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Capacity enhancement of multicarrier code division multiple access (MCCDMA) using orthogonal complete complementary codes and adaptive constellations

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The multicarrier code division multiple access (MCCDMA) is a strong candidate for the future wireless mobile communication systems put forth by service quality and system capacity. In order to exploit the maximum possible channel diversity and desirable correlation properties, the modification of MCCDMA system is addressed here to pave the way to remove the multiple access interference (MAI) effect and to increase the spectral efficiency (SE) due to the possible integration of space-time block coding (STBC) and multi input multi output (MIMO) techniques with two-dimensional orthogonal complete complementary (OCC) codes. The impact on modifications in the MCCDMA system is studied. Due to frequency selective fading and multipath effects, MCCDMA suffers from MAI due to loss of orthogonality among the users. In this paper, the constellation movement scheme is proposed to break the interference limitation in order to increase the SE and system capacity. In this scheme, the constellation of one of the users is moved adaptively relative to the other by an optimal angle based on quantized estimation to counteract MAI, caused by multipath effects without varying the transmit power in order to satisfy minimum distance threshold at the detectors. The simulation result shows that this modified MCCDMA system and proposed constellation movement scheme achieves significant performance improvement in terms of bit error rate (BER) and SE compared to conventional MCCDMA systems using unitary spreading codes. It also shows that the proposed scheme combats MAI against frequency selective fading and multipath effects and achieves a significant improvement in user capacity as the number of users increased.

Key words: Multicarrier code division multiple access (MCCDMA), multiple access interference (MAI), orthogonal complete complementary (OCC) codes, channel states, adaptive constellations.

INTRODUCTION

With the ever increasing demands on bandwidth efficiency and system capacity, the multicarrier code division multiple access (MCCDMA) has become strong technology for the current and next generation (5G)

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wideband cellular mobile wireless communication systems where multimedia applications and flexible and high data rate services are standard. Among its many advantages, it is worth mentioning the high spectral efficiency (SE) deriving from the performance of orthogonal frequency division multiplexing (OFDM) in a Rayleigh fading environment (Varzakas, 2007) and the capability of collecting the received signal energy scattered in the frequency domain, which results into a remarkable frequency diversity gain (Hara and Prasad, 1999) to mitigate fading effect. In a MCCDMA system, the user's data are spread in the frequency domain using orthogonal spreading codes (Fazel and Kaiser, 2008).

After passing through a frequency selective channel, however, the received codes are no longer orthogonal due to non-ideal correlation properties of spreading codes and multiple access interference (MAI) will arise. Interference mitigation is traditionally accomplished at the receiver side by resorting to well-known multiuser detection schemes (Verdu, 1998). Due to heavy processing load as number of users' increases, these schemes may be unfamiliar. The problem of optimum Multiuser Detection (MUD) with less complexity in CDMA communication systems was considered in Abdulhamid and Hamidreza (2013) based on sign detector and longer code lengths. This improves the processing gain but there is no effect on system capacity. The code scheme based on the complementary code was proposed in Chen et al. (2006) to design a MAI-free CDMA system in a flat fading channel. These codes are derived from the sets of auto complementary codes, any two of which are cross complementary codes (Li and Huang, 2009). This can be constructed by using a $\sqrt{N}$-dimensional orthogonal matrix. Though this scheme achieves optimum spectrum efficiency using offset stacked spreading modulation than conventional CDMA system, the number of user supported is less. Interference suppression against MAI effect with respect to the number of users is achieved by inter-group complementary (IGC) codes (Jing et al., 2008). This increases complexity of the implementation due to user groupings. As an effective method to increase the diversity gain and combat the effects of fading, transmit diversity has been studied extensively in the past. The space-time block coding (STBC) (Alamouti, 1998) provides full diversity gain as well as full rate and does not sacrifice bandwidth efficiency. Space-time (S-T)-coding based multi input multi output (MIMO) systems (El-Hajjar and Lajos, 2010) have emerged as an extremely important enabling technology for 4G wireless to offer substantially improved detection efficiency and system throughput by exploiting its unique spatial diversity gain and spatial multiplexing capability without consuming extra spectrum. In order to exploit the maximum possible channel diversity and desirable correlation properties, the advantages offered by STBC and MIMO schemes are utilized in this paper for the modification of MCCDMA system employing two- dimensional orthogonal complete complementary (OCC) codes to remove the MAI effect and to increase the SE. The development issues are addressed here. The impact on the performance of this modified MCCDMA system is studied in terms of bit error rate (BER) and SE for further improvement.

