Low -Complex ICI Reduction due to Channel Estimation Error in OFDM systems using VSB-VBL Technique for High Mobility Applications

K. Vinoth Babu, K.V.N. Kavitha and K. Murali Babu

Abstract—**OFDM based wireless systems are spectrally efficient but they are vulnerable to Inter carrier interference (ICI). The rapid variation of the channel can induce ICI. ICI will significantly increase the difficulty of OFDM channel estimation. ICI due to carrier frequency offset can be mitigated by accurate frequency synchronization but ICI due to fast fading channel is more difficult to handle. This kind of ICI can be easily reduced by increasing the sub carrier spacing. In this paper we proposed an OFDM system which will use Variable Sub carrier Bandwidth (VSB) with Variable Bit Loading (VBL) to minimize the effect of ICI due to channel estimation error. We investigate the performance of such VSB-VBL OFDM system with Fixed Subcarrier Bandwidth (FSB-OFDM) system based on Signal Interference to Noise Ratio (SINR) and Symbol Error Rate (SER).**

Index Terms—**Channel Estimation Error, FSB-OFDM, ICI, VSB-VBL OFDM.**

I. INTRODUCTION

OFDM has recently been used widely in wireless communication systems. Till now OFDM systems are targeted for fixed and low mobility applications. More recently, high mobility applications are targeted; examples DAB, DVB-H [5].

OFDM requires time and frequency synchronization to maintain its orthogonality among sub carriers and it is very sensitive to frequency offset which can be caused either by Doppler shift due to relative motion between transmitter and receiver or by the differences between the frequencies of the local oscillators at the transmitter and receiver. This causes loss of orthogonality between the sub carriers and introduces ICI.

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 all existing systems, the sub carrier bandwidth is kept constant.

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ICI is inversely proportional to sub carrier bandwidth. Authors in [1] have proposed flexible OFDM system which can adaptively select sub carrier bandwidth and bit loading based on the impairments like carrier frequency offset, sampling frequency offset, carrier phase noise, Doppler spread. They have not considered the impairments like channel information feedback delay, channel estimation error etc. In this paper we have taken the channel estimation error impairment. The focus of this work is to investigate the performance of VSB OFDM system for ICI due to this impairment.

The successful ICI cancellation relies on that channel can be accurately estimated. ICI makes greater difficulty in channel estimation. ICI can be easily reduced by increasing the sub carrier spacing (i.e.) making OFDM symbols shorter [5].

The organization of this article is as follows; channel estimation error is described in section II. Section III contains the system description and section IV contains the analytical model. An algorithm to implement VSB is discussed in section V. Results and Discussion are in section VI, which is followed by the conclusion in section VII.

II. CHANNEL ESTIMATION ERROR

To detect the input signal the channel needs to be known. As channel knowledge is not known to the receiver a priori, the channel has to be estimated from the training data or the statistics characteristics of the channel.

The estimation of channel impulse response at the pilot frequencies for both block and comb types are based on LS or MMSE. The MMSE method has better performance and is also much more complex. With the assumption that the OFDM protection guard time Tg is greater than channel impulse response.

The LS estimate is simply,

$$H(K) = \frac{Y(K)}{Z(K)} \qquad 0 \le K \le N-1 \qquad (1)$$

Where Y(K) is the received sequence and Z(K) is the training input sequence. The difference between the estimated channel and actual channel is channel estimation error. It also introduces ICI. The effect of channel estimation error is briefly explained section IV.

III. SYSTEM DESCRIPTION

VSB can be implemented in time division multiplexing (TDM) framework. The number of sub carriers in each slot is varied to generate different sub carrier bandwidths [1].

As mentioned earlier, variable bit loading (VBL) is done along with VSB. In VBL generally data rate and power are varied to maximize the spectral efficiency. It has been observed that the gain obtained in keeping the power constant while varying the rate is very close to being optimal. So the power per sub carrier is fixed and equally distributed on all data sub carrier. The rate is varied on each sub carrier by means of adaptive modulation [1], [2].

IV. 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,

$$z_n = \frac{1}{N}\sum_{k=0}^{N-1} Z_k \, e^{j\frac{2pkn}{N}} \quad n=0, 1,...N–1 \qquad (2)$$

Let the received sequence i.e input to FFT is denoted by y0, y1, … yN – 1 Let Hk, n denote the transfer function of channel for carrier k and sample n of sent signal.

