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MODIFIED DYNAMIC SUBCARRIER BANDWIDTH (MDSB) OFDM SYSTEMS FOR ENERGY EFFICIENT TRANSMISSION IN HIGH MOBILITY APPLICATIONS

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ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) is a fast growing technology which is frequently used in all high data rate applications. The standards like Long Term Evaluation (LTE) promise to offer a good data rate at high mobility. But the high mobility destroys the orthogonality of OFDM systems and also reduces the transmission energy efficiency. The transmit power is a very important resource in the OFDM based communication systems which determines the reliability, data rate and energy consumption of the system. Energy minimization is a very critical component in wireless OFDM applications. Minimization of energy and Inter Carrier Interference (ICI) is mainly concentrated in this work. In this paper we propose a new algorithm, Modified Dynamic Subcarrier Bandwidth (MDSB), which is a combination of Simple Bit Loading (SBL) algorithm with Dynamic Subcarrier Bandwidth (DSB) to minimize energy consumption and ICI. The results show that MDSB algorithm optimally minimizes ICI and Energy when compared to the other algorithms.

Keywords: *Simple Bit Loading (SBL), Dynamic Subcarrier Bandwidth (DSB), Modified Dynamic Subcarrier Bandwidth (MDSB), Carrier Frequency Offset (CFO)*

1. INTRODUCTION

OFDM is a fast developing technology used in wireless mobile systems. Better mobility and data rates at high speeds is the subject of recent studies [1,6]. The demand for high speed reliable wireless communication is rapidly growing. The current OFDM based systems like Wi-MAX and LTE aims at more than 100 Mbps in higher mobility. In Long Term Evaluation-Advanced (LTE-A) the peak spectral efficiency for a downlink connection using 8×8 antenna will be 30 bps/Hz and for an uplink connection 15 bps/Hz using 4×4 antenna.

Most studies today focus on boosting the throughput of the system by exploiting various higher order modulation schemes and variable code rates. [1,2].In any case energy efficiency is a growing concern since there has been no new innovation in battery technology. In addition , the advantage of anytime , anywhere multimedia applications is alluring and therefore link adaptation needs to be more energy conservative [3].

The mobility of the user causes frequency selective fading in channel and the subcarriers experience different amount of fading. To make error free transmission more energy has to be allocated for faded subcarriers. When the mobility is high user experiences fast fading which needs more energy for error free transmission [7].

Several ICI cancellation methods were discussed in the literature [1,9]. Self cancellation algorithms lead to wastage of bandwidth [9]. Kalman Filtering and Maximum likelihood based approaches makes the receiver structures complex. Many a time domain and frequency domain equalization methods were proposed which also makes receiver structures complex. Channel coding techniques reduces ICI at the cost of reduced spectral efficiency. The above mentioned methods do not discuss the following two major issues. ICI varies from user to user even though they are served by the same Base Station (BS). Different services will have different BER requirement. The authors in [1] have proposed an algorithm which dynamically varies the sub carrier bandwidth & bit loading

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based on Doppler spread and BER requirement. This method makes receiver design simple since it does not use any complex ICI cancellation algorithms. The proposed method mainly talks about ICI reduction and throughput improvement and not of energy efficient bit allocation [1].

Many energy efficient bit loading algorithms were proposed in the literature. Algorithms like Hughes-Hartogs [2] gives optimum result but it takes many iterations to converge. It is proved that the simple bit loading algorithm gives optimum solution in initial iteration itself [2].

Energy efficient transmission is important for mobile devices since they are battery operated. In energy efficient transmission both circuit power and transmit power has to be considered. We combine simple bit loading algorithm with dynamic subcarrier allocation scheme to make energy efficient MDSB system. The steps involved in MDSB scheme is clearly explained in Figure 1.

