EFFICIENT VIRTUAL TERMINAL MANNER IN WAVELET PACKET BASED MC-CDMA SYSTEM

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ABSTRACT

Wavelet Packet modulation has been recently attracted many researchers as a mean to achieve high performance in fast wireless communication systems. The performance of wavelet packet modulation can be increased by sending the data over some unused nodes, which are commonly called as virtual terminals, in the wavelet packet tree. In this paper, we propose an efficient algorithm to select the best sub bands for sending data packets and the position of virtual terminals with respect to the characteristics of the channel frequency response. Simulation results show the efficiency of the proposed method for wavelet packet based MC-CDMA systems in comparison with conventional methods.

1. INTRODUCTION

The basic idea behind the use of multicarrier transmission in a code division multiple access (CDMA) system is to extend the symbol duration so that a frequency selective fading channel is divided into a number of narrow band flat fading sub channels. In this way the complex time domain equalization can be replaced with a relatively simple frequency domain equalizer. Normally, an inverse fast Fourier transform (IFFT) block is used at the transmitter to modulate user data into different subcarriers, and a fast Fourier transform (FFT) block is used at the receiver to demodulate the data so as to achieve fast computation [1]. Using wavelet packets in MC-CDMA systems is a good alternative for the FFT block due to high flexibility in the choice of the wavelet packet decomposition tree [2, 3]. Moreover, wavelet packet transform can be implemented efficiently using a tree structure to achieve fast computation [4, 5]. It is shown in [6] that by leaving some unused terminal nodes in the wavelet packet tree, the performance of wavelet packet modulation (WPM) based MC-CDMA systems can be improved. These unused nodes are called as “virtual terminals”. However, choosing particular virtual terminals was not comprehensively justified. In this paper, we investigate connection between the channel frequency response and the choice of number and position of virtual terminals. In other words, according to the channel frequency response characteristics, we take advantage of virtual terminals to lead to the minimal noise level at the output of the equalizer. In this way, we adapt the structure of virtual terminals to the actual channel frequency response characteristics and mitigate the distortion imposed by the multipath fading channels.

2. WAVELET PACKET BASED MC-CDMA

Wavelet packets were introduced for data analysis and compression [7, 8]. They are functions well localized in both time and frequency domains. The input signal $x(n)$ is decomposed by a low pass filter with impulse response denoted by g and a high pass filter with impulse response denoted by h. The low pass and high pass output filters are then down sampled by two given approximation and detail coefficients. These coefficients are given by [8]:

$$\begin{aligned} y_{low}(n) &= \sum_{k=-\infty}^{\infty} x(k)g(2n-k) \quad k = 0,1,\dots,\tfrac{N}{2}-1. \\ y_{high}(n) &= \sum_{k=-\infty}^{\infty} x(k)h(2n-k) \end{aligned} \tag{1}$$

Both the detail and approximation coefficients are further decomposed by a series of high and low pass filters. The performance of any transform in a particular application is highly dependent on the chosen basis functions. The system model for WPM based MC-CDMA is shown in Fig. 1. At first, each user’s binary data $\{b_k\}, k = 0,\dots,K-1.$ is modulated by any particular constellation. After multiplying each sample of user K^{th}, d_k by its corresponding spreading code vector $C_k = (c_0^k, c_1^k, \dots, c_{L-1}^k)^T$, of length L, the superposition of K vector $\boldsymbol{s_k} = d_k \boldsymbol{C_k}$ is obtained as follow :

$$\boldsymbol{S} = \sum_k \boldsymbol{s_k} = (S_0, S_1, \dots, S_{L-1})^T \tag{2}$$

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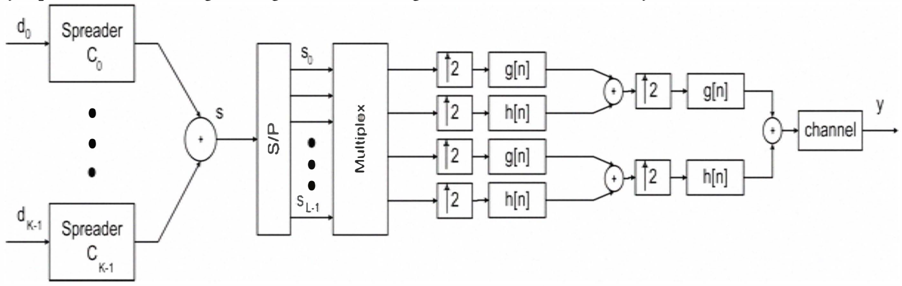


Figure 1. The system model for wavelet packet based MC-CDMA transmitter.

