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Experiment and Analysis for Air-to-Ground Channel in 400 MHz Band

Gyeong-Mo Nam[1], So-Young Ju[1], Eui-Rim Jeong[2,*]

[1]Department of Mobile Convergence Engineering, Hanbat National University, Korea
[2]Department of Information and Communication Engineering, Hanbat National University, Korea

Abstract **Background/Objectives**: Recently, air-to-ground wireless communication systems have been used in various equipment such as unmanned aerial vehicle (UAV). In this paper, we analyze the air-to-ground channel in 400 MHz band with experiment using light aircraft. **Methods/Statistical analysis**: The characteristics of the air-to-ground channel are analyzed as follows. We generate and store a pilot signal in commercial vector signal generator and an aircraft equipped with the signal generator takes off. As a pilot signal, Zadoff-Chu sequence is used for its good autocorrelation characteristics. In the ground station, the received waveform is stored by using spectrum analyzer. When an airplane approaches near the ground station, airplane transmits the pilot signal and the ground station begins to store the received signals. After completing the signal storing, air-to-ground channel analysis is performed. **Findings**: From the experiments, we obtained several hundreds of received waveforms, and those waveforms are used for statistical air-to-ground channel analysis. According to the analysis results, most of the measurement channels are single path or line of sight channels. However, in a certain measurement, multiple paths or non-line of sight channels are observed. Those results confirm that multipath environments exist at certain air-to-ground condition. The maximum number of multipath components is 4 and the maximum delay spread is 0.4 μ sec. Therefore, when designing a wireless communication system considering air-to-ground environments, the design should consider 4-path fading channels and maximum delay spread over 0.4 μsec. When designing air-to-ground wireless communication systems such as aircraft and drone systems, the experimental and analyzed channels in this paper might be useful. **Improvements/Applications**: In this paper, we analyze the air-to-ground channel characteristics of a mountainous area in Korea with field experiment using light aircraft. The analyzed channel characteristics are helpful to those who want to design wireless communication systems between aircraft to ground or UAV to ground. In addition, the analyzed channel can be used for verification of compatibility for the existing communication systems to air-to-ground applications.

Keywords Channel Analysis, Zadoff-Chu Sequence, Air-to-Ground Channel, Auto Correlation, Unmanned Aerial Vehicle

1. Introduction

Recently, air-to-ground wireless communication systems for UAV and light aircraft have been attracting much attention in commercial and military purposes [1-2]. Through such studies, transmission schemes such as Orthogonal Frequency Division Multiplexing (OFDM) and Single Carrier Frequency Domain Equalization (SC-FDE) have been developed and widely used [3-6]. However, since wireless communication is greatly influenced by the channel condition, the system design should guarantee the communication reliability in the worst case of the channel condition. Thus, the experiment and analysis for the worst case channel in the target communication environments should precede the design of the communication systems. Existing literatures for the air-to-ground channel analysis based on field experiments are mostly focused on foreign terrains, and no researches can be found for the Korean mountainous terrain. According to the existing works, it was turned out that the air-to-ground channel characteristics are much influenced by the ground terrain. Therefore, to develop air-to-ground communication systems for the Korean terrain, field experiment for the channel analysis should be made [14-15].

In this paper, we analyze the domestic air-to-ground channel characteristics from the field experiment with a light aircraft. The airplane equipped with a signal generator transmits pilot signals and the ground station receives and saves the signal to analyze the air-to-ground channels. Since the Zadoff-Chu (ZC) sequence has good auto correlation property [7-9], the ZC sequence is used for the pilot signal. The ground station is located in mountainous area since the Korean terrain is mostly mountain. The transmitted pilot waveform from the aircraft is received and saved in the wideband spectrum analyzer at the ground station. The saved waveform are analyzed by MATLAB to obtain channel characteristics. According to the results, one path channel happens most frequently, but sometimes, large multipath components are observed [13]. The maximum number of multipath components is 4 and the maximum delay spread is about 0.4 μsec.

2. Channel Analysis Procedure

Figure 1 shows the block diagram of the air-to-ground channel analysis system.

