

EMBEDDING DATA IN AN AUDIO SIGNAL, USING POWER CONTROLLED ACOUSTIC OFDM

Tejas V.Sagathia¹, Dharmesh N. Khandhar²

¹M.E. (E.C.) Student, Department of Electronics & Communication Engineering
C.U. Shah College of Engineering and Technology, Wadhwan City, Gujarat, India.

²Professor, C.U. Shah College of Engineering and Technology, Wadhwan City, Gujarat, India.

Abstract: *The OFDM technology has been extensively used in many radio communication technologies. For example, OFDM is the core technology applied in WiFi, WiMAX and LTE. Its main advantages include high bandwidth utilization, strong noise immunity and the capability to resist frequency selective fading. However, OFDM technology is not only applied in the field of radio communication, but has also been developed greatly in acoustic communication, namely the so called acoustic OFDM. Thanks to the acoustic OFDM technology, the information can be embedded in audio and then transmitted so that the receiver can obtain the required information through certain demodulation mechanisms without severely affecting the audio quality. This paper mainly discusses how to embed and transmit information in audio by making use of acoustic OFDM. Based on the theoretical systematic structure, it also designs a simulation system and a measurement system respectively. In these two systems, channel coding, manners of modulation and demodulation, timing synchronization and parameters of the functional components are configured in the most reasonable way in order to achieve relatively strong stability and robustness of the system. Moreover, power control and the compatibility between audio and OFDM signals are also explained and analyzed in this paper. Based on the experimental results, the author analyzes the performance of the system and the factors that affect the performance of the system, such as the type of audio, audio output level and so on. According to this analysis, it is proved that the simulation system can work steadily in any audio of wav format and transmit information correctly. However, due to the limitations of the receiver and sender devices, the measurement system is unstable to a certain degree. Finally, this paper draws conclusions of the research results and points out unsolved problems in the experiments. Eventually, some expectations for this research orientation are stated and relevant suggestions are proposed.*

Keywords: *acoustic, acoustic OFDM, power control, embed.*

I. INTRODUCTION

In the development of today's communication technology, the widely used techniques of information exchange such as WiFi, WiMAX and LTE are achieved through radio communication technologies. These techniques share one common feature by using Orthogonal Frequency Division Multiplexing (OFDM). As a core technology in many communication standards, OFDM has been extensively

applied mainly due to its high bandwidth utilization rate, strong noise immunity and the capability to resist frequency selective fading [1]. Also, OFDM technology cannot only be applied in radio communication technology, but in acoustic signal transmission, namely the so called acoustic OFDM [2]. Making good use of the advantages of the OFDM technology, acoustic OFDM can modulate the useful information, which is then transmitted in air or water with the help of sound sending devices such as loudspeakers. In this way, the receiver, such as a microphone could obtain such useful information through some kind of demodulation mechanisms, once they received the sound. Acoustic OFDM is mostly applied in underwater information exchange [3], for example in the short distance information exchange between different hulls. However, another more updated application of acoustic OFDM is embedding data in different audio to transmit the information. The high frequency band of the audio is partly replaced by OFDM signals and the impact on the audio quality can be mitigated by using power control of OFDM signals [2]. The idea behind acoustic OFDM is showed in Figure 1.1. Before acoustic OFDM, several approaches have been proposed to derive useful data from the audio signals such as echo hiding [4], phase coding [5] and spread spectrum [6]. However these methods can only achieve a very low data rate. Thanks to this technology, some short information such as a URL or media information advertising can all be effectively transmitted to the terminal end like a mobile phone through the manner of audio such as music.

II. PRINCIPLE OF THE ACOUSTIC OFDM

In common acoustic OFDM technology, the sender could directly broadcast the OFDM signals through an audio generator such as a loud speaker. This kind of sound is usually screaming noise similar to white Gaussian noise, which would impact people's normal life once used in the real world. However, if the OFDM signal is embedded in an audio signal and transmitted in the manner of power control, no noise will be produced and the audio quality will not be affected much. More importantly, the useful information could be transmitted effectively in this way. There are mainly three issues discussed in this paper. One is how to embed OFDM information into an audio signal and to transmit information without affecting the audio quality too much. Second, how to control the power of OFDM information and realize the compatibility between audio and OFDM signals. Third, how to make use of MATLAB

simulation results to study the factors that affect the stability and robustness of the acoustic OFDM system as well as to which degree those different factors affect the audio quality and the performance of the communication system.

