DEVELOPMENT OF SDR-BASED EQUIPMENT WITH CHANNEL MONITORING FUNCTION FOR COGNITIVE RADIO

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ABSTRACT

As one of research activities regarding the cognitive radio, we have developed the Software Defined Radio (SDR) equipment for the OFDM signal such as the WiMAX. We have also developed an equipment which has the capability to monitor the amplitude and phase spectra of the transmission path, by using functionality of the SDR. In this paper, we introduce the evaluation of its performance and the experimental results of the transmission channel monitoring. In addition, we have made analytical studies which can be obtained based on the propagation theory considering the path delay and path loss among multi-paths. From the experimental study and analytical one, it is concluded that the scheme proposed obtains superior estimation for the case of multi-path channel. The developed SDR-based equipment has the feature which is easily possible to provide the channel monitoring function without addition of hardware elements.

1. INTRODUCTION

Authors have been studying the Cognitive Radio [1] which selects and utilizes the optimum system parameters such as the frequency band, bandwidth and modulation method, by appropriately having the knowledge of the encountered radio environments [2]-[5]. Use of multi-band and multi-channel wireless communication schemes is a key issue to successfully provide the Cognitive Radio network. Furthermore, the use of Software Defined Radio (SDR) technology which enables to implement multi-channel schemes on one communication board is essential to realize such terminal in a compact and economical manner [6]. We have developed an SDR-based wireless communication terminal set facilitating WiMAX communication scheme.

Such wideband channels tend to be degraded under multi-path transmission environment, which can be represented as the characteristics of amplitude and phase of received signal over the channel bandwidth. The authors have adopted the OFDM receiver from which a set of received signal amplitude and phase of each sub-carrier is monitored.

SDR technology has a good feature that the additional monitoring function can be realized easily in software as required. We describe the transmission channel monitoring function so as to see the real behavior of wireless channels spreading over about 10-MHz channel bandwidth. This paper shows the design and implementation of the SDR-based terminal. Basic principle of the measurement is to utilize the given fixed data pattern such as the preamble signal. The transmission status estimation can be performed by the information produced by the channel equalizer at the demodulator.

Based on the design, we developed an SDR terminal set including the measuring unit of the amplitude and phase spectra characteristics as a function of frequency. Some evaluations have been conducted, where fading signal is produced by the Signal Generator (SG) with the simulated faded base-band signal. As an experimental result, we have obtained the distinguished characteristics of the amplitude and phase spectra which are equal to the transfer function of the transmission path.

For the verification of monitoring function, first of all, we have tried the condition of non-fading. The obtained phase spectrum is reasonable compared to the analytically derived characteristic. Then, we tried the cases of two-path model and multi-path model, where the former model consists of the direct signal and one reflected signal, so-called the LOS (Line-of-Sight) model. The latter model is encountered in the environment of the cellular phone service, which corresponds to the NLOS (None-Line-of-Sight) status.

From the experimental study and analytical one, it is concluded that the scheme proposed obtains superior estimation for the case of multi-path channel. The developed SDR-based equipment can easily provide the channel monitoring function without addition of hardware elements.

The developed equipment can easily monitor the characteristics in the hardware itself, which would have to use the high performance measurement instrument, so far. Those monitoring results are to be fed to the Cognitive control for utilization of frequency resource.

2. OUTLINE OF EXPERIMENTAL SDR EQUIPMENT

2.1. Specification of Equipment

Figure 1 shows experimental SDR (Software Defined Radio) - based communication receiver developed, whose specifications are listed in Table 1 for the hardware equipment consisting of two FPGA specifications. Table 2 shows the communication scheme.

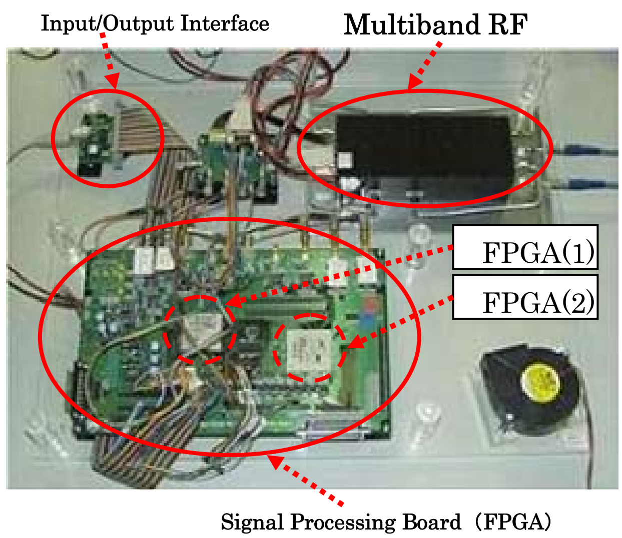


Figure 1 Experimental SDR-based Equipment.

