Center for Embedded Systems (CES)
Request for Proposals Template – YEAR 6

DUE: Monday, March 31, 2014, by 5 p.m.

TITLE:	Reliable Wireless Communications in Aircraft and Other Challenging Environments				
PI:	Xiangwei Zhou	**EMAIL:**	xzhou@engr.siu.edu	**TEL:**	(618) 453-7064
DEPT:	ECE	**SCHOOL:**	Southern Illinois University		

ABSTRACT: (250 OR FEWER WORDS)

Replacing wired interconnections with wireless connections in aircraft and other challenging environments has attracted a lot of attention nowadays with the fast development of wireless communication technologies. It reduces the complexity of electrical wiring and improves the operational efficiency. However, the deployment of wireless communications in these environments must meet very high standards for reliability.

In the proposed research, we focus on novel techniques for reliable wireless communications in challenging environments. Environment modeling, system design, and overall performance in terms of reliability, delay, and implementation complexity will be addressed, enabling both safety-critical and other applications such as maintenance and diagnosis. Our proposed techniques, including interference identification, interference avoidance, and redundancy and diversity schemes, is an innovative and integrated way to guarantee system reliability and provide safety and environmental benefits.

PROBLEM:

Electrical wiring in aircraft has become more and more complex nowadays. According to [1], the total number of wires in an Airbus A380-800 is around 100,000, and they are 470 kilometers in total length and 5700 kilograms in total weight. The use of wiring brings a number of issues in terms of weight, cost, safety, and maintainability. It is therefore desirable for aerospace industry to replace wired interconnections with wireless connections in aircraft. Similarly, the use of wireless communications in other environments such as hazard detection systems is also preferred and thus has attracted a lot of attention.

However, the deployment of wireless communications in aircraft is a challenging task that must meet very high standards for reliability [2], which is also the case in other challenging environments. For safety-critical applications, the connections should be close to 100 percent reliable. Meanwhile, for other applications such as maintenance and diagnosis, the connections still need to be reliable enough with a cost-effective solution. To address the above design and implementation issues, we propose to study novel techniques for reliable wireless communications in challenging environments. While these techniques can be applied to different applications, we will focus on applications in aircraft and access the performance of selected techniques for aircraft.

RATIONALE:

The evolution of wireless communication technologies in terms of data rate and quality of service enables their use in many different industries. However, existing wireless communication systems are not specifically designed for aircraft or other challenging environments, and may not satisfy the imposed requirements, especially high standards for reliability. The investigation of novel techniques for wireless communications in challenging environments with the desired properties is therefore critical.

With the proposed research on reliable wireless communications in aircraft, the complexity and life-cycle cost of electrical wiring in the state-of-the-art aircraft will be greatly reduced. As it is easier to provide redundancy with wireless connections, flight safety can be improved as well. Without the limit of wired connections, it is also possible to obtain more data from aircraft surfaces for the enhancement of operational efficiency. Furthermore, aircraft weight reduction will save fuel cost and result in environmental benefits.

APPROACH:

As shown in Figure 1, we propose to investigate from the aspects of environment modeling, system design, and performance analysis. All of them are closely related to each other. **Environment modeling is to be completed before the start of this continuing project.**

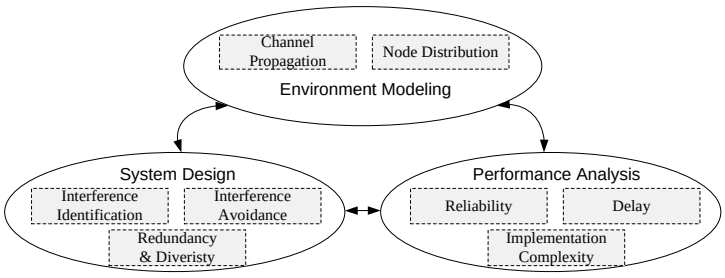

Fig. 1. Framework of proposed research.

