Wireless Sensor Payload Design for Sounding Rocket

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Abstract

A quick turnaround Sub-Orbital Student Experiment Module sounding rocket experiment has been designed and built to initiate the Old Dominion University wireless spacecraft bus project for the Mid Atlantic Institute for Space and Technology. The sounding rocket was launched on the 8th of June 2006 from NASA Wallops Flight Facility on Virginia's Eastern Shore. This wireless sounding rocket experiment is the first step directed toward replacing wired data interfaces with their corresponding wireless counterparts for low-cost access to space. The sounding rocket experiment is designed to achieve two objectives: wireless sensor network data acquisition on board the payload and Radio Frequency (RF) environmental characterization in wireless personal area network frequency domain. The wireless sensor data collected on board provided us valuable information needed to simulate the RF environment that will exist in future space flights.

1. Introduction

Old Dominion University proposed the development of an orbital payload experiment to demonstrate wireless technologies as part of the Mid Atlantic Institute for Space and Technology (MIST) thrust to develop systems supporting low-cost access to space. The intermediate-term goal is to evaluate wireless sensor network concepts and protocols, then design and fly a wireless orbital experiment. In order to orient the overall effort toward the development and delivery of flight hardware, it was determined that a near-term sounding rocket payload utilizing commercial-off-the-shelf (COTS) wireless sensor network elements would be a useful bridge between developing expertise required to design and build an orbital payload and gaining the necessary experience. These expertise and experience are needed to meet the demanding schedule, quality control and testing requirements associated with a space-qualified experiment.

The sounding rocket uses a single stage *Improved Orion* launch vehicle carrying a payload whose nominal total weight is on the order of 250 lbs [1]. The sounding rocket flight opportunity has the following attributes:

- Payload design, engineering and testing constraints are similar to orbital payload requirements.
- The payload is exposed nominally to a space environment (altitude and microgravity) that is similar to low-Earth orbital flight.
- The short duration of the flight permits pressurized payload bays, facilitating the use of COTS hardware that is not required to achieve the stringent outgassing and electric discharge standards associated with prolonged operation in low-Earth orbit—greatly reducing hardware costs.
- The acceleration/vibration environment produced during the propulsive phase of the sounding rocket flight is generally more severe than for a typical orbital launch.
- Launch operations and payload control are similar to an orbital flight.

The rest of the paper is organized as follows. Section 2 introduces the wireless sensor payload objectives and experiments. Section 3 presents the system design. Section 4 provides the experimental data and their analyses. Finally, Section 5 concludes the paper.

2. Wireless Payload Experiment

2.1 Objectives

The objectives of the wireless sensor payload experiments are to investigate the

- Influence of sounding rocket launch acceleration and vibration environment on the ability of a low-cost small-scale, wireless sensor network (or Wireless Personal Area Network–WPAN) to maintain communications during the thrust or propulsive phase of the flight.
- Characterization of the radio frequency, space electromagnetic and instrumentation noise that occurs during the entire sounding rocket flight in order to provide data for a ground-based simulated satellite

RF environment (over the frequency range encountered by anticipated wireless devices).

2.2 Experiments

Three experiments have been designed to achieve the aforementioned objectives. The first one monitors and recorders the wireless data acquisition activities. This is performed in a WPAN consisting of wireless sensor devices and a central base station. From the results of this experiment we expect to learn the following:

- Reliability of data transfer from the wireless sensor devices to the base station during the propulsive and microgravity phases of the flight.
- Operational efficiency of the wireless devices in a sounding rocket environment.
- Ability of the base station to receive correct data from the wireless sensor devices in the presence of noisy RF contamination.

The second experiment is a radio frequency analysis in the 2.4 to 2.5 GHz range performed using a modified portable spectrum analyzer. From the results of this experiment we expect to gain the following:

- Characterization of spurious RF signals in the 2.4-2.5 GHz range, starting from launch and continuing through the parabolic high-altitude coast phase.
- Assessment of the impact of interference from spurious signals on the signals generated by the wireless sensor network

The third experiment is a magnetometer based data acquisition to measure the magnetic field during the flight trajectory. From the results of this experiment we will learn the following

- Magnetic field variations experienced within the sounding rocket environment
- Impact of the sounding rocket dynamic behavior on the data transmission due to the presence of the magnetic field.