Table 1 Specification of SDR-based Equipment.

Device	Item	Specifications
FPGA	FPGA(1)	XC2VP40-5FF1152C
	FPGA(2)	XC2VP70-5FF1517C
	Operation Clock	60MHz
A/D Converter	Device	Analog Devices AD9432
	Bit Count	12
D/A Converter	Device	Analog Devices ADV7123
	Bit Count	10

Table 2 Specification of Communication Scheme.

Parameter	802.16e
Frequency	2.5GHz
Bandwidth	8.75MHz
FFT size	1024
Modulation	QPSK, 16QAM,64QAM
PHY Mode	OFDM

2.2. Features of Equipment

Figure 2 depicts the functional block diagram of the developed SDR equipment. In the case of TDD (Time Division Duplex) such as the WiMAX scheme, the signal processing does not simultaneously occur in the transmitting duration and receiving duration. Considering this condition, the developed equipment switches the FFT block and IFFT block in time division manner, which results in the efficient utilization of the software tool. Furthermore, it is possible to select the communication scheme by downloading software from the memory onboard the signal processing unit. Although such function is installed, herein we focus on the monitoring capability of the transmission status.

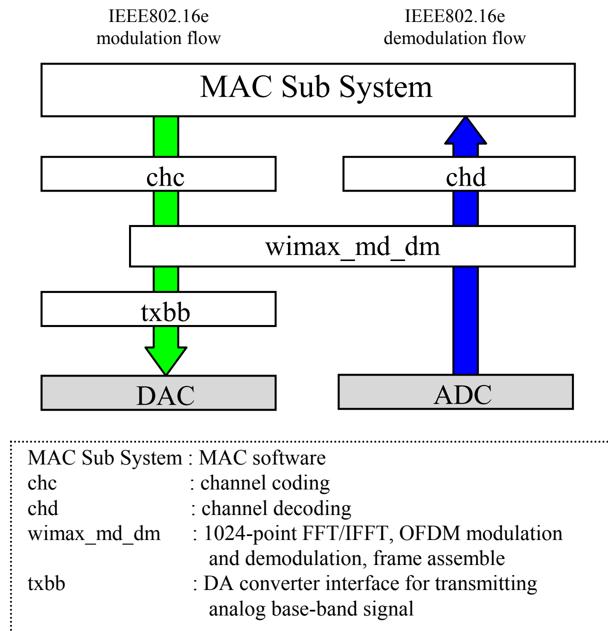


Figure 2 Functional Block Diagram of SDR Equipment.

3. TRANSMISSION CHANNEL MONITORING

The transmission channel monitoring function described herein principally utilizes the channel estimation capability which the 802.16e specification usually facilitates as a basic function. The functional block diagram is shown in Fig. 3.

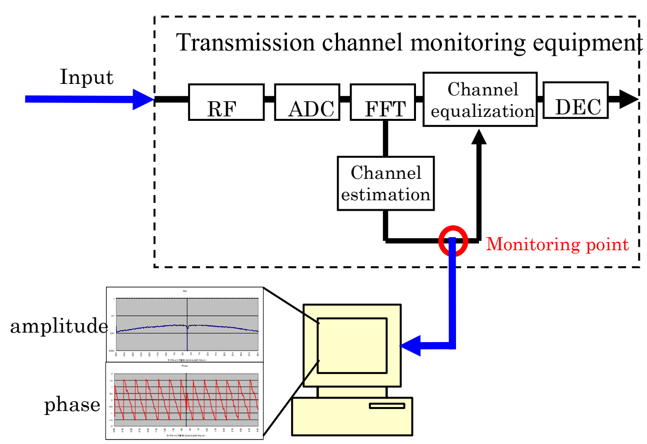


Figure 3 Monitoring Function and Monitoring Point.