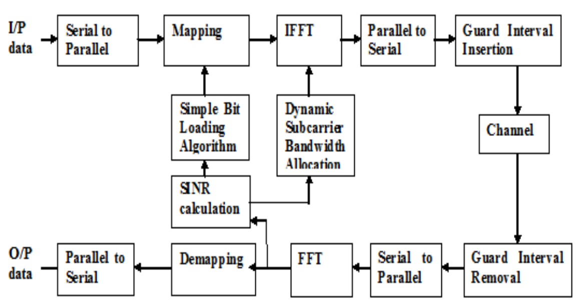

Figure 1.MDSB OFDM Block Diagram

2. ANALYTICAL MODEL

The s[th] discrete OFDM symbol in time domain is

$$a_s(q) = \frac{1}{N}\sum_{p=0}^{N-1} A_s(p) e^{\frac{j2\pi pq}{N}} \quad (1)$$

where $A_s(p)$ is the modulated symbol, N is the number of subcarriers, p is the subcarrier index, q time index.

After passing through the multipath fading channel

$$b_s(q) = \frac{1}{N}\sum_{p=0}^{N-1} A_s(p) G_s(p) e^{\frac{j2\pi(p+\varepsilon)q}{N}} + z_s(q) \quad (2)$$

where ε is the Normalized Carrier Frequency Offset (NCFO) and $z_s(q)$ represents noise.

$$\varepsilon = \frac{\theta_f}{\Delta f} \quad (3)$$

where θ_f is the carrier frequency offset (CFO) and Δf is the sub carrier bandwidth. Here we made the assumption that the carrier frequency offset is mainly due to the mobility and not due to local oscillator inaccuracies.

$$\theta_f = \frac{v f_c}{c} \quad (4)$$

where v is the velocity of the user, f_c is the carrier frequency and c is the velocity of light. From the equation it is clear that CFO increases with mobility.

Normalized Carrier Frequency Offset is

$$\varepsilon = \varepsilon_{IFO} + \varepsilon_{FFO} \quad (5)$$

where ε_{IFO} is Integer Carrier Frequency Offset (ICFO) and ε_{FFO} is Fractional Carrier Frequency Offset (FCFO).

ICFO cyclicly shifts the received signal by ε_{IFO}. ICFO does not create ICI because the orthogonality between the sub carriers is maintained. FCFO destroys the orthogonality between the subcarriers and causes ICI.

The frequency domain received signal is

$$B_s(p) = \sum_{q=0}^{N-1} b_s(q) e^{\frac{-j2\pi pq}{N}} \quad (6)$$

Then received data on p[th] subcarrier will be

$$B_s(p) = A_s(p) G_s(p) e^{j\pi(1-\frac{1}{N})\varepsilon_{FFO}} \frac{\sin \pi \varepsilon_{FFO}}{\sin(\frac{\pi \varepsilon_{FFO}}{N})} + \frac{1}{N}\sum_{\substack{m=0 \\ m\neq p}}^{N-1} A_s(m) G_s(m) e^{j\pi(1-\frac{1}{N})(m-p+\varepsilon_{FFO})} \frac{\sin \pi(m-p+\varepsilon_{FFO})}{\sin(\frac{\pi(m-p+\varepsilon_{FFO})}{N})} + Z_s(p) \quad (7)$$

The ICI power on p[th] subcarrier is [1]

$$\sigma^2_{ICI_{A_s(p)}} \cong P_A P_{G(p)} \frac{1}{N}\sum_{\substack{m=0 \\ m\neq p}}^{N-1} \frac{\sin^2 \pi(m-p+\varepsilon_{FFO})}{\sin^2(\frac{\pi(m-p+\varepsilon_{FFO})}{N})} \quad (8)$$

where

$$P_A = E\left\{|A(p)|^2\right\} \quad (9)$$

is the average power per subcarrier and $P_{G(p)}$ is the power of the channel gain at p[th] subcarrier.

For small values of ε_{FFO}

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$$\sigma^2_{ICI_{A_s(p)}} \cong \frac{1}{3} P_A P_{G(p)} (\pi\varepsilon_{FFO})^2 \quad (10)$$

Signal to Interference plus Noise (SINR) ratio is

$$\Gamma_p = \frac{P_{A_s(p)} P_{G_s(p)} \dfrac{\sin^2(\pi\varepsilon_{FFO})}{\sin^2(\frac{\pi\varepsilon_{FFO}}{N})}}{\sigma^2_{Z(p)} + \sigma^2_{ICI_{A_s(p)}}} \quad (11)$$

$\sigma^2_{Z(p)}$ is the noise variance at p^{th} subcarrier.

