Implementation of ICI Self Cancellation in User's Velocity From 0 to 700 Km/h to Mitigate Inter-Carrier Interference

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***Abstract*—The effect of Inter-Carrier Interference (ICI) makes Orthogonal Frequency Division Multiplexing's (OFDM's) performance getting worst. ICI itself can be caused by 2 causes, miss synchronization at transceiver and Doppler phenomenon. But Doppler phenomenon takes the highest responsibility for increasing the value of Carrier Frequency Offset (CFO). Doppler phenomenon is closely related to the movement or velocity of the user. The higher the velocity, the higher the value of CFO. In this paper, we evaluate ICI Self Cancellation method to reduce the impact of ICI while the increasing of the user's velocity. The simulation results show that the application of ICI Self Cancellation in iterated velocity from 0 to 700 km/h gives BER's correction.**

***Index Terms*—ICI; OFDM; CFO; Doppler Phenomenon; ICI Self Cancellation; Velocity.**

I. INTRODUCTION

OFDM divides high-rate data stream into low-rate multiple sub-stream and transmitted over different orthogonal sub-channels called subcarriers [2]. So each subcarrier experiences a flat-fading and less complexity of equalization at the receiver [1].

Nowadays, OFDM is the most popular technique which applied in many wireless communication systems such as Wireless Local Area Network (WLAN), High Performance Local Area Network (HIPERLAN2), Digital Video Broadcasting (DVB) and Worldwide Interoperability for Microwave Access (WiMAX) [1]. In OFDM, each sub-channel must orthogonal, but in many cases the ICI ruins the orthogonality of subcarriers. The main parameter of ICI be known as Carrier Frequency Offset (CFO). The increasing of the CFO value makes the damage getting worst to the subcarrier's orthogonality. CFO can be produced by the Doppler phenomenon which closely related with the velocity of the user. Orthogonality can be lost because of the enhancement of the user's velocity because the higher user's velocity, the higher the value of the CFO. In this paper, many input parameters, such as subcarrier spacing, FFT size, mapper and frequency band, are referring to IEEE 802.16e standard showed in [6].

Currently, there are many methods can be used to combat the effect of ICI. In literature, various methods are discussed to mitigate ICI, such as ICI Self Cancellation [1], Maximum Likelihood (ML) [3], estimation and Extended Kalman Filter (EKF) [3], time-domain windowing [4] and so on. The ICI Self Cancellation method is easy to be applied in OFDM system and very effective to cancel the ICI. So this paper is using ICI Self Cancellation method to mitigate the effect of ICI. Actually in [1], there was a similar research with this paper. But it was not discussed about the increasing of user's velocity makes the CFO increase too. The CFO directly inputted to the simulation without telling where the CFO came from.

In this paper, we present the mitigation of ICI caused by user's velocity and compared the performances of OFDM without ICI Self Cancellation (conventional OFDM) with OFDM using ICI Self Cancellation method (evaluated system).

II. OFDM & ICI MODELLING

Description of the conventional OFDM's block diagram is followed the same procedure given in [1] except the type of mapper and the additional of cyclic prefix. The procedure of conventional OFDM shown in Figure 1.

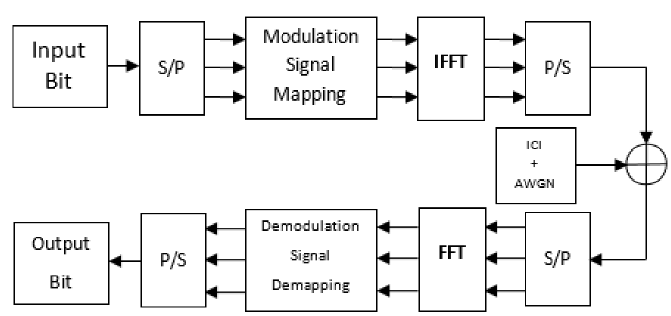

Figure 1: Block diagram of conventional OFDM

Firstly a stream of input serial bit transformed into parallel performed by S/P, then each output of block S/P are mapped by modulation signal mapping (the mapper used are 16QAM, 32QAM and 64QAM), then perform IFFT on N-parallel subcarriers and transmit the signals after adding the ICI through AWGN channel in serial form after get in into block P/S. At the receiver side, the signals are transformed into parallel performed by block S/P, then perform FFT, demapped into bits using block demodulation signal demapping, and perform block P/S to change the form become serial back.