The specific signal for monitoring is the input fixed data stream such as the preamble words, which is usually attached for the clock, phase and word synchronizations, periodically in each transmitting packet signal. At the output of the channel estimation, the given data stream is observed and the amplitude and phase spectra are obtained.

4. BASIC CHARACTERISTICS OF MONITORING

As for the transmission of the WiMAX signal, we use the SG (Signal Generator) which has the capability to generate the RF OFDM signal from the base-band waveform data. Figure 4 is the experimental configuration for evaluation of transmission channel monitoring function. By using such function, we can generate arbitrary RF signals including both non-fading and fading signals for the experimental hardware simulation. For example, when the waveform data is the composite one through the multi-path fading channel, we can simulate such multi-path effect, as described later. Presently, the waveform data base occupies much memory size, the time duration of the generated RF signal is 5 msec.

Figure 5 shows the amplitude and phase spectrum characteristics measured at the monitoring point in Fig. 3, in the case of the non-fading signal. Herein, since the frequency characteristic of the RF elements in the equipment such as the RF band-pass filter is not constant, the compensation is performed. Furthermore, in the position of the null sub carrier of the WiMAX signal, we conveniently do not plot its value not so as to induce the confusion. Regarding the phase spectrum characteristics, we indicate the "arctan" value, so the phase characteristic has the periodical duration of π and its appearance is saw-shape.

The reasons why the phase characteristic is not constant at the monitoring point are that the transmission channel delay exists between the transmission side (SG) and receiving side (monitoring equipment) and also that the transmitting frequency and receiving frequency are not the same in the case of the hardware experiments.

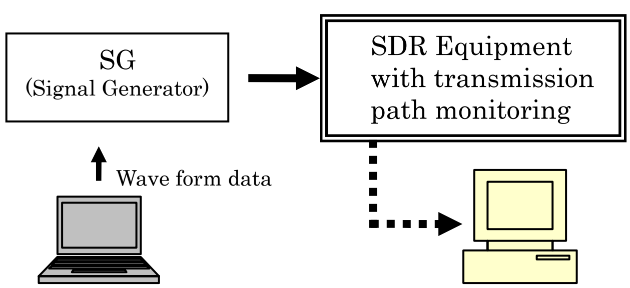


Figure 4 Experimental Configuration for Evaluation of Transmission Channel Monitoring Function.

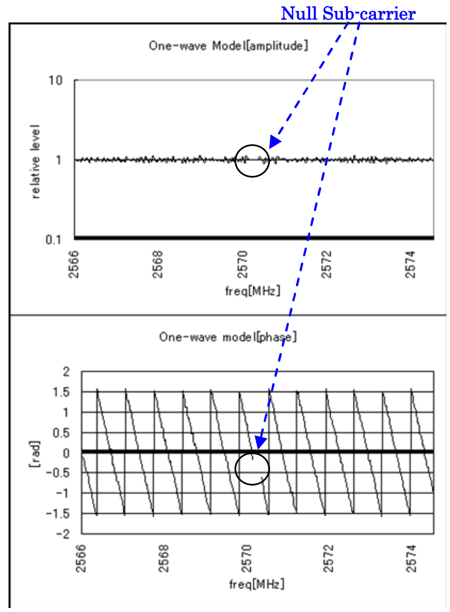


Figure 5 Amplitude and Phase Spectrum Characteristics at the Monitoring Point in the case of Non-fading.

5. MONITORING STUDIES IN TWO-PATH MODEL

Herein, experimental and analytical monitoring results of the simulated signal passing through the two-path channel are demonstrated. The experimental results are obtained by the use of the configuration depicted in Fig. 4.