The sequence $\boldsymbol{S}$ is serial to parallel converted to L chips. These chips are sent to an inverse wavelet packet transform with J level of decomposition, also called tree depth, where the maximum depth of J is defined as $J_{\max} = \log_2(L)$. If data blocks are only sent to some terminals, and others left unused, the unused terminals are called virtual terminals [6]. At the receiver, in order to perform channel equalization, received signal is passed through a frequency domain equalizer such as MRC or ZF. The output of the equalizer is decomposed by the analysis wavelet packet with depth J and then, demultiplexed into L sub channels. After removing user's spreading codes, symbols of each user are demodulated.

3. PROPOSED ALGORITHM

Let s and y respectively denote the transmitted and received data vectors of the wavelet packet based MC-CDMA system in presence of additive Gaussian noise.

$$y = s.h + n \tag{3}$$

Where h is multipath channel impulse response vector and n is considered as a zero mean Gaussian noise. After taking the Fourier transform of the received data, we have

$$Y = HS + N \tag{4}$$

Where H is channel frequency response and Y, S and N are Fourier transform of y, s and n respectively. The estimated signal can be obtained by both ZF and MRC equalizers as follows:

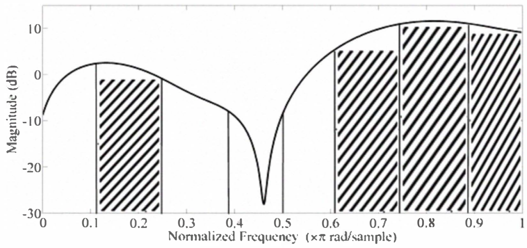
$$S_{ZF} = F^{-1}\left(\frac{H^*}{|H|^2}(H.S+N)\right) \approx S + n^{\circ}$$
$$S_{MRC} = F^{-1}(H^*(H.S+N)) \approx S + n^{\circ\circ} \tag{5}$$

Where n° and $n^{\circ\circ}$ are equivalent noises at the output of equalizers, and F^{-1} indicates inverse Fourier transform matrix. At the equalizer, there are frequency sub bands that lead to more noise level enhancement. Accordingly, the sub bands with large/small correspond channel frequency response in the MRC/ZF equalizer are caused noise enhancement. So in each case, the sub bands with more noise enhancement are replaced by virtual terminals. In this way, zeros are sent over virtual terminals while data symbols are sent over the left sub bands. This matter is well exhibited in Fig. 2 and Fig. 3. In virtual manner, due to zero insertion in virtual terminals, the length of the output stream becomes longer.

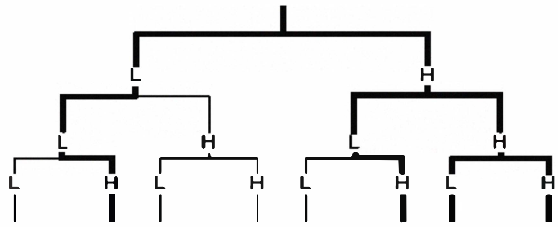
For example, assuming a symbol vector of length N is sent in bold branches in Fig. 2(b). The length of the signal at the output of the wavelet packet transform is equaled to $2N$. In general, the length of the output stream for a tree with depth J is equal to $\frac{2^J N}{2^J - V}$, where V is the number of the virtual terminals. In order to avoid an extensive increase of the output vector length, we propose the following considerations:

- The wavelet packet decomposition level J should be increased as much as possible. It improves frequency resolution.
- We select the type of equalizer with respect to the channel frequency response characteristics. In other words, the ZF equalizer is chosen when the number of sub bands with large channel frequency coefficients is more than the number of sub bands with small channel frequency coefficients and vice versa for the MRC equalizer. In this way, the number of virtual terminal is kept small.