In OFDM system, the transmitted signal is given by [2]:

$$x_n = \frac{1}{N}\sum_{k=0}^{N-1} x_k\, e^{j2\pi nk/N} \tag{1}$$

where x_n denotes the n^{th} sample of transmitted signal, x_k denotes the modulated symbol for the k^{th} subcarrier (where k=0,1,2,…,N) and N is number of subcarriers.

At the receiver side, the time domain's signal is given by [1]:

$$y(n) = x(n)e^{\frac{j2\pi n\varepsilon}{N}} + w(n) \tag{2}$$

ε is the normalized frequency offset and *w(n)* is AWGN channel. Then, the received signal at the k^{th} subcarrier is determined by [1]:

$$Y(k) = X(k)S(0) + \sum_{l=0;\, l\neq k}^{N-1} X(l)S(l-k) + W(k)\,;\ k = 1,2,3,\dots,N-1 \tag{3}$$

where *W(k)* is the output of block FFT from *w(n)* as the input. On the equation 3, *S(l – k)* is the ICI components in the received signal. The ICI components become the interference to the others. Then, the *S(l – k)* is given as [1]:

$$S(l-k) = \frac{\sin[\pi(l+\ \varepsilon - k)]}{N.\sin\left(\frac{\pi(l+\varepsilon-k)}{N}\right)}\ e^{j\pi\left(1-\frac{1}{N}\right)(l+\varepsilon-k)} \tag{4}$$

The *S(l – k)* is the complex coefficients for ICI. This components are added to the k^{th} subcarrier and become the interference for that subcarrier. The main parameter of this component is CFO (ε), where ε is given as [1]:

$$\begin{aligned}\varepsilon &= f_d\ x\ T_s \\ &= \frac{f_d}{\Delta f}\end{aligned} \tag{5}$$

where Δf is the subcarrier spacing between a subcarrier to another subcarrier. On the other hand, f_d is Doppler Frequency shift. This parameter is used to determine the shifting of the frequency. Furthermore, Doppler Frequency shift is following this equation [5]:

$$fd = \frac{v}{\lambda}\cos\theta \tag{6}$$

where v is the velocity of user, this parameter is dynamic. The value will be iterated and plotted into the chart. θ is the angle between transmitter and receiver assumed 0°. λ is wavelength given as [5]:

$$\lambda = \frac{c}{f} \tag{7}$$

where c is light speed equal to 3 x 10^8, and f is the carrier frequency. So, the equation for the value of ε is:

$$\varepsilon = \frac{v\ x\ f\ x\cos\theta}{c\ x\ \Delta f} \tag{8}$$

III. ICI Self Cancellation Description & System Input Parameters

ICI Self Cancellation is an ICI mitigation method where some redundancy of subcarriers are created for every single genuine subcarrier. The creation of subcarriers in the transmitter are given by [1]:

$$X'(k) = X(k), X'(k+1) = -X^*(k)\,; (k = 0,2,4,\dots, N-2 \tag{9}$$

where *X'(k)* are the transmitted signals and *X(k)* are the genuine signals. Meanwhile, in the receiver side, the desired signals are performed by [1]:

$$Z(k) = \frac{1}{2}(Y'(k) - Y'^*(k+1)) \tag{10}$$

Furthermore, OFDM using ICI Self Cancellation mitigation method is explained by block diagram below:

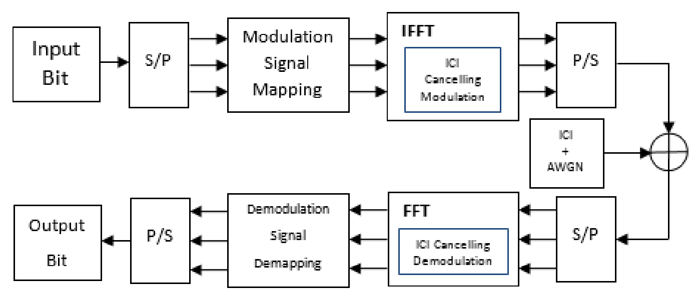

Figure 2: Block diagram of OFDM using ICI Self Cancellation method

Figure 2 and Figure 1 showed the same process except in the block IFFT and FFT. In Figure 2, block IFFT and FFT perform ICI Self Cancellation method. In IFFT block, the ICI Cancelling Modulation is following equation 9. In the FFT block, the ICI Cancelling Demodulation is following equation 10. Table 1 shows the input parameters to the simulation.

Table 1
Input Parameters of Simulation

Parameter	Specification
FFT size [6]	512
Subcarrier (N) [6]	512
Mapper [6]	16QAM, 32QAM, 64QAM
Channel	AWGN
Frequency *(f)* [6]	2300 MHz
Subcarrier spacing *(Δf)* [6]	10.94 KHz
Eb/No	17 dB
No. of bit transmitted	10^6 bits

IV. Results

The implementation of ICI Self Cancellation in OFDM compares with the conventional OFDM. There are 3 mappers used in this paper to evaluate the performance of the implementation of ICI Self Cancellation that are 16QAM, 32QAM and 64QAM. As the results, we figured out the value of BER to the velocity.

As we can see in Figure 3 to Figure 5, ICI Self Cancellation gives correction to the OFDM performance. Even at 700 km/h the implementation of ICI Self Cancellation is still better than the conventional OFDM at all mappers for Eb/No = 17 dB. Here are the simulation results of this paper.

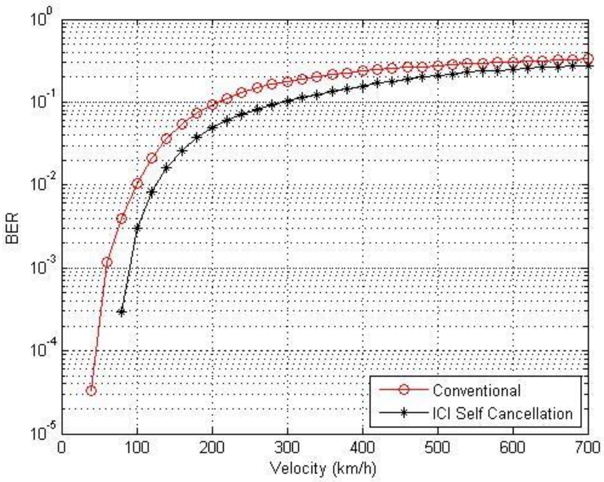

Figure 3: BER comparison of conventional OFDM and ICI Self Cancellation using 16QAM to user's velocity with Eb/No = 17 dB

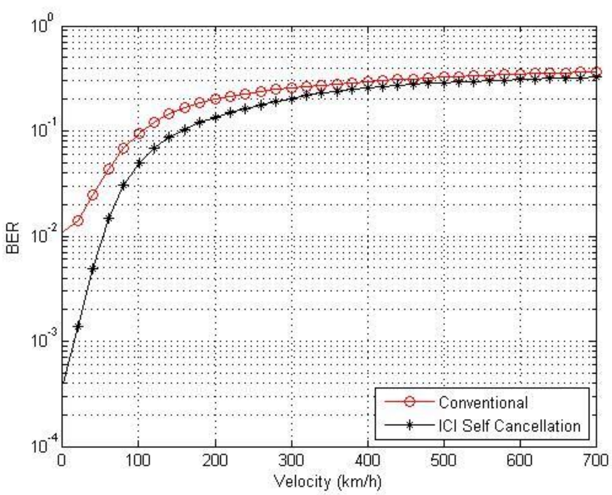

Figure 4: BER comparison of conventional OFDM and ICI Self Cancellation using 32QAM to user's velocity with Eb/No = 17 dB

