Adaptive OFDM for High Mobility Computer Application

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Abstract—OFDM based wireless systems are spectrally efficient but they are very sensitive to Doppler shift. The high mobility causes the channel to vary fast and the rapid variation of the channel can induce Inter Carrier Interference (ICI). ICI due to fast fading channel is more difficult to handle and it causes loss of orthogonality between the sub carriers. This kind of ICI can be easily reduced by increasing the sub carrier bandwidth. In this paper we proposed an Adaptive OFDM system which will use Variable Sub carrier Bandwidth (VSB) and Variable Bit Loading (VBL) based on the Doppler velocity to minimize the effect of ICI. We investigate the performance of such Adaptive OFDM system with conventional OFDM system based on throughput.

Index terms—Adaptive OFDM, ICI, VSB-VBL Technique

I. INTRODUCTION

OFDM has been used for wireless applications, like digital broadcasting of digital audio, digital television, and the mobile radio communication. Initially OFDM systems are targeted for fixed and low mobility applications. More recently, high mobility applications are targeted. The high mobility introduces more Doppler shift which causes loss of orthogonality between the sub carriers and introduces ICI.

In conventional OFDM systems most of the approaches to combat ICI are towards using frequency synchronization and interference cancellation. They are usually very complex and sometimes there is loss in bandwidth efficiency [1]. In the conventional OFDM system sub carrier bandwidth is kept constant for all the Doppler velocities. Authors in [1] have proposed VSB-VBL technique to select variable sub carrier bandwidth based on the Doppler velocity. The same technique is used in this paper to design Adaptive OFDM.

The organization of this article is as follows; High mobility and channel estimation error is described in section II. Section III contains the Analytical Model and section IV contains algorithm to find VSB-VBL. Results and Discussion are in section V, which is followed by the conclusion in section VI.

II. HIGH MOBILITY AND CHANNEL ESTIMATION ERROR

To detect the input signal the channel needs to be known. For low mobility applications the channel is assumed to be constant within one OFDM symbol. But for high mobility applications the channel is variant within one OFDM symbol. So the channel has to be estimated from the training data or the statistics characteristics of the channel. The difference between the estimated channel and actual channel is channel estimation error. The high mobility contributes more channel estimation error which also introduces ICI.

III. ANALYTICAL MODEL

In OFDM, IFFT is used at the transmitter side and FFT at the receiver side. The sent sequence is formed by first taking IFFT and then pre-appending CP [5]. It is given by,

$$z_n = \frac{1}{N} \sum_{k=0}^{N-1} Z_k e^{j \frac{2\pi kn}{N}} \quad n=0,1,\dots,N-1 \quad (1)$$

Let the received sequence i.e input to FFT is denoted by $y_0, y_1, \dots, y_{N-1}$. Let $H_{k,n}$ denote the transfer function of channel for carrier k and sample n of sent signal.

Considering the K th sub carrier at the output of FFT [5],

$$Y_K = \sum_{n=0}^{N-1} y_n e^{-j \frac{2\pi}{N} Kn} \quad (2)$$

$$Y_K = \sum_{n=0}^{N-1} \frac{1}{N} \sum_{k=0}^{N-1} Z_k H_{k,n} e^{j \frac{2\pi(k-K)n}{N}} \quad (3)$$

$$Y_K = \sum_{k=0}^{N-1} Z_k \sum_{n=0}^{N-1} \frac{1}{N} H_{k,n} e^{j \frac{2\pi(k-K)n}{N}} \quad (4)$$

Here the channel for the K th sub carrier during the reception of one OFDM symbol is assumed to vary in a linear fashion [5].

$$H_{K,n} = \overline{H_K} + \left(n - \frac{N-1}{2} \right) \frac{H'_K}{N} \quad (5)$$

Where H'_K is the channel change during the symbol and H_K is the average channel experienced during the OFDM symbol. Consequently, the ICI on sub carrier K caused by the symbol sent on sub carrier $K+L$ is given by [5],

$$Y_{K,K+L} \approx Z_{K+L} H'_{K+L} \frac{1}{j2\pi L} \quad (6)$$

In case Jake's model is assumed for the Doppler spectrum the well known formula for the ICI power caused by Doppler is obtained,

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$$P_{ICI} = \frac{\pi^2}{6} f_d^2 \quad (7)$$

Where $f_d = \frac{f_D}{\Delta f}$ is normalized Doppler i.e actual

Doppler divided by sub carrier bandwidth.

When there is only one path the received signal is

$$y_i = h_i * z_i + w_i \quad 0 \leq i \leq N \quad (8)$$

Where w_i is the white Gaussian noise.

The estimate of the input is

$$z_i = \frac{y_i}{\hat{h}_i} = z_i + \frac{z_i \cdot e_i}{\hat{h}_i} + \frac{w_i}{\hat{h}_i} \quad 0 \leq i \leq N \quad (9)$$

Where $\hat{h}_i$ is the estimate h_i and e_i is the channel estimation error.

The signal to interference plus noise ratio is

$$SINR = v_{rx} [K, \Delta f_m] = \frac{z_i^2}{\left| \frac{z_i \cdot e_i}{\hat{h}_i} + \frac{w_i}{\hat{h}_i} \right|^2} \quad (10)$$

IV. ALGORITHM TO FIND VSB-VBL

Here we propose an algorithm to select sub carrier bandwidth and bit load per sub carrier based on Doppler velocity to achieve target BER.