From the above study, this modified MCCDMA system fails to remove MAI completely in a multipath environment. It is observed that the overlapping of received symbols results at particular channel conditions due to the fact that received signals from multipath add destructively causing multi-user interference which results in high error rates. With increasing MAI, the transmission quality for all users worsens and the number of subscribers able to be facilitated (user capacity) is limited by a specified BER threshold. To overcome such propagation effects, channel estimation and compensation applied for it to reduce BER as the channel parameters varies randomly (Mario et al., 2007). Adaptive loading algorithms for OFDM system with imperfect channel state information (CSI) were proposed in Ye et al. (2006). The network coding approach was used to mitigate these random constellations for two way relay networks (Koike-Akino et al., 2009). In this approach, the performance of end to end throughput was achieved but requires complex optimization procedure. In Musavian et al. (2011), variable rate and the constellation size were adapted according to the channel conditions for reducing the error rates. Adaptive modulation scheme was proposed, which vary various transmission parameters based on different modulation schemes according to existing channel conditions to minimize the error rates (Kugalur and Veerappa, 2013). All these schemes failed to recover the faded overlapped symbols due to MAI caused by multipath effects at poor channel conditions and also it require complex perfect CSI at the transmitter. The perfect CSI at the transmitter is not easily feasible, as it would require additional processing for feedback. These factors severely limit the performance of the system. To solve these discussed problems, the MCCDMA system is modified in the architecture and effective constellation movement scheme is proposed.

The contributions of this paper are as follows:

1) Modification of MCCDMA system is presented which exploits the diversity gain and ideal correlation properties for mitigating MAI in order to increase the user capacity while considering the development issues on integration of MIMO and STBC in two-dimensional to support the group of OCC codes (in system model section).
2) The constellation movement scheme is proposed for the users which move the angle of constellation of one of the users adaptively with respect to the other based on simple quantized estimation in order to satisfy minimum distance threshold at the detectors.
3) Procedure for simple quantized estimation alternate to complex estimation of perfect CSI is developed. The procedure is illustrated for obtaining the quantized details

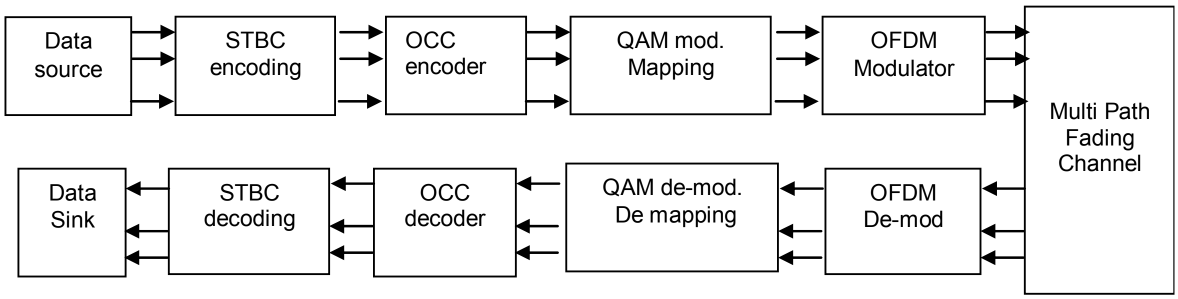

Figure 1. Simplified transceiver structure of MCCDMA system model.

of channel states to recover faded symbols.
4) The procedure to compute the optimal angle for movement is explained for the M-QAM signal set.
5) The threshold of minimum distance and condition to avoid overlapping are developed.
6) The modified MCCDMA system and proposed constellation movement scheme are evaluated for the performance improvement in terms of BER and SE
7) Simulation results are discussed to demonstrate the capability of the modified MCCDMA and proposed scheme to outperform the conventional MCCDMA system with unitary spreading codes.

METHODOLOGY

System model

Figure 1 illustrates a simplified transceiver structure of modified MCCDMA system model. The modification of MCCDMA system is addressed here in addition to the system description to counteract the loss of orhtogonality in frequency selective fading and multipath environment for increasing the interference mitigation efficiency. Modification exploits ideal correlation properties of spreading code, the diversity gain and chip based modulation to minimize the correlation among the users, reduce the error rate and increase the SE, respectively.

Orthogonal complete complementary (OCC) codes

For minimum correlation among the users, the OCC code is employed based on ideal correlation properties which spread user data in time and frequency domains. The OCC codes are kind of ideal orthogonal code and defined by three parameters, set size (*K*), flock size (*M*) and element code length (N). The processing gain of OCC code is N.M=N$\sqrt{N}$ since each symbol bit will be spread by the whole set of CC code sequences instead of a single sequence. The system robustness against the adverse effects of the channel and the division among users depends on the orthogonality of the spreading codes. The orthogonality of this code is based on its correlation functions. The auto correlation function (ACF) of the OCC codes is zero for any shifts except zero shift which help to remove the delayed version of received signals due to multipath propagation and its cross correlation function (CCF) is zero for any possible number of shifts which allow the receiver to remove undesired other user's signals. The correlation function of the OCC code is based on a group of element codes jointly. This implies that each user should use group of *M* element codes as its spreading code instead of a single code.

