ASCI 691 Graduate Capstone

Low-Power High Speed Multimedia Radio for Amateur Sounding Rockets

Richard Witherspoon

Embry-Riddle Aeronautical University

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Abstract

Reducing the ground segment costs to operate sounding rockets will increase research opportunities for universities. We hypothesize that low-power high speed multimedia radio operating under FCC Part 97 will allow adequate data transfer rates up to a distance of 100km. A research experiment will be performed to determine what transmission power and 802.11 modulation schemes are required to achieve adequate data transfer rates while minimizing bit error rates. Collected data will be compared to estimates via least squares fit to validate regression model. Analysis of results will be completed through a real-world application example. This research project addresses a need for low-cost space operations in research and development.

Keywords: high speed multimedia radio, sounding rockets, FCC Part 97

Proposal

The research presented in this proposal will analyze the feasibility of low-power high speed multimedia radio on the PSAS rocket for telemetry up to 100km. This graduate capstone proposal (GCP) must be applicable to Program Outcomes 1, 2, 3, 4, and 12 in order to fulfill the requirements of my degree.

Low-Power High Speed Multimedia Radio for Amateur Rocketry

Problem Background

The radio equipment used on high altitude sounding rockets is expensive and requires complex ground segments. The Portland State Aerospace Society (PSAS) launches amateur rockets to altitudes of 6km and would like to operate up to 100km as a low altitude sounding rocket. If a low-cost telemetry system can be designed using commercially available equipment, PSAS can offer no-cost flight services to local universities. Because PSAS operates from many locations, the ground segment must be quick to setup, highly mobile, and use commercially available equipment. Using the 802.11 wireless standard but operating under FCC Part 97 is known as high speed multimedia radio (HSMM). HSMM offers the opportunity to use inexpensive and commercially available equipment for long distances.

Problem Statement

The problem to be examined in this proposed experimental research project is the feasibility of using low-power high speed multimedia radio (HSMM), operating under FCC Part 97 with the Portland State Aerospace Society (PSAS) curvilinear patch antenna up to an altitude of 100km.

Technological Overview

Wireless fidelity (WiFi) using the IEEE 802.11 standard has become the primary method for data communications on wireless local area networks. The IEEE 802.11 a/b/g/n standards have evolved to address frequency, polarization, and spatial diversity to meet increasing demands for throughput and coverage.

The 802.11b standard allows for data transmission rates up to 11Mbit/s using a direct-sequence spread spectrum modulation technique while 802.11g allows for 54Mbit/s transmission rates using orthogonal frequency-division multiplexing (Information technology-telecommunications and information, 2006).

There is significant commercially available equipment at low costs (<$150) because of WiFi's ubiquity around the globe. The 802.11b and 802.11g specification allows wireless transmission of data in the 2.4GHz (2.40GHz – 2.483GHz) Industrial, Scientific, and Medical (ISM) band with 20MHz wide channels. Under FCC Part 15 rules, which govern ISM band transmissions in the United States, ISM radio equipment is limited to 30 dBm (1 Watt) of peak envelope power (PEP) or Maximum Effective Isotropic Radiated Power (EIRP) of 36 dBm (4 watt) (Radio Frequency Devices, 2013). Most commercial WiFi equipment operates around 0.5 Watts PEP (Linksys, 2007).

Amateur radio operators using their amateur license and operating under FCC Part 97 rules may operate the same 802.11 equipment in the ISM band with significantly greater transmit power which increases transmission range and overcomes interference from other ISM devices. Under 802.11b modulation, output power is allowed up to 10 Watts PEP and 802.11g is allowed up to 1500 Watts PEP (Amateur Radio Service, 2013). When operating within the amateur license at increased power output, this mode of operation is referred to as high-speed multimedia radio (HSMM).

