Application of Multicarrier CDMA to Mobile Communication Technology

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I. INTRODUCTION

Modern cellular mobile system work on either the time division multiple access (TDMA) or code-division multiple access (CDMA) principle. In CDMA system every user is assigned a unique signature sequence to spread his information bearing signal over the available channel bandwidth irrespective of the information bandwidth. The signature sequence consists of a number of chips which is proportional to the symbol duration. This type of cellular transmission is known as direct-sequence (DS) spread spectum (SS).

The conventional receiver for DS-CDMA system is a matched filter receiver. However, mobile channel being a multipath and multiple access channel, performance of the matched filter receiver is not adequate and gives rise to near-far-problem. In the wireless channel, power from an interfering user who is closer to the base station than the desired user affects the decision of the matched filter receiver. This is called near-far-problem. Thus precise power control must be practised to avoid this problem. Hence, it is required to design a receiver for DS-CDMA system which can satisfactorily handle the above mentioned major problems suffered by the matched filter.

In a frequency selective fading envirionment, use of a single carrier for the transmission of the encoded data from the transmitter to receiver, causes signal distortion resulting in poor performance. But if the same encoded data is transmitted using more than one carrier then the received data from each subcarrier can be combined to achieve improved performance. This type of transmission is called multicarrier (MC) CDMA scheme. The MC-CDMA has following advantages: First, it is roboust to multipath fading; second, it has narrowband interference suppression capability; and finally, a lower chip rate is required, which is proportional to the subcarrier bandwidth or to the number of subcarriers. Another significant advantage of the MC-CDMA scheme is that the transmitter and receiver can be implemented using fast Fourier transform (FFT) devices to reduce their complexity. This is possible because of orthogonal frequency division multiplexing (OFDM).

II. MULTICARRIER MODULATION

The transmitted signal suffers from frequency selective fading when the signal bandwidth exceeds the coherence bandwidth of the channel. To overcome such problem multicarrier modulation is useful. In this method the available bandwidth

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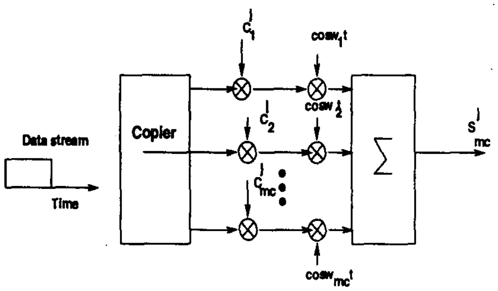

Fig. 1: MC-CDMA transmitter:first method

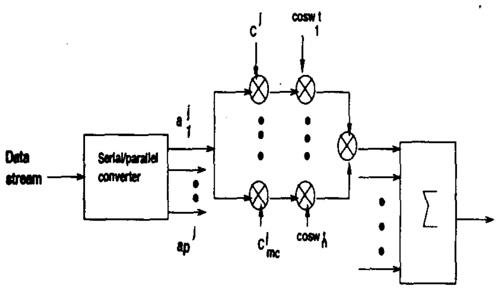

Fig. 2: MC-CDMA transmitter:second method

is divided into a number of non-overlaping bands with distinct center frequencies. The subcarriers are modulated simultaneously by users data and transmitted. Application of this multicarrier technique to the CDMA scheme is known as multicarrier CDMA scheme. In this scheme each user after spreading his information bearing signal by the assigned unique spreading code, modulates all the subcarriers simultaneously. The MC-CDMA schemes are mainly divided into two categories [2]. In first method the original data stream is spread using the spreading code and then each chip modulates a different subcarrier. In the other method the information bearing symbol is first serial-to-parallel converted and each data stream is then used to modulate a different subcarrier. The first method for generating MC-CDMA signal is shown in the fig. 1 and the second method in fig 2.

