

Performance Analysis of Parallel Acoustic Communication in OFDM-based System

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Abstract— Acoustic communication is transmission technology with sound and data by using speaker and microphone. In this paper, we propose a parallel acoustic communication system that is able to transmit text data in office environment using unused high frequency band in audio signal. So, we analyze the performance of acoustic communication. This system sends both sound in low frequency band and OFDM (orthogonal frequency division multiplexing) data in high frequency band at the same time. In the case of acoustic communication system, frequency offset is generated from speaker and microphone. Therefore, we compensate frequency offset and perform real experiment to ensure the good system performance.

Keywords— OFDM, Acoustic OFDM, Acoustic communication, Sampling Clock offset, Synchronization

I. INTRODUCTION

Recently, people have increasing interest about acoustic communication because of development of mobile and PDA technology. Acoustic communication is used audio frequency band. But, human ears cannot perceive hidden information of propagated audio signal. Acoustic communication is not required of additional equipment because it use microphone and speaker as input and output.

There are several techniques about audio watermarking such as echo hiding which can transmit data at very short time, spread spectrum which hide data in frequency of sound signal, and acoustic OFDM method which can send more data than other methods. Echo transmission method is easy to implement because echo data is inserted at time domain regardless of frequency domain [1], [2]. Spread spectrum is method that overlap data signal by using lower Pseudo-random-Noise (PN) than frequency masking threshold value [3].

This method is robust with respect to aerial propagation and environmental noise. But its data throughput is low because the system has to spread data. Acoustic OFDM signal remove high band by low pass filter (LPF) to generate a low-frequency audio signal. Then, power of each OFDM subcarrier is controlled as the spectral envelope of the original sound source. Afterward, generated OFDM signal is inserted in high frequency band of audio signal and is transmitted. Acoustic OFDM system has better sound quality than different ways as well as more data throughput. However, acoustic OFDM generate decreasing sound quality and

performance of communication because of using low pass filter [4], [5].

First, we propose a system that Frequency bandwidth for suitable quality of voice signal is 4 KHz. Also, voice signal is made as a recording of 8 KHz sampling rate to satisfy Nyquist-Shannon sampling theorem. After that, recorded voice signal goes through the process of 2 times re-sampling.

OFDM data is transmitted in unused high frequency band of audio signal. This system can transmit short text with voice and audio signal using low cost speaker and microphone.

In this paper, using acoustic system for short distance communication, our goal is system that is possible to transmit audio and message simultaneously in office environment.

We conducted the experiment using speaker and microphone in the laboratory and using MATLAB program.

The experiment is performed when noise level is about 50dB in office environment. The distance from Speaker to microphone is changed within 5 meter and we confirm the performance. BER performance is improved as compared with acoustic OFDM system.

II. ACOUSTIC OFDM SYSTEM

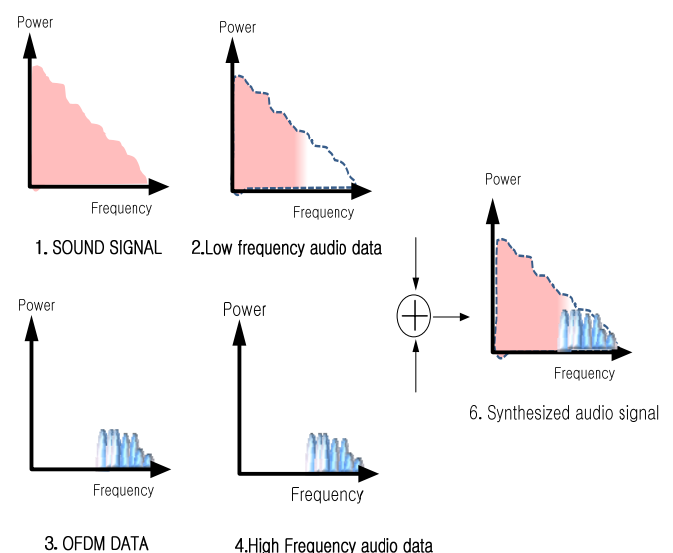


Figure 1. Acoustic OFDM modulation method.

Figure 1 shows the basic modulation method of Acoustic OFDM. First, the original sound source makes a frequency band signal using Fourier transform. Audio signal is limited to certain frequency bandwidth by using low pass filter. OFDM signal is inserted in high frequency band of limited audio signal. We perceived OFDM signal as the AWGN because OFDM signal has same subcarrier power. So, OFDM signal is controlled power like to audio signal spectrum envelope. Power controlled OFDM signal can reduce decreasing sound quality. Because it has same effect original audio signal. Also it is robust with respect to environmental noise. Last, this method increase data throughput by ten times.