3. System Design

A schematic diagram of the overall design for all three experiments is shown in Fig. 1. The figure highlights the data and power flow among the various devices used in the experiments. Next, we introduce the four main modules in the system. They are 1) power distribution, 2) wireless data acquisition, 3) characterization of the RF environment, and 4) magnetic field measurement.

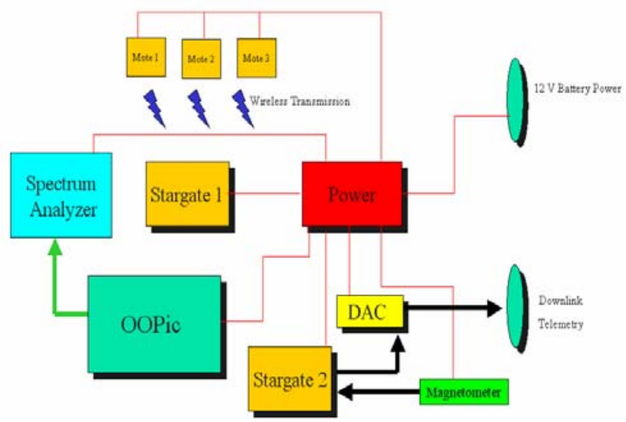

Fig.1. Schematic diagram of data and power flow design of the three experiments

3.1 Power Distribution

The power distribution system provides power to all devices by dividing and regulating the 12V, 2 amps power provided by the Wallops Support Module (WSM). The WSM power distribution system utilizes a 25-pin D-Sub connector, providing discrete control elements as well as power and ground connections, power distribution board interface and the power wires for the devices. The power distribution board provides output voltages of 3V, 5V and 12V. Since WSM power is 12V, the distribution board only affects the lower voltages. In order to obtain 5V output, a DC-to-DC converter is used. For 3V output, an LM317T (KA317) Adjustable Voltage Regulator was used along with two resistors (100 and 150 Ohms)[6]. The layout of the power distribution board is shown in Figures 2 and 3.

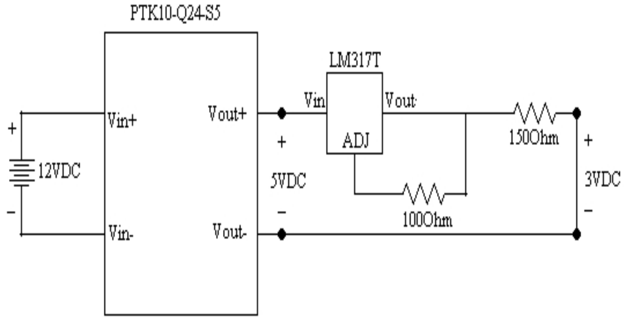

Fig. 2. Schematic diagram of the power distribution board

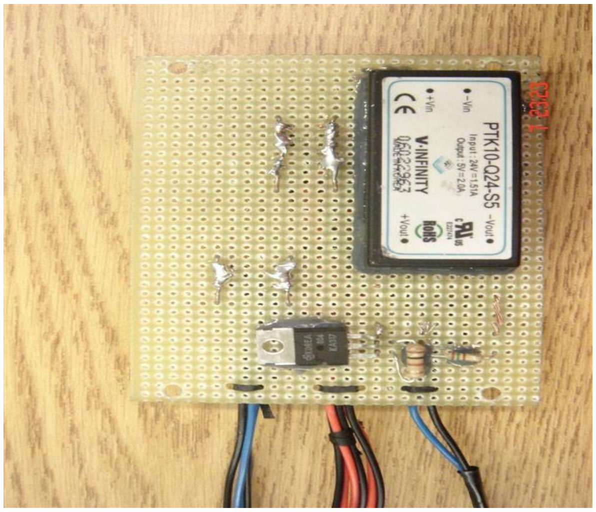

Fig. 3. Photograph of the Power Circuit Board as built.

