Channel Measurements and Device-Dependent Variation for Audio-Band OFDM Communication

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Abstract

This paper shows experimental results of audio-band OFDM communication system of PC-based prototype system, especially focusing Channel delay profiles and Transmitter (TX) - Receiver (RX) sampling frequency offset (SFO) and carrier frequency offset (CFO) to optimize the OFDM parameters for audio band communication.
The experiment results shows that the multi path delay length of indoor channel is order of a few milli-seconds, maximum SFO is less than 100 ppm, and maximum CFO is less than 0.1 Hz using three notebook PCs.

Keywords: OFDM, Audio Band, Sampling Frequency Offset, Carrier Frequency Offset, SFO, SCO, channel measurement

1. Introduction

Audio-Band OFDM Communication is a form of wireless communication based on Orthogonal Frequency Division Multiplexing (OFDM) in order to increase the communication bandwidth. Main OFDM parameters are sub-carrier spacing and Cyclic Prefix (CP) length. In order to optimize those parameters, channel delay profile and sampling clock drift between TX – RX has to be taken into account. Because long delay profile over CP length causes Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI), and sampling frequency offset (SFO) and carrier frequency offset (CFO) degrade Orthogonality between subcarriers.

2 Variation

Main variations between TX-RX are sampling frequency offset (SFO) and carrier frequency offset (CFO). In PC audio system, analog audio signal is sampled and converted to digital signal. Since the audio sampling frequency is determined by a crystal local oscillator (XO), the sampling frequency might drift depending on the device characteristics, voltage, and temperature and so on. In addition, audio digital signal processing such as down-conversion is performed assuming correct sampling frequency. Then SFO also cause the carrier frequency offset (CFO). Those offsets destruct the orthogonality between OFDM subcarrier and degrade the communication Bit Error Rate (BER) performance.

3 Measurement Algorithm

3.1 Delay profile

In order to measure the delay profile of acoustic channel, pilot based OFDM communication method is used as shown in figure 1. At transmitter side, BPSK signals such as 1 or -1 are randomly generated. By performing IFFT and adding Guard Interval (same as CP), transmission signals are generated. At receiver side, received BPSK data are calculated by GI remove and FFT. The received data is divided by corresponding original pilot data then Channel Transfer Function (CTF) is obtained. Then Delay profile is obtained by performing IFFT to the CTF.

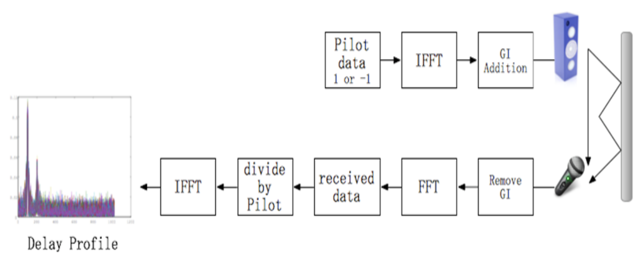

Fig 1: Delay profile

3.2 SFO and CFO Detection Algorithm

SFO and CFO detections are based on CP correlation calculation equation (11) in [1]. Since CP is the copy of the tail part of OFDM symbol, CP correlation peak (negative peak in figure 2) can be found. By calculation CP rotation as shown in upper part of figure 2, CFO can be calculated. By adding positive pass filter (PSS) and negative pass filter (NSS), SFO also can be detected as shown in lower part of figure 2.

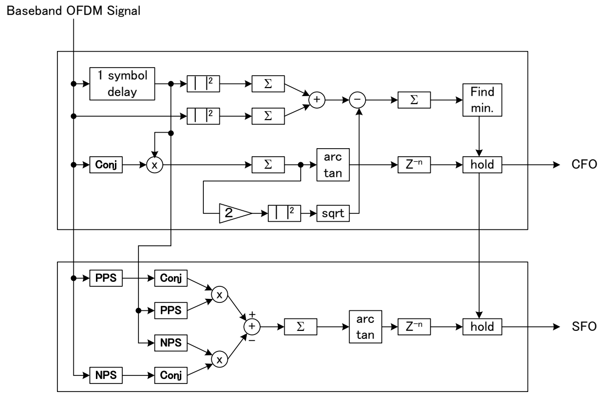

Fig 2: Detection algorithm

4 Simulation

We evaluated the detection algorithm to change the clock accuracy by adding from -300 ppm to 300ppm. The figure 3 and 4 represents the simulation results of the SFO and CFO that the algorithm detects. In the figure 3 and 4, the vertical axis is the detected simulation value and detected CFO respectively, and the horizontal axis is added clock accuracy. These are used as conversion charts in the experimental section.

