Graduate School of Global Information and Telecommunication Studies, Waseda University

Abstract of Doctoral Dissertation

Studies on Multiple Access for Aeronautical Wireless Network

航空無線ネットワークにおける多元アクセスに関する研究

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ABSTRACT

There are two major studies presented in this thesis. The first study concentrates on the communications between the commercial aircrafts and the ground air traffic controller (ATC) systems. The second study is about the communication between an unmanned aerial vehicle (UAV) and a wide area wireless sensor network (WSN) on the ground. The UAV is an emerging dimension in aeronautical communication, so the studies for UAV in terms of air traffic control is essential to the current aeronautical telecommunication network. However, this concern can be covered by the first study. This dissertation further considers the communication capability between the UAV and various kinds of systems on the ground. Regarding to the former study, it aims to provide a revolution in the communications between the aircraft and the air traffic controller as well as the communication between the aircraft and the aircraft. For the case of communication between the aircraft and the ATC system at the areas near the airport since from the aircraft, the study has deeply conducted an empirical study for a new wideband, 5 GHz band. This study has also provided a novel solution for improving the receiving signal power at the area located above the dimensional transmitting antenna. The feasibility of this wideband is validated by comparing with VDL-2 in terms of system performance. It has been also preliminarily evaluated with the use of multi carrier transmission scheme, MC-CDMA for air traffic control communication. Regarding to the communication between the aircrafts, our studies provide another breakthrough to the aeronautical communication system where the direct communication between any pair of two aircrafts has first been proposed and evaluated. Our proposals show the benefits of TDMA and S-TDMA based multi hop ad hoc data relay networks built among the aircrafts on the ocean with and without the control functions at ground stations. These system have significantly improved the situational awareness for the oceanic flights which is now very limited in avionic communication. This is the essential condition for the airlines authority to reduce the separation distance between the two aircrafts in order to use airspace more efficiently. In addition, in order to prepare for these system designs which require the effective communication distance between the two aircrafts on the ocean, a unique experiment has been conducted. Furthermore, several supporting mechanisms and algorithms are proposed to enhance these systems. The full contents are consequently presented in following chapters 3, 4, and 5. More interestingly, the latter study is presented in chapter 6. This content introduces a new communication model with another aerial vehicle which operates at a lower altitude comparing to aircraft’s altitude. In this system model, UAV (Unmanned Aerial Vehicle) is employed for collecting information from a large area WSN (Wireless Sensor Network) on the ground. The proposed frame based random access and prioritized frame selection schemes

are the core of the proposed communication protocol. The detail content of UAV and ground communication is described in chapter 6.

The content of each chapter is described as the followings:

- Chapter 1 introduces the research and plan in this thesis.
- Chapter 2 presents the current air to ground communication systems in aeronautical field. Because the major frequency spectrum used in this sector is HF and VHF, this chapter mainly describes HF and VHF based radio/data communication systems. In addition to these two bands, the description about satellite based communication system is also presented. The brief introduction of UAV and its potential will finalize the content of the chapter.
- Chapter 3 introduces our studies on the new frequency band, the MLS band, for aeronautical communications. This chapter starts with a description of a novel experiment for the two communication systems installed on the ground and the airplane. Then, our evaluation on radio channel characteristics at this band is described in details. More specifically, Rice factor and propagation model are derived from the measurements. Another supplemental experiment has also been conducted to improve the signal strength at the areas right above the ground system which uses the directional antenna. Finally, our estimation in terms of system performance has shown that this band is suitable for employing a wideband service air to ground communication at the airport surfaces or the areas near the airport. The reasons that eliminate its applicability to further distant aircrafts include a strong Doppler shift effect and a large transmitting power because its high frequency.
- Chapter 4 describes our detail proposal of a mobile ad hoc network based data relaying system used for oceanic flight routes in aeronautical communication. This system uses only one VHF channel which is designed to accommodate all the flights i.e. the aircrafts pass through the North Pacific Ocean between Japan and North America. Before demonstrating the communication protocol, we explain in details our novel experiment on the air to air communication between the two practical aircrafts. Both aircrafts are in the en-route phase of flight during the measurements. From this experiment, we have found the two major results. The first result is the formula to express the relationship between the signal receiving power and the relative distance between the transmitting and receiving aircrafts. The found second one is the effective distance for the air to air communications between the two en-route aircrafts. We also introduce our proposed mechanism in terms of SNR (Signal Noise Ratio) adjustment in order to increase the successful packet relayed ratio when many aircrafts join the TDMA multiple access scheme. This mechanism is called IB-NS (Interference Based Node Selection). Another scheme for improving the packet error rate during the sparse aircraft situations is also illustrated, named NADA (Node Additional Delay Allowance). The evaluation of the system