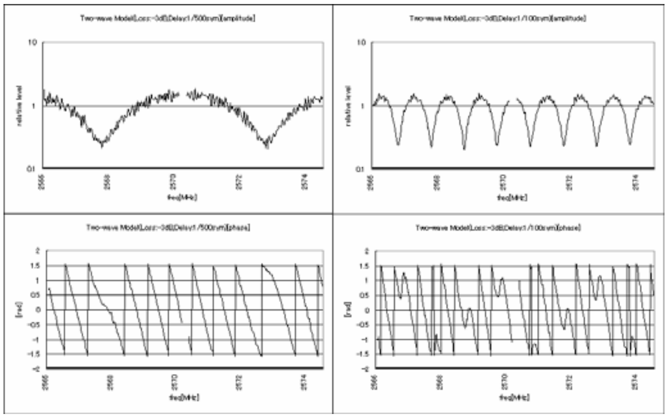
5.1. Experimental Studies

Figure 6 (a) – (d) is the experimental monitoring results of the amplitude and phase spectra of the OFDM signal, which is equal to the transfer function of the transmission channel. Because of the interaction between the two signals (usually, direct signal and reflected signal), amplitude of the transfer function is not constant and has periodic characteristics. The periodic cycle of the amplitude is equal to reciprocal of the time difference between the two signals in the two-path model. The depth which is the difference between the top and bottom in the amplitude characteristic, is also calculated by the power difference between the two signals in the two-path model.

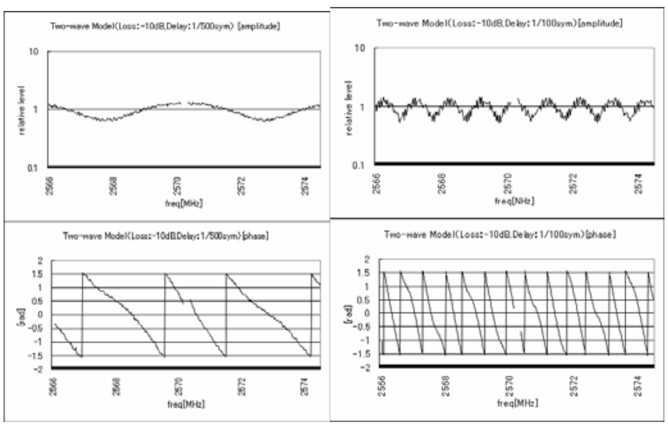
5.2. Analytical Studies

(a) Transmission Channel Model

It is commonly known that the two-path propagation can be modeled by the parameters such as the amplitude, delay, phase shift, as shown in Figure 7.



(a) R/D: -3 dB, delay : 0.2μs (b) R/D:- 3 dB, delay : 1.0μs



(c) R/D: -10 dB, delay : 0.2μs (d) R/D:- 10 dB, delay : 1.0μs

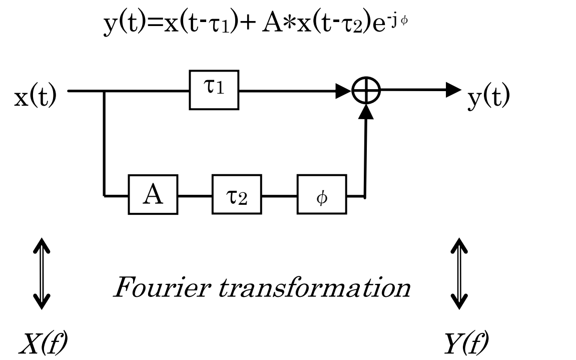
Figure 6 Monitoring Results in Two-path model
(R/D : reflected/direct power ratio)

(b) Transfer Function

When the channel model has been made, the transfer function of the channel is obtained by Fourier transformation, as depicted in Fig. 7, which is expressed in the complex number. The amplitude and phase characteristics are calculated by means of the absolute and arctan ($\tan^{-1}$) operations respectively.

(c) Impulse Response

The impulse response of the transmission channel is obtained by the inverse Fourier transformation of the transfer function Eq. (1) as shown in Fig.7. Impulse response function can also be interpreted as delay profile of the transmission channel.



Transfer Function : $T(f)=Y(f)/X(f)=e^{-j\omega\tau_1}+A\,e^{-j(\omega\tau_2+\phi)}$ Eq.(1)

Amplitude : abs($T(f)$)

Phase : arctan($T(f)$)

A : amplitude

τ_1, τ_2 : delay

ϕ : phase

Figure 7 Channel model and Transfer Function

5.3. Comparison of Experimental and Analytical Studies

(a) Non-fading Case

Herein, we compare the experimental results and analytical results of the channel characteristics. At the beginning, the amplitude and phase spectra of the OFDM signal (equal to the transfer function of the channel) is measured by the developed experimental equipment, then we operate inverse Fourier transformation of it so as to calculate the impulse response. In the measured results, there are some noise and error, so we make the simplification and modification so as to fit to the pure delta function δ (t-τ). Hereafter, we call it the "modified impulse response". Moreover, we operate the Fourier transformation of such impulse response, where we finally reach at the transfer function.

