Performance Analysis of Subcarrier Index Modulation-OFDM in Doppler Spread Environments

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***Abstract*—In this paper, the effect of Doppler spread in Subcarrier Index Modulation-OFDM (SIM-OFDM), one of the multicarrier transmission systems, is compared to OFDM system that the most widely used multi-carrier transmission method. For this purpose, average subcarriers interval was derived from SIM-OFDM. The results showed the performance improvement by calculating Signal-to-Interference Ratio (SIR) and by the simulation.**

Keywords — SIM-OFDM, Dopplar spread, sub-carriers

I. INTRODUCTION

SIM-OFDM is one of the multicarrier transmission methods based on OFDM [3]. As shown in Figure 1, first, the data stream is divided into two parts. One part is modulated by QPSK (or M-PSK or M-QAM) and the other one is modulated by OOK. After that, the part of QPSK modulates the data and the part of OOK modulates the location of subcarriers. If the number of ones in OOK is less than N/2, it cant be used for sub-carriers smoothly. Then, all ones and zeros should be inversed to each other. The performances of SIMOFDM such as BER, transmission rates, power reallocation has been analyzed in previous papers [3]. However, these papers have never analyzed the performances in the Doppler spread environment. So, this paper attempts to do this work.

II. CONVENTIONAL OFDM MODEL

OFDM is orthogonal frequency-division multiplexing. It is a method of encoding digital data on multiple carrier frequencies. It is suited for frequency selective channels and high data rates. This technique transforms a frequency-selective wide-band channel into a group of non-selective narrowband channels, which makes it robust against large delay spreads by preserving orthogonality in the frequency domain [2].OFDM works by splitting the radio signal into multiple smaller subsignals that are then transmitted simultaneously at different frequencies to the receiver.

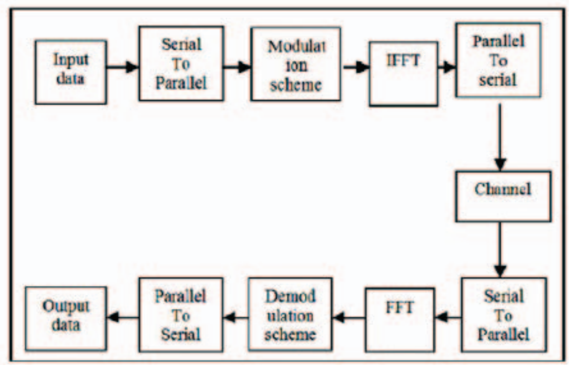

Fig. 1. The flow diagram of OFDM model

The block diagram of OFDM model is shown in Figure 1. The basic concept is the division of the available frequency spectrum into several subcarriers. To obtain a high spectral efficiency, the frequency responses of the subcarriers are orthogonal and overlapping. This orthogonality can be completely maintained with a small price in a loss in SNR, even though the signal passes through a time dispersive fading channel.

Therefore OFDM symbol can be represented as

$$x(n) = \frac{1}{N}\sum_{m=0}^{n-1} X(m)e^{j2\pi nm/N} \tag{1}$$

where x(n) denotes the sample of the OFDM signal, X(m) denotes the modulated symbol within subcarrier and N is the number of subcarriers. On receiver side this symbol are converted back to parallel stream and mapped with FFT then with demodulation scheme and converted to serial data as output data.

$$y(m) = \sum_{n=0}^{N-1} y(n)e^{-j2\pi nm/N} + w(m) \tag{2}$$

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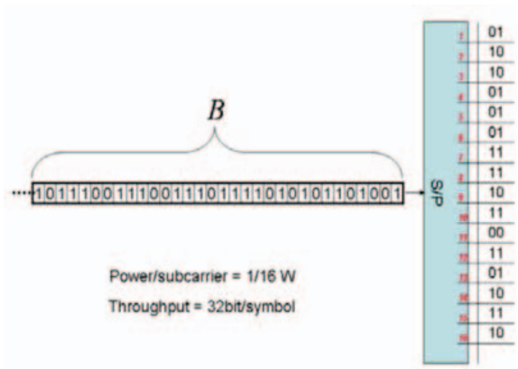

