Proceedings of ISAP2012, Nagoya, Japan

POS2-47

Connectivity Evaluation for Unmanned Aircraft System using 5GHz WLAN

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1. Introduction

The volume of aeronautical communication will increase if the number of aircraft increases further in the future. Therefore, development of technical standards has already begun for future mobile aeronautical communication system using 5091–5150 MHz bands in the aeronautical standards in the United States and the Europe [1]. The data communication protocol in the technical standards of the high-speed aeronautical communications system will use the technique of MIMO (Multiple-Input Multiple-Output) antenna system. Therefore, we have to estimate the characteristics to install MIMO antenna system in comparison to SISO (Single-Input Single-Output) antenna system. It costs so much to execute the trial using actual aircraft because of the operating cost and workload on the coordination for permission of the flight test. For the development of preliminary experimental system with low-operating cost, we made some experiments based on the Unmanned Aerial Vehicle (UAV), such as radio-controlled model aircraft, equipped with the wireless communication system used in the continental area.

This paper describes aeronautical radio communication system for Unmanned Aircraft System (UAS). UAS consists of UAV and ground systems. We introduce flight experiments for evaluation of the benefit to install MIMO for aeronautical communication as shown in some experiments and analysis.

2. Aeronautical Communication Systems and MIMO

2.1 Aeronautical Communication Systems

The purpose of Air Traffic Control (ATC) is keeping safety and efficiency of the sky. Wireless communication systems must be required for ATC. They are called aeronautical communication systems. However, these technologies are not modern. For example, VHF AM voice communication systems are the most popular of aeronautical communication systems. Typical communication speed of digital aeronautical communication system is 31500 bit/sec [2]. Then, higher speed aeronautical digital communication systems are required to cope with air traffic growth.

2.2 MIMO antenna systems

Mobile WiMAX (IEEE 802.16e) is a candidate system for future aeronautical communication systems on airports. WiMAX uses MIMO antenna systems to increase channel capacity than SISO. Average communication speed improvement is important for typical communication systems, however, worst case analysis is important for aeronautical communication systems because they are safety communication.

3. Experimental Environment and Measurement Systems

We experimentally measured communication speeds and positions in the field using UAV. The experiments were performed on Edogawa dry riverbed in Saitama, Japan. Approximate location in WGS84 is 35.96631N°, 139.83250E°. Experimental system of UAV and a base station on the ground are shown in the Figure 1. Total experimental block diagram of the system is shown in Figure 2. System configuration in the UAV is shown in Figure 3. Two antennas for 2.4/5GHz inside USB Wireless Local Area Network (WLAN) adapter are shown in Figure 4. The wooden aircraft, which is driven by a battery and controlled by an operator, has a telemetry system and an on-board CPU with WLAN. Length of the aircraft is 1.173 m, width is 1.40 m, weight is 1.9 kg, wing area is 0.364 m^2, wing load is 5.21 kg/m^2. The telemetry system sends pitch, roll, heading, and location information measured by GPS to the ground. It sends one or more datasets per second. The CPU on the UAV works with 600MHz ARM Cortex-A8 CPU, 128 MB RAM, Android OS 2.3. Buffalo WLI-UC-AG300N 802.11 a/b/g/n USB WLAN is connected with the on-board CPU by USB 2.0 interface. Total weight of the computer, cables, WLAN adapter is about 150g. The base station is placed on the desk in the field. Two antennas of the station are installed with 14 cm distance, and 45 degree elevation angles.

We measure communication speeds between the UAV and the base station. We choose 802.11a is an instance of SISO, and 802.11n is an instance of MIMO. 802.11a and 802.11n communications are used channel 100 in W56 band. In the measurement system, bandwidth of 802.11n is 40MHz and that of 802.11a is 20MHz. Then, we compare the two systems by communication speed per bandwidth (bit/sec/Hz) in order to compare under the same conditions. The speeds are measured by iperf 2.0.5 in TCP/IP mode with 64kBytes window size. Server is on the on-board CPU, and client is the PC. The communication speeds are logged on the PC every second. Red lines in the figure show wireless datalinks.

4. Results and Discussion

The UAV flies around the base station. We choose a communication either 802.11a or 802.11n for each flight. 2 antenna directions of the base station, parallel and perpendicular to the direction of the river, are tried.