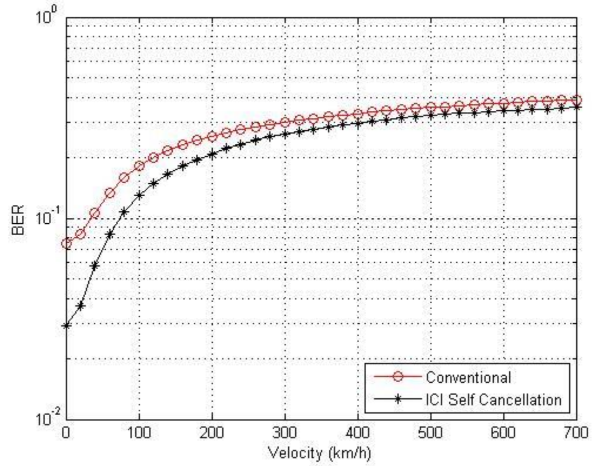

Figure 5: BER comparison of conventional OFDM and ICI Self Cancellation using 64QAM to user's velocity with Eb/No = 17 dB

For example at velocity = 200 km/h, for 16QAM mapper, the BER value of conventional OFDM is 0.2353 and for OFDM using ICI Self Cancellation is 0.1566, so the difference between them is 0.0787, for 32QAM mapper, the BER value of conventional OFDM is 0.2954 and for OFDM using ICI Self Cancellation is 0.2557, so the difference between them is 0.0397, for 64QAM mapper, the BER value of conventional OFDM is 0.3310 and for OFDM using ICI Self Cancellation is 0.2976, so the difference between them is 0.0334. It means, in BER performance, at velocity = 200 km/h for Eb/No = 17 dB, OFDM system using ICI Self Cancellation is better than conventional OFDM in all mappers tried. To simplify the analysis, Figure 6 shows the bar chart of BER comparison between conventional OFDM and OFDM using ICI Self Cancellation at velocity = 200 km/h and Eb/No = 17 dB.

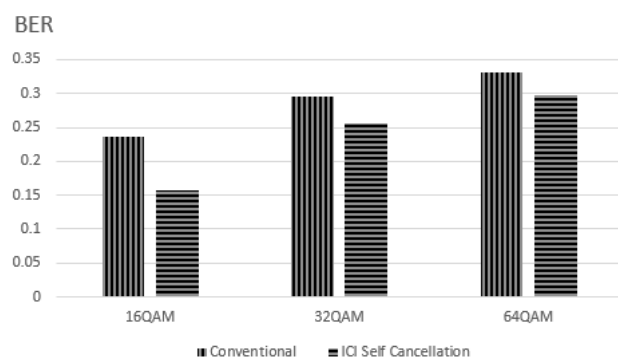

Figure 6: BER comparison bar chart between conventional OFDM and OFDM using ICI Self Cancellation at velocity = 200 km/h and Eb/No = 17 dB

V. Conclusions

In this paper, we evaluated the implementation of ICI Self Cancellation in OFDM system to conventional OFDM in high mobility of user. The results showed that in all mappers simulated (16QAM, 32QAM and 64QAM) with E_b/N_o = 17 dB, the implementation of ICI Self Cancellation gives BER corrections in all ranges of velocity (0-700 km/h). From all of the results, we conclude that the usage of ICI Self Cancellation is very suitable to use in user's high mobility.

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