3.2 Wireless Data Acquisition

Wireless data acquisition system includes a network of wireless sensor devices and a central data repository was required. We selected a Crossbow sensor (MTS 310[2])/mote (MPR2400 [3]) combination device, and a base station (Stargate [4]) for the central data repository for the wireless sensor devices. Fig. 4 shows the layout of the Crossbow devices in the payload. The wireless sensor network devices are mounted on the top deck of the rocket. The three MPR2400/MTS310 sensor mote modules are placed at the edges of the top deck and the SPB400 base station is placed at the center. The antenna used by the Crossbow motes MICAz (MPR2400) is a half wave dipole 1.2 inches in length. The transmission frequency is in the 2.4 – 2.5 GHz band.

The sequence of events that occur in order to generate, transmit, receive, collect and store data are as follows:

- Power up all devices.
- Initialize the MPR2400 MICAz motes to “listening mode”. (The motes wait for a signal from the base station, instructing them to transmit sensor data.)
- Stargate Base station initializes to “sending mode”. In this mode, the base station sends a signal to motes instructing them to “start transmission”. Once the signal is sent, the base station switches to “listening mode”.
- The MPR2400 motes receive the START signal from the base station. The MPR2400 motes send a signal to their corresponding MTS310 sensor module to start gathering sensor information.
- On receipt of the signal from MPR2400, the MTS310 sensor module gathers environment information and sends data to the mote.

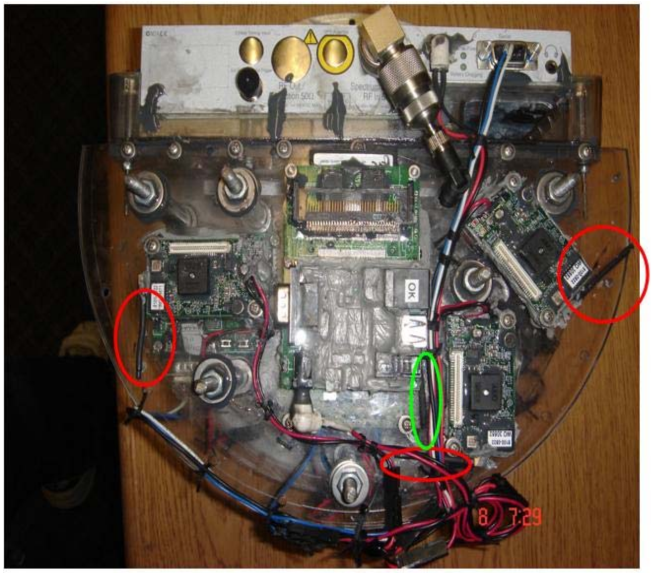

Fig. 4. Photograph of mote and base station antennas

The MPR2400CA mote reads the sensor values from all 5 sensors. These sensor data values are stored in a 30-byte packet. The packet size is configurable and is set to 30 byte based on the length of the sensor data values. Since there are 5 sensor data values to be sent, each data item except for accelerometer and magnetometer values is 2 bytes long. The accelerometer and magnetometer data values are each 8 bytes long to accommodate X and Y range values. In addition to the data values, the packet contains the unique sensor board ID, which makes the task of the base station easier during reassembly of packets from all three motes. Each mote transmits this packet to the base station once every second on the RF 2480 MHz frequency.

The mote transmission speed is 250 kbps. Presently, there is no communication among the motes. However, motes are capable of communicating with each other. This capability is most needed in situations wherein the base station is vulnerable to message overload. Motes can act as relays delivering their data and the data received from peer motes. This ensures that the entire network of motes do not communicate with the base station thus limiting its overhead.

3.3 Characterization of the RF Environment

The RF environment measurement involves measuring the frequency spectrum. The COTS device selected for this flight was designed originally as a handheld spectrum analyzer, Anritsu MS2711D [9]. It was selected because it met the size, weight, on-board memory storage, and frequency specifications we had defined for the wireless RF environment.