HSMM began active development in early 2002 with the first article being published in QST magazine in 2003. In that article the techniques for using modified COTS equipment and directional antennas were discussed (Mraz, Sablatzky, & King, 2003). By 2006 the American Radio Relay League (ARRL) has established a working group to advise on non-interference of ISM equipment by HSMM and a group in Michigan was working on a 10 mile range HSMM project (Ford, 2006). Current uses of HSMM include supporting long distance marathons and establishing network communications after natural disasters (Jelinski, 2013).

There is limited literature and no experimental data available on the use of HSMM for a sounding rocket application. The primary reason is that FCC Part 97 rules restrict using amateur radio frequencies for commercial ventures. Because the operator of a service cannot charge for providing those service under Part 97, commercial entities have no interest. Literature available on the topic of HSMM under amateur bands has limited applicability due to antennas and equipment used. Amateur radio HSMM applications typically use multiple access points to relay the radio signal greater distances while using 5-10 Watts PEP. This research project is focused on two single points communicating with a maximum of 5 Watts PEP. Terrestrial HMSS networks utilize two directional antennas for maximum bandwidth and range (Balanis, 2008; Chen, Qing, See, & Toh, 2012; Volakis, 2007). This research project uses an omnidirectional antenna for the transmitter. Some past space applications have used used the ISM bands on CubeSats but they did not utilize the 802.11 modulation scheme. This is because the protocol has additional overhead that decreases throughput compared to other available protocols (Wu, Vladimirova, & Sidibeh, 2008).

The limited research on the use of HSMM for a rocket application necessitates a pure research study to determine effectiveness of using the PSAS curvilinear antenna which is an omnidirectional antenna. A radio link budget has been developed to verify the feasibility of antenna selection but only empirical evidence will validate the link budget model.

Importance of the Study

An overarching goal of PSAS is open source development of technologies that can be used anywhere in the world. The International Traffic in Arms Regulations (ITAR) limit what technologies can be openly shared. It is the goal of this research project to utilize radio technology that would not be subject to ITAR.

The ISM band has been approved for unlicensed use globally which means there is minimal concern about using HSMM for rocket launches in foreign countries. The only variation in the ISM band is two additional 802.11 channels in Europe and Japan. However, operating under Part 97 rules allows access to those channels globally. Additionally, the amateur radio frequencies 2.400GHz - 2.450GHz which overlay the ISM bands are approved in all 3 International Telecommunications Union (ITU) regions (International Telecommunications Union [ITU], 2012a; ITU, 2012b).

This global usability of the ISM band allows this low-cost solution to be used by universities and private individuals anywhere in the world. Providing a complete antenna solution with quantitative evidence will shorten development of simple rocket platforms. As the price to perform research drops, the opportunity to perform scientific research goes up. This is evidenced by the increasing use of CubeSats by universities to perform space research at a fraction of the cost (Piattoni, Candini, Pezzi, Santoni, & Piergentili, 2012; Selva & Krejci, 2012).

Research Scope

This research project will investigate using HSMM with the Cylindrical Patch Antenna currently built into the PSAS rocket. The patch antenna is designed and verified to operate at the center frequency of 2.390GHz (LeBrasseur, Wilson, & Bergey, 2011). Research project will investigate the lowest transmit power required for near-error-free transmission using various modes in the 802.11b and 802.11g modulations. Investigation will be done through a pure-research experiment.

Research Limitations

During rocket flight, radio frequencies must be constantly adjusted for Doppler shift caused by high rate of motion towards or away from receiving antenna. The Doppler effect will be ignored for this research project. Doppler effect will be studied in a follow-on research program.

Atmospheric propagation and RF interference during testing are unavoidable. These environmental factors will affect the testing by possibly limiting range distance. Travel limitations of the researcher will limit tests to 1 or 2 days of testing so test results will be affected by conditions. Follow-on research is planned to perform same test series in a humid environment and a desert environment during planned rocket launches in 2014.