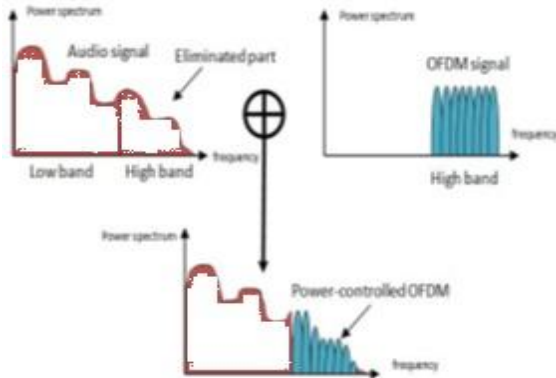


Fig. 1 The algorithm of acoustic OFDM

III. POWER CONTROL

To understand the functionality of power control we can refer to Figure 2 which compares the difference when using power control or not.

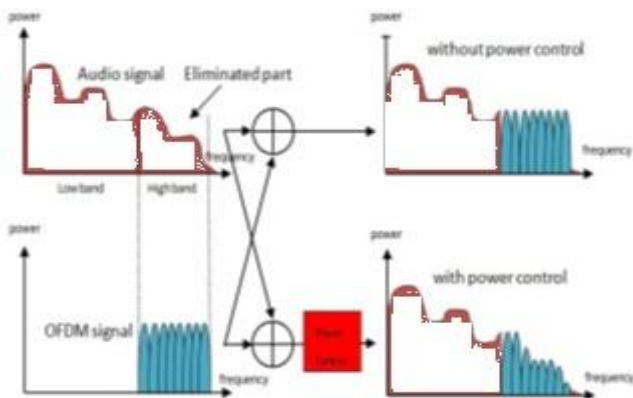


Fig.2 The power spectrum of the system with and without power control.

From the figure 2 we know that if we combine the audio signal and the OFDM symbols without power control, the spectrum of the mixed signal in the high frequency band will maintain at a constant value. This situation will bring a lot of noise to the audio signal. However, if we use power control, the power of the high frequency band will vary continuously and mimic the power of the original audio to diminish the noise and mitigate the audio distortion. In particular, the power control procedure is performed in the frequency domain. Once the audio is converted to the frequency domain, the amplitude values of the corresponding pass band will be extracted to control the power of the modulated symbols [10]. The schematic diagram is shown in Figure 2. According to this diagram, the power control takes place in the frequency domain after the modulation. The power in the

corresponding frequency band of the audio signal will be derived to control the power of useful signals. Then the audio signal in the low frequency band is combined with the useful symbols which are OFDM-modulated before they are emitted. One problem of power control is that the power of the useful signals will not be zero while the audio power at some frequencies will be zero. Hence, we need to set a threshold value for the audio control module, and this will prevent the power of the useful signals from becoming zero and avoid the occurrence of higher bit error rate.

IV. COMPATIBILITY BETWEEN AUDIO AND USEFUL DATA

The low frequency band of the audio signal needs to be combined with the power controlled OFDM symbols before being transmitted through the air. Therefore, the two signals can be mixed together only if they share some common characteristics. Since the frame mode is used for the signal transmission in the experiment, the audio signal and the useful symbols should be the same in terms of the frame length and the frame interval. It also means that the sampling frequencies of these two signals must be the same. However, it is not easy to meet this demand. The sampling rates of the useful signals are different before and after OFDM modulation. Meanwhile, the power control of the audio data takes place before the modulation and its combination with useful signals takes place after the modulation. Considering this fact, we need to re-sample the audio signals to ensure the same sampling rate corresponding to the useful signals. Figure 3 illustrates the way how audio signals are combined with the OFDM symbols. As shown in figure 3, re-sampling consists of two steps: up sampling with larger factor and down sampling with smaller factor. Since the factor for the up sampling is greater than the factor for the down-sampling, the audio quality will not be affected from this procedure. Finally, the overall sampling rate will be in accordance with the modulated useful signals. More details about the factor configurations will be described in the following chapters.