STBC encoding

For diversity gain, STBC encoding integrates STBC in two-dimensional with OCC encoding with *M* subcarriers modulation using OFDM architecture. The signal spectrum is modulated by an OCC code set, which is unique for each user. The flock of *M* element codes, $\{c_{k,1}, c_{k,2},.. , c_{k,M}\}$ are allocated to *K* users. Each element code $c_{k,m}$ consists of *N* chips where k ϵ (1,K) and m ϵ (1,M). The information symbols which are typically coming from the outputs of data source are first space-time block-encoded into *P* parallel independent symbol streams. Based on the Alamouti STBC algorithm, an encoded signal block for the m^{th} element code of the k^{th} user in this MCCDMA system can be written as:

$$s_{1,k,m} = (b_{1,o}\, c_{o\ k,m} + b_{1,e}\, c_{e\ k,m}), \quad (1)$$

$$s_{2,k,m} = (b_{1,e}\, c_{o\ k,m} - b_{1,o}\, c_{e\ k,m}), \quad (2)$$

The *P* parallel symbol streams are fed into OCC encoding module that consists of *M* OCC encoding branches, each of which has *P* OCC slices. There are in total up to *M* replicas of *P* parallel symbol streams encoded by different OCC code sets to implement diversity order of P and parallel transmission order of *M.* Therefore, the family size of the OCC must be at least MP.

OCC encoding

For SE, OCC encoding configures chip based spreading modulation and QAM modulation based on group of OCC codes. This MCCDMA combines its OCC spread-coded bits together using chip based spreading modulator. This modulator improves the SE which is defined in unit of bit(s) per chip to measure the bandwidth efficiency. The spreading modulator used by every user in which the input data stream is from the k^{th} user, $b_k = (b_{k1}, b_{k2},. . b_{kj} . .,)$. The input bit sequence of each user is spread with the corresponding element code, $c_{km} = (c_{1km}, c_{2km}. . . c_{Nkm})$. Also, each information bit is shifted by one chip relative to one another and then added. The OCC encoding output from user *k* is expressed as:

$$d_{K,m}(t) = \sum_{i=0}^{\infty} . \sum_{n=0}^{N-1} b_{K,i}\ C_{m,n} \prod \frac{(t-(i+n+\frac{1}{2})Tc)}{Tc}\ X \prod \frac{(t-(\frac{T}{2})-iTc)}{T}, \quad (3)$$

Where

$$\Pi\left(\frac{t}{T\omega}\right) = \begin{cases} 1, & t \in \left(-\frac{T\omega}{2}, \frac{T\omega}{2}\right), \\ 0, & \text{otherwise} \end{cases} \quad (4)$$

where $d_{K,m}(t)$ represents the m^{th} OCC encoding output from user *K*, $b_{K,i}$ denotes the i^{th} information bit from user *K*, $C_{m,n}$ denotes the n^{th} chip of the m^{th} element code and Tc and T denote chip and bit duration, respectively. Then, each element code, c_{km} is carrier modulated with sub-carrier, *fm*. Thus, in effect, the user data information has been spread in both the time and frequency domains. The time domain spreading is carried out by each individual element code, while the frequency spreading is fulfilled across different sub-carriers in different carrier frequencies. The two-dimensional spreading offers much more degrees of freedom to achieve orthogonality of the spreading codes in both the time and frequency domains.

To maintain good performance in the presence of fading, for the element code length of 'N' of the OCC code the chip based spreading modulator is followed by a QAM map to transmit the L=(N-1) different levels in symbol duration for its robustness in detection efficiency. In the case of the downlink, the m^{th} OCC encoding output is the sum of all OCC spread streams from all the users associated with the m^{th} element code of each code family; for example, A_0, B_0, C_0, and D_0 belong to family 0. It is expressed as:

$$s_m(t) = \sum_{k=0}^{M-1}, d_{K,m}(t), \quad (5)$$

Where *M* denotes the flock size, K=M =√N.

To maintain good performance in the presence of frequency selective fading and hardware architecture simplification, the transmitter is implemented using OFDM architecture. Each transmitter will use *M* different subcarriers to transmit *M* element codes and the whole MCCDMA system will share the same *M* sub-carriers. The sub-carriers carry the same data information but encoded by different element codes belonging to the same code flock. It is assumed to use only two antennas (n_t = P = 2) to achieve transmitter diversity. It is also assumed that signals from different antennas in a transmitter experience independent Rayleigh fading and additive white Gaussian noise (AWGN).

At a receiver, the received symbol streams go to maximum ratio combining (MRC) from *M* replicas to extract *P* parallel symbol streams. The combining of outputs from the *M* chip matched-filters using MRC improves the frequency diversity gain. Also, the correlation properties of element sequences along with MRC scheme achieve a MAI-free performance (Wei et al., 2013). The carrier demodulation should be carried out first, and then the correlation takes place between local sub-codes and the incoming signals in the *M* sub-channels, and is given by:

$$Cor_K(t) = \sum_{m=0}^{M} r_K(t) * C_{K,m}, \quad (6)$$

Where $r_K(t) * C_{K,m}$ is the correlation between the received signal of user *K* and element code *m* of the flock assigned to user *K*. The *M* correlation outputs are then added together to obtain the decision variable. The receiver performs coherent decoding with perfect or estimated CSI. Then,

$$b_{K,i}(t) = \text{sgn}(cor_K(t), \quad (7)$$

Where $b_{K,i}(t)$ denotes the i^{th} demodulated information bit of user K and sign(.) denotes signum function.