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

$$Y_K = \sum_{n=0}^{N-1} y_n \, e^{-j\frac{2p}{N}Kn} \qquad (3)$$

$$Y_K = \sum_{n=0}^{N-1} \frac{1}{N} \sum_{k=0}^{N-1} Z_K \, H_{k,n} \, e^{\frac{j2p(k-K')n}{N}} \qquad (4)$$

$$Y_K = \sum_{k=0}^{N-1} Z_K \sum_{n=0}^{N-1} \frac{1}{N} H_{k,n} \, e^{\frac{j2p(k-K')n}{N}} \qquad (5)$$

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].

$$H_{K,n} = \overline{H_K} + \left(n - \frac{N-1}{2}\right)\frac{H'_K}{N} \qquad (6)$$

Where $H¢_K$ is the channel change during the symbol and H_K is the average channel experienced during the OFDM symbol. $Y_{i,j}$ denote how the *j* th symbol Z_j affects the *i* th output. It then follows that [5],

$$Y_{K,K} = Z_K \, \frac{1}{N} \sum_{n=0}^{N-1} \overline{H_K} \qquad (7)$$

$$Y_{K,K} = \overline{H_K} \; Z_K \qquad (8)$$

$$Y_{K,K+L} = Z_{K+L} \, \frac{1}{N} \sum_{n=0}^{N-1} H_{K+L,n} \; e^{j\frac{2p}{N}nL} \qquad (9)$$

$$Y_{K,K+L} = Z_{K+L} \, H'_{K+L} \sum_{n=0}^{N-1} \frac{n}{N} \, e^{j\frac{2p}{N}nL} \qquad (10)$$

Where the last step follows from that the different sub carriers are orthogonal if channel is static. To proceed, we use that if *N* becomes larger then [5],

$$\sum_{n=0}^{N-1} \frac{n}{N} \, e^{j\frac{2p}{N}nL} \, \frac{1}{N} \approx \int_0^1 t \, e^{j2ptL} \, dt = \frac{1}{j2pL} \qquad (11)$$

Consequently, the ICI on sub carrier *K* caused by the symbol sent on sub carrier *K*+*L* is given by [5],

$$Y_{K,K+L} \approx Z_{K+L} \, H'_{K+L} \, \frac{1}{j2pL} \qquad (12)$$

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

$$P_{ICI} = \frac{p^2}{6} \; f_d^2 \qquad (13)$$

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

$$y_i = h_i * z_i + w_i \quad 0 £ i £ N \qquad (14)$$

Where w_i is the white Gaussian noise.

The estimate of the input is

$$z_i = \frac{y_i}{\hat{h}_i} = z_i + \frac{z_i . e_i}{\hat{h}_i} + \frac{w_i}{\hat{h}_i} \qquad 0 £ i £ N \qquad (15)$$

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

$$SINR = n_{rx}\left[K, \Delta f_m\right] = \frac{z_i^2}{\left|\frac{z_i . e_i}{\hat{h}_i} + \frac{w_i}{\hat{h}_i}\right|^2} \qquad (16)$$

V. ALGORITHM TO FIND VARIABLE BANDWIDTH FOR SUB CARRIERS

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

The following steps are executed in sequence.

1) Select one sub carrier bandwidth from the available options.
2) Evaluate (16), i.e. SINR at each sub carrier for the selected sub carrier spacing.
3) Bit load per estimate [1], [3] is calculated using (17).

$$b_L(K, \Delta f_m) = 2\left\lfloor \frac{1}{2}\log_2\left(1 - \frac{1.6}{\ln\left(\frac{b0\,req}{0.2}\right)} n_{rx}\left[K, \Delta f_m\right]\right)\right\rfloor \qquad (17)$$

where $\lfloor . \rfloor$ operator is the floor operation. In the above expression *b0 req* is the target BER which is to be satisfied.

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

$$b_0(K, \Delta f_m) = 0.2 \; e^{\frac{-1.6 n_{rx}\left[K, \Delta f_m\right]}{2^{bL(K,\Delta f_m)-1}}} \qquad (18)$$

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]

$$Df_{chosen} = min\,[BER\,(Df_m)] \qquad (19)$$

VI. Results and Discussion

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. VSB is implemented in TDM mode. The number of bits that can be loaded on a sub carrier are 0, 2, 4, 6, 8, 10, where '0' means no transmission. The curve labelled with VSB, is for variable sub carrier bandwidth system. The system with 2048 sub carrier has Δfm=2.4 kHz. The system with 1024 sub carrier has Δfm=4.88 kHz. The system with 512 sub carrier has Δfm=9.77 kHz. The system with 256 sub carrier has Δfm=19.531 kHz.

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.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.

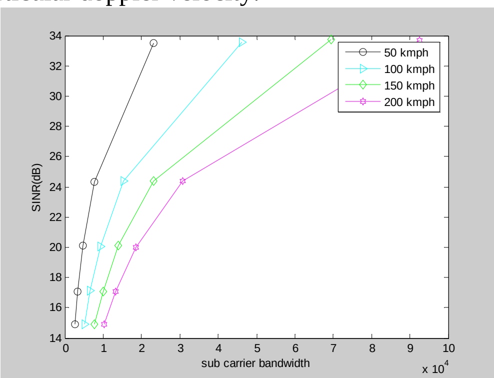

Fig.1. SINR vs. Sub carrier bandwidth at SNR of 60 dB.

