URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020

Evaluation of a Low-Cost ADS-B Receiver as a Tool for Investigating Air-Ground Propagation

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Abstract

Automatic Dependent Surveillance - Broadcast (ADS-B) is an emerging civil aviation system, in which an aircraft periodically broadcasts its information such as identification, position, and velocity. Although the original purpose of ADS-B is air traffic control, it is now attracting attention as a new tool of air-ground propagation study. By measuring signals from opportunistic flights, a massive data set under various conditions of flight route, weather, and aircraft models can be obtained and analyzed with a relatively low cost. In the work presented in this paper, potential of a low-cost commercial receiver as a measurement tool was evaluated, which was aiming at further reducing the cost of the measurement. The accuracy of received signal strength (RSS) and the number of signals as a measure of reception performance were evaluated in comparison with a reference receiver.

1 Introduction

Automatic dependent surveillance - broadcast (ADS-B) is an emerging means of aeronautical surveillance in civil aviation. An aircraft periodically broadcasts surveillance information such as its identification, position, and velocity (Fig. 1). The information obtained via ADS-B is used for air traffic control. Compared with the traditional means of aeronautical surveillance, i.e. radars, ADS-B can be economically viable because ground facility can be significantly simpler.

In addition to the original surveillance purpose, ADS-B is recently attracting attention as a new tool of air-ground propagation study. By measuring signals from opportunistic flights, a massive data set can be obtained and analyzed. One biggest advantage of the ADS-B approach is that the cost of the measurement is lower than channel sounding by a flight experiment. No dedicated aircraft, transmitter, and radio-license are needed; only a receiver and antenna are sufficient. Another advantage is that measurement can be made under various conditions of propagation environment, weather, aircraft model, and aircraft maneuver.

Just to be fair, it should be noted that the ADS-B approach has some disadvantages. Accuracy is limited because of using opportunistic signals. For example, the uncertainty of

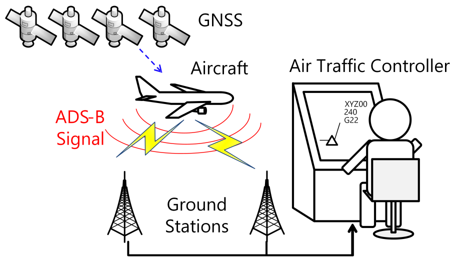

Figure 1. Aeronautical surveillance for air traffic control by ADS-B, where an aircraft broadcast its surveillance information and ground facility receive it.

the exact transmit power results in the uncertainty of the path loss when it is estimated. Also, measurable propagation characteristics are limited, e.g. the exact impulse response is difficult to be estimated. However, the advantages of the ADS-B approach can outweigh these disadvantages. In fact, there are several works that applied ADS-B to radio propagation or related study.

In [1, 2], an participatory ADS-B sensor network was proposed and measurement data from which yielded a log-distance model. In [3], the air-ground link-level performance was evaluated by using a massive dataset obtained from the sensor network. In [4], an application of ADS-B to ionospheric measurement using a satellite receiver was discussed. In [5, 6], received signal strength (RSS) of ADS-B signals was compared with the free space model and a Physical-Optics-based model. In [7], a statistical model of RSS was proposed.

In the work presented in this paper, performance of a low-cost commercial receiver as a measurement tool was evaluated. The accuracy of RSS and the number of signals as a measure of reception performance were evaluated in comparison with a reference receiver. The evaluated low-cost receiver was a radarcape[8]. The reference receiver was an in-house receiver developed with a software-defined-radio (SDR) transceiver USRP. A low-cost receiver can further reduce the cost of the measurement. Therefore, this work was aiming at making propagation research more affordable, which is attractive especially to developing countries.

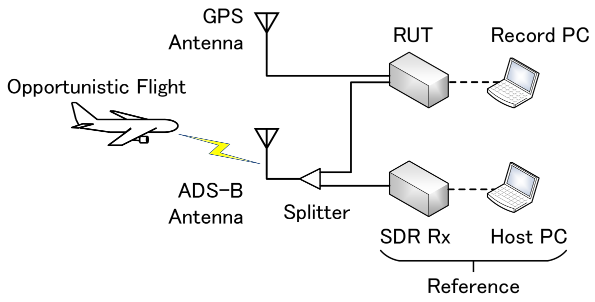

Figure 2. Schematic of the measurement for RSS evaluation.