III. BLIND RECEIVER

An adaptive multiuser receiver is a right choice for this situation which takes care of the presence of other interferers in the channel . The adaptive receiver adaptively equalizes itself to the varying characteristics of the interfering signals which is analogous to slowly varying channel. This requires an adaptive algorithm. The adaptive receiver which minimizes the minimum mean square error (MMSE) requires a sequence of training symbols to be transmitted by the transmitter before the begining of the actual transmission to initialize the coefficients of the adaptive multiuser receiver. The receiver compares the received training sequence with its stored sequence and initializes its filter coefficients following some algorithm. Then, when the actual transmission starts the adaptation is done in a decision directed mode. This type of adaptation is suitable for channels with slowly varying characteristics. For rapidly varying channels the decision directed mode of adaptation fails frequently and a fresh trainging sequence is required every time the link breaks. Hence, for rapidly varying channels use of training sequence should be avoided for initial adaptation of the receiver. Class of receivers which do not require training sequences for initial adaptation are called 'Blind receivers'. These receivers assume some prior knowledge of the user and use some adaptive algorithm for demodulation. The blind receivers have been categorized into three categories [1] depending on the assumed knowledge about the user. They are

- C1) The receiver knows the timing and spreading waveform of the desired user.
- C2) The receiver knows only the spreading waveform of the desired user.
- C3) The receiver does not know any information about the desired user, other than the

fact that the desired signal is digitally modulated at a given symbol rate.

In this paper MC-CDMA transmission has been considered using a blind receiver. The blind receiver for C1 category has been used (which assumes that the timing and the signature sequence of the desired user is known) for demodulation. The same can be extended for the C2 category.

IV. SYSTEM MODEL

The proposed system model is given in fig 3. The system assumes there are K simultaneous users each of which is assigned a unique signature waveform. There are M subcarriers which every user uses to transmit its encoded data. The signature sequence for the kth user for $1 \leq k \leq K$, is given by

$$a^{(k)} = (..., a_0^{(k)}, a_1^{(k)}, ..., a_{N-1}^{(k)}, ...) \quad (1)$$

where the elements $a_i^{(k)}$ are assumed to be independent and identically distributed (i.i.d) random variables such that $\Pr(a_i^{(k)} = -1) = \Pr(a_i^{(k)} = 1) = \frac{1}{2}$. The kth transmitter for $1 \leq k \leq K$, generates a stream of data symbols b^k given by

$$b^k = (\ldots, b_0^{(k)}, b_1^{(k)}, \ldots) \quad (2)$$

The data symbols $b_j^{(k)}$ are random variables with $E[|b_j^{(k)}|^2] = 1$. The kth transmitted signal can be expressed as the real part of the complex signal given by [3]

$$x(t) = \sum_{m=1}^{M} \sqrt{2P_k c_m^{(k)}} \left\{ \sum_{i=-\infty}^{\infty} b_{i/N}^{(k)} a_i^{(k)} \psi(t - iT_c) \right\} . \exp jw_m t \quad (3)$$

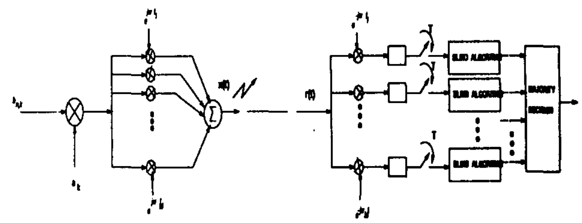

Fig. 3: Transmitter and receiver structure

The channel is assumed to be additive Gaussian channel. The received signal is given by

$$r(t) = \sum_{k=1}^{K} \sum_{m=1}^{M} \sqrt{2P_k c_m^{(k)}} \left\{ \sum_{i=-\infty}^{\infty} b_{i/N}^{(k)} a_i^{(k)} \psi(t - T_k - iT_c) \right\} . \exp(jw_m t - T_k)\alpha_{k,m} + n(t) \quad (4)$$

where $\alpha_{k,m}$ accounts for the overall effects of phase shift and fading for the mth carrier of the kth user, T_k represents the delay of the kth user signal, and $n(t)$ represents other noise. The receiver for each user consists of M-branches of demodulator and each branch is responsible for the demodulation of one carrier. The subcarrier is removed from the received signal and then the base band signal is observed over an interval. The blind algorithm is applied to the observed vector in each branch. The output from each branch is given to a decision making device which decides whether a symbol bit is +1 or -1 on a majority decision basis.