III. PARALLEL ACOUSTIC COMMUNICATION SYSTEM

A. Parallel Acoustic Communication System

Figure 2 shows a parallel acoustic communications in based on OFDM system. OFDM data is located in high frequency bandwidth over audio signal. It is true that OFDM data has not affect on BER performance. Modulation method based on OFDM has the merit of frequency efficiency compared with single carrier method.

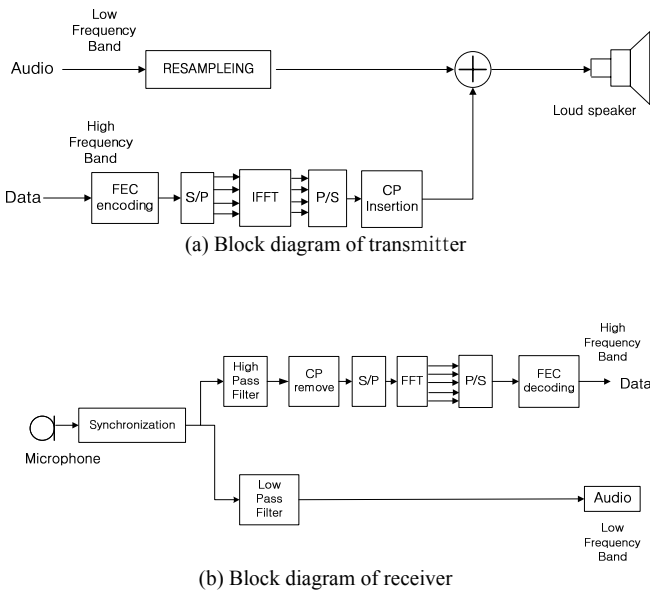


Figure 2. Parallel acoustic communication system

The OFDM signal is represented as

$$x(n) = \sum_{k=0}^{N-1} X(k) e^{j \frac{2\pi}{N} k n}, \quad (1)$$

where k is subcarrier number.

The guard interval and cyclic prefix is inserted in OFDM symbol to reduce ISI (inter-symbol interference) effect which be caused by multi-path channel. The received OFDM signal is represented as

$$r(n) = \sum_{k=0}^{N-1} X(k) H(k) e^{j \frac{2\pi}{N} k n}. \quad (2)$$

$$\begin{aligned} R(k) &= \frac{1}{N} \sum_{n=0}^{N-1} r(n) e^{j \frac{2\pi}{N} k n} \\ &= \frac{1}{N} \sum_{k=0}^{N-1} \sum_{l=0}^{N-1} X(l) H(l) e^{j \frac{2\pi}{N} l n} e^{-j \frac{2\pi}{N} k n} \\ &= \frac{1}{N} \sum_{k=0}^{N-1} \sum_{l=0}^{N-1} X(l) H(l) e^{j \frac{2\pi}{N} (l-k) n} \\ &= \frac{1}{N} \sum_{k=0}^{N-1} \sum_{l=0}^{N-1} X(l) H(l). \end{aligned} \quad (3)$$

The acoustic communication system transmits a sound at low frequency under 4KHz and OFDM data at high frequency above 4 KHz. First, the voice signal has about 3.6KHz bandwidth and we do sampling of 8 KHz for sampling without frequency loss. Sample of the voice signals in 8 KHz has the maximum frequency 4 KHz. Voice and low sampling audio signal does not affect OFDM signal as interference. Because OFDM signal is transmitted over 4 KHz.

However, OFDM signal should be transmitted after subcarrier's power control because sounds data in high frequency band heard like AWGN noise. As a result, OFDM signal doesn't listen well.

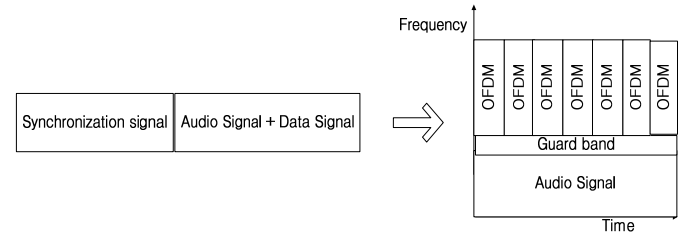


Figure 3. Synchronization signal and data frame structure.