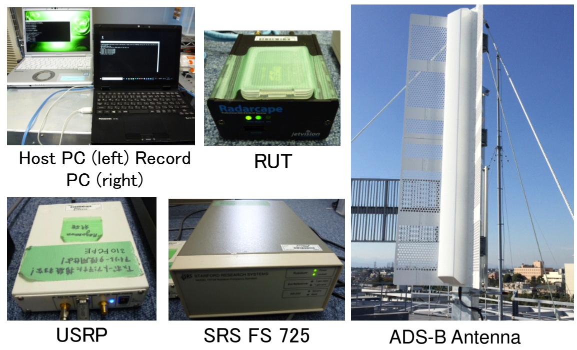

Figure 3. Photo of the equipment.

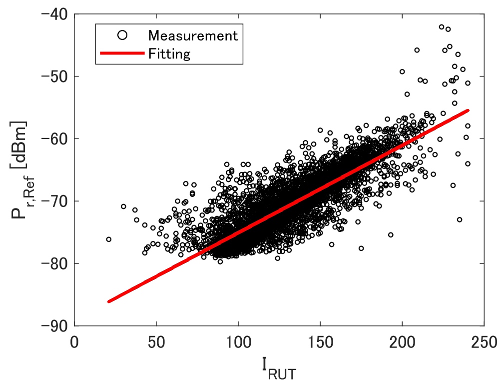

Figure 4. Relationship between RSS in integer and RSS in dBm.

2 Measurement

2.1 Receivers

A radarcape was the evaluated low-cost receiver, which is referred to as a receiver under test (RUT) in the rest of this paper. RUT can detect and decode an ADS-B signal and output the result in various formats. In this paper, RUT was configured to 1) output a detected signal in the Mode-S beast format [9][1] and 2) output a value of RSS in an one-byte integer[2].

The reference receiver was an in-house receiver developed with a SDR transceiver (USRP 2901), a host computer, a rubidium oscillator (SRS FS 725), and a programming environment (MATLAB), which is the same receiver as [7]. The USRP continuously generates a base-band signal with a carrier frequency of 1090 MHz and a sampling frequency of 10 MHz. The base-band signal is processed in the host computer by preliminary signal detection in real-time. The base-band signal that may contain an ADS-B signal is stored in the host computer, and demodulation and decoding are processed offline after completing a measurement. The receiver employs a technique for improving RSS accuracy [10] by rejecting interference signals. The justification of using this receiver as a reference will be examined in Section 4.

2.2 Setup

Fig. 2 shows a schematic of the measurement. The ADS-B antenna was connected to RUT and the reference receiver via a RF splitter. The power imbalance due the RF splitter and cables was measured as less than 0.1 dB. The GPS antenna was also connected to RUT for time-synchronization. The time-synchronization of the reference receiver was achieved via network. Note that this measurement is for evaluating RSS, therefore, accurate time-synchronization is not necessary.

[1]This format provides raw-data bits without decoding an aircraft position and other surveillance information. Another format of csv provide decoded information.

[2]This is the definition of Mode-S beast format. When the csv format was selected, RSS is in text and has a 1 dB resolution.

Upon detection of a signal, RUT generated a TCP packet containing the time of arrival (TOA), data bits, and the RSS value. The generated packets were recorded in the record computer. The reference receiver stored the TOA and the base-band signal that contains an ADS-B signal. The detection threshold of the reference receiver was −80 dBm. After completing the measurement, the base-band signals were decoded and analyzed offline to produce data bits and a RSS value.

Fig. 3 shows a photo of the measurement equipment. The measurement period was a 90 minutes starting from 13:37 on January 20 2020 Japan Standard Time.

2.3 Preprocessing

As a preprocessing before analysis, pairing of the received signals was made. Pairing is a process to link a signal measured by one receiver with the same signal measured by another receiver. The conditions that pairing was made for two signals are 1) the two signals have the same data bits and 2) the difference in TOA between the two signals is within two seconds. Further, the signal that were correctly decoded as a valid airborne position squitter were selected for the following process and analysis.