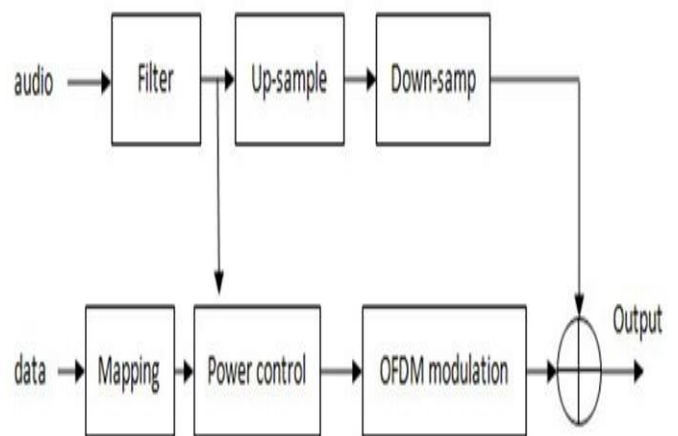


Fig. 3 The combination mechanism for audio and OFDM signals

V. TIMING SYNCHRONIZATION

The role of timing synchronization is to obtain the starting position of the useful signals at the receiver, and then demodulate the OFDM signals and recover the transmitted information. This paper mainly adopts coarse synchronization to obtain the start position of the useful signal. We add some kind of pseudo-random noise into the low frequency band of the audio signal, and then at the receiver an autocorrelation module will be utilized to derive a peak point which will be the coarse start point of the useful symbols. This principle is mostly utilized in the measurement system and in simulation system we use simulation channel to substitute the real channel. Moreover, for the simulation system the influences from Doppler Effect will not be considered and the environment noise will also be set to a low level. Therefore, we do not use coarse synchronization technology in the simulation system. The specific implementation of these systems will be explained clearly in the following chapter.

VI. SIMULATION RESULT AND ANALYSIS

A. Simulation Environment

The simulation experiment is carried out in Matlab/Simulink. The detailed simulation model is based on Matlab/Simulink (Version 7.11.0.584 (R2010b)), is used in the evaluation. The Matlab/Simulink can be used to define the structure of power controlled acoustic OFDM, to configure the source and the receiver, to create the statistical data and so on. Table illustrates the system parameters.

Subcarriers	33+4(pilots)
OFDM carrier frequency	5400 - 6400 Hz
Symbol interval	1024 samples
Cyclic prefix	600 samples
Modulation method	QAM
Channel coding	Convolution coding + Interleaving
Timing synchronization	Coarse synchronization
Sampling frequency	44100 Hz
Data rate	896 bit/s

Table 1 the System Parameters

Figure 4 is the combination of the audio signal with type of piano and the OFDM signal without power control.

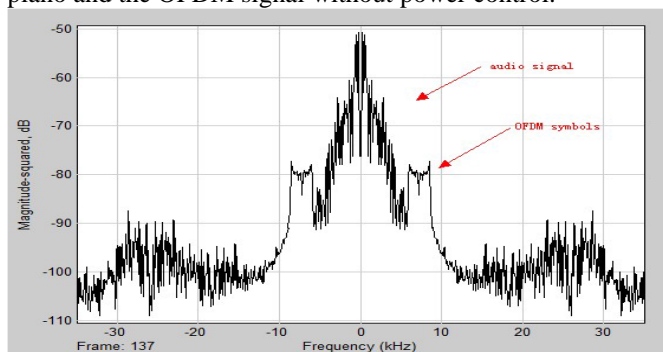


Fig. 4. The power spectrum of the combined signals without

power control

So as we can see in the figure it is just a simple addition operation between the audio signal and the OFDM signal. This will bring a lot of noise to the original audio signal and it is unacceptable in our real life. Figure 5 illustrates the power spectrum of the combination between the audio signal and the power-controlled OFDM signal. From this figure we can see that the power spectrum of OFDM signal varies over time to mimic the power spectrum of the audio signal. As a result, the noise caused by the OFDM signal will be weakened or eliminated. This is the primary feature of acoustic OFDM.

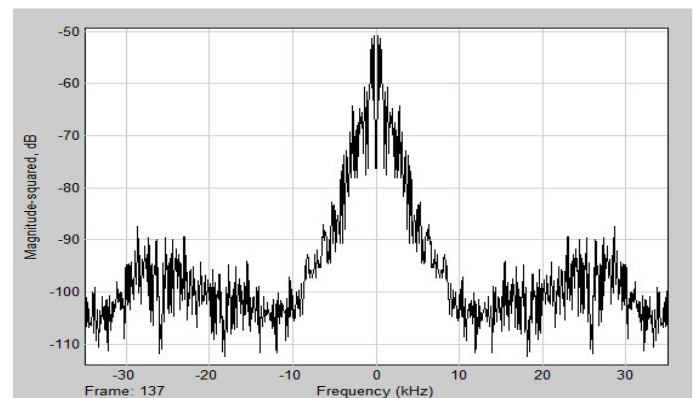


Fig. 5 The power spectrum of the combined signals with power control

For figure 5 we assume that the average power of the power-controlled OFDM signal is around -85dBW/Hz. Due to that the environment noise for the measurement system is controlled under an acceptable level, so for the simulation system we also set a low level environment noise to make sure that the system can work stably and obtain a good enough experiment result. We have also tested the system at different noise levels to analyze how the noise can influence the system performance in the following sections.