3. SIMPLE BIT LOADING ALGORITHM

SBL is a marginal adaptive (MA) algorithm which aims to

$$\begin{aligned} &\text{minimize} \\ &E_T = \sum_{p=0}^{N-1} E(p) \\ &\text{subject to required rate} \\ &D_T = \sum_{p=0}^{N-1} b(p) \\ &0 \le b(p) \le M \end{aligned} \quad (12)$$

where E(p) is the energy allocated to p^{th} sub carrier , b(p) is the bits allocated to p^{th} sub carrier and M is maximum number of bits that can be assigned to each subcarrier. The steps involved in SBL algorithm is

(1) Estimate the channel gain $|G|^2$ using a suitable estimation method.

(2) Partition the sub carriers into n groups

$$n = \left\lfloor \log_2 \frac{|G_{max}|^2}{|G_{min}|^2} \right\rfloor + 1 \quad (13)$$

Where G_{max} and G_{min} is the Maximum and Minimum channel gains respectively.

(3) Group the subcarriers as defined by

$$H(i) = \left\{ p : \frac{|G_{max}|^2}{2^{n-i+1}} \le |G(p)|^2 \le \frac{|G_{max}|^2}{2^{n-i}} \right\} \quad (14)$$

$i = 1, 2, ...n$

(4) Calculate the number of subcarriers that fall under each group nn(i) such that

$$\sum_{i=1}^{n} nn(i) = N \quad (15)$$

(5) Assign total number of bits U(i) to each group by

$$U(i) = \begin{cases} \text{round}[(\beta + i) \times nn(i)] & i = 1, 2...n-1 \\ D_T - \sum_{j=1}^{n-1} U(j) & i = n \end{cases} \quad (16)$$

where

$$\beta = \frac{D_T - \sum_{i=1}^{n} i \times nn(i)}{N} \quad (17)$$

is a constant.

(6) Distribute these bits to each subcarrier available in each group

$$b_u(i) = \left\lfloor \frac{U(i)}{nn(i)} \right\rfloor + 1 \quad (18)$$

$$b_l(i) = b_u(i) - 1$$

where $b_u(i) \& b_l(i)$ are bits assigned to the subcarriers in each group [2].

4. MODIFIED DYNAMIC SUBCARRIER BANDWIDTH ALGORITHM

Adaptive Subcarrier Bandwidth (ASB) algorithm proposed by authors in [1] uses equation (22) for bit loading which is energy inefficient. We modify the ASB algorithm by changing the bit loading scheme to SBL as described in section 3. The steps involved in MDSB algorithm are

(1) Select a particular Doppler velocity.

(2) From the available options select one subcarrier bandwidth.

(3) Find SINR at each sub carrier using equation (11).

(4) Find bit loading ($bl(p,\Delta f)$) for each subcarrier using simple bit loading algorithm

(5) Find BER($\Lambda(p,\Delta f)$) related to each subcarrier using

$$\Lambda(p,\Delta f) = 0.2e^{\frac{-1.6\times\Gamma(p,\Delta f)}{2^{bl(p,\Delta f)}-1}} \quad (19)$$

(6) Using bit loading and BER find throughput

$$Tpt(\Delta f) = \frac{1}{BW(Tu+Tg)} \sum_{p=0}^{N-1} bl(p,\Delta f)(1-\Lambda(p,\Delta f)) \quad (20)$$

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where BW is the bandwidth, T_u is the useful symbol duration and T_g is the guard interval duration.

(7) Repeat all the steps from 2 to 6 with different subcarrier bandwidths and store all throughput values.

(8) Choose the subcarrier bandwidth (Δf) such that

$$\Delta f_{selected} = \max[Tpt(\Delta f)] \quad (21)$$

(9) Repeat the same steps from 1 to 8 to select subcarrier bandwidth for different Doppler velocities [1,5].

The Base Station (BS) will allocate the subcarrier bandwith based on the mobility of the user.

Bit loading is done in ASB OFDM systems based on

$$bl(p,\Delta f) = 2\left\lfloor \frac{1}{2}\log_2\left(1 - \frac{1.6}{\ln(\frac{bo}{0.2})}\Gamma(p,\Delta f)\right) \right\rfloor \quad (22)$$

where bo is the target BER [1].