To control the MS2711D, we used an RS-232 port as an OOPIC (Object Oriented Programmable Integrated Circuit) microcontroller interface [7]. The OOPic microcontroller uses preprogrammed multitasking Objects from a library of highly optimized objects to interact with external hardware[8]. Programming for the OOPic can be accomplished using higher level languages including JAVA, C, or Basic, making the speed of programming the device much faster than for an FPGA (field programmable gate array) device or Assembly language. This was one of the determining factors in the OOPic microcontroller specification for this project. During the operation of the program, the scripts run in the foreground controlling what the objects should do, which are running in the background.

3.4 Magnetic Field Measurement

A Crossbow CXM539 Magnetometer [10] was selected to measure the magnetic field. The CXM539 is a high-speed, digital output, 3-axis fluxgate magnetometer. The system can convert and transmit over its serial port all three axes outputs at a rate of up to 200 samples per second at 38400 baud. A dedicated base station interfaces with the CXM539 on the RS-232 port to collect and store the magnetic field data. This magnetic field data is important for interference analysis, since radio frequencies are affected by external electrical and magnetic fields. Comparing the signal strength of the radio waves detected by the spectrum analyzer and the magnetic field data we can deduce the severity of the magnetic field influence.

Fig. 5 illustrates the final payload deliverable based on the above design methodologies.

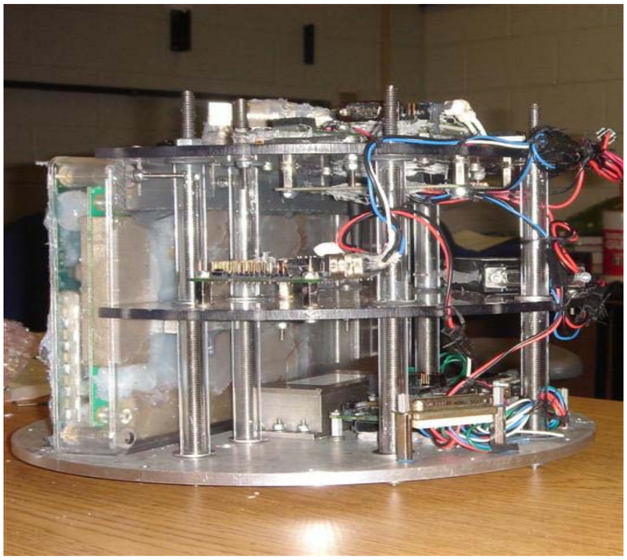

Fig.5. Picture of the final payload deliverable

4. Wireless Data Analysis

Due to the space limit, we will only provide the data analysis for the first experiment. The payload-mounted Stargate base station was connected to a computer via its Ethernet connection for data recovery on June 11. The wireless data were stored on a compact flash card contained within the base station, and the data were retrieved from the compact flash card using a Crossbow application called Moteview [5]. Moteview presented all the wireless sensor data from the base station in a tabular format that could be copied into an Excel spreadsheet formatted file in the laboratory computer. The extracted data included recorded testing data taken prior to the launch. The first step in analyzing the data was to separate the relevant flight data from the test data. This process was accomplished by comparing the acceleration and temperature values gathered from WFF with corresponding values in the extracted data. For reference purposes, the WFF Instrumentation Flight Summary [3], reported the event sequence for this flight. Next, we performed analyses of the collected data in terms of the accuracy of sensor data and the performance of wireless data communications.

4.1 Accuracy of Sensor Data

All three-mote sensor suite combinations transmitted data throughout the flight. Of the five active sensor types, we chose temperature and acceleration readings for accuracy assessment. For verification purposes, we employed the WFF telemetry readings as our reference.