1. Environment Modeling

The environment in an aircraft is very different from where conventional wireless communication systems operate. Understanding the operational environment, including channel propagation model and communication node distribution, is very important for the design and analysis of wireless communication systems for aircraft.

Channel propagation: The environment inside an aircraft is heavily reverberant because of metal materials. To characterize the resonant environment, ray tracing techniques [3] may be applied and signal propagation characteristics at different parts of the aircraft can be determined. By properly modeling the channel propagation, we will be able to address the system design and performance analysis inside an aircraft.

Node distribution: Due to the special structure of an aircraft, the installation of communication nodes including their antennas is always restricted. Based on possible locations of communication nodes, the physical topology of the communication network can be determined. The distribution of different nodes is also needed for system design and performance analysis.

2. System Design

In this part, we focus on robust system design against interference from operating radar and other avionics equipment. Different aspects to achieve interference immunity, including interference identification, interference avoidance, and diversity techniques will be explored.

Interference identification: To avoid possible interference, a communication node may identify if there is detrimental interference over certain channels before transmission. This can be realized through clear channel assessment or spectrum sensing [4]. However, stringent delay requirement for data transmission in aircraft may prevent the use of these conventional interference identification techniques. We have proposed in [5] a sequential detection scheme to allow quickest detection of interference before receiving a fixed number of samples. Based on our existing work, we will evaluate the feasibility of sequential detection as well as other candidate techniques for interference identification under delay constraints in aircraft.

Interference avoidance: After identifying channel availability and interference information, a communication node may select proper channels without detrimental interference to transmit data. Although the channels with no or lower level of interference should generally be chosen, the imperfection of interference identification can result in incorrect ordering of channel interference levels. We have introduced in [6] a probabilistic resource allocation scheme to use soft information from spectrum sensing for system performance improvement. In the proposed work, we will study joint optimization of interference identification and channel selection to improve the performance based on our previous work. Given the history of data transmission over different channels, we can further narrow down the channels for upcoming interference identification, as an extension of our work in [7].

Redundancy and diversity: Due to the multipath propagation environment inside aircraft, some locations suffer from deep fading and wireless signals are severely degraded. At the same time, there may be interference from other systems. Thus it is essential to build redundancy to guarantee reliability. Although retransmission is a simple solution, it is not suitable for delay-sensitive applications. We will investigate the options to use multiple channels to provide desired redundancy and greater assurance for successful transmission. For example, we will address the use of spread spectrum with error correction across different channels. We will also explore other techniques, such as time-frequency interleaving, to reduce burst errors. Furthermore, if we introduce user diversity and allow relaying, forward and relay links can be used to enhance the direct link and boost link availability. Based on our previous work on relay selection in [8], we will compare different relaying schemes and study the feasibility and end-to-end performance with multiple hops.

3. Performance Analysis

Throughout the study of system design, it is necessary to determine the feasibility of selected techniques and access the performance of the system as a whole via mathematical analysis and simulation. The following aspects of system performance will be addressed in the proposed work.

Reliability: As we have already emphasized, the reliability of wireless communications in aircraft is especially important. In [9], we have analyzed the performance of femtocell networks in a practical self-organizing and auto-configuring framework. We will extend the analysis to the aircraft environment and investigate the probabilities of bit error and packet loss.

Delay: For delay-sensitive applications, we will verify the delays associated with selected techniques for interference identification as well as proposed redundancy and diversity schemes.

Implementation complexity: While we may sacrifice complexity for higher reliability for safety-critical applications in aircraft, we must balance cost and performance for other applications such as maintenance and diagnosis. Therefore, the implementation complexities of candidate techniques will be evaluated in our research.