The PSAS antenna has been tuned to a specific center frequency and all tests will be performed at the frequency. Other frequencies in the 2.4GHz ISM band may have better propagation properties but will not be studied during this research project.

One receiving antenna will be selected based on the radio link budget. All test will be performed given this antenna and no test will be performed using alternate antenna styles, configurations, and gain.

Additional 802.11 standards have been developed and are available in commercially available equipment (i.e. 802.11a/n/p). This research project will limit itself to studying only the 802.11b and 802.11g standards because the operating frequencies are in the ISM bands. Alternate modulations use additional frequencies outside the range of the PSAS antenna.

Methodology

Experiment Methodology

The research experiment has three independent variables and two dependent variables. The first independent variable is range between transmitting and receiving antenna (measured in km). The second independent variable is modulation technique (802.11b or 802.11g). The third independent variable is the transmitter output power (measured in watts). The two dependent variables are data transfer rate (measured in Mbit/s) and data error rate (measures as number of corrupted data packets per second).

A stationary transmitting station consisting of the PSAS Rocket and its patch antenna will be established. Transmitting PSAS antenna will be raised to a height necessary to keep objects out of the Fresnel zone allowing maximum 20% occlusion (El-Sallabi, 2011). Specific locations used will be selected based on topography allowing unobstructed long-distance radio paths. RF interference in the selected location will be relatively low due to topography shielding RF emissions from nearby cities.

A mobile receiving station with a high gain directional antenna will be positioned 1.0km from the transmitter. Transmission tests will be performed and then the receiving station will be moved to a greater distance. Ideally, tests will be done starting at 1km and increasing in 5km increments up to 100km. Distance tests will be limited to actual environmental condition during testing, topographical logistics, and transmit power limitations. Once error rates have reached a threshold that the modulation technique can no longer be used, one additional distance test will be attempted. This last test will verify loss of transmission but potentially allow further testing due to long-distance multipath creating a viable receive zone at a greater distance. At each range increment, radio throughput and error-detection tests will be performed at 0.25W increments using the 802.11b and 802.11g modulations.

Data Collection Methodology

Data will be collected through the use of Kismet software. Kismet captures all data packets on a network connection and analyzes them to determine the error rate from corrupted data packets. Kismet also calculates the maximum, minimum, and average data transfer rates for the network conditions. Kismet output will be logged and analyzed using a statistical software package similar to SPSS.

Analysis Methodology

A radio link budget (RLB) will be developed to predict the viability of HSMM at various transmit powers and ranges. Regression analysis will be performed on this link budget to fit it to any transmit power and range up to 5 Watts PEP and 100km respectively. The performance of the HSMM tests will be fit to the RLB prediction using a least squares method to analyze the validity of the RLB. An accurate RLB will allow additional antenna configurations to be modeled without physical testing.

Viability of using HSMM in the given application boundaries is determined by the signal to noise ratio (SNR) and the bit error rate (BER). For any modulation scheme, a BER of better than 10e-5 is considered acceptable (Fainberg, 2001; Yee & Pezeshki-Esfahani, 2012). Using the formula for calculating BER, the corresponding SNR can be determined for a given date rate.

For example, to achieve a data rate of 54Mbits/s using 802.11b modulation the SNR must be at least 24.56dB.

The data collected from the Kismet software will be compared to the calculated threshold cutoff for each modulation and bit rate. From this threshold analysis, a correlated table of ranges, transmit power, and modulations will be developed. This table can be utilized by researchers to determine the feasibility of using HSMM for their project based on their unique data transfer needs.

Final analysis will consist of presenting a hypothetical transfer-rate scenario based on previous PSAS flight telemetry. This analysis will use the correlation table to determine what modulation and transmit power would be required along with the attainable flight altitude.

Statement of how the Program Outcomes will be met

Program Outcome #1.