Fig. 2. Conventional OFDM

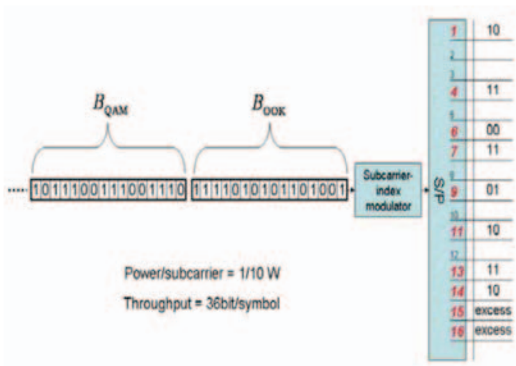

Fig. 3. SIM OFDM

Where w(m) corresponds to the FFT of the samples of the w(n). The received signal is given by,

$$y(n) = x(n)e^{j2\pi n\varepsilon/N} + w(n) \tag{3}$$

ε represents the normalized frequency offset, w(n) is the channel [1].

III. SIM-OFDM Model

Now let us focus on a new technology of SIM OFDM. The main concept of SIM OFDM can be demonstrated by the system model which is shown in Fig. 3. From the Fig. 2, we can see that in the conventional OFDM, any arbitrary bit-stream is transmitted using all subcarriers. While what difference for the OFDM is that it splits B_{OOK} the bit-stream into two bit-streams of the same length. Typically, the first bit-substream has the same size as the FFT size. Besides, it is supposed that all the subcarriers are dedicated for data transmission. In the point of this view, SIM OFDM system has an additional module named subcarrier-index modulator comparing with the traditional OFDM system.

The additional module has two main functions. Firstly, according to the first bit-steram B_{OOK}, the subcarrier-index modulator gets two subsets from B_{OOK}. The type of majority bit-value can be fixed by comparing the cardinality of the two subsets. Secondly, the position of every bit in B_{OOK} can be determined by the index of each subcarrier. After these two step, the group of subcarriers which are associated with the subset of the majority bit-value can be selected, which is used to be modulated by the second bit-substeam. In other words, the first bit-substream B_{OOK} is used in an OOK fashion to activate those subcarriers whose indices correspond to the majority bit-value [5].

IV. Analytical Derivation

Ease of use the normalized Doppler spread is defined as

$$\varepsilon_d = \frac{f_d}{\Delta f} = \frac{v f_c}{c} \times \frac{1}{\Delta f} \tag{4}$$

where $_d$ is Doppler spread frequency, Δf_d is sub-carriers interval, v is the relative speed between transceiver and receiver, c is the speed of the electromagnetic wave.

If there is no other influence in the OFDM, Δf remains steady. However, Δf does not remain steady in SIM-OFDM because of OOK. In this paper, we derive the average sub-carriers interval $\Delta f'$ after considering the total number of sub-carriers is given by,

$$\begin{aligned}\frac{\Delta f'}{\Delta f} &= (\sum_{m=0}^{N/2-1} \sum_{k=N-m-1}^{N-1} C_{k-1}^{N-m-2} \frac{k(N-k)}{N-m-1})/2^N \\ &+ (\sum_{m=N/2}^{N} \sum_{k=m-1}^{N-1} C_{k-1}^{m-2} \frac{k(N-k)}{m-1})/2^N\end{aligned} \tag{5}$$

where N is the total number of sub-carriers, and we dont consider odd number of N because of the application of FFT in OFDM. If the number of ones of OOK is less than N/2 in the left term of equation, all ones and zeros will be inversed to each other. SIM-OFDM modulation is not very different from OFDM as follows

$$x[n] = \sum_{k=0}^{N-1} X[k] e^{j2\pi kn/N} \tag{6}$$

But, X[k] is different either changing 0 in OOK or be modulated original QPSK signal. If the frequency transition occurs because of Doppler spread, the effect of phase change is similar to that of OFDM [6].