NOVELTY:

Current systems for wireless communications aboard aircraft platforms are not reliable enough and sometimes even inadequate due to susceptibility to radio frequency (RF) interference from other devices. Our proposed research on wireless communications in challenging environments, consisting of interference identification, interference avoidance, and redundancy and diversity schemes, is an innovative and effective way to guarantee system reliability. Besides, delay performance and implementation complexity are also emphasized in our system, enabling both safety-critical and other applications in aircraft and other challenging environments.

POTENTIAL BENEFITS TO INDUSTRY MEMBERS:

The industry member(s) can use the techniques in the proposed research for the development and integration of reliable wireless communication systems. Meanwhile, our performance analysis can help to validate the feasibility of wireless communication solutions and products for the industry member(s).

DELIVERABLES:

During the one-year period, 1 midterm report and 1 final report will be submitted. Simulating programs will be also provided to the industry member(s) related to this project.

TIMELINE/MILESTONES: (PER QUARTER)

The proposed research will be conducted according to the plan depicted in Figure 2. During the first and second quarters, different techniques for system design will be investigated and simulated. Starting from the third quarter, the performance of the system will be analyzed both mathematically and via simulation.

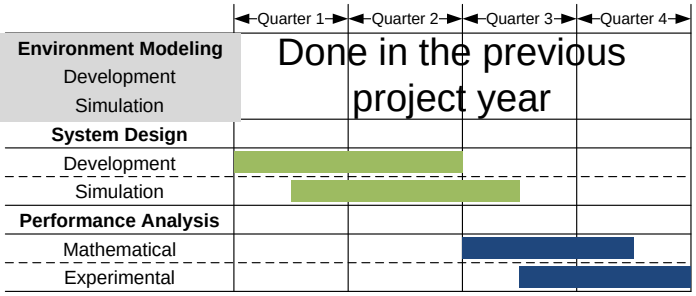

Fig. 2. Plan of proposed research.

TECHNOLOGY TRANSFER:

We have discussed with researchers at UTC Aerospace Systems via email correspondence, teleconferences, and face-to-face meetings on their interest and needs for reliable wireless communications in aircraft. We plan to continue our discussion and collaborate with researchers at UTC Aerospace Systems through email exchanges and teleconferences during the project period.

BUDGET:

Professional Staff: Xiangwei Zhou	$9,690/mo for 1 mo	$ 9,690
Other Personnel: Graduate Assistant	$3,328/mo for 12 mos @ 25%	$ 9,984
Fringe Benefits for Professional Staff	@ 47.9%	$ 4,642
Primary Care Fee for Graduate Assistant		$ 291
Travel: Midterm Meeting in AZ		$ 763
(Air $300, Mileage $0.56/mi* 234 mi, Lodging $150/night *2 night, $32 per-diem *1 day)		
Annual Meeting in MO		$ 259
(Mileage $0.56/mi* 234 mi, Lodging $100/night *1 night, $28 per-diem *1 day)		
Total Cost		**$25,629**

REFERENCES

[1] R. Zakrzewski, "Protected spectrum for wireless avionics intra-communications," *Passive Wireless Sensor Technology Workshop, ISA Communications Division Symposium*, June 6, 2012.
[2] RTCA/DO-160G, "Environmental Conditions and Test Procedures for Airborne Equipment," RTCA, Inc., Dec. 8, 2010.
[3] C. J. Debono, R. A. Farrugia, and K. Chetcuti, "Modelling of the wireless propagation characteristics inside aircraft," *Aerospace Technologies Advancements*, T. T. Arif, ed., InTech (2010): pp. 361-378.
[4] D. Cabric, S. M. Mishra, and R. W. Brodersen, "Implementation issues in spectrum sensing for cognitive radios," in *Proc. IEEE Asilomar Conf. Signals, Syst. and Comput.*, Pacific Grove, CA, Nov. 2004, pp. 772–776.
[5] L. Lu, X. Zhou, and G. Y. Li, "Optimal sequential detection in cognitive radio networks," in *Proc. IEEE Wireless Commun. and Networking Conf. (WCNC)*, Apr. 2012.
[6] X. Zhou, G. Y. Li, D. Li, D. Wang, and A. C. K. Soong, "Probabilistic resource allocation for opportunistic spectrum access," *IEEE Trans. Wireless Commun.*, vol. 9, pp. 2870-2879, Sept. 2010.
[7] X. Zhou, G. Y. Li, Y. H. Kwon, and A. C. K. Soong, "Detection timing and channel selection for periodic spectrum sensing in cognitive radio," in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Nov. 2008.
[8] L. Li, X. Zhou, H. Xu, G. Y. Li, D. Wang, and A. C. K. Soong, "Simplified relay selection and power allocation in cooperative cognitive radio systems," *IEEE Trans. Wireless Commun.*, vol. 10, pp. 33-36, Jan. 2011.
[9] X. Zhou, H. A. Hraishawi, and Y. Jia, "Analysis and design of spectrum sharing in cognitive femtocell networks," in *Proc. 51st Annual Allerton Conf. Commun., Control, and Comput.*, Oct. 2013.