5. RESULTS & DISCUSSION

For the simulations Jakes Rayleigh fading channel model [7] is considered. We evaluate the performance of Simple Bit Loading algorithm based on the following parameters. The target bits $D_T = 256$ and total number of subcarriers N=64.Each subcarrier can carry a maximum number of bits of M=8. The estimated channel gain is shown in Figure 2.

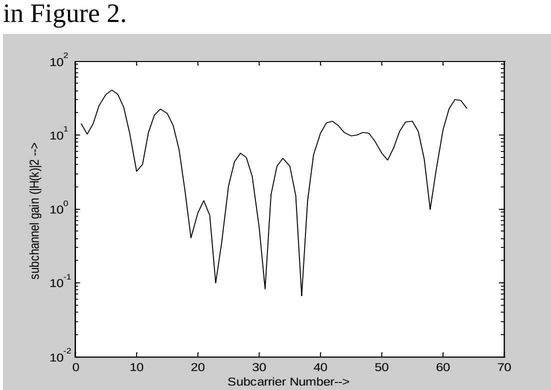

Figure 2.channel gain vs. Subcarrier index

The number of groups is divided based on equation (13) is 9. The upper and lower index of each group is found using the equation (14) and the values are listed in Table 1. It also gives the number of subcarriers in each group. The number of bits allocated to each group is found by equation (16). Then these bits are distributed to each subcarrier as per the equation (18).

Table 1. Group Indices and the number of subcarriers

Lower Index	Upper Index	Number of subcarriers
0.0391	0.0785	1
0.0785	0.3128	2
0.3128	0.6256	3
0.6256	1.2512	3
1.2512	2.5023	6
2.5023	5.0047	11
5.0047	10.0093	7
10.0093	20.0186	21
20.0186	40.0373	10

The bits allocated to each subcarrier is given in Figure 3. It can be observed that more number of bits are allocated when the channel is good and less number of bits or no bits are allocated when the channel gain is poor.

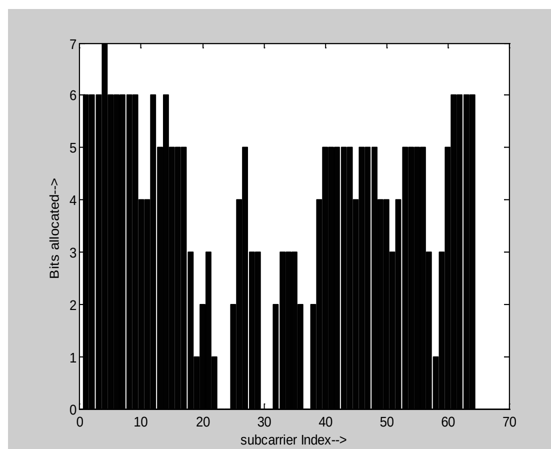

Figure 3.Bits allocated to each subcarrier

The energy allocated for each subcarrier based on SBL [2], Chow [8] and ASB bit loading algorithm [1] is shown in Figure 4. The simulations are performed over 1000 different Rayleigh fading channel conditions and the average energy required to transmit target bits are displayed in Table 2. The bit loading algorithm used in ASB requires energy of 10.5579 J to transmit the target bits of 256. But the MDSB algorithm based on SBL requires only 1.6056 J to transmit the same target bits which is

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approximately 10 times lesser than the previous one.

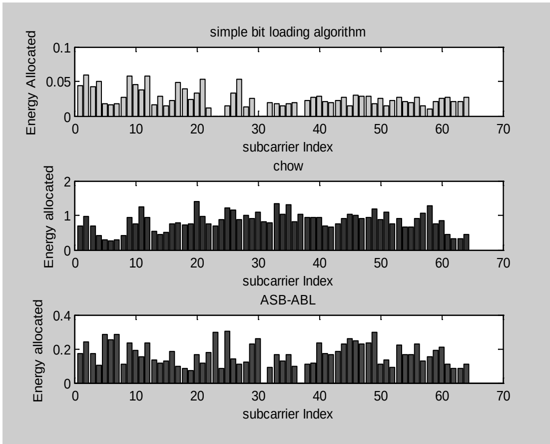

Figure 4.Energy comparison between various algorithms.

For the simulations of MDSB algorithm we take Bandwidth of 5 MHz, carrier frequency of 3.6 GHz, total number of input bits as 2048 and Jakes Rayleigh Fading channel model.