V. ANALYSIS

The C1 category blind receiver assumes the knowledge of timing and signature waveform of the desired user. Knowing the timing and signature waveform of the desired user the received signal can be observed over an interval. The length of the observation interval depends on the timing delay of the desired user. It should be choosen suitably so that it includes one symbol of the desired user. An observation interval of 2T (T = length of one symbol duration) is sufficient if the timing delay varies between 0 and T. The observed received vector is the sum of the information due to the desired user and the other users. The timing delay of the users' data is assumed to vary between zero to one symbol duration or 0 to N chips. Since the timing of the other users' is not known, the interference due to them can not be removed. The received vector can be given by [1]

$$\mathbf{r}_n = b_0[n]\mathbf{u}_0 + \sum_{j=1}^{J} \mathbf{u}_j + \mathbf{w}_n \tag{5}$$

where, $b_0[n]$ is the desired symbol for the nth observation interval and $\mathbf{u}_0$ is is the desired signal vector. The symbols $b_0[n], 1 \leq j \leq J$ are interfering symbols, with the interfering vectors $\mathbf{u_j}, 1 \leq j \leq J$ respectively. The vector $\mathbf{w}_n$ is discrete time gaussian noise. The blind algorithm which can be used for demodulation is constrained minimum output energy (CMOE) algorithm which minimizes the mean output energy $E\left[\langle \mathbf{c}, \mathbf{r}_n \rangle^2\right]$ subject to the constraint $\langle \mathbf{c}, \mathbf{u}_0 \rangle = 1$. There are also other algorithms which can be used for blind adaptation of the receiver namely subspace-based algorithm and the constant modulus algorithm (CMA) [1]. The CMA, which minimises the $E\left\{\left[|\langle \mathbf{c}, \mathbf{r}_n \rangle|^2 - 1\right]^2\right\}$, gives rise to a number of local minima resulting in complexity of the algorithm. The subspace-based algorithm requires the received signal vector to be decomposed into signal and noise subspaces. This needs the eigen decomposition of the correlation matrix of the received vector which is a difficult task. In comparision to the volume of work involved in the subspace-based method and the CMA metheod, the CMOE algorithm is less complex and it converges quickly. Since we are considering multi-carrier transmission, the received signal at the receiver from different subcarriers show good correlation property for which the CMOE method is suitable. When the timing and signature waveform of the desired user is known, the adaptive multiuser coefficients determined from the CMOE algorithm is given by [5]

$$c_1 = \zeta_{min} \mathbf{R}_y^{-1} \mathbf{s}_1 \tag{6}$$

$$\zeta_{min} = \left(\mathbf{s}_1 \mathbf{R}_y^{-1} \mathbf{s}_1 \right)^{-1} \tag{7}$$

where, $\mathbf{R}_y = E\left[\mathbf{r}_n \mathbf{r}_n^T\right]$ is the cross correlation matrix of the observed vector and $\mathbf{s}$ is the known signature waqveform of the desired user, $\mathbf{s}$ is the actual signature waveform of the desired user which includes multipath components and channel distortion and ζ_{min} is the minimum output energy. The coefficients thus obtained to decide on the received symbols by the following standard formula

$$b = sgn\langle \mathbf{c}, \mathbf{r}_n \rangle \tag{8}$$

where, b is the estimated symbol.

VI. SIMULATION RESULT

For simulation the number of users K=2 has been taken. The length of the siganature waveform of each user has been taken to be N=7 (generated from the modulo polynomial $X^3 + X + 1 = 0$). Here a blind receiver in the C1 category has been considerd. The timing of the desired user has been assumed to be zero and the other user has been assumed to have a random delay varying between 0-7 chips. Since the delay of the desired user has been assumed to be zero, the length of the observation interval is taken to be T which is sufficient to include one symbol. The channel is assumed to be additive gaussian channel. The simulation has been done for one subcarrier for 4000 symbols with varying SNR. The SNR Vs no. of bits in error is shown in fig. 4

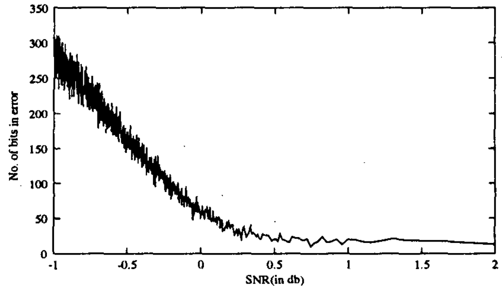

Fig. 4: SNR vs. biterror curve

VII. CONCLUSION

From the fig 4 it is clear that the bit error rate is decreasing with the increase of SNR. The above simulation can be repeated for a number of subcarriers and by taking a majority decision on the outcome of each of the subcarriers an acceptable performance can be achieved. The blind receiver considered here is of C1 category. The same can also be extended for the C2 category where assuming unknown delay for the desired user but limiting to the symbol duration will require an observation interval of twice the symbol duration. A modified CMOE algorithm can be used for timing acquisition of the desired user subject to the constraint.

VIII. REFERENCES

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