performance in terms of packet repayable rate at the actual air traffic between Japan and North America finalizes this chapter. The actual air traffic used in the simulation is from the actual air traffic on the oceanic routes after applying an estimated increasing air traffic rate.

- Chapter 5 adds another proposal which also provides a multi hop ad hoc relay network for oceanic aircrafts. This system uses not only a single channel but also a multi channels and all are in VHF frequency band. The communication protocol of this system will be explained in details in both single channel and multi channel cases. The obtained results in air to air communication channel from chapter 4 and the proposed IB-NS scheme are all applied to the system in this chapter. In connection with the proposal in chapter 4, this communication system is a fully autonomous multi hop ad hoc network which is based on Space Time Division Multiple Access (S-TDMA). After the aircrafts has joined this system, it still can work autonomously even if there is a loss in connection with the ground station. Furthermore, other two additional schemes are proposed for autonomous operating aircrafts in order to utilize and allocate timeslot more efficiently. These schemes are PATR (Position Aid Timeslot Reuse) and DBTA (Distance Based Timeslot Assignment). The evaluation of system performance shows the benefits of using this system for oceanic flight routes. This system can save cost for airlines companies, and also increase the safety of each flight while the safe distance between those flights can be much reduced.
- Chapter 6 provides a novel model for the communication between the UAV and ground system. In this case, the ground system is a Wireless Sensor Network (WSN) which includes a large number of randomly distributed sensors. This kind of communication is expected to become a new approach in several kinds of systems used for data collection, area monitoring, disaster aids, and so on. The major content of this chapter is to describe our detail proposal on a novel communication protocol. This communication protocol is used for the communications between the sensor network on the ground and a UAV in the air. The core of this protocol includes a novel PFS (Priority Frame Selection) and FRA (Frame based Random Access) schemes. The purpose of the PFS scheme is to control the priority of the channel access and the data transmission of each priority group. Three kinds of PFS schemes are introduced in this thesis. They are High Power High Priority (HH), High Power Low Priority (HL), and Dimensional-HHHL (D-HHHL). This chapter will end with a simulation results and its evaluation in terms of PER (Packet Error Rate). The results have shown the promising of applying this simple access scheme while the communication between the UAV and the ground WSN is maximized.
- Chapter 7 presents our conclusions on the achievements and our discussions for future studies which relate to the air to ground communication, the air to air communication, and the communication between UAV and the ground system.

List of academic achievements

Category (Subheadings)	
Articles in refereed journals	① Dac-Tu Ho, Jingyu Park, Shigeru Shimamoto, and Jun Kitarori, Performance Evaluation of Multi hop Relay Network for Oceanic Air Traffic Control Communication, IEICE Transaction on Communications, Volume E94-B, No. 1, pp. 86-96, January 2011. ② Dac-Tu Ho and Shigeru Shimamoto, Mobile Ad-Hoc Network Based Relaying Data Sysem for Oceanic Flight Routes in Aeronautical Communications, International Journal of Computer Network and Communication (IJCNC), ISSN: 0975- 2293, pp. 33-44, April 2009.
Presentations at international conferences	③ Dac-Tu Ho, Jingyu Park, and Shigeru Shimamoto, Performance Evaluation of the PFSC Based MAC Protocol for WSN Employing UAV in Rician Fading, in Proceeding of IEEE WCNC, Cancun Mexico, March 2011. ④ Dac-Tu Ho, Jingyu Park, and Shigeru Shimamoto, QoS Constraint with Prioritized Frame Selection CDMA MAC Protocol for WSN Employing UAV, in Proceeding of IEEE GLOBECOM Workshop of Wireless Networking for Unmanned Aerial Vehicles: Architectures, Protocols and Applications, Miami, December 2010. ⑤ Dac-Tu Ho, Jingyu Park, and Shigeru Shimamoto, Novel Multiple Access Scheme for Wireless Sensor Network Employing Unmanned Aerial Vehicle, in Proceeding of IEEE/AIAA 29th Digital Avionics System Conference (DASC), pp. 5.C.5.1-5.C.5.8, Salt Lake City, Utah, October 2010. ⑥ Dac-Tu Ho, Jingyu Park, Shigeru Shimamoto, and Jun Kitarori, Performance Evaluation of Communication System Proposed for Oceanic Air Traffic Control, in Proceeding of IEEE WCNC, pp. 1-6,