Throughput vs. subcarrier bandwidth plot is shown in Figure 5. By varying subcarrier bandwidth throughput values are calculated for a particular Doppler velocity. The subcarrier bandwidth for which throughput is maximum is taken as the subcarrier bandwidth for that velocity. Similarly the experiment is repeated for different Doppler velocities and the subcarrier bandwidth for each Doppler velocity is found and is listed in Table 3. The Base Station will allocate these subcarrier bandwidth values to the user based on their mobility.

Table 2.Total Energy Consumed

Bit Loading Algorithms	Energy required(J)
Chow	52.8091
ASB-ABL	10.5579
SBL	1.6056

Table 3. Subcarrier bandwidth selected for different Doppler velocities

Doppler Velocity (kmph)	Subcarrier Bandwidth (kHz)
0 - 100	5
100-200	10
200-250	25
250-350	30

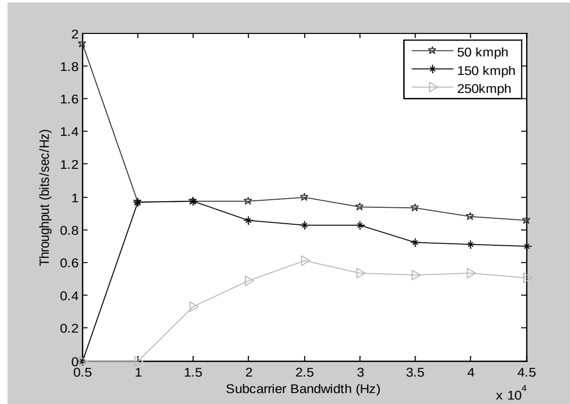

Figure 5.Throughput vs. subcarrier bandwidth

Throughput comparison between fixed subcarrier bandwidth systems and MDSB based OFDM Systems for various velocities is shown in Figure 6.The numbers 2048, 1024,512,256 used in Figure 6 represents the number of subcarriers used. Table 4 shows the subcarrier bandwidths corresponding to the number of subcarriers. These systems use same subcarrier bandwidth for all velocity conditions. But MDSB based OFDM system will use different subcarrier bandwidth for different velocity as per the Table 3.

Table 4.Subcarrier bandwidths corresponding to number of subcarriers for 5MHz bandwidth

Number of subcarriers	Subcarrier bandwidth (KHz)
2048	2.4
1024	4.88
512	9.77
256	19.531

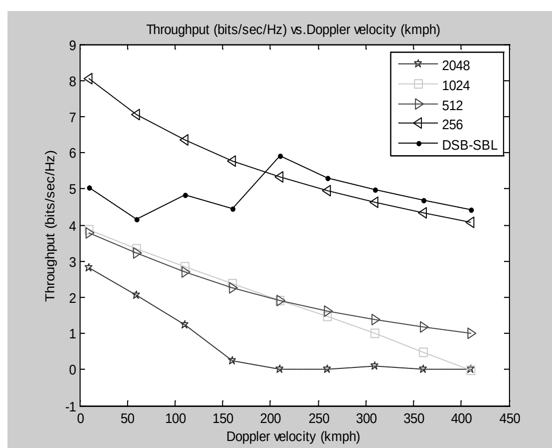

Figure 6. Throughput comparison between fixed subcarrier bandwidth systems and MDSB for various velocities.

From the Figure 6 it is clear that MDSB OFDM outperforms all fixed subcarrier bandwidth OFDM

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systems. In low mobility regions up to 200 kmph 256 fixed subcarrier bandwidth OFDM systems appears to offer more throughput but it does not support high spectral efficiency at high mobility beyond 200 kmph. The MDSB-OFDM provides optimal throughput in both low and high mobility regions.

6. CONCLUSIONS

It can be concluded that the Modified Dynamic Subcarrier Bandwidth (MDSB) OFDM systems presented in this work improves throughput of OFDM systems. It also reduces the energy required to transmit the target bits by 10 times lesser than the previous optimum bit loading algorithm used in ASB systems .simple bit loading algorithm needs channel gains as the input. In this work we used supervised training for channel estimation. Blind channel estimation methods will further increase the throughput performance.

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