Figs. 6 and 7 represent the WFF telemetry measurements of x- direction acceleration, and Payload Compartment Module (PCM) stack temperature, respectively. Since WFF did not measure temperatures in the experiment section, the PCM stack temperature readings were considered to be characteristic temperatures rather than reference temperatures. Figures 8 and 9 are the measured x- and y-direction acceleration histories for the three motes and the temperature readings for the experiment rack. Since the mote accelerometers were relatively coarse when compared with the Wallops Flight Facility (WFF) accelerometers, the results were used solely to evaluate the wireless mote communication efficiency and accuracy. Although the readings varied from mote to mote and in comparison with the WFF accelerometer, the characteristic variations associated with the payload vibration environment were similar.

The wireless mote readings are known to be affected by the range/sensitivity of the sensors, sampling rate and positioning with respect to payload axes. The wireless mote accelerometers were range limited to ± 2g with a sampling rate of 1 reading per second, whereas the WFF accelerometer, embedded in GLN-MAC-200

Inertial Attitude Sensor, had an acceleration sensing range of ± 40g with a sampling rate of 10 readings per second. The liftoff vibrations along with propulsive acceleration and the onset of payload spin, visible in the WFF accelerometer histories, is also obvious for all three of the wireless sensor mote histories. The differences between the mote readings were due primarily to their lack of sensitivity and an absence of individual mote calibration data. Similarly, the thermistor measuring the PCM stack temperature and the mote thermistors measuring the experiment rack temperatures were not subject to the same thermal environments, but the temperature increase histories were similar in all four cases. The initial temperature differences between the motes were caused both by lack of sensitivity and the absence of individual calibrations for the wireless mote thermistors. However, these inconsistencies were considered to be unimportant since the recorded temperature histories were in the acceptable tolerance band of ±2%.

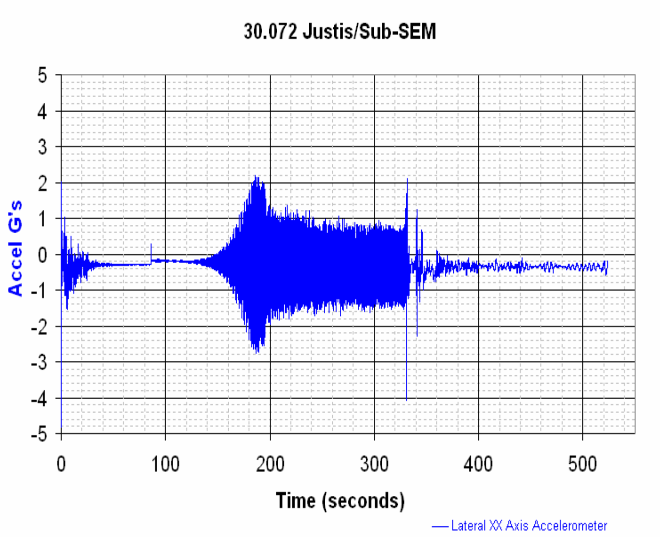

Fig 6. X-Axis Accelerometer Data (WFF)

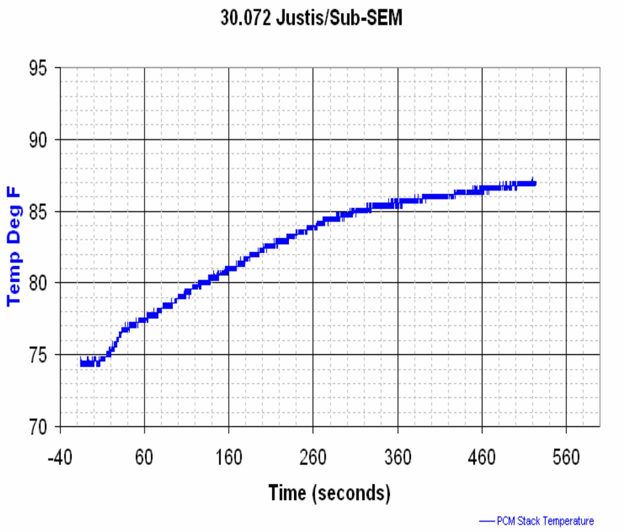

Fig. 7 PCM Stack Temperature (WFF)