For the case of non-fading, the impulse response obtained from the measured transfer function is shown in Fig. 8. In the figure, only one delayed impulse is seen, which is estimated to be induced by both the transmission delay and reference frequency difference between the Signal Generator and the monitoring equipment. Two ambiguous parameters can not be distinguished at the present experiment stage.

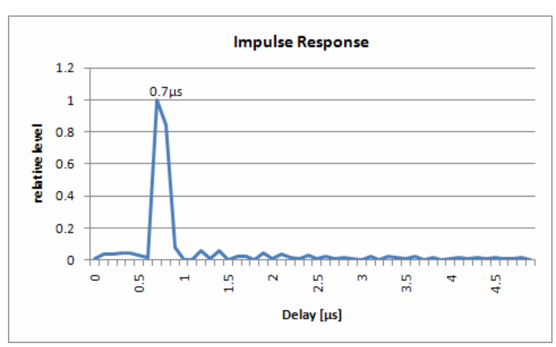
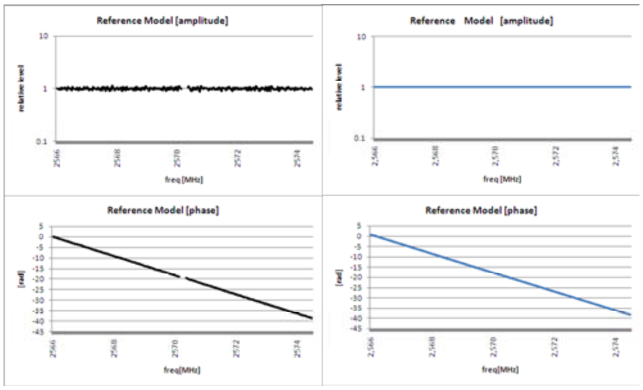


Figure 8 Impulse Response calculated from Fig.5

(for case of Non-fading)



(a) Experimental Transfer Function (equivalent to Fig. 5) (b) Analytical Transfer Function

Figure 9 Transfer Function (Non-fading)

Figure 9 (a) shows the experimental transfer function which is equivalent to Fig. 5, where the phase spectrum is expressed in the continuous way, not in periodic one limited within π. Figure 9 (b) is the inverse Fourier transformation of the modified one of the impulse response shown in Fig.8, which we call the “analytical transfer function”. Comparing the analytical one with the experimental one, it can be seen that both have the same features.

(b) Two-path Model

The impulse response calculated from the measured result depicted in Fig. 6 (b), is shown in Fig. 10 as typical two-path case (reflected/direct power:- 3dB, delay:1.0μs). The left-side impulse of 0.9 μs seems to be the composite effect of both transmission delay and frequency difference, as described before.

Figure 11 (a) and (b) show the measured transfer function equivalent to Fig. 6 (b) and the analytical transfer function obtained from the modified impulse response of Fig. 10, respectively.

As seen in Fig. 11, the experimental and analytical transfer functions are sufficiently coincident. Therefore, we can say that the scheme proposed in this paper will estimate the transmission status with good accuracy.

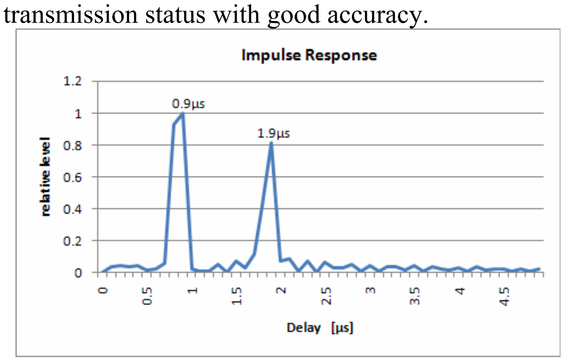
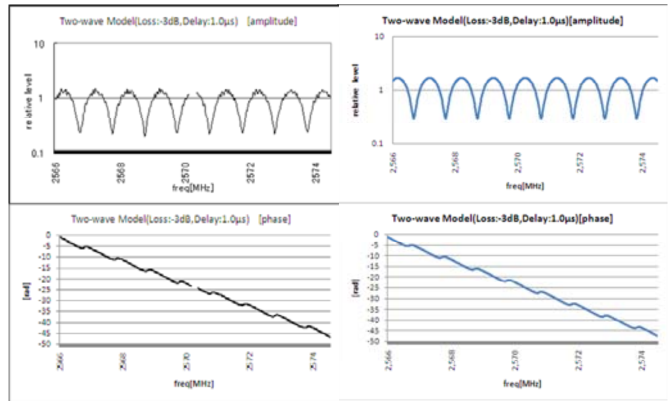


Figure 10 Impulse Response calculated from Fig. 6 (b) (R/D:- 3dB, delay : 1.0μs).