For the pilot signal, we use ZC sequence. The ZC sequence of length 1,999 is generated at a clock rate 14 MHz, and a Pulse Shaping Filter (PSF) is applied to limit the signal bandwidth. For the PSF, the Square Root Raised Cosine (SRRC) filter with roll-off 1 is used [10-11]. The bandwidth of the SRRC filter is generated by the following formula (1).

$$BW = F_s(\beta + 1) \quad 0 \le \beta \le 1 \qquad (1)$$

In (1), F_s represents the sampling frequency and β represents the roll-off factor. To accurately recognize multipath components, the roll-off factor is 1. This value causes a low side-lobe in the time domain. Using the highest roll-off factor value increases the bandwidth in the frequency domain and increases the resolution in the time domain due to the lower side-lobe. In this paper, we use a sampling clock frequency of 14MHz which is the maximum affordable sampling frequency of the vector signal generator. The transmitted pilot signal has a bandwidth of 28MHz. The output signal of the generated PSF is stored at the vector signal generator. The vector signal generator is installed on the aircraft. The center radio frequency (RF) can be configured by the signal generator. In our experiment, the RF frequency is 445MHz. On the ground station, the transmission signal is received through the antenna and spectrum analyzer, and the received signal is stored. The stored waveform is passed through the matched filter which is the same filter with the pulse shaping filter at the transmitter. Then, the channel impulse response is observed by auto correlation of the output signal of the matched filter and the ZC pilot sequence. If the channel is clear LOS, single peak like impulse will be observed at the correlator output while the multiple peaks will happen if there are multipath components in the air-to-ground channels.

The next section explains the ZC sequence used for the pilot signal in detail.

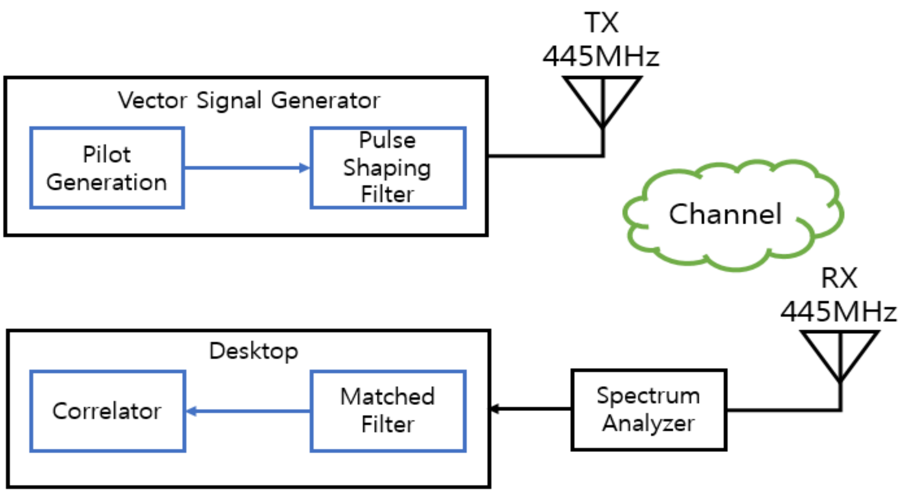

Figure 1. Block diagram of experiment process

3. Zadoff-Chu Sequence

Since the auto correlation of the ZC signal is close to the impulse signal, by using the ZC sequence as pilot, the channel multipath component can be accurately analyzed. The ZC signal used in this paper is generated by the following expression.

$$x(m) = e^{\frac{-j\pi Rm(m+1)}{N}}, \quad m = 0, \cdots, N-1 \qquad (2)$$

In (2), N is the length of the ZC sequence (should be odd number), and R is the design number of the ZC sequence. Different R provides different ZC sequence. In this paper, the value of N is set to 1999 and the value of R is set to 3. Figure 2 shows the auto correlation of the ZC sequence.