BIBLIOGRAPHY: (ATTACH IN IEEE CONFERENCE OR JOURNAL FORMAT)

Xiangwei Zhou received his Ph.D. degree in Electrical and Computer Engineering from Georgia Institute of Technology, Atlanta, Georgia, in 2011. He received his M.S. degree in Information and Communication Engineering from Zhejiang University, Hangzhou, China and his B.S. degree in Communication Engineering from Nanjing University of Science and Technology, Nanjing, China, in 2007 and 2005, respectively.

Since 2013, Dr. Zhou has been with the Department of Electrical and Computer Engineering at Southern Illinois University Carbondale as an Assistant Professor. Prior to that, he was a Senior Systems Engineer with Marvell Semiconductor, Santa Clara, California, from 2011 to 2013.

Dr. Zhou's general research interests include wireless communications and statistical signal processing, with current emphasis on cognitive radio and heterogeneous coexistence, cyber-physical systems, and cross-layer optimization. He is now serving as an Editor for IEEE Transactions on Wireless Communications.

PI INFORMATION: (ATTACH 2-PAGE CV)

XIANGWEI ZHOU
Department of Electrical and Computer Engineering
Southern Illinois University

Professional Preparation

• Nanjing Univ. of Sci. & Tech., China	Telecom Engineering	B.S., 2005
• Zhejiang Univ., China	Information and Telecom Engineering	M.S., 2007
• Georgia Institute of Technology	Electrical and Computer Engineering	Ph.D., 2011

Appointments

• Assistant Professor	Southern Illinois Univ., Carbondale, IL	Jan. 2013 – Present
• Senior Systems Engineer	Marvell Semiconductor, Santa Clara, CA	Sept. 2011 – Jan. 2013

Five Relevant Publications

[1] X. Zhou, H. A. Hraishawi, and Y. Jia, "Analysis and design of spectrum sharing in cognitive femtocell networks," in *Proc. 51st Annual Allerton Conf. Commun., Control, and Comput.*, Oct. 2013.
[2] L. Lu, X. Zhou, and G. Y. Li, "Optimal sequential detection in cognitive radio networks," in *Proc. IEEE Wireless Commun. and Networking Conf. (WCNC)*, Apr. 2012.
[3] L. Li, X. Zhou, H. Xu, G. Y. Li, D. Wang, and A. C. K. Soong, "Simplified relay selection and power allocation in cooperative cognitive radio systems," *IEEE Trans. Wireless Commun.*, vol. 10, pp. 33-36, Jan. 2011.
[4] X. Zhou, G. Y. Li, D. Li, D. Wang, and A. C. K. Soong, "Probabilistic resource allocation for opportunistic spectrum access," *IEEE Trans. Wireless Commun.*, vol. 9, pp. 2870-2879, Sept. 2010.
[5] X. Zhou, G. Y. Li, Y. H. Kwon, and A. C. K. Soong, "Detection timing and channel selection for periodic spectrum sensing in cognitive radio," in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Nov. 2008.