The following steps are executed in sequence.

- 1) Select one sub carrier bandwidth from the available options.
- 2) Evaluate (10), i.e. SINR at each sub carrier for the selected sub carrier spacing.
- 3) Bit load per estimate [1], [3] is calculated using (11).

$$b_L(K, \Delta f_m) = 2 \left\lfloor \frac{1}{2} \log_2 \left(1 - \frac{1.6}{\ln \left(\frac{b0req}{0.2} \right)} \right) v_{rx} [K, \Delta f_m] \right\rfloor \quad (11)$$

where $\lfloor \cdot \rfloor$ operator is the floor operation. In the above expression $b0req$ is the target BER which is to be satisfied.

- 4) Calculate BER[1],[4] by using the following expression

$$b_0(K, \Delta f_m) = 0.2 e^{\frac{-1.6 v_{rx} [K, \Delta f_m]}{2^{b_L(K, \Delta f_m)} - 1}} \quad (12)$$

- 5) Store the value of BER along with the value of sub carrier band width and associated bit loads per sub carrier.
- 6) Repeat all the above steps for all possible values of sub carrier bandwidth.
- 7) Execute the following to find best sub carrier bandwidth[1],[2]

$$\Delta f_{chosen} = \min [BER (\Delta f_m)] \quad (13)$$

V. RESULTS AND DISCUSSIONS

In this paper we use Jake's model for each path of time

varying Rayleigh Fading channel. The channel is modelled as three tap delay line. The carrier frequency is 5GHz and bandwidth of one channel is 20 MHz. The target BER is kept at 10^{-3} . The number of bits that can be loaded on a sub carrier are 0,2,4,6,8,10, where '0' means no transmission. Four different conventional Fixed Sub carrier Bandwidth systems are taken for the comparison purpose. The system with 2048 sub carrier has $\Delta f_m = 2.4$ kHz (C-2048). The system with 1024 sub carrier has $\Delta f_m = 4.88$ kHz (C-1024). The system with 512 sub carrier has $\Delta f_m = 9.77$ kHz (C-512). The system with 256 sub carrier has $\Delta f_m = 19.531$ kHz (C-256). The Adaptive OFDM system is named as A-OFDM in the figures.

Fig.1. is the plot between SINR and sub carrier bandwidth at SNR of 60 dB. Here four different velocities (50,100,150,200 kmph) are taken for the analysis. It can be seen from the figure that SINR improves with increasing sub carrier bandwidth for a given Doppler velocity.

Fig.1 SINR vs. Sub carrier bandwidth at SNR of 60 dB.

Fig.2 BER vs. Sub carrier bandwidth at SNR of 60 dB

Fig.2. is plot between BER and sub carrier bandwidth at SNR of 60 dB. Each curve is for a particular velocity. The BER value decreases upto certain bandwidth then keeps on increasing. The sub carrier bandwidth at which BER value is minimum that bandwidth is taken as variable bandwidth for that particular doppler velocity.

Fig.3. shows the average sub carrier bandwidth selected by Adaptive OFDM system based on VSB-VBL technique for different values of velocity at a received SNR of 60 dB.

Fig.3 Sub carrier bandwidth selected by VSB system

Fig.4 Transmitted A-OFDM signal for 50 kmph Doppler velocity

Fig.4. shows the transmitted A-OFDM signal for the Doppler velocity of 50 kmph. A-OFDM has longer symbol duration for low Doppler velocities. The sub carrier bandwidth selected by A-OFDM system for the Doppler velocity of 50 kmph is 5 kHz. Fig.5. shows the spectrum generated for A-OFDM at 50 kmph Doppler velocity.

Fig.6. shows the transmitted A-OFDM signal for the Doppler velocity of 200 kmph. A-OFDM has shorter symbol duration for high Doppler velocities. The sub carrier bandwidth selected by A-OFDM system for the Doppler velocity of 200 kmph is 19 kHz. Fig.7. shows the spectrum generated for A-OFDM at 200 kmph Doppler velocity.

Fig.5 A-OFDM Spectrum for 50 kmph Doppler velocity

Fig.6 Transmitted A-OFDM signal for 200 kmph Doppler velocity

Fig.7 A-OFDM Spectrum for 200 kmph Doppler velocity

Fig.8. is the Throughput comparison of A-OFDM and various C-OFDM systems at SNR of 60 dB. Up to the doppler velocity 200 kmph the C-256 OFDM system has higher throughput when compared to all other systems. Then upto 100 kmph C-512 OFDM system has high throughput when compared to A-OFDM, C-1024, C-2048 systems. Then upto 50 kmph the C-1024 OFDM system has high throughput when compared to A-OFDM and C-2048 systems. When the doppler velocity reaches 200 kmph throughput value of all C-OFDM systems (including C-256) becomes lower when compared to A-OFDM system. So A-OFDM system has optimal throughput performance.

Fig.8 Throughput comparison of A-OFDM and various C- OFDM systems at SNR of 60 dB.

VI. CONCLUSIONS

It has been found that the Conventional OFDM system is optimum over a small range of Doppler velocity and it is not well suited for high mobility applications. Adaptive OFDM system has optimum throughput performance for low and high mobility conditions. It improves throughput [2.95% to 23.41%] when compared to conventional OFDM systems for high mobility applications.

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