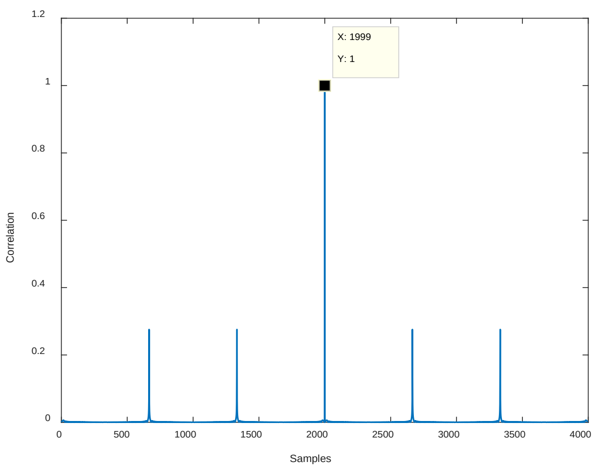

Figure 2. Auto correlation of zadoff-chu sequence

In Figure 2, we can see main peak and small peaks at regular intervals around the main peak. This is a phenomenon caused by linear autocorrelation. Actually, ZC sequence has the ideal circular autocorrelation characteristics, but non-ideal linear autocorrelation characteristics. In our experiment, circular correlation cannot be used so that linear autocorrelation characteristics are important. According to Figure 2, linear correlation near main peak also looks like impulse and it is sufficient to use for analysis of the air-to-ground channel. The side peaks varies for different R values. In this paper, auto correlation characteristics close to the impulse were found through exhaustive search for possible R values.

4. Experiment and Results

The experimental environment is as follows. After storing the pilot signal of the bandwidth of 28MHz in the vector signal generator, it is mounted on the airplane and take off. The ground station for signal acquisition is located in the mountainous area. The aircraft transmits the pilot signal at a predetermined route and time with an altitude of 5 km, and on the ground station, the signal is received through the antenna and spectrum analyzer [12]. After the signal storage is completed, auto correlation is performed between the pilot signal and the received signal to analyze the Channel Impulse Response (CIR). Here, a multipath component below -30 dB from the main peak are discarded, and only strong multipath components are observed

Figure 3 shows the correlation output for a typical received signals. As shown in the figure, only single path is observed and there is no multipath components.

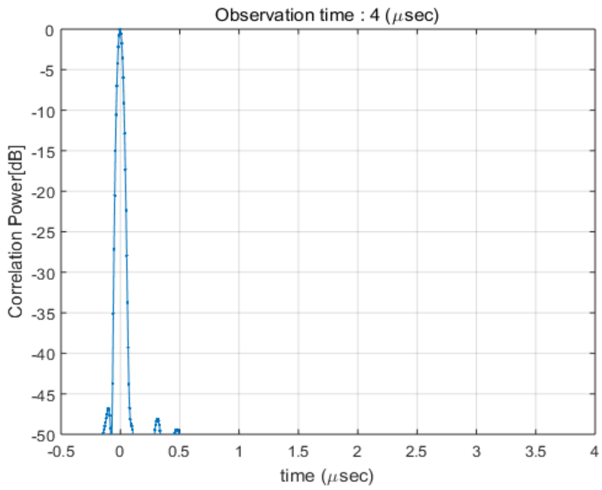

Figure 3. Single path channel

Most correlation output turned out to be single path channels as Figure 3.

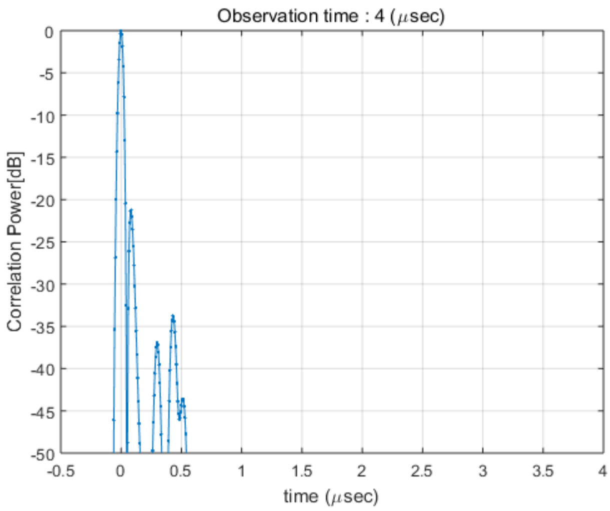

Figure 4. Two path channel

Figure 4 is a case when there are two paths. The main peak may be the LOS component and the second peak may be considered as the non-LOS component.