"*Students will be able to apply the fundamentals of air transportation as part of a global, multimodal transportation system, including the technological, social, environmental, and political aspects of the system to examine, compare, analyze and recommend conclusion.*"

The research and analysis of this project will show evidence of meeting Program Outcome #1 by demonstrating a detailed understanding of the dynamic, multimodal air transportation system. Specifically,

- <u>Fundamentals of air transportation</u> as part of a <u>global, multimodal transportation system</u> will be addressed by examining how the use of HSMM expands opportunities for non-governmental entities to run rocketry programs.
- <u>Technological aspects</u> will be addressed by determining the feasibility of low-power HSMM for rocket use.

- Social, environmental, and political aspects will be addressed by identifying the regulations that affect the use of HSMM across geographic boundaries. Also addressed will be how low-cost research opportunities open up opportunities for students.

Program Outcome #2.

"*The student will be able to identify and apply appropriate statistical analysis, to include techniques in data collection, review, critique, interpretation and inference in the aviation and aerospace industry.*"

The research and analysis of this project will show evidence of meeting Program Outcome #2 by demonstrating a detailed understanding of statistical analysis techniques, data collection, review, critique and interpretation related to HSMM. Specifically,

- The appropriate statistical analysis aspect will be demonstrated through use of least squares fit to draw conclusions on feasibility. Bit error rate (BER) calculations are performed in Kismet using industry standard methods including Rayleigh probability density functions, quantization errors, and probability of error methods (Breed, 2003).
- Data collection, review, and critique will be shown by using industry standard software for wireless network packet transfer monitoring (Kismet), using industry standardized assessment tools (Kismet; Spectools) and discussing the validity and reliability of the data.
- Interpretation and inference will be demonstrated through the application of bit-error-rate analysis and regression models to extend conclusions on hypotheses to additional transmit power levels and ranges not performed during testing.

Program Outcome #3.

"*The student will be able across all subjects to use the fundamentals of human factors in all aspects of the aviation and aerospace industry, including unsafe acts, attitudes, errors, human behavior, and human limitations as they relate to the aviators adaption to the aviation environment to reach conclusions.*"

The research and analysis of this project will show evidence of meeting Program Outcome #3 by demonstrating a detailed understanding of human factors and human limitations as it relates to the application of HSMM in a production environment. Specifically,

- <u>Human behavior and attitudes</u> will be discussed through a discussion on how low-cost research options affect the attitudes of the scientific community and commercial service providers.
- <u>Human limitations including unsafe acts, attitudes and errors</u> will be discussed within the context of the researcher performing the experiment.

Program Outcome #4.

"*The student will be able to develop and/or apply current aviation and industry related research methods, including problem identification, hypothesis formulation, and interpretation of findings to present as solutions in the investigation of an aviation / aerospace related topic.*"

The research and analysis of this project will show evidence of meeting Program Outcome #4 by demonstrating a detailed description and application of an appropriate research method, detailed problem identification, hypotheses or research questions and interpretations of findings as a solution to an aviation topic, in this case HSMM. Specifically,

- The appropriate research method will be demonstrated through a discussion of the research problem and why the quantitative method and least squares regression fit was chosen.
- Problem identification and hypothesis formulation will be shown through an analysis of a research problem and to what extent it pertains to the aerospace community.
- Interpretation of findings and presenting solutions will be completed through analyzing the statistical data using Kismet and SPSS; and concluding implications for the aerospace community.

Program Outcome #12.

"*The student will understand and be able to apply and solve problems presented to current aviation, aerospace, and industry related topics in space operations, including earth observation and remote sensing, mission and launch operations, habitation and life support systems, and applications in space commerce, defense, and exploration, operations research, information management, advanced planning systems, and production and procurement.*"

The research and analysis of this project will show evidence of meeting Program Outcome #12 by addressing how HSMM increases the availability of low cost rocketry while decreasing operating costs through a quantitative pure-research study. Specifically,

- The ability to understand, apply, and solve problems presented to space operations will be shown through an analysis of a research problem, discussion on its application to the industry, and analysis of research results.

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