acid, Ni-Cd, and Ni-MH batteries. The battery is chargeable before any flight and is expected to perform for the specified number of Ampere-Hours; it is designed for long life, high reliability with excellent overcharge capability. The design is made up of independent pressure vessel (IPV) cells, where each cell is hermetically sealed in a pressure vessel. Each cell is automatically monitored for best performance (Voltage and Current) using state-of-the-art electronic assemblies during the flight. The battery can also be designed using common pressure vessels (CPV) cells or single pressure vessel (SPV) cells; but the IPV design provides the best capacity (Ampere-Hours).

CONCLUSION

The novel application and design of a MANET solution to replace slip rings in a data acquisition system has been described. The system configuration shown in Figure 2 is currently being used to determine WR-DAS performance. Early installation and testing results have already proven the capabilities of the proposed, significantly lower cost, solution compared with the current slip ring solution. While waiting for actual flight test performance data, the MANET radio performance was characterized using a data link between an aircraft to a ground station. The range of the radio for a data link application has been shown to be more than 37 miles at 1,000 ft altitude (60 miles according to simulation) for a transmission path between a helicopter and a ground station. The MANET solution avoids the complexity of fixed infrastructure design and maintenance by providing dynamic routing capability that is quick and accurate based on real time network performance. The network is self-forming, self-maintained, and self-healing and provides extreme network flexibility compared to current solutions.

REFERENCES

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