Figure 5 is a case when there are three paths, one LOS and two non-LOSs. Non-LOS components are about -23dB and -14dB from the main peak.

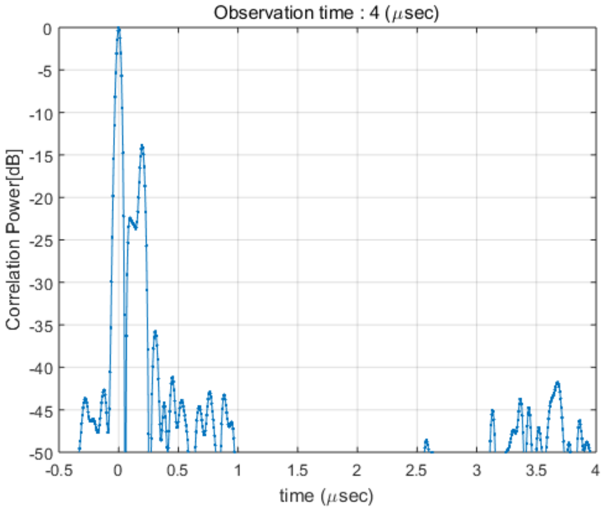

Figure 5. Three path channel

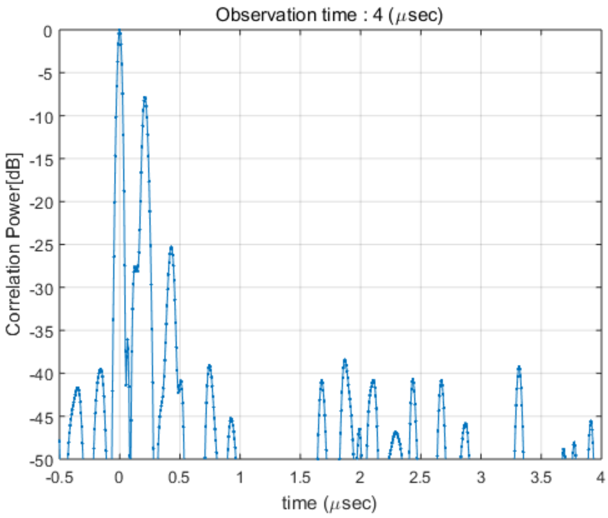

Figure 6. Four path channel

Figure 6 is the case when four paths exist. The NLOS components are -28dB, -7dB, and -25dB from the main peak. Compared with Figure 4 and Figure 5, the magnitude of the NLOS component is larger and the noise power is also larger.

As a measurement result, most of the channel characteristics are single path but sometimes, multipath components are occasionally observed. In our experiment, the worst channel characteristics are 1 LOS and 3 NLOS components, and the maximum delay spread is 0.4 μsec. Table 1 shows the analysis results of the acquisition data.

Table 1. Data analysis results

	Percentage	Maximum delay	Maximum multipath distance
Single path	82%		
Two path	12%	0.18 μsec	54m
Three path	5%	0.21 μsec	63m
Four path	1%	0.4 μsec	120m

Of the total 3,000 acquisition data, 82% of data were observed as single path (LOS), 12% of data were observed for two path, 5% for three path and 1% for four path. In addition, the maximum delay and maximum multipath distance for each multipath are measured as shown in Table 1.

5. Conclusions

In this paper, we describe the method and results of air-to-ground channel analysis using pilot signals. Air-to-ground channel analysis is performed on mountainous terrain using airplane, and most CIRs are single path channel (LOS). However, when an airplane crosses a certain location, a few multipath components are observed, and the worst case channel has four paths including the LOS path, and the maximum delay spread is 0.4 μsec. The maximum power of the multipath is -7dB from the main path. Those analyzed channel characteristics can be used for the channel model for the design of wireless air-to-ground communication systems.

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