Proposed constellation movement scheme

The overlapped symbols results at particular channel conditions due to the fact that received signals from multi-paths add destructively causing multi-user interference. This results in high error rates, worst transmission quality for all users and the number of subscribers able to be facilitated (user capacity) is limited. The constellation movement scheme is proposed to break the multi-user interference limitation in order to improve the performance In terms of SE and system capacity. In this scheme, the constellation angle is adaptively controlled by moving the constellation of one of the users relative to the other with an optimal angle based on simple quantized estimation so that the distance between the symbols can be increased above the minimum distance threshold at the detectors without varying the transmit power. This will increase the interference mitigation efficiency against multipath effects.

It is assumed that destination knows details of channel gains, h_k for the users-k separately. The channel amplitude ratio, $\gamma = \left|\frac{h_B}{h_A}\right|$ and phase difference $\theta = \frac{\sqrt{h_B}}{\sqrt{h_A}}$, are calculated. The pair (γ, θ) is used to represent the channel state, $\gamma e^{j\theta}$ in the complex plane (Γ,Φ). The received symbols are represented collectively as additive constellation, $S_{ADD}(h_A, h_B) = \sqrt{P_A}\, h_A S_{grp}(\gamma, \theta)$ where $S_{grp}(\gamma, \theta)$ is group constellation, $(S_A + \gamma e^{j\theta} S_B)$.

Minimum distance threshold

The minimum squared Euclidean distance between the transmitted data $(s_A, s_B)_{ADD}$ and its candidate $(s'_A, s'_B)_{ADD}$ is measured as performance metric at the destination. The normalized squared distance can be written as:

$$d^2_{(SA,\, SB) \leftrightarrow (S'A,\, S'B)} = |((S_A - S'_A) + \gamma e^{j\theta} (S_B - S'_B))|^2, \quad (8)$$

At particular channel conditions, the squared Euclidean distance $d^2_{(sA,\, sB) \leftrightarrow (s'A,\, s'B}$ goes to zero whenever,

$$\gamma e^{j\theta} = -\frac{(S_A - S'_A)}{(S_B - S'_B)} \quad (9)$$

That is, the two received symbols are overlapped due to MAI caused by multipath effects. These values of γ and θ are called singular channel fade state at which the minimum distance, d_{min} is zero or very low, resulting in poor error performance at the destination. Thus, it is necessary to fix the threshold of minimum distance, *δ* to reduce the error rate such that any channel states (γ,θ) lying close to any singular channel states should be controlled so that $d_{min} > \delta$. This requires identification of channel fade states which reduce minimum distance below distance threshold and avoiding this using adaptive control of constellation angle of one of the users relative to the other based on channel quantized estimation and adaptive control of constellation angle.

Procedure for quantized estimation

The proposed idea of the quantized estimation is to collect the quantized details of channel states using channel distance mapping with respect to the singular channel states, indicate the details of channel states which reduce minimum distance to the users.

The set of singular channel states (γ_i, θ_i) are obtained for the QAM signal set in the plane for γ ≥1 and θ ∈ [0, π/M] where 1 ≤ i ≤

N_S and the number of singular channel state, $N_S = \frac{M^2}{8} - \frac{M}{4} + 1$. The channel states are mapped into distance d_{ci} using the distance functions which gives the value of the distance between the transmitted data $(s_A, s_B)_{ADD}$ and its candidate $(s'_A, s'_B)_{ADD}$ for the channel states. The same distance pair of elements are collectively called as distance class, $d_C(\gamma, \theta)$ and corresponding region in complex plane is C. For each singular channel states (γ_i, θ_i), the distance set of minimum class distance functions $d_{Cimin}(\gamma, \theta)$ are obtained among the sets of class distance functions, $d_{Cij}(\gamma, \theta)$, $1 \le i \le N_s$ $1 \le j \le J$ which gives zero value of the distance between the two additive constellation points. The minimum distance threshold $d_{min}(S)$ is also obtained. The partitions P_S (c_i) corresponding to $d_{Cimin}(\gamma, \theta)$ are found by equating the curves $d^2_{Ci} = d^2_{Cj}$, $1 \le i \ne j \le N_s$ and $d^2_{Ci} = d^2_{min}(S)$. The partition exterior to all these partitions, is denoted as $P_S(c_{dmin})$ lying within the space [0, π/M]. In this way, the channel states are mapped into partitions. It is thus required to identify the channel states (γ, θ) which lies inside the partitions, centered at the singular channel state (γi, θi) and radius $\delta / |s_{2,i} - s'_{2,i}|$ where the distance function values, d_{Ci} (γ, θ) below threshold, that is,

$$\left|\gamma e^{j\theta} - \gamma_i e^{j\theta_i}\right| < \frac{\delta}{|(S_{B,i} - S'_{B,i})|}, \quad (10)$$

These partitions are called as disturbance circles because the minimum distance requirement of $S_{grp}(\gamma, \theta)$ is disturbed. Therefore, the minimum distance, d_{min} should be maximized above minimum distance threshold, δ in order to increase the interference mitigation efficiency.