In addition, because the RSS measured by RUT is ex-

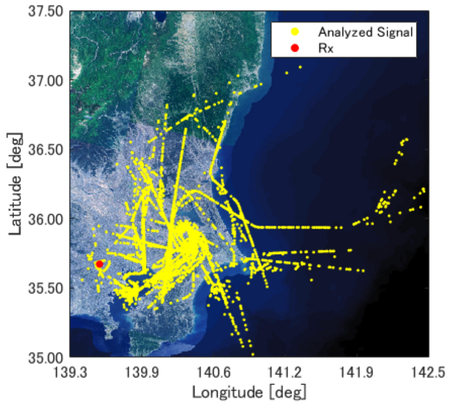

Figure 5. The aircraft positions corresponding to the measured signals. The map data is obtained from [11]. Data source: Landsat8 Image (GSI, TSIC, GEO Grid/AIST), Landsat8 Image (courtesy of the U.S. Geological Survey), Bathymetric chart: GEBCO.

pressed by an one-byte integer, this value was converted into a value in dBm. To do so, the following equation was used:

$$P_{r,\mathrm{RUT}} = a \cdot I_{r,\mathrm{RUT}} + b. \quad (1)$$

where $I_{r,\mathrm{RUT}}$ is the RSS in integer, $P_{r,\mathrm{RUT}}$ is the RSS in dBm, and a and b are the coefficients. a and b were obtained such that $\Delta P_{r,\mathrm{RUT}} = \Delta P_{r,\mathrm{Ref}}$. In other words, the least square method for obtaining a and b was applied with the following equation:

$$P_{r,\mathrm{Ref}} = a \cdot I_{r,\mathrm{RUT}} + b. \quad (2)$$

Fig. 4 shows the result of the fitting, observing that an adequate equation was obtained. As will be presented in Section 4, these coefficients were checked in the bench-test environment as well. Another observation of Fig. 4 is saturation of RUT around $P_{r,\mathrm{Ref}} > -55$ dB.

As the result of the preprocessing, 5823 signals were obtained for evaluation. Fig. 5 shows the aircraft positions corresponding to these signals. Note that the ADS-B antenna is directional, therefore, the positions were not uniform.

3 Evaluation

The dB difference ΔP_r is calculated as a measure of accuracy by

$$\Delta P_r = P_{r,\mathrm{RUT}} - P_{r,\mathrm{Ref}}. \quad (3)$$

Fig. 6 shows a histogram of ΔP_r. Fig. 7 shows a cumulative distribution function of ΔP_r. The mean and standard deviation of ΔP_r were 0.00 dB and 2.44 dB, respectively. ΔP_r is non-biased, suggesting that large-scale effect such as path loss can be measured after collecting much sample. However, the spread is relatively large. Therefore, for

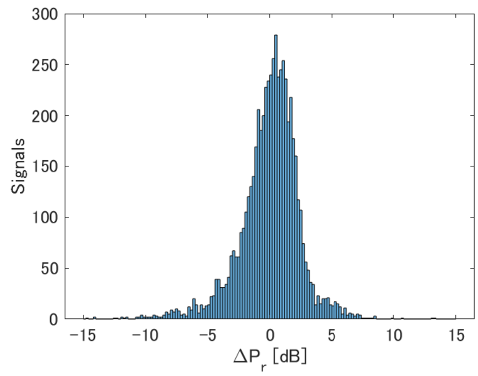

Figure 6. Histogram of the dB difference ΔP_r.

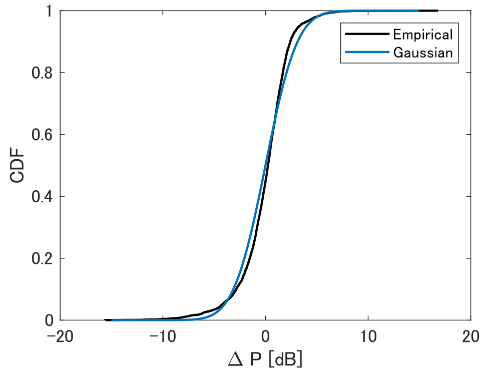

Figure 7. CDF of the dB difference ΔP_r.

a propagation effect to be observable, its RSS change must be larger than this measurement uncertainty. This suggests that instantaneous effects such as fading might be difficult to be measured. Terrain shadowing could be measurable (but perhaps as a signal loss).