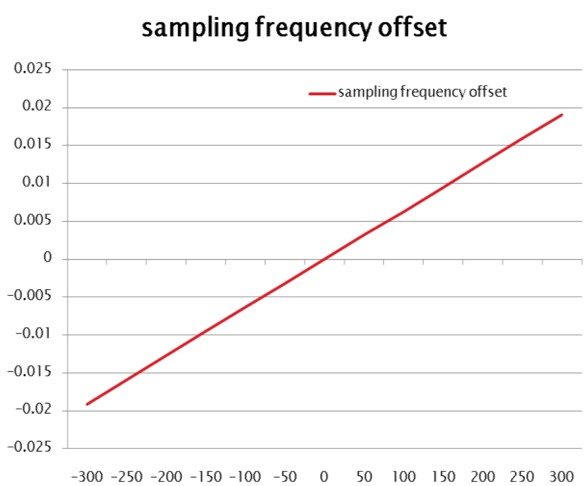

Fig 3: evaluated SFO

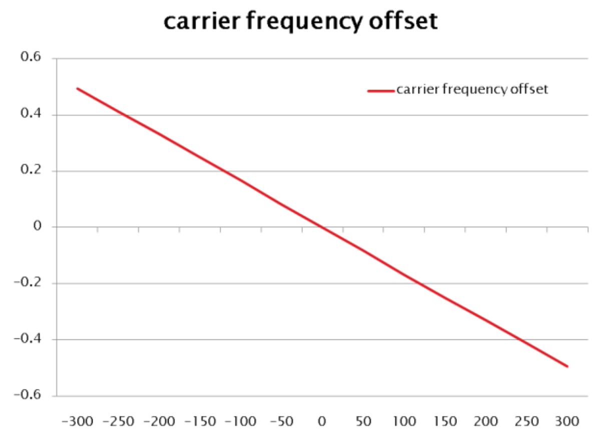

Fig 4: Evaluated CFO

5 Experiments

5.1 Parameters

We have set up the measurement system using two laptops in the delay profile measurements and BER measurements. One PC transmits signals through the speaker and the other pc receives it through using microphone.

Table 1 is the common parameters of the experiments.

Table 1: Experimental parameters

Multiplexing	OFDM
Data(Pilot) Mapping	QPSK(BPSK)
FFT Size	1024
Frequency Band	0.61~2.82kHz
Sampling Rate	44.1kHz
Symbol Length	23.2 ms
CP Length	11.6 ms
Number of Sub-carrier	51
Desirable target SFO	Less than 100 ppm
Desirable target CFO	Less than 0.43Hz

5.2 Result of delay profile measurements

5.2.1 Delay profile

Table 2 represents the Location Dependent parameters, and the figure 3.1 is experimental result. The x axis is Location, and the y axis is the Multipath delay. The result in the graph shows that the large room and corridor have longer multipath delay time.

Table 2: Location-dependency delay profile parameters

Disctance between Microphone & speaker	60 cm
Center frequency	4.74 kHz
Location	Lab room 610, Meeting room, Corridor

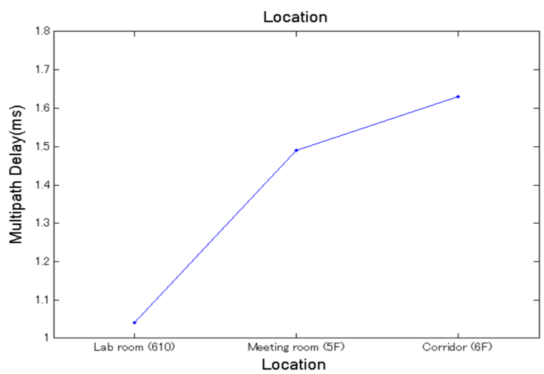

Fig 5: Location-dependency delay profie

Table 2 shows the Distance Dependent parameters, and the figure 3.2 is the experimental result. The x axis is distance between microphone and speaker. According to the experiment, the multipath delay time is increases to the distance.