(a) Experimental Transfer Function (equivalent to Fig.6 (b)) (b) Analytical Transfer Function

Figure 11 Transfer Function (two-path model)

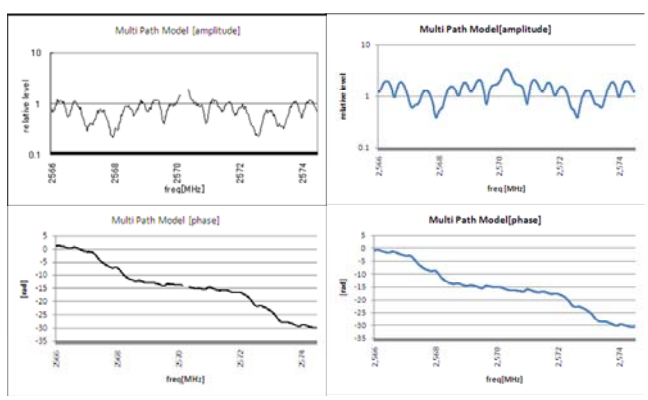
6. MONITORING STUDIES IN MULI-PATH MODEL

6.1. Transmission Channel Model

In the case of multi-path model, transmission channel model is an extension of two-path model, which has usually more reflected paths and no dominant. Herein, we assume the ITU-R Recommendation M.1225 so as to discuss the realistic multi-path model [7].

6.2. Comparison of Experimental and Analytical Results

Figure 12 (a) shows an example of the measured transfer function for the case of multi-path channel. Figure 13 shows the impulse response obtained from Fig. 12 (a). Furthermore, the transfer function calculated from the modified impulse response of Fig. 13 is shown in Fig. 12 (b). The shift in the phase spectrum on the frequency domain is due to the relative phase difference. It can be concluded that there is no significant difference in two figures in Fig. 12.



(a) Experimental Transfer Function (b) Analytical Transfer Function

Figure 12 Transfer Function (ITU-R Rec. M1225, multi-path model)

The measured delay, which is depicted in Fig.13, and the set-up delay in the Signal Generator for the hardware simulation are summarized in Table 3. As seen in Table 3, relative delays between adjacent impulses are the same. Therefore, the scheme proposed will also provide superior estimation for the case of multi-path channel.

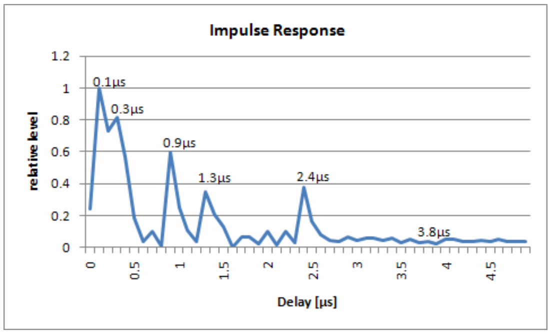


Figure 13 Impulse response calculated from Fig. 10 (a)

Table 3 Set-up delay and measured delay in multi-path channel

	set-up delay in SG [μs]	Measured delay [μs]
1	0.0	0.1
2	0.2	0.3
3	0.8	0.9
4	1.2	1.3
5	2.3	2.4
6	3.7	-

6. CONCLUSIONS

In this paper, we have proposed the estimation scheme of the propagation status such as the number of multi-path and the path delay in the wireless OFDM channel, which utilize the given data stream. The scheme is easily facilitated by the Software Defined Radio (SDR) equipment without adding hardware elements.

The communication equipment itself is able to have the knowledge of transmission status, so it will equip with the capability to judge the several conditions of the communication channels. This feature will be useful and effective for the cognitive radio technique, which select the optimum communication link among the several communication channels while monitoring radio circumstances.

Due to hardware limitations, the experiment is one packet monitoring. As the extension of the experiment, we try the continuous signal monitoring and investigation of the time-variant characteristics of the transmission channel status.

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