Fig.3. shows the average sub carrier bandwidth selected by VSB system for different values of velocity at a received SNR of 60 dB. Now the performance, in terms of SINR and SER, of VSB system is compared against FSB systems. The symbol Error Rate (SER) for QAM modulation can be computed using

$$SER \le 4Q\left(\sqrt{\frac{3\ SINR}{2(M_0-1)}}\right) \quad (20)$$

Where $Q(x) = \frac{1}{2}\, erfc\left(\frac{1}{2}\right)$, M_0 is the modulation order.

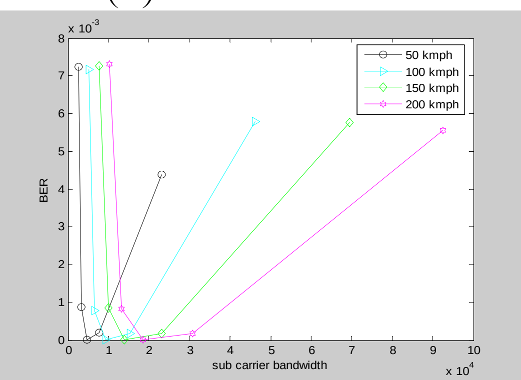

Fig.2. BER vs. Sub carrier bandwidth at SNR of 60 dB

Fig.4. is the SINR comparision of VSB and FSB OFDM systems at SNR of 60 dB. Upto the doppler velocity 200 kmph the 256 FSB system has higher SINR when compared to all other systems. Then upto 100 kmph 512 FSB system has high SINR when compared to VSB, 1024, 2048 systems. Then upto 50 kmph the 1024 FSB system has high SINR when compared to VSB and 2048 systems. When the doppler velocity reaches 200 kmph SINR value of all FSB systems (including 256) becomes lower when compared to VSB system. So VSB system has optimal SINR performance.

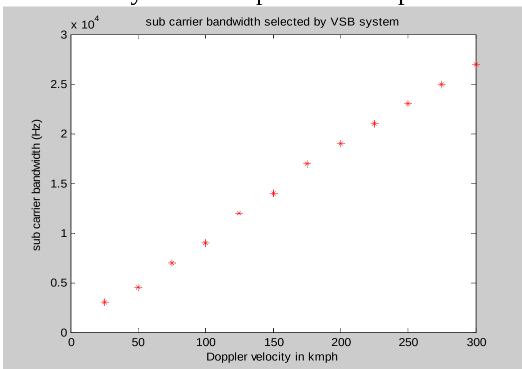

Fig.3. Sub carrier bandwidth selected by VSB system.

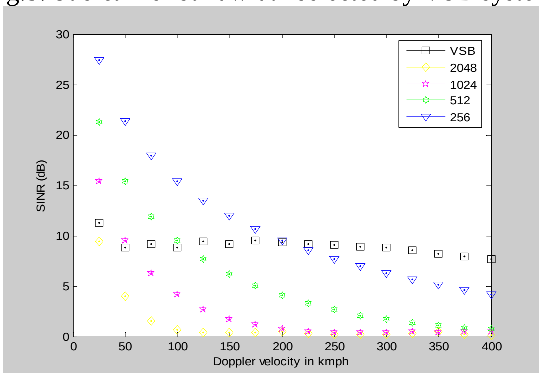

Fig.4. SINR comparison of VSB and FSB OFDM systems at SNR of 60 dB.

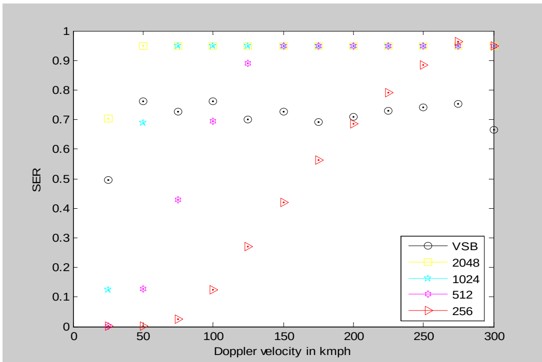

Fig.5. SER comparison of VSB and FSB OFDM systems at SNR of 60 dB.

Fig.5. is the SER comparison of VSB and FSB OFDM systems at SNR of 60 dB. The 256 FSB OFDM system has low SER when compared to all other system up to 200 kmph. The 512 FSB system has low SER up to 100 kmph when compared to VSB and 1024, 2048 FSB OFDM systems. When the Doppler velocity exceeds 200 kmph the SER value of VSB OFDM system low when compared to all other FSB OFDM systems. So VSB OFDM system has optimal SER performance.

VII. CONCLUSIONS

It has been found that a chosen sub carrier bandwidth for a FSB OFDM system is optimum over a small range of velocity and received signal strength conditions. When different users with various mobility conditions suffer from different distributions, VSB-OFDM system has optimum performance for low and high mobility conditions. VSB technique avoids complex ICI cancelation schemes at the receiver. The promising results pave the path for further investigation with realistic impairments such as channel information feedback delay, synchronization error in COFDM.

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