Figure 3 is frame structure. Firstly, we send synchronization signal for synchronization process, as shown in the figure 3. After audio signal and OFDM data is transmitted at the same time. Audio signal is located in low frequency band and OFDM signal is located in high frequency band. OFDM data and audio signals are transmitted at the same time in time domain. But, these two signals are separated in frequency domain, as shown in the figure 3.

B. Synchronization Signal

When sound signal is recorded at the receive part through microphone, we do not know start point of sound signal. Therefore we need synchronization signal $x[k]$ to know start point of receive signal. The synchronization is basically a correlation of our signal with a known synchronization signal.

$$x[k] * x[-k] = \sum_{n=0}^N x[n] \cdot x[n+k] \approx NE \{x[n] x[n+k]\} = N \delta[k] \quad (4)$$

When the received signal is synchronized, the correlation value has the maximum value $N \delta[k]$. Thus we can gain start point of signal through k -th signal with maximum values $N \delta[k]$.

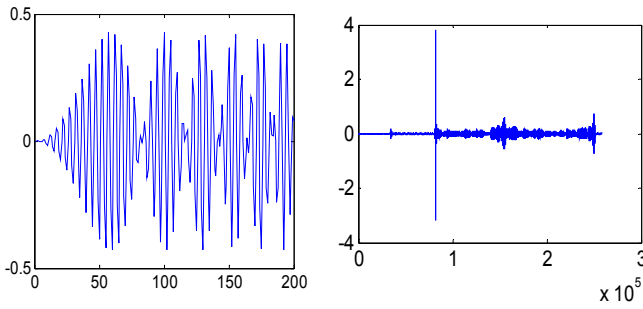


Figure 4. Synchronization signal and correlation.

Figure 4 shows synchronization signal and correlation value. We used synchronization signal in figure 4 (left). When the received signal is synchronized, the correlation value has the maximum value $N\delta[k]$ shown in figure 4 (right).

C. Frequency Offset Effect

A frequency offset is generated between transmitter and receiver in the real acoustic communication system. The computer sound devices we use exist clock' difference in two sound card between A/D converter and D/A converter. And these problems are more serious because those devices did not be made for acoustic communication.

Those problems that are made by different symbol periods between transmitter and receiver make ICI (inter-carrier interference). ICI is increased when subcarrier frequency are receded from DC in FFT demodulation process. The follow formulas express how the problems, sampling clock offset, are generate in receive part.

$$\tilde{Y}[k] = Y[k] \frac{\sin(\pi\Delta k)}{\sin(\pi\Delta k / N)} e^{\frac{j\pi\Delta k(N-1)}{N}} + Z_{ICI}[k]. \quad (5)$$

Equation (5) shows that changed amplitude and phase of received signal be caused by ICI effect. Delta Δ is a sampling clock mismatch as $(T_s - T_s') / T_s$. Therefore we compensate changed signal amplitude and phase by using the normalized four pilots.

IV. EXPERIMENTAL RESULT

A. Simulation Result

TABLE 1. SIMULATION PARAMETERS

Parameter	Value
Sampling frequency	16KHz
Audio signal frequency	0 – 4000KHz
OFDM carrier frequency	4781-6781KHz
Carrier modulation	BPSK /QPSK
Number of carriers	33(+4 pilot symbols)
Symbol interval	2048samples (128ms)
Guard interval	512samples (32ms)

The table 1 shows simulation parameters. The OFDM simulation is to implement by BPSK and QPSK modulation and used frequency band 4781~6781 Hz. The figure 5 is the spectrum of audio signal after re-sampling. This is re-sampling signal at double those 8000 samples of audio signal.

The figure6 is signal amplitude at frequency domain after OFDM data signal is inserted at voice signal. The two figures show that signals is located in a different frequency band.

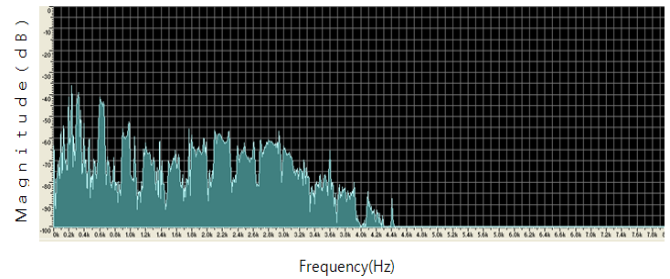


Figure 5. Spectrum of audio signal.