If it is demodulated,

$$\begin{aligned}&Y[k] \\ &= \frac{1}{T_{sym}} \int_0^{T_{sym}} \{\sum_{i=0}^{N-1} X[i] e^{j2\pi(i+\varepsilon_d)t/T_{sym}}\} e^{-j2\pi kt/T_{sym}} dt \\ &= \sum_{i=0}^{N-1} X[i] \{\frac{1}{T_{sym}} \int_0^{T_{sym}} e^{j2\pi(i+\varepsilon_d+k)t/T_{sym}} dt\} \\ &= \sum_{i=0}^{N-1} X[i] \{\frac{1}{j2\pi(i+\varepsilon_d+k)} \int_0^{T_{sym}} (e^{j2\pi(i+\varepsilon_d+k)} - 1)\}\end{aligned} \tag{7}$$

When $\varepsilon_d = 0$,

$$\frac{1}{j2\pi(i-k)}(e^{j2\pi(i-k)} - 1) = 1, \quad i = k$$

$$\frac{1}{j2\pi(i-k)}(e^{j2\pi(i-k)}-1)=0, \quad i \neq k$$

The interference in SIR can be calculated as follows,

$$1-\sum_{i}\sum_{j}\frac{1}{j2\pi(j+\varepsilon_d-k)}(e^{j2\pi(i-k)}-1) \tag{8}$$

V. Numerical Simulation

In this simulation, we assume that all the users are uniformly distributed in the local cell. Table 1 shows the system parameters considered for the simulation. We consider the multipath time-varying channel model whose parameters are generated by Monte Carlo method. Besides, we assume that the speed of the variation of channel is slow enough to make sure that the channel is constant for one OFDM symbol duration. With N=32, the comparisons of the performances of SIR between SIM-OFDM and OFDM are shown in Fig. 4.

TABLE I
The parameters of the simulation

N	$\Delta f'/\Delta f$	N	$\Delta f'/\Delta f$
4	1.3750	32	1.7283
8	1.5078	64	1.8043
16	1.6291	128	1.8063

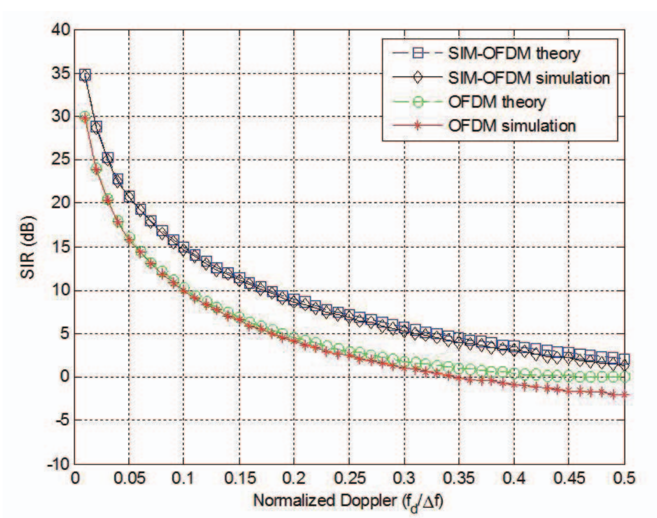

Fig. 4. SIR vs normalized Doppler for OFDM and SIM-OFDM

In the simulation result, the performances of Signal to Interference Ratio (SIR) versus normalized Doppler for both OFDM and SIM OFDM are simulated. From the result, we can see that the theoretical values and simulation results are nearly matched, and the performance of SIR for SIM-OFDM modulation is about 3dB better than that of OFDM modulation.

VI. Conclusion

In this paper, the performance of SIM-OFDM was compared with conventional OFDM in the Doppler spread environment. Theoretical values and simulation results showed that the performance of SIR for both curves are nearly matched, and the performance of SIR for SIM-OFDM modulation is about 3dB better than that of OFDM modulation. However, if SIM-OFDM uses high order modulation such as M-QAM, there is disadvantage in terms of transmission speed because a lot of sub-carriers are wasted by OOK. For the further research, more various channel models will be considered for this specific analysis. In particular, we will focus the performance in underwater environment in which Doppler spread is very large and the transmission speed is low.

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