Five Other Significant Publications

[6] X. Zhou, G. Y. Li, and G. Sun, "Multiuser spectral precoding for OFDM-based cognitive radio systems," *IEEE J. Selected Areas Commun. (JSAC)*, vol. 31, pp. 345-352, Mar. 2013.
[7] L. Lu, X. Zhou, U. Onunkwo, and G. Y. Li, "Ten years of research in spectrum sensing and sharing in cognitive radio," *EURASIP J. Wireless Commun. and Networking*, Jan. 2012.
[8] J. Ma, X. Zhou, and G. Y. Li, "Probability-based periodic spectrum sensing during secondary communication," *IEEE Trans. Commun.*, vol. 58, pp. 1291-1301, Apr. 2010.
[9] X. Zhou, J. Ma, G. Y. Li, Y. H. Kwon, and A. C. K. Soong, "Probability-based combination for cooperative spectrum sensing," *IEEE Trans. Commun.*, vol. 58, pp. 463-466, Feb. 2010.
[10] X. Zhou, J. Ma, G. Y. Li, Y. H. Kwon, and A. C. K. Soong, "Probability-based optimization of inter-sensing duration and power control in cognitive radio," *IEEE Trans. Wireless Commun.*, vol. 8, pp. 4922-4927, Oct. 2009.

Synergistic Activities

- *Editor* for IEEE Transactions on Wireless Communications.
- *Technical Program Committee (TPC) Member* for 2012 and 2013 IEEE Symposium on Industrial Electronics and Applications (ISIEA), 2013 and 2014 IEEE/CIC International

Conference on Communications in China (ICCC), 2013 International Conference on Wireless Communications and Signal Processing (WCSP), 2014 International Symposium on Wireless Personal Multimedia Communications (WPMC), and etc.

- *Technical Reviewer* for top journals, including IEEE Proceedings, IEEE Communications Magazine, IEEE Journal of Selected Topics in Signal Processing, IEEE Journal on Selected Areas in Communications, IEEE Transactions on Signal Processing, IEEE Transactions on Communications, IEEE Transactions on Wireless Communications, IEEE Transactions on Vehicular Technology, IEEE/ACM Transactions on Networking, IEEE Signal Processing Letters, IEEE Communications Letters, IEEE Wireless Communications Letters, and etc.
- *Technical Reviewer* for international conferences, including IEEE International Conference on Communications (ICC), IEEE Global Communications Conference (GLOBECOM), IEEE Wireless Communications and Networking Conference (WCNC), IEEE Vehicular Technology Conference (VTC), IEEE Personal, Indoor and Mobile Radio Communications Symposium (PIMRC), IEEE Military Communications Conference (MILCOM), IEEE Consumer Communications and Networking Conference (CCNC), and etc.

Collaborators & Co-authors

- Prof. Chunyan Feng, Beijing University of Posts and Telecommunications
- Dr. Nageen Himayat, Intel
- Mr. Hayder Al Hraishawi, Southern Illinois University
- Dr. Yupeng Jia, National Instruments
- Dr. Young Hoon Kwon, Huawei
- Dr. Dongdong Li, AT&T
- Prof. Geoffrey Ye Li, Georgia Institute of Technology
- Prof. Liying Li, University of Electronic Science and Technology of China
- Prof. Fangfang Liu, Beijing University of Posts and Telecommunications
- Ms. Lu Lu, Georgia Institute of Technology
- Dr. Jun Ma, MediaTek
- Dr. Uzoma Onunkwo, Sandia National Laboratories
- Dr. Anthony Soong, Huawei
- Dr. Srikathyayani Srikanteswara, Intel
- Prof. Guolin Sun, University of Electronic Science and Technology of China
- Dr. Shilpa Talwar, Intel
- Dr. Dandan Wang, Alcatel-Lucent
- Prof. Hongbin Xu, University of Electronic Science and Technology of China
- Dr. Shu-ping Yeh, Intel