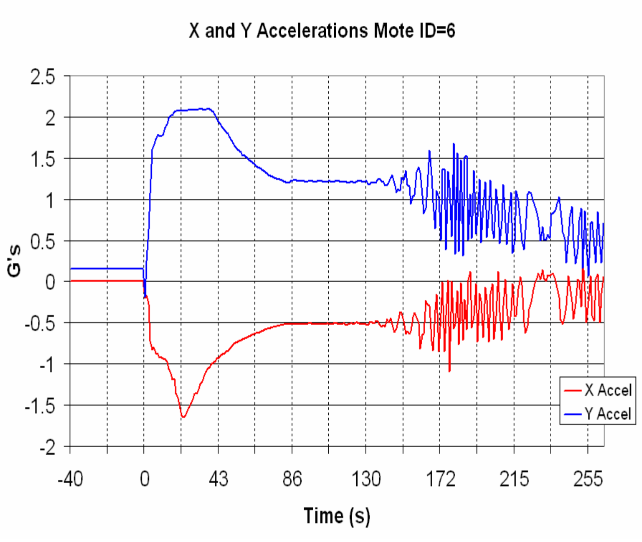

Fig. 8 Mote (ID = 6) X and Y Axes Accelerometer Data

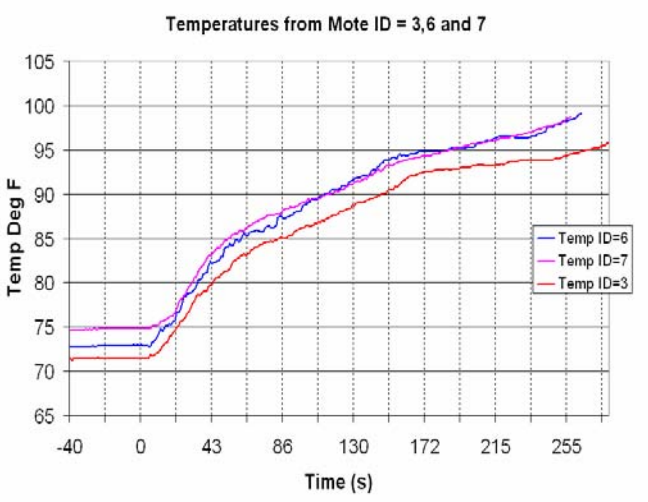

Fig. 9 Mote ID = 3, 6 and 7 Temperature Readings

4.2 Performance of Data Communications

To comment on the wireless data communications, we analyzed the packet transmission and packet loss statistics. The packet transmission characteristics are shown in Figs. 10 and 11. Fig. 10 shows the number of packets transmitted by all nodes in one minute. Fig. 11 shows the number of packets lost by all three nodes during each minute. Both figures show the pre-flight ($t \leq 0$) and flight time ($t > 0$) packet transmissions and we can see that there is no significant difference between the number of packets transmitted before and after launch time. During the 5th minute of the recorded flight data the transmission duration was only 16 seconds, creating the erroneous result that packets lost and transmitted were lower than the other minutes. The packet losses are more pronounced during the minute immediately after peak launch accelerations.