Communication speed per bandwidth and distance between the base station and the UAV are plotted in Figure 5. Horizontal axis of the figure 5 is distance between the base station and the UAV. Vertical axis of the figure 5 is communication speed per bandwidth (bit/sec/Hz). Communication speed per bandwidth is plotted against moving speed in Figure 6. Horizontal axis of the figure 6 is moving speed of the UAV. Vertical axis of the figure 6 is communication speed per bandwidth (bit/sec/Hz). These two graphs are plotted the same data. 682 red points in the figures 5 and 6 are the data from flights using 802.11n. 446 blue points in the figures are the data of 802.11a flights. Red solid lines in the figures are an average of communication speed per bandwidth for 802.11n. The average value is 1.066 bit/sec/Hz. Blue solid lines in the figures 5 and 6 is an average for 802.11a. The average value is 0.844 bis/sec/Hz. A comparison between 802.11a and 802.11n in Figures 5 and 6 shows that a variance of 802.11n is greater than that of 802.11a. For instance, minimum value of communication speed per bandwidth is 0.11 for 802.11n, and 0.26 for 802.11a. Maximum value of that is 2.11 for 802.11n, and 1.15 for 802.11a. In the case, 802.11n is 26.3% faster than 802.11a on average. However, 802.11a is better over 2 times than 802.11n in the worst condition. Also, these Figures 5 and 6 imply that strong correlations are not shown between the communication speed per bandwidth and the distance and moving speed. Therefore, next we investigate the angular dependency.

Figures 7 and 8 are graphs of heading angle rate and communication speed per bandwidth against time. Figure 7 plots data of 802.11n, and figure 8 plots data of 802.11a. Horizontal axis of the figures are time. Vertical axis of the figures are communication speed per bandwidth (bit/sec/Hz) and heading angle rate (degree/sec). Red lines of the figures indicate heading angle rate (left vertical axis), and blue lines of the figures indicate communication speed per bandwidth (right vertical axis). Figures 7 and 8 show that communication speed slows down when angle rate is high. High heading angle rate is not only the reason of communication speed slow down because communication speed down is shown in the figures when the heading angle rate is low. This is a subject of investigation in the future.

5. Conclusion

We used two kinds of WLAN systems of 5GHz band and evaluated in exprimental UAS, which consist of UAV and ground systems. Relationship between distance and communication speed was not found in our experiments. Also, we showed relationship between moving speed and communication speed. Both WLANs available about 100km/h. We showed MIMO (802.11n) was better than SISO (802.11a) on average of communication speed. However, communication speed of SISO was more stable and better than that of MIMO in terms of the minimum communication speed. We also investigated heading angle dependecy. We found that communication speeds slow down when the UAV turns. More investigation was necessary in the detail why communication speed of MIMO systems had a large variance.