Next, the position of the channel states is indicated to the users whether inside/outside the disturbance circles. This needs a feedback of $|\log_2(N_S + 1)|$=5 bits for 16QAM in this scheme such that the incurred overhead is minimum compared to feedback required for perfect CSI at transmitter in other systems.

Adaptive control of constellation angle

The proposed idea is to move the constellation of user-j adaptively by an optimal angle β relative to the adjacent user without changing the transmit power if the channel state (*γ, θ*) lies inside any of the disturbance circles in order to meet the minimum distance threshold and no constellation movement is required for channel states utside the disturbance circles.

In order to obtain the optimal angle of movement $\beta_{i,opt}$ for channel state lies inside the disturbance circle, it is required to compute the value of optimal phase $\theta = \theta_{i,opt}$, $\theta \in [0, \pi/M]$ which maximizes the minimum distance and transforms channel state from θ to θ + β lies outside the disturbance circles after movement. During the movement of constellation phase away from θ_i but with fixed radius, γ_i, the phase and minimum distance are computed at the points of intersection of the arc $\gamma = \gamma_i$ and the boundaries between the partitions surrounding other singular channel states. Among all the above points, the maximum of minimum distance is selected for the channel state corresponding to that point of intersection $(\gamma_i, \theta_{intersect})$. The optimal phase $\theta_{i,opt} = \theta_{intersect}$. Then, the optimal angle of movement $\beta_{i,opt}$ for the constellation of user-A relative to user-B is calculated based on optimal phase $\theta_{i,opt}$ as:

If $\theta_i = \pi/M$, then, $\beta_{i,opt} = \pi/M - \theta_{i,opt}$ in a clockwise direction.
If $\theta_i = 0$, then, $\beta_{i,opt} = \theta_{i,opt}$ in an anticlockwise direction.

Thus after movement, the disturbance circle is called as the changed circle since its center at (γ_i, θ_i) is changed to $(\gamma_i, \theta_{i,opt})$.

In order to avoid the overlap during the movement of angle of constellation with other states, it is necessary that the distance between the center of each of the changed circle $(\gamma_i, \theta_{i,opt})$, $1 \le i \le N_S$ and other singular channel states (γ_j, θ_j), $1 \le j \le N_S$ should be at least equal to the sum of the radius of the changed circle and the radius of the disturbance circles centered at (γ_j, θ_j). This can be written as:

$$r(\gamma_i, \theta_i) + r(\gamma_j, \theta_j) \le d_{(\gamma_i, \theta_{i,opt}) \leftrightarrow (\gamma_j, \theta_j)}, \forall\ 1 \le j \le N_S \quad (11)$$

Thus, the proposed constellation movement scheme mitigates the MAI effect through adaptive control of constellation angle by keeping the squared Euclidean distance between the transmitted data and its received candidate above minimum distance threshold. The quantized estimation reduces the complexity by considering only the quantized details of channel states and send to the user for controlling the constellation angle.

RESULTS AND DISCUSSION

Based on the discussion given in the earlier sections, the performance of this modified MCCDMA systems and proposed constellation movement scheme are evaluated in terms of BER and SE using MATLAB against signal to noise-ratio (SNR) with different spreading codes such as Walsh, Gold and OCC codes. In the simulations, downlink frequency selective Rayleigh fading channel with AWGN floor and multipath environments are considered. It is assumed that the path components are different and independent for all paths. The receiver had perfect knowledge of the CSI. The Gold and Walsh codes are taken as examples for traditional quasi-orthogonal codes and typical orthogonal codes, respectively. The data packet of 256 symbols, the symbol length of 64, the modulation of 16-QAM, the number of subcarriers of 128 and the following key parameters of those spreading codes used in the simulations are:

1) OCC: flock size (*M)* = 4, element code length (*G)* = 16, Sequence length N = 64,
2) Walsh code: sequence length *G* = *N* = 64
3) Gold code: sequence length *G* = *N* = 63

Figure 2 shows the BER curves simulated against SNR among the MCCDMA system with different spreading codes for increased number of users (K = 16) under a two-ray multipath channel with its delay profile being [1/2, 0,1/2] and one chip inter path delay. The BER curves for the unitary spreading codes (Walsh and Gold codes) deteriorate obviously because of loss of orthogonality due to increased MAI in frequency selective fading, while OCC code performs nearly the same as that in the single user scenario. Hence, the orthogonality of the spectral modulated signal using OCC code is retained. Thus, the user capacity increases due to this increased interference mitigation efficiency.