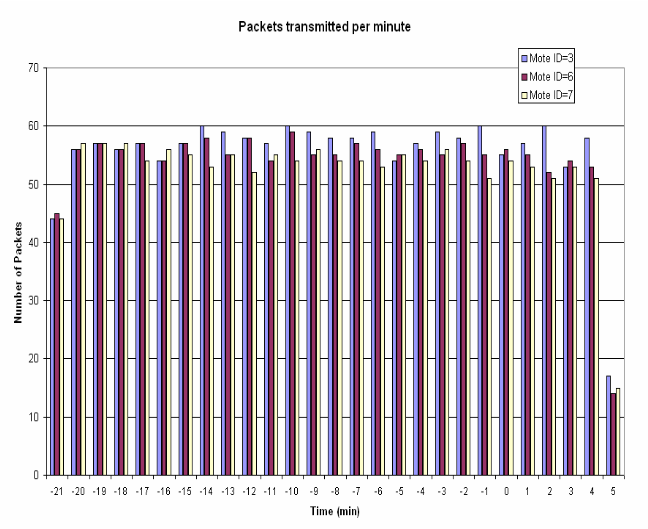

Fig 10. Number of packets transmitted by each mote per minute

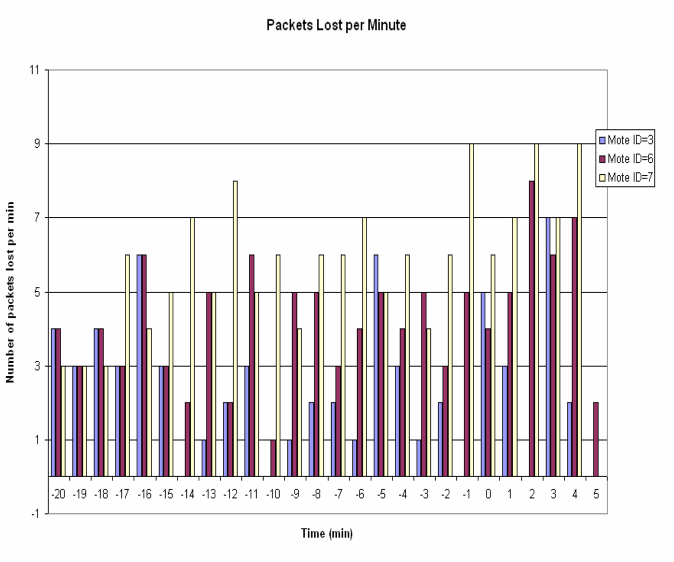

Fig 11. Number of packets lost by each mote per minute

5. Conclusion

In this paper, we presented the design and implementation of the wireless sounding rocket payload. The components used in the design were COTS devices. The experimental data procured provided us valuable information on space based wireless data acquisition process inside the sounding rocket. The information gathered from this data would help address wireless research issues like co-existence, interference, power management, and redundancy avoidance in future flights. The data is also valuable in helping build a mock spacecraft environment wherein the above wireless research issues will be tested.

References

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[9] MS2711 D Spectrum Analyzer Datasheet http://www.us.anritsu.com/downloads/regdriver.aspx?fileName=11410-00322.pdf&fileID=1663&fileType=7

[10] CXM539 Magnetometer Datasheet http://www.xbow.com/Products/Product_pdf_files/Mag_pdf/CXM539_Datasheet.pdf

The sounding rocket experiment is designed to achieve two objectives: wireless sensor network data acquisition on board the payload and Radio Frequency (RF) environmental characterization in wireless personal area network frequency domain. The wireless sensor data collected on board provided us valuable information needed to simulate the RF environment that will exist in future space flights. Sachin Shetty, Min Song, Robert Ash, Ersin Ancel, Real-time Traffic. Low cost sounding rockets and high altitude balloons, Robots and low cost environmental sensors, Internet and data sharing.Â Both the Imaging Board and the particulate matter sensor are designed to mounted to the aft outer side of the 1p package to face downward as S4 is deployed for parachute or parawing recovery. S4Qube is a 3D printed 5x5x5 cm plastic enclosure designed to hold the core processor+memory, baseline sensors, battery, antennas, and additional sensors.Â Communications and Telemetry. An emerging wireless standard for the Internet of things, LoRa, is used as the S4 basis for inexpensive, long range, low power S4 telemetry service in the 902-928 MHz unlicensed band in the Americas. Micro-X is a NASA-funded, sounding rocket-borne X-ray imaging spectrometer that will allow high precision measurements of velocity structure, ionization state and elemental composition of extended...Â One of the biggest challenges in payload design is to maintain the temperature of the detectors during launch. There are several vibration damping stages to prevent energy transmission from the rocket skin to the detector stage, which causes heating during launch. Each stage should be more rigid than the outer stages to achieve vibrational isolation.Â Vibration isolation Transition-edge sensors Sounding rockets X-ray spectrometers. This is a preview of subscription content, log in to check access. References.