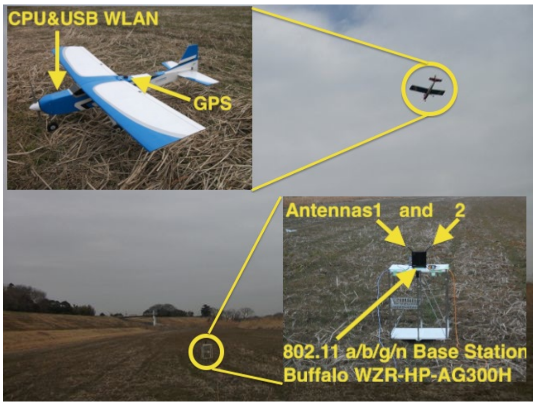

Figure 1: UAV and Base station

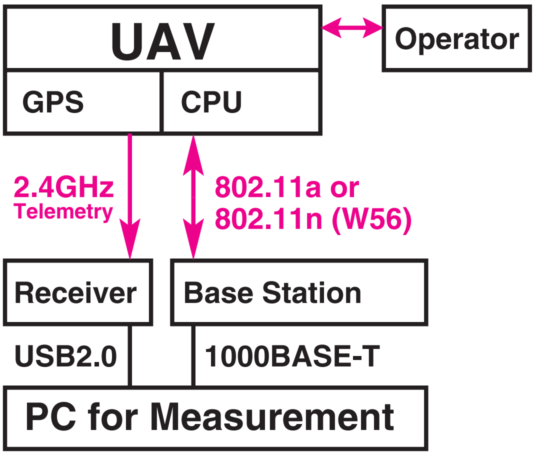

Figure 2: Measurement System

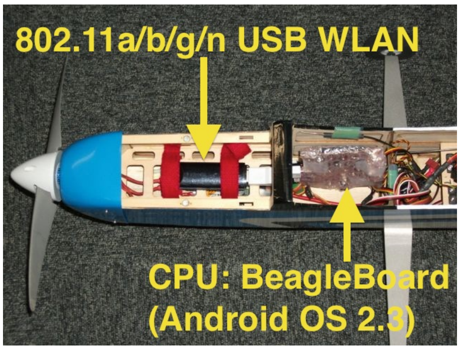

Figure 3: Settings in the UAV

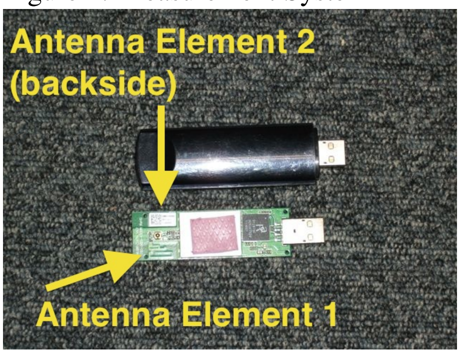

Figure 4: Antennas of USB WLAN

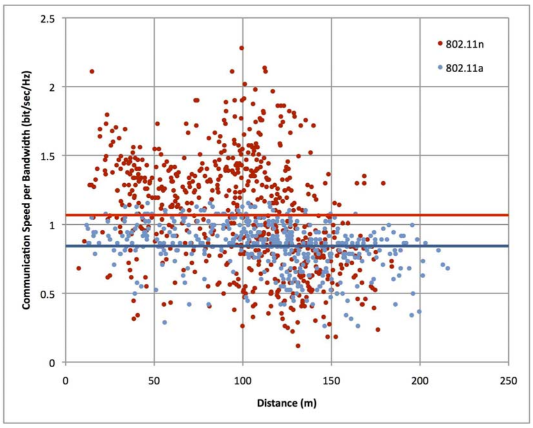

Figure 5: Distance and Communication speed

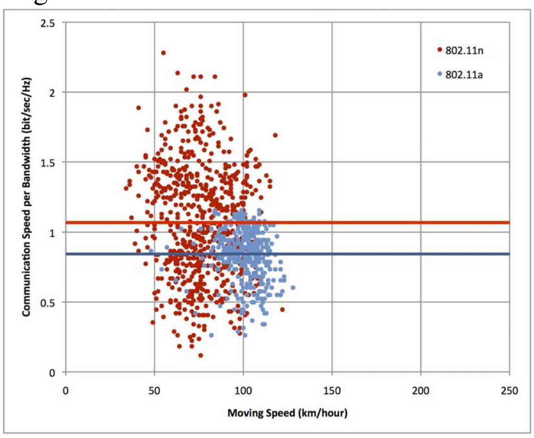

Figure 6: Moving and Communication speed

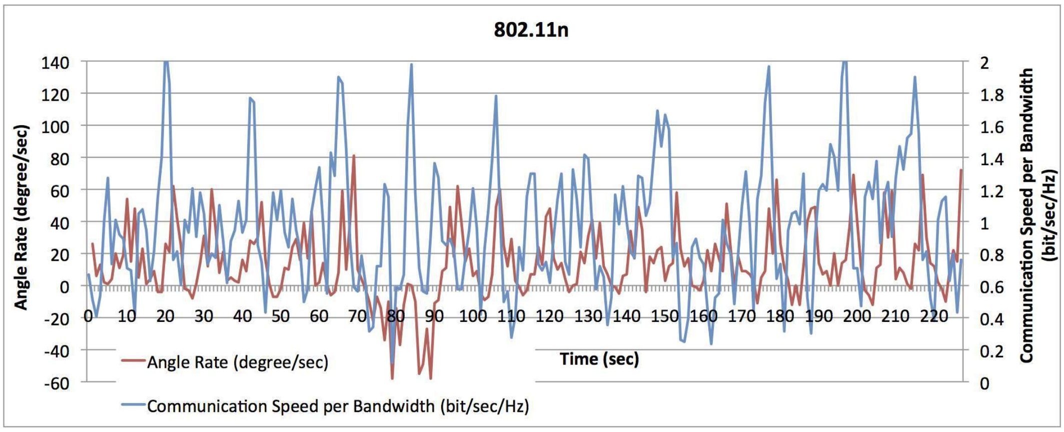

Figure 7: Result of 802.11n (Red: Heading Angle Rate, Blue: Communication Speed per Bandwidth)

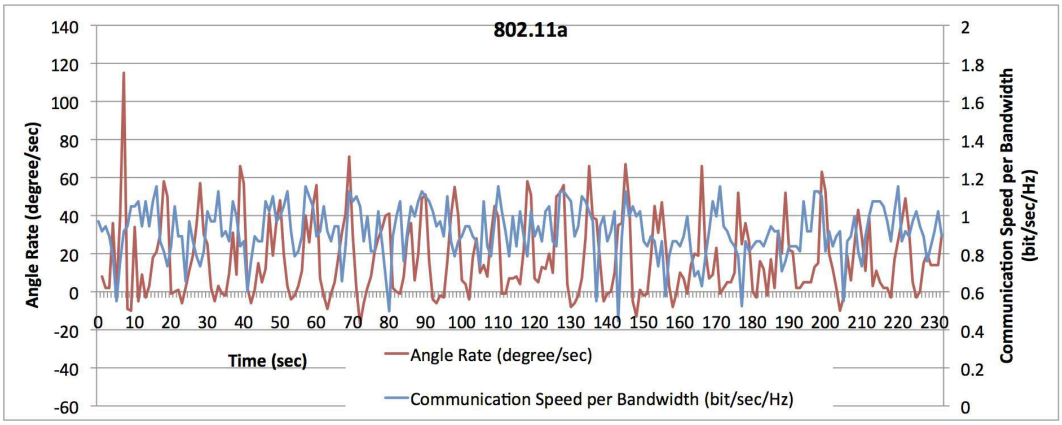

Figure 8: Result of 802.11a (Red: Heading Angle Rate, Blue: Communication Speed per Bandwidth)

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