Fig. 2(a) shows a typical channel frequency response in which the number of sub bands with large magnitude coefficients is higher than the number of sub bands with small magnitude coefficients. So, it is better to select the ZF equalizer and to choose terminals as shown in Fig. 2(b). In this figure, bold branches indicate data terminals and the others are virtual terminals. Also, data terminals related to sub bands with good channel conditions, for $J = 3$ decomposition level, are represented by striped mark. Fig. 3(a) shows the same channel frequency response as Fig. 2(a) in which the wavelet packet depth is $J = 4$. The more increasing the wavelet packet decomposition level, the higher frequency resolution is obtained. We take advantage of this point to have more sub bands with large magnitude coefficients.

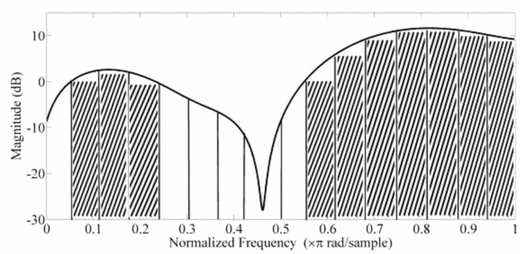


(a)

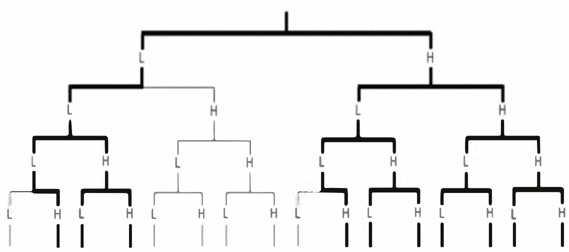


(b)

Figure 2. a)An instance of channel frequency response, stripped areas correspond to data terminals; b)The corresponding wavelet decomposition tree with $J = 3$, bold branches indicate data terminals, the ZF equalizer is suitable in this case.



(a)



(b)

Figure 3. a)An instance of channel frequency response stripped areas correspond to data terminals; b)The corresponding wavelet decomposition tree with $J = 4$, the number of data terminals are increased, the length of the output vector decreases compared to the case with $J = 3$.

So, the number of data terminals is increased, shown as bold branches in Fig. 3(b). Moreover, considering the relation $\frac{2^J N}{2^J - V}$, the length of the output stream is decreased from $2N$ to $\frac{16N}{10}$ comparing the case of $J = 3$ with $J = 4$.

Fig. 4(a) shows a channel frequency response in which the MRC equalizer is the best choice.
In this channel the number of sub bands with small magnitude coefficients is higher than the number of sub bands with large magnitude coefficients.

Assuming a slow-fading channel at the transmitter, the procedure for selecting the number and the position of virtual terminals is summarized as follows:

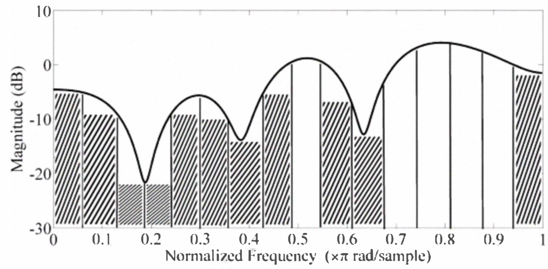
1. Send the first data packet over the channel without any virtual terminals.
2. Estimate the channel frequency characteristics and send it to the transmitter.
3. Select the type of equalizer in accord with channel frequency characteristics.
4. Select the optimum number of decomposition level and virtual terminal positions.
5. Send zero and the data packets over virtual terminals and non-virtual terminals respectively.
6. For each new channel realization go back to step 1.