Table 3: Distance-dependency delay profile parameters

Distance between Microphone & Speaker	10cm, 60cm, 110cm, 160cm, 210cm, 260cm
Center frequency	4.74 kHz
Location	Corridor

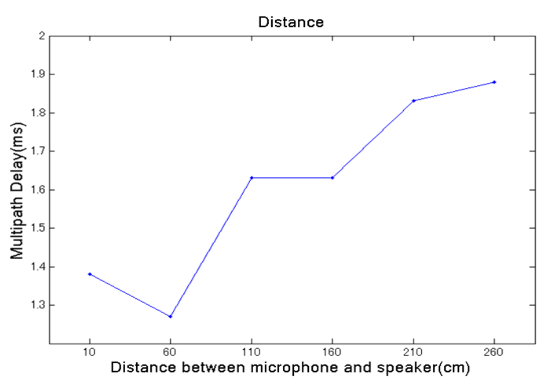

Fig 6: Distance-dependency delay profie

Table 4 expresses the Frequency Dependent parameters, and the figure 3.3 is the experimental result. The x axis is frequency. According to the experiment, the higher frequencies show a longer multipath delay.

Table 4: Frequency-dependency delay profile parameters

Distance between Microphone & Speaker	60 cm
Center frequency	1.72 kHz, 4.74 kHz, 7.75 kHz, 10.77 kHz
Location	Corridor

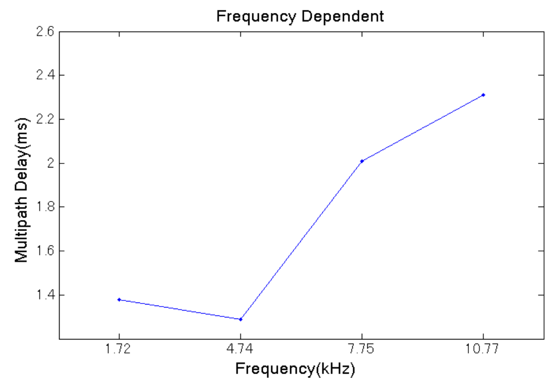

Fig 7: Frequency-dependency delay profile

5.2.2 Bit Error Rate

Table 5 indicates the Location Dependent parameters, and the figure is the experimental result. The x axis is Location, and the y axis is Bit Error Rate. According to experiment, the meeting room showed the lowest Bit Error Rate.

Table 5: Location-dependency BER parameters

Distance between Microphone & Speaker	60 cm
Center frequency	4.74 kHz
Location	Lab room610, Meeting room, Corridor

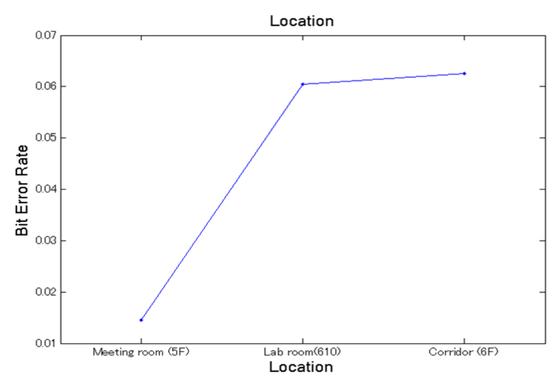

Fig 8: Location-dependency BER

Table 6 expresses the Distance Dependent parameters, and the figure is the experimental result. The x axis is distance between microphone and speaker. The result in the graph shows that the Bit Error Rate is degraded by the increase of the distance.