Graduate Advisors

- Ph.D. Dissertation Advisor: Prof. Geoffrey Ye Li, Georgia Institute of Technology
- Master Thesis Advisor: Prof. Zhaoyang Zhang, Zhejiang University

Graduate Students

- Ph.D. Students: Shengjie Guo and Feixiang Zhang, Southern Illinois University
- Master Students: Jason Stegman, Southern Illinois University
- Total Number of Graduate Students: 3

I/UCRC Executive Summary - Project Synopsis	**Date:** March 31, 2014
Project Title: Reliable Wireless Communications in Aircraft and Other Challenging Environments	
Center/Site: SIUC	
Principle Investigator: Xiangwei Zhou	**Type:** Continuing
Tracking No.: (CES office to input) **Phone :** (618) 453-7064	**E-mail :** xzhou@engr.siu.edu
	Proposed Budget: $25,629

Abstract: (250 words max)
Replacing wired interconnections with wireless connections in aircraft and other challenging environments has attracted a lot of attention nowadays with the fast development of wireless communication technologies. It reduces the complexity of electrical wiring and improves the operational efficiency. However, the deployment of wireless communications in these environments must meet very high standards for reliability. In the proposed research, we focus on novel techniques for reliable wireless communications in challenging environments. Environment modeling, system design, and overall performance in terms of reliability, delay, and implementation complexity will be addressed, enabling both safety-critical and other applications such as maintenance and diagnosis. Our proposed techniques, including interference identification, interference avoidance, and redundancy and diversity schemes, is an innovative and integrated way to guarantee system reliability and provide safety and environmental benefits.

Problem:
Electrical wiring in aircraft has become more and more complex nowadays. The use of wiring brings a number of issues in terms of weight, cost, safety, and maintainability. It is therefore desirable for aerospace industry to replace wired interconnections with wireless connections in aircraft. Similarly, the use of wireless communications in other environments such as hazard detection systems is also preferred. However, the deployment of wireless communications in these environments is a challenging task, which must meet very high standards for reliability.

Rationale / Approach:
Existing wireless communication systems are not specifically designed for aircraft or other challenging environments, and may not satisfy the imposed requirements, especially high standards for reliability. The investigation of novel techniques for wireless communications in challenging environments with the desired properties is therefore critical. We propose to investigate from the aspects of environment modeling, system design, and performance analysis. Different aspects to achieve interference immunity, including interference identification, interference avoidance, and diversity techniques will be explored.

Novelty:
Current systems for wireless communications aboard aircraft platforms are not reliable enough and sometimes even inadequate due to susceptibility to radio frequency (RF) interference from other devices. Our proposed research on wireless communications in challenging environments, consisting of interference identification, interference avoidance, and redundancy and diversity schemes, is an innovative and integrated way to guarantee system reliability. Besides, delay performance and implementation complexity are also emphasized in our system, enabling both safety-critical and other applications in aircraft and other challenging environments.

Potential Member Company Benefits:
The industry member(s) can use the techniques in the proposed research for the development and integration of reliable wireless communication systems. Meanwhile, our performance analysis can help to validate the feasibility of wireless communication solutions and products for the industry member(s).

Deliverables for the proposed year:
During the one-year period, 1 midterm report and 1 final report will be submitted. Simulating programs will be also provided to the industry member(s) related to this project.

Milestones for the proposed year:
During the first and second quarters, different techniques for system design will be investigated and simulated. Starting from the third quarter, the performance of the system will be analyzed both mathematically and via simulation.

Progress to Date: **THIS SECTION TO BE UPDATED IN JANUARY**

Estimated Start Date: August 15, 2014	**Estimated Knowledge Transfer Date**: August 31, 2015