SUITABILITY OF CARRIER INTERFEROMETRY CODE FOR NCMC-CDMA BASED COGNITIVE RADIO

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Abstract
Cognitive radio system improves spectrum efficiency dealing with quantities like operating frequency, protocol, networking etc. This concept can be realized using FDM and multicarrier system like OFDM or MC-CDMA. MC-CDMA is a CDMA based technique where spreading code selection affects the performance of the system. Various orthogonal codes are used for implementing such system. In This paper comparison of Walsh and CI code is carried out for AWGN and Rayleigh channel environment. The BER performance of MC-CDMA and CI/MC-CDMA is done for contiguous and non-contiguous channel environment.
Keywords: BER; Coginitive Rdaio; Multi-carrier CDMA;OFDM; Specrum Efficiency.

I. INTRODUCTION

Recently communication over a wireless channel increased rapidly. Abundant use of wireless channel may not seem too easy as it look like. The spectacular growth of video, voice and data communication justifies great expectation of user's demand which can be satisfied high data rate communication. Using single carrier transmission high data rate communication lead to increase complexity at receiver side, and it also increase ISI over a fading channel. Multicarrier transmission can mitigate this effect easily, where more diversity are provided and can avoid single channel can goes in deep fade. OFDM and MC-CDMA is widely used multi carrier transmission.

The multi-carrier code division multiple access (MC-CDMA) scheme has been proposed for wireless indoor or mobile communications systems to transmit data at a high bit rate. As MC-CDMA is a combination of OFDM and CDMA, where
OFDM is well suited for high data rate multicarrier transmission for selective fading and CDMA is a multiplexing technique where number of users simultaneously available to access channel making suitable for synchronous transmission. MC-CDMA have advantages of smaller delay spread and small Doppler spread also it is fading resistance using diversity make it suitable for indoor environment multimedia services and power line communication. To use MC-CDMA in cognitive radio transmission, the SU base station can only deploy the non-contiguous spectrum holes by turning off the sub carriers that are within the spectrum used by the PU. Such system is called Non- Contiguous (NC) MC-CDMA. In this case, the number of available sub carriers could be any integer values. The conventional orthogonal Hadamard Walsh (HW) codes only exist when their length is multiple of four. So these codes cannot provide the desired orthogonality in CR environment. CI code is supersede Walsh by tranquilize the non orthogonality of spreading code in noncontiguous transmission.
To detail the proposed work, the paper has been organized as follows. Section II presents the cognitive radio environment for mobile communication. Section III describes the system model. Section IV describes the transmitter structure of MCCDMA using CI code. Section V explains modeling of multipath frequency selective channel. Section VI presents the simulation results and Section VII concludes the paper.

II. COGNITIVE RADIO

Radio environment are distributed to user as per standard, they are called as licensed user of particular spectrum. Radio spectrum is a limited frequency band and they are allocated to license users, no other user can use that spectrum and license users never use those spectrums efficiently. To make spectrum usage efficiently and to mitigate the lake of spectrum band to new users can avoided by the concept of Cognitive radio. For mobile communication CR based communication can increase the efficiency of spectrum usage. Dynamic allocation of channel is a main concept of the Cognitive Radio.

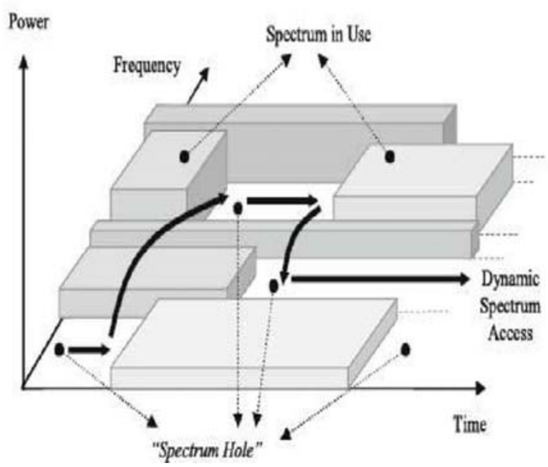

Fig. 1. Spectrum Utilization [1]

As shown in fig. 1. Spectrum holes are the spectrums which are not used by licensed users. By allocating spectrum hole to unlicensed users efficiency of radio spectrum utilization can be increased. Dynamic allocation of spectrums which are temporary unallocated by primary user this concept is introduced by Cognitive radio.