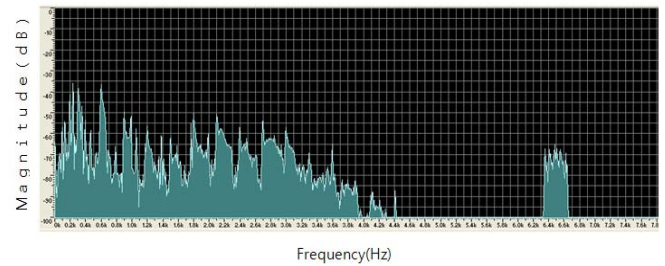


Figure 6. Spectrum of audio and OFDM signal.

Parallel acoustic communication heard environment noise compared with Acoustic OFDM method. But OFDM signal that has controlled power is not perceived because of low signal compared with audio signal. In the case of voice signal, the proposed system has decreases of a little sound quality because the voice signal is located mainly in low frequency band. But in the case of music signal, the proposed system has decreases of much sound quality because music signal is located mainly in high frequency band. However, this system has better BER performance of received signal because interference between voice and music signals doesn't exist.

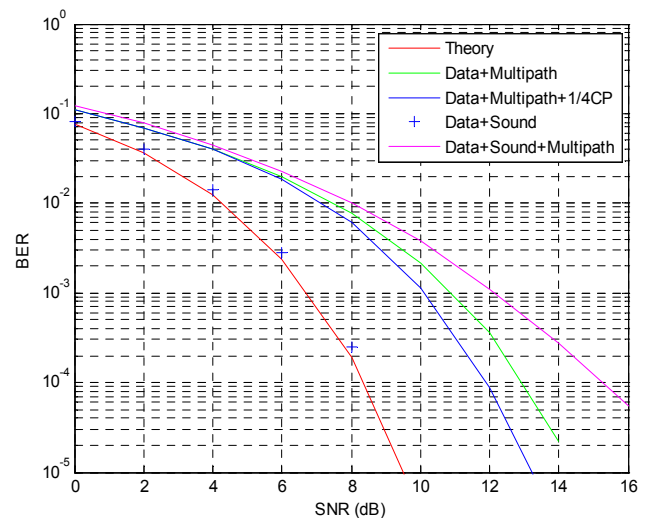


Figure 7. Simulation result of QPSK method.

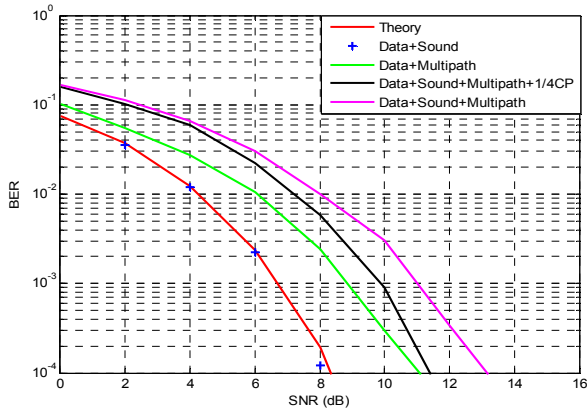


Figure 8. Simulation result of QPSK method.

In figure 7, the vertical axis is the BER, and the horizontal axis is SNR. This figure shows that BER simulation result in AWGN channel environment when data sequence is modulated by QPSK. In multipath environment, BER performance is deteriorated when compared with the system without multipath. Therefore, to reduce bit error rate caused by channel characteristic, we adopt 1/4 length cyclic prefix. After adding cyclic prefix, BER performance is improved. Because parallel acoustic communication system is FDM transmission method, data signal have not an effect on the sound signal. However, in multipath channel, BER of parallel acoustic communication system is worse than in only AWGN channel. This BER degradation is caused by time delay of sound propagation.

Figure 8 shows that guard interval can solve BER degradation in multipath channel environment. With guard interval, parallel acoustic communication system has better BER performance.

B. Experiment Result

TABLE 2. EXPERIMENTAL CONFIGURATION

	Loudspeaker	Microphone
Model	SAMSUNG SMS-M2100	ONESTEC OST-101
Frequency characteristics	20 ~ 20KHz	50~50,000Hz

Table 2 shows the basic specifications of the loudspeaker and microphone used in experiment and Table 3 shows transmission parameters.

TABLE 3. EXPERIMENTAT PARAMETERS.