The reception performance was measured by the number of correctly decoded ADS-B signals, which was denoted by N_{RUT} and N_{Ref} respectively for RUT and the reference receiver. The result was $N_{\mathrm{RUT}} = 19,912$ and $N_{\mathrm{Ref}} = 114,370$ for the measurement period of 90 minutes, showing that a lower reception performance of RUT. As will be presented in Section 4, performance of RUT is almost the same in the bench-test environment. Therefore, it was suggested that co-channel interference degraded reception performance of RUT. From the view point of propagation measurement, this will be a limitation of sampling interval.

4 Bench-test

To support the evaluation result in the previous section, a bench-test was conducted. Instead of the ADS-B antenna, an ADS-B signal generator implemented by an additional USRP was used. The signal generator was configured to transmit an ADS-B signal at a rate of 20 signals per sec. Then, the generated signals were measured by both RUT and the reference receiver. The measurement period was 10 minutes. The power of the generated signal was set con-

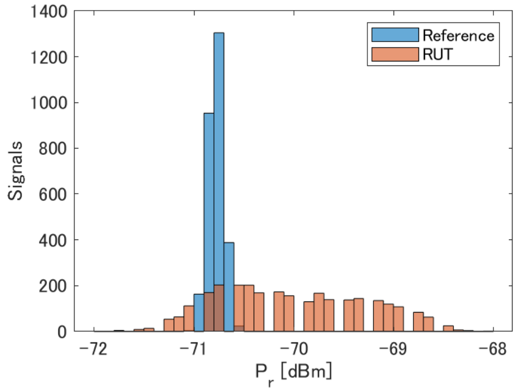

Figure 8. Histogram of the RSS measured at the bench-test.

stant. The measurement by the reference receiver showed $P_{r,\mathrm{Ref}} = -70.78$ dBm as the average value.

First, (1) was verified. The measurement by RUT obtained $I_{r,\mathrm{RUT}} = 135.87$ as the average value. Substituting this into (1) yielded $P_{r,\mathrm{RUT}} = -70.06$ dBm, which is an acceptable agreement with $P_{r,\mathrm{Ref}}$.

Second, in order to justify to use the in-house receiver as a reference receiver, the distribution of the measured RSS was plotted as in Fig. 8. The standard deviation of $P_{r,\mathrm{Ref}}$ and $P_{r,\mathrm{RUT}}$ was 0.0761 dB and 1.49 dB, respectively. Thus, the in-house receiver showed a more stable RSS than RUT, being justified as a reference receiver.

Finally, the number of correctly decoded signal was evaluated. The result was $N_{\mathrm{RUT}} = 2,728$ and $N_{\mathrm{Ref}} = 2,838$, showing that the reception performance is almost the same. This indicates that the factors that are unique to the actual environment caused the performance degradation. Multipath and co-channel interference are such factors. Considering the measurement setup (an open-air channel and an antenna with a sharp-cut off pattern), multipath is not a likely factor. Therefore, the effect of co-channel interference was suggested as the possible factors degraded the reception performance of RUT.

5 Conclusion

The purpose of this work is to make the ADS-B-based propagation research more affordable. To do so, reception performance and RSS accuracy of a low-cost commercial receiver was evaluated in comparison with a reference receiver. The difference in RSS between the two receivers was non-biased but had a spread with a standard deviation of 2.44 dB. This may limits the application of the low-cost receiver into path loss or terrain shadowing. The degradation of reception performance was also observed in the actual environment, which limits the sampling interval. In future work, different models of low-cost receivers will be evaluated.

6 Acknowledgements

This work was supported by the Japan Society for the Promotion of Science (JSPS) KAKENHI under Grant 17K14688.

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