The higher processing gain can be possible when element code length increases but it does not increase

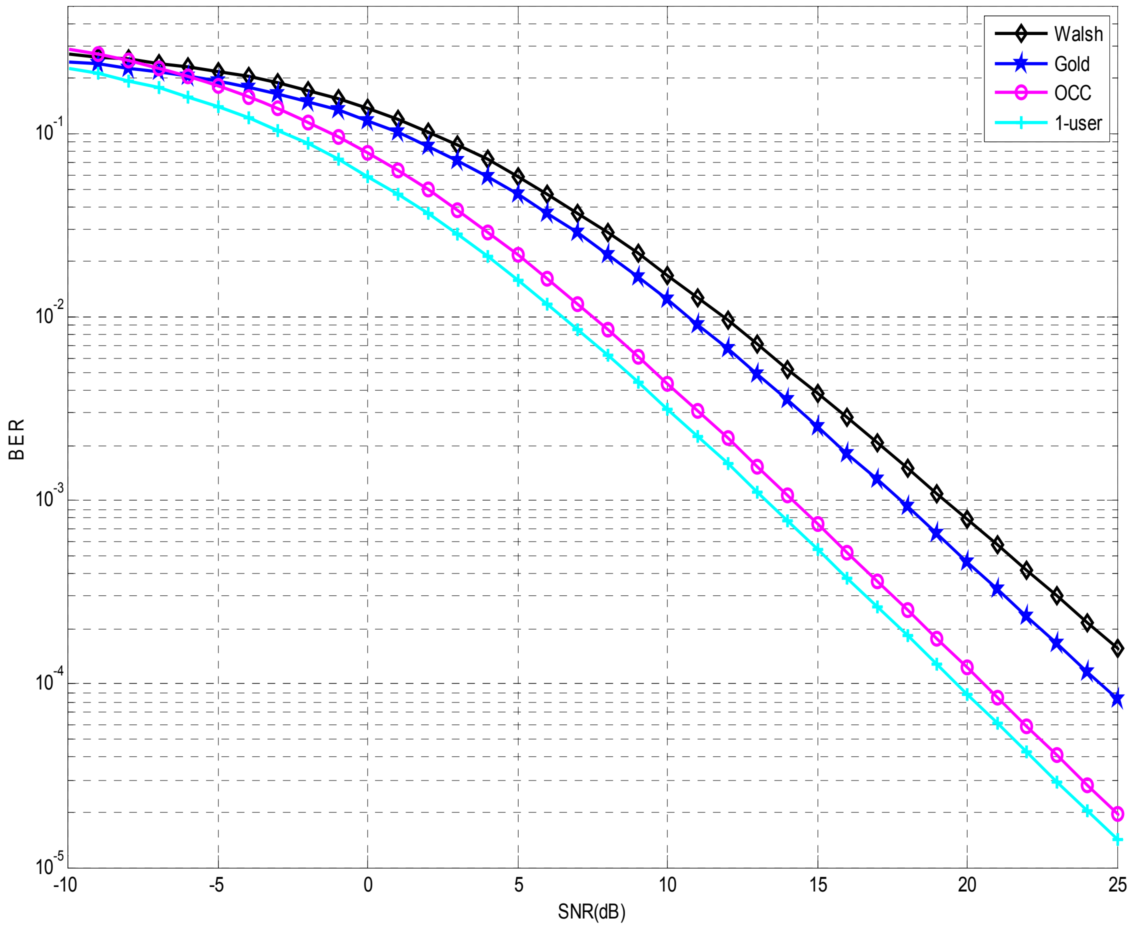

Figure 2. BER comparison for the increased number of users (16) among MCCDMA system with different spreading codes.

the system capacity. The user capacity and frequency diversity can be increased further when the flock size of OCC code and corresponding number of subcarriers increases but complexity of the system grows. So, it is one design issue.

It was assumed that perfect channel knowledge is available at the coherent Rake receiver using pilot-based channel estimation. However, the time varying conditions in the mobile communication channels limits the performance and system capacity. The channel conditions should be estimated and compensated using equalization methods based on the fading statistics for minimizing the error rates. This equalization method for multiple carriers and multiple antennas in multiuser application is difficult and computationally intensive to estimate the amplitude and phase shift caused by the multipath propagation effects. As the number of users' increases, the performance is degraded due to the non-ideal channel estimation results and increased multiuser interference. The complex estimation is demanded. This increases computational complexity in the order of $O\ (2^K)$ with K users.

BER performance is compared for MAI robustness among the MCCDMA system using Walsh and OCC codes with and without constellation movement in Figure 3 for increased number of users (K = 16). The BER curves for the Walsh codes deteriorate obviously due to increased MAI, whereas the system with OCC code outperforms that with Walsh codes due to good correlation among the users provided by OCC codes and diversity gain. It is observed that the performance gain of SNR of 3 dB is achieved using constellation movement scheme compared to that without this scheme. It shows that the detrimental effects of MAI are reduced by keeping the squared Euclidean distance between the transmitted data and its received candidate above minimum distance threshold. This increases the interference mitigation efficiency against random constellations caused by multipath effects so that the receiver can decode the messages very easily from the received symbols. The results reveal that the minimum distance threshold ensures large channel amplitude ratio $\{\gamma = \left|\frac{h_B}{h_A}\right|\}$. This results in more reliable communications;