4. SIMULATION RESULTS AND DISCUSSION

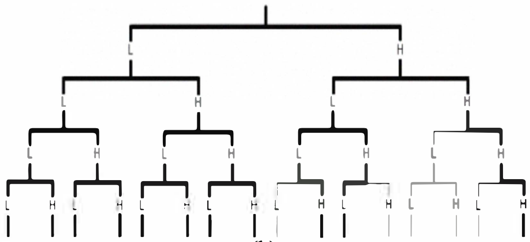
In this section the performance of the wavelet based modulation based MC-CDMA systems over multipath fading channel is evaluated. The ZF and MRC frequency domain equalizers are utilized over wavelet packet trees with and without virtual terminals. In simulated system model, Hadamard spreading codes of length $L = 16$ and 4QAM mapping are used for three users. Also, the Daubechies wavelet family (db8) is considered.

Considering Fig. 2(b), bold branches indicate sub bands which are suitable choice for the ZF equalizer and vice versa for the MRC equalizer. Let us represent the virtual terminal by *0* and a data terminal by *1* in the wavelet packet tree. In this way, the suitable terminal patterns for the ZF and MRC equalizers are labeled as *'01000111'* and *'10111000'* respectively.
Fig. 5 shows the performance of the proposed optimal choice of sub bands, with respect to channel frequency characteristics, in comparison with regular configurations. In Fig. 5, the performance of the ZF and MRC equalizers with no virtual terminals is depicted. Besides displaying the suitable choices of terminals for the both equalizers, an unsuitable terminal arrangement for each equalizer has also been shown. More precisely, terminal patterns *'10111000'* for the ZF equalizer and *'01000111'* for the MRC equalizer are improper choices.

Fig. 6 shows the performance of the typical wavelet packet based MC-CDMA systems in comparison with the proposed algorithm. As can be seen, using virtual terminal manner outperforms conventional wavelet packet based system.



(a)



(b)

Figure 4. a)An instance of channel frequency response where the number of deep fades is large, stripped areas correspond to data terminals; b)The corresponding wavelet decomposition tree with J=4, bold branches indicate data terminals, the MRC equalizer is suitable in this case.

5. CONCLUSION

In this paper, we propose an efficient virtual terminal manner to improve the performance of wavelet packet based MC-CDMA systems. Considering channel frequency response characteristics, we take advantage of virtual terminals in the wavelet packet tree structure. Data symbols are only sent over sub bands with large/small magnitude coefficients for the ZF/MRC equalizer and zeros are sent over left sub bands. Through comparison with regular wavelet packet based MC-CDMA systems, the proposed algorithm shows significant improvement in relatively slow-fading multipath channels.

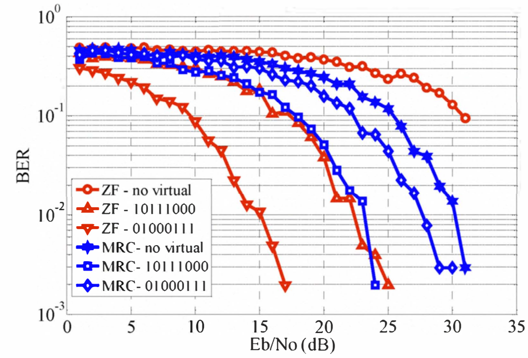


Figure 5. Bit error rate performance over Rayleigh fading channels by using virtual terminals in wavelet packet based MC-CDMA systems, terminal pattern=*'01000111'* and *J = 3*.

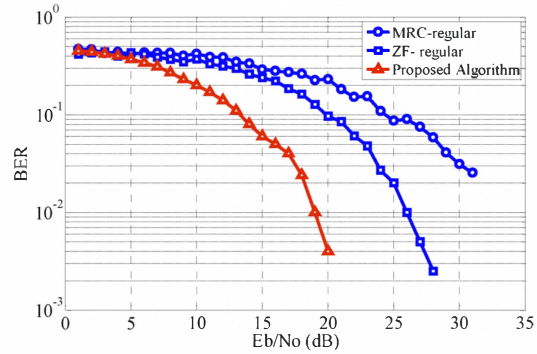


Figure 6. Comparing bit error rate performance of regular equalizers, MRC and ZF, with proposed virtual terminal based algorithm over Rayleigh fading channel.

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