Parameter	Value
Sampling frequency	16KHz
Audio signal frequency	0 – 4000KHz
OFDM carrier frequency	4500-8000KHz
Carrier modulation	BPSK /QPSK
Number of carriers	33(+4 pilot symbols)
Symbol interval	2048sample(128ms)
Guard interval	512samples (32ms)
FEC coding	1/3 convolution coding

We perform experiment on noise level about 50 dB noise level environments. This is similar noise level in office environment.

Generally speaker and microphone are used for experiment. So, we measure the BER performance according to distance change between transmitter and receiver. We transmit short text message or image as OFDM data using 1/3 convolution coding.

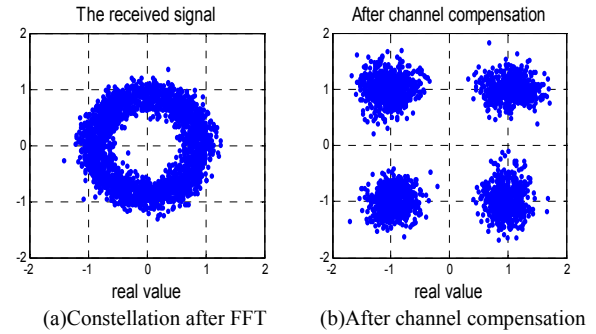


Figure 9. Experiment constellation of QPSK.

Figure 9(a) shows constellation of received data at 1m from speaker. Our experiments confirm phase rotation and changed magnitude because of different sampling clock between transmitter and receiver. Figure 9(b) shows constellation of received signal after channel compensation technique using four-comb type pilots.

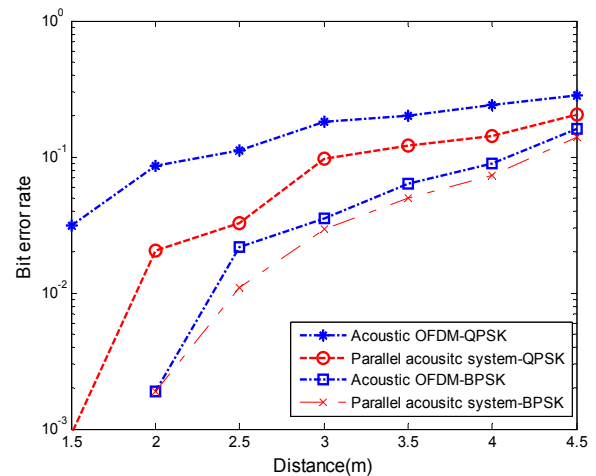


Figure 10. BER performance according to distance change.

Figure 10 shows the result between propagation distance and Bit Error Rate. The result shows more improved BER performance on noise level about 50 dB noise level environments than on 35dB noise level environment in experiment based on acoustic OFDM system.

V. CONCLUSION

In this paper, we implemented simulation about performance of acoustic communication system based on OFDM in various environments. So we perform experiment

on 50dB noise level environment by using two computers that has different sound card.

Frequency offset and phase rotations occur at the received signal because of the clock speed difference of sound card device. We compensated phase rotation using channel compensation techniques, and we measured BER performance. Acoustic communication system has demerit of environment noise. But we ensure the better system performance than existing acoustic OFDM under 35dB noise level environment although we experiment the system under 50dB noise level environment.

REFERENCES

- [1] D. Gruhl and W. Bender, "Echo hiding," in *Proc. Information Hiding Workshop*, Cambridge, U.K., pp. 295–315, 1996.
- [2] H. O. Oh, J. W. Seok, J. W. Hong, and D. H. Youn, "New echo embedding technique for robust and imperceptible audio watermarking," *Proc. ICASSP 2001*, May 2001.
- [3] I. J. Cox, J. Kilian, T. Leighton, and T. Shamoan, "Secure spread spectrum watermarking for multimedia," *IEEE Trans. Image Processing*, vol.6, pp.1673-1687, Dec.1997.
- [4] H. Matsuoka, Y. Nakashima, and T. Yoshimura, "Acoustic communication system using mobile terminal microphones," *NTT DoCoMo Tech. J.*, vol. 8, no. 2, pp. 2–12, Sep. 2006.
- [5] Y. Nakashima, H. Matsuoka, and T. Yoshimura, "Evaluation and demonstration of acoustic OFDM," in *Proc. 40th Asilomar Conf. Signals, Systems and Computers*, pp. 1747–1751 Oct.-Nov. 2006.