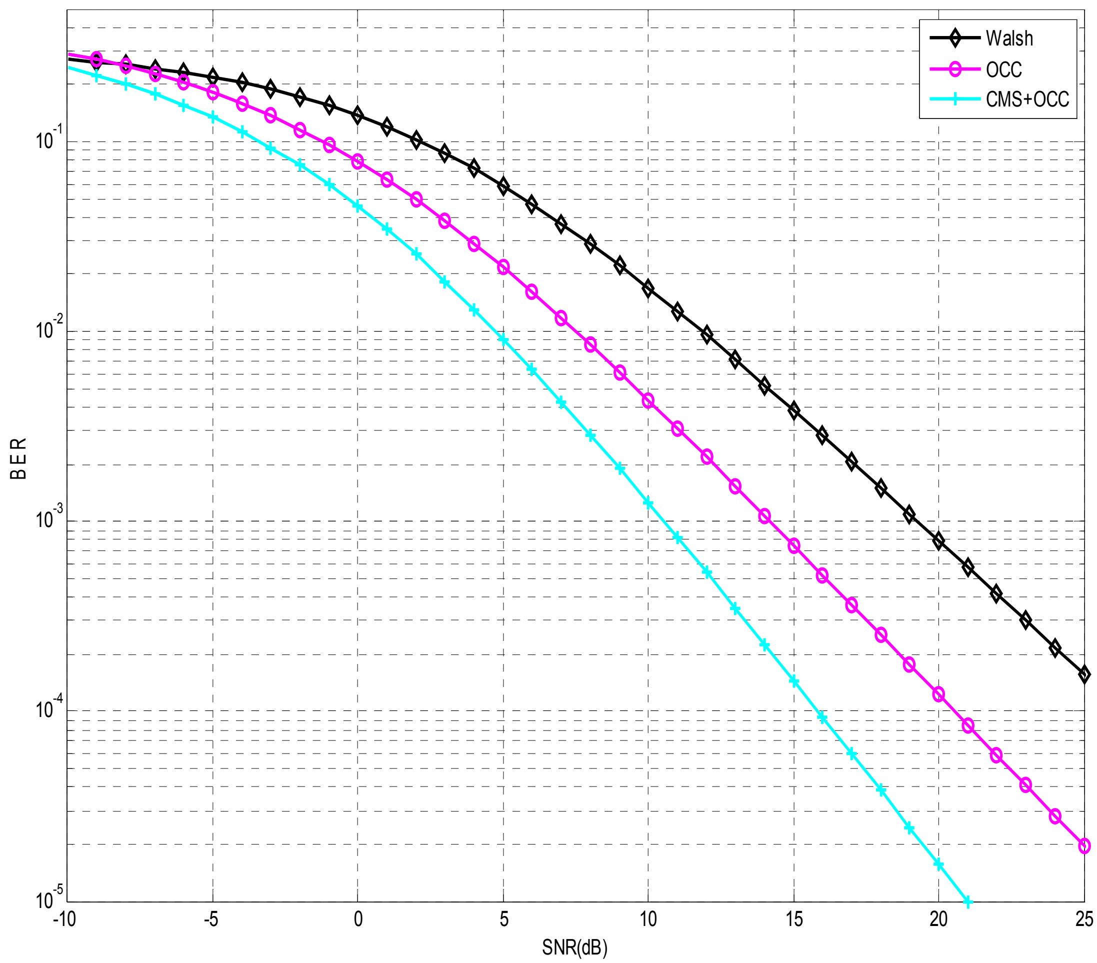

Figure 3. BER comparison for MAI robustness against SNR among MCCDMA system using Walsh and OCC codes with and without constellation movement scheme.

In order to solve the channel estimation issues and reduce the computational complexity based on the above discussion, the simple quantized modified estimation design strategy based on the minimum distance criterion is implemented in the proposed constellation movement scheme. This simple estimation and constellation movement scheme can provide much robustness to amplitude and phase shifts caused by difficult multipath effects.

Another significant dividend of quantized estimation method is that it limits the amount of required channel information at the users so that associated overhead is nominal compared to perfect CSI requirement.

The feedback of $\lceil \log_2(N_S + 1) \rceil$=5 bits for 16QAM signal set is required as channel estimation load in this simplified quantized estimation procedure. When comparing with the perfect CSI, the required bits for feedback of channel states to the users reduces from 16 symbols to 5 bits and that the required computational complexity reduces from the order of $O(2^K)$ to O(k) with K users by the simple quantized modified estimation.

Figure 4 compares average SEs of MCCDMA system using Walsh and OCC codes with and without constellation movement scheme against SNR. The SEs for Walsh code cannot be improved further beyond some high SNR due to the excessive interferences. Obviously, the SE of the MCCDMA system using OCC code outperforms that using the Walsh codes. This improvement in SE is obtained jointly by the chip width of the chip based spreading modulation through increased processing gain and the desirable correlation properties of OCC code. The MCCDMA system using constellation movement scheme outperforms that using OCC code without this scheme. This scheme achieves SNR gain of 2 dB compared to system using OCC code and of 4 dB compared to system using Walsh code for achieving an average SE of 1.8 bits/ch.use (90%). This is certainly obtained through adaptive control of position of the constellation angle against random constellation. This result shows significant improvement of SE due to interference mitigation efficiency of the proposed adaptive constellation movement scheme.