The term "Cognitive Radio" (CR) was coined by Joseph Mitola in 1998. A radio based on cognitive radio concept use an intelligent system which can sense unused spectrum and allocate to other unlicensed user on temporary base. In the process of improvements and reliability of wireless communication, cognitive radio system employs a system which continuously monitors receiving signals and adapts collection, interpretation and enhancements of various parameters. Main objective to furnish this cognitive approach is to get optimized implementation and usage of allotted frequency to the communication [1].For dynamic allocation of user Cognitive radio system uses a cognitive cycle.

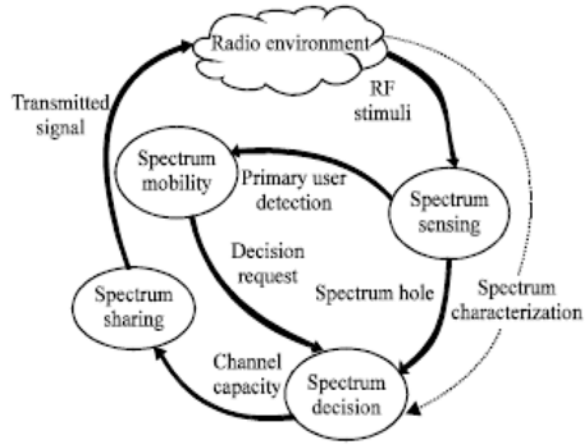

Fig.2. Cognitive Radio Cycle [1]

Fig. 2. shows cognitive cycle for cognitive radio. It will first sense the spectrum a cognitive radio monitors the available spectrum bands, captures their information, and then detect the spectrum holes. Spectrum analyses done by spectrum decision phase where spectrum sensing is estimated. A cognitive radio determines the data rate, the transmission mode, and the bandwidth of the transmission. Then, the appropriate spectrum band is chosen according to the spectrum characteristics and user requirements. Many secondary users are awaited to use a spectrum, spectrum sharing can be done by policy rules. Once the operating spectrum band is determined, the communication can be performed over this spectrum band. However, since the radio environment changes over time and space, the cognitive radio should keep track of the changes of the radio environment. If the current spectrum band in use becomes unavailable, the spectrum mobility function is preferred to provide a seamless transmission. Any environmental change during the transmission such as primary user appearance, user movement, or traffic variation can trigger the adjustment [2].

III. SYSTEM MODEL

Consider primary user and four secondary users using a same Cognitive Radio system. A model for such system where four user's transmitters are nearer to primary user shown in fig.3. In this case we are assuming spectrum allocated to primary user and secondary user's are having Cognitive radio system. Presences of secondary user indicate that un utilization of the licensed user's spectrum.

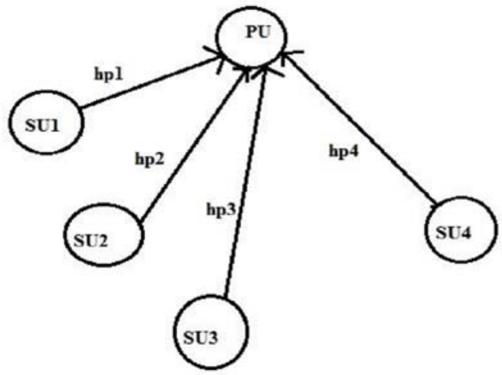

Fig. 3. System Model

The channel gain between i^{th} secondary user SU_i to primary user PU is denoted as h_{pi}.SU transmission may cause interference to PU and efficient cognitive radio system is qualified by transmission with less interference between SUs and PU. MC-CDMA technique is used for the transmission between secondary user"s transmission and receiver.

IV.CI/MC-CDMA TRANSMITTER MODEL

In cognitive radio Primary users may or may not be present but when they start