	Sydney, Australia, April 2010. ⑦ Dac-Tu Ho, Jingyu Park, Shigeru Shimamoto, and Jun Kitarori, Oceanic Air Traffic Control Based on Space-Time Division Multiple Access," in Proceeding of IEEE/AIAA 28th DASC, 7.D.2-1 - 7.D.2-13, Orlando, FL, October 2009. ⑧ Dac-Tu Ho, and Shigeru Shimamoto, A Proposal of Wide-Band Air-to-Ground Communication at Airports Employing 5-GHz Band, in Proceeding of IEEE WCNC, pp. 1777-1782, Budapest, Hungary, April 2009. ⑨ Dac-Tu Ho and Shigeru Shimamoto, A Proposal for High Air-Traffic Oceanic Flight Routes Employing Ad-hoc Networks, in Proceeding of IEEE WCNC, pp. 1-6, Budapest, Hungary, April 2009. ⑩ Dac-Tu Ho, S. Shimamoto, and J. Kitaori, A Proposal of a Wide Band for Air Traffic Control Communications, in Proceeding of IEEE WCNC, pp. 1950-1955, Las Vegas, Nevada, March 2008. ⑪ Dac-Tu Ho, Yoshio Tsuda, Shigeru Shimamoto, Jun Kitaori, S. Kato, The Next Generation Air to Ground Communication System for Air Traffic Control, in Proceeding of IEEE/ACES International conference on Wireless Communication and Applied Computational Electromagnetic, Catalog No. 05EX1049, ISBN: 0-7803-9068-7, Honolulu, Hawaii, April 2005. ⑫ Dac-Tu Ho, Jingyu Park, and Shigeru Shimamoto, Power Consumption and BER Tradeoff of MAC Protocol for Wireless Sensor Network Employing UAV, in Proceeding of IEEE International conference on Advanced Technologies for Communications (ATC), pp. 33-38, Ho Chi Minh, Vietnam, October 2010. 13. Dac-Tu Ho, Shigeru Shimamoto, A proposal of relaying data in aeronautical communication for oceanic flight routes employing mobile ad-hoc network" in Proceeding of IEEE ACIIDS, pp. 436-441,

	Dong Hoi, Vietnam, March 2009. 14. Dac-Tu Ho and Shigeru Shimamoto, A Study of Multi-Carrier Transmission for Air Traffic Control Communications C band, International Symposium on Electrical Electronics Engineering-ISEE, Ho Chi Minh, Vietnam, November 2005. 15. Dac-Tu Ho, Yoshio Tsuda, Shigeru Shimamoto, and Jun Kitaori, C band and OFDM for air traffic control communications system, in Proceeding of 32nd AIC International conference, Halong, Vietnam, May 2005.
Presentations at domestic conferences	16. Jingyu Park, Dac-Tu Ho, and Shigeru Shimamoto, Wireless Sensor Networks Employing Unmanned Aerial Vehicle, IEICE Technical Report, Vol. 110, No. 8, SANE 2010-5, pp. 25-30, Okinawa, Japan, April 2010. 17. Dac-Tu Ho, Yoshio Tsuda, Shigeru Shimamoto, Jun Kitaori, S. Kato, "The Next Generation Air to Ground Communication for Air Traffic Control", in Proceeding of Simulation conference, Saitama, Tokyo, Japan, November 2004. 18. X. Guan, Dac-Tu Ho, Yoshio Tsuda, Shigeru Shimamoto, Jun Kitaori, Y. Nakatani, and S. Kato, A Study on 5GHz Digital Data Communication for Air Traffic Control, IEICE Technical Report, SANE-35, Tokyo, Japan, July 2004.