B. Bit Error Rate

Figure 6 illustrates the experiment result when different types of audio are sent with embedding data. There are eight curves in the figure below. The curve represents the relationship between the bit error rate and the signal-to-noise ratio (SNR) for the different types of audio, which is power-controlled and combined with the data signal. From figure 6 we know that the bit error rate of the system will increase for different types of audio when SNR of the system rises for the curve, meanwhile, the system with the OFDM signal with wav audio will achieve a better performance than the system with the OFDM signal embedded in an audio signal of other types.

From figure 6 we apparently find that the audio in wav format can achieve lower bit error rate than any other kind of audio in au, mp3, mp4, m4a, wma, flac, ogg format. We found that the system with the OFDM signal embedded in different types of audio signal the SNR value is around 8dB

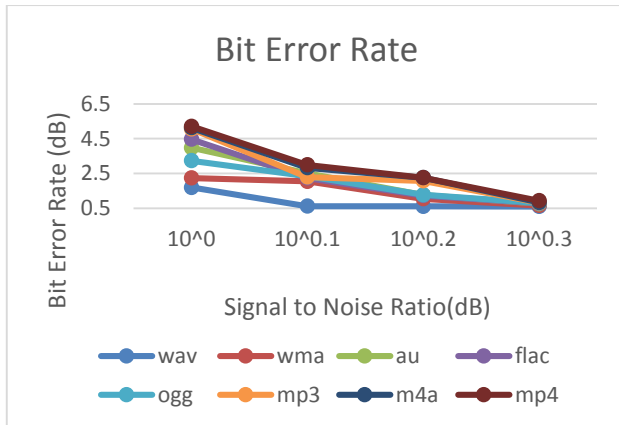


Fig. 6 The relationship between SNR and the bit error rate for the simulation System

and BER is around 0.047 when the messages can be correctly and stably transmitted.

C. Audio Distortion

Figure 7 shows the comparison of the audio distortion between the different types of audio signal with the OFDM signal embedded.

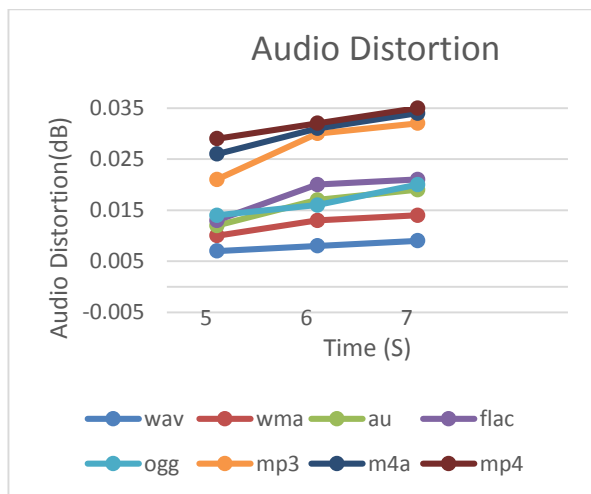


Fig. 7. The comparison of audio distortion for power-controlled system and non-power controlled system

Figure 7 illustrates the relationship between the audio distortion and the time of the acoustic OFDM signal for different kinds of audio. From figure 7 we apparently find that the audio with wav format can achieve lower audio distortion than any other kind of audio in au, mp3, mp4, m4a, wma, flac, ogg format, when the frequency of the acoustic OFDM signal rises.

VII. CONCLUSIONS

This paper has mainly researched how to embed data in an audio signal using acoustic OFDM. These two systems can transmit the standalone OFDM signal, as well as the OFDM

signal embedded in an audio signal. In the experiment we also tested the systems from different aspects such as the audio type and bit error rate to analyze how these factors can affect the system performance. As a result, we found that the measurement system can still transmit the acoustic OFDM signal correctly when the audio type is wav or wma format than au, mp3, mp4, m4a, wma, flac, ogg format. Because speech with wav or wma format most of its frequency components concentrate at the low frequency band which is normally less than 5 kHz. So the whole experiment could be considered as efficient and successful.

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