Table 6: Distance-dependency delay BER parameters

Distance between Microphone & Speaker	10cm, 60cm, 110cm, 160cm, 210cm, 260cm
Center frequency	4.74 kHz
Location	Corridor

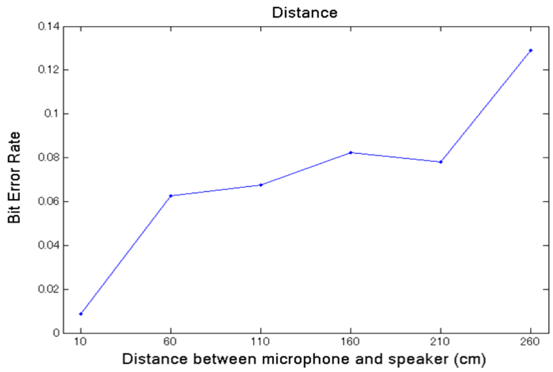

Fig 9: Location-dependency BER

Table 7 represents the Frequency Dependent parameters, and the figure is the experimental result. The x axis is frequency. The higher frequencies showed worse Bit Error Rate in our experiment.

Table 7: Frequency-dependency BER parameters

Distance between Microphone & Speaker	60 cm
Center frequency	1.72 kHz, 4.74 kHz, 7.75 kHz, 10.77 kHz
Location	Corridor

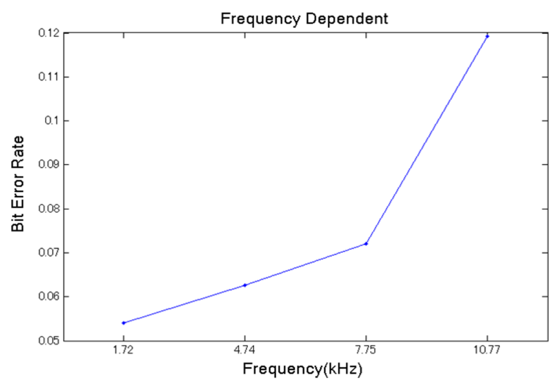

Fig 10: Location-dependency BER

5.3 Results of SFO and CFO measurement

Figure 11, 12 shows results of measured SFO and CFO from the experiment respectively. Horizontal axes are the name of notebook PCs. Vertical axes of SFO and CFO are ppm(parts per million) and the Hz respectively. The results show the maximum SFO is approximately +35 ppm. And the maximum CFO is approximately -0.06Hz.

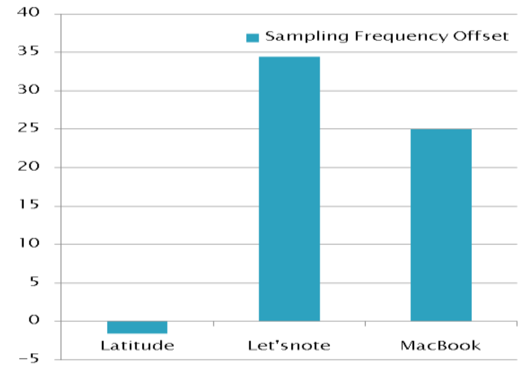

Fig 11: SFO and CFO

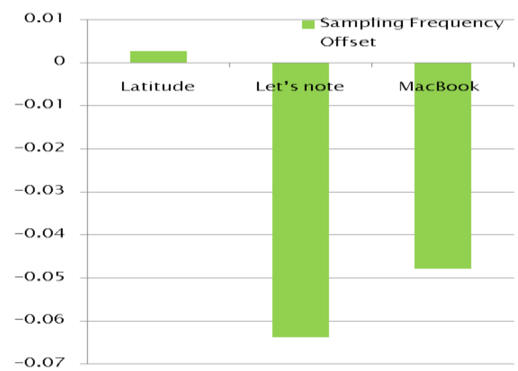

Fig 12: SFO and CFO

6. Conclusion

The measured data shows 1 – 2 ms multipath delay exists in the meeting room, the Lab room and the corridor. By increasing distance, the multipath delay increases and the BER is degraded. Higher frequencies show longer multipath delay and worse BER. Following two results are obtained. First, Longer Multipath delay degrades Bit Error Rate. Second, BER in Meeting room is better than that in Lab room, Silent room shows better BER. The measured multipath delay is small.

This paper also measured the variation which is SFO and CFO among the 3 notebooks. We conclude that the variations are low value which is less than target goal respectively.

[1] Speth M., Classen F., Meyr, H., "Frame synchronization of OFDM systems in frequency selective fading channels," 1997 IEEE 47th Vehicular Technology Conference, pp1807 – 1811, vol.3, Date: 4-7 May 1997.