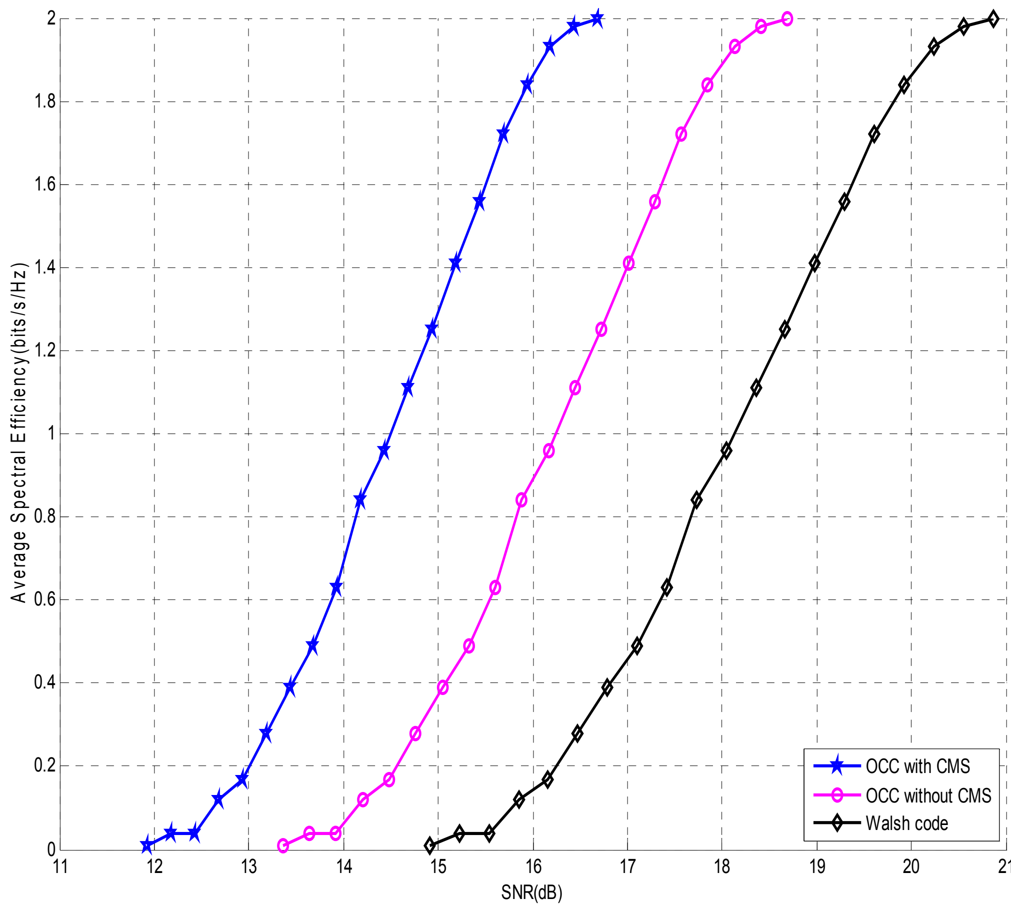

Figure 4. Spectral Efficiency comparison against SNR among MCCDMA system using Walsh and OCC codes with and without constellation movement scheme.

The modified MCCDMA and constellation movement scheme have several advantages compared to conventional MCCDMA systems with unitary spreading codes. The robustness to difficult multipath channel and interference mitigation efficiency are increased. The SE improvement and reduced error rate are achieved.

On the other hand, complexity of the system is increased. However, the complexity of the simple quantized estimation is reduced compared to the perfect CSI. Generally, the complexity of estimation scheme increases for large constellations if the required CSI is large, which implies that the constellation movement scheme might be feasible for the scenario intended for large signaling constellations.

Moreover, it is power efficient because it does not requires extra power to control the constellation angle adaptively in the proposed constellation movement scheme where only the phase is changed with same amplitude.

Conclusion

In this paper, the modification of MCCDMA system is studied for ideal correlation properties and maximum channel diversity gain to solve the problem of loss of orthogonality among the users due to MAI in frequency selective fading channel in order to increase the user capacity. The constellation movement scheme is proposed in the MCCDMA system to recover the overlapped symbols due to random constellation caused by MAI at particular channel conditions in order to increase the SE and the user capacity. The performance of modified MCCDMA and constellation movement scheme are evaluated in terms of BER and SE and it outperforms the conventional MCCDMA systems. The interference mitigation efficiency of the system improved against the frequency selective fading effects by the orthogonality of the OCC codes and OCC encoding of the modified MCCDMA system and by the adaptive control of random constellation in the constellation movement scheme. The system robustness to multipath effects improved by combined quantized estimation and adaptive control of random constellation in the constellation movement scheme and correlation properties of OCC codes. Furthermore, the issues for modification of MCCDMA system, procedure for simple quantized estimation, procedure to compute the optimal angle for movement are given. Design criterions such as condition for singular channel fade states; minimum distance threshold and condition to avoid overlapping with other channel states for MQAM signal set are developed. Thus, this modified MCCDMA system has MAI-free capability regardless of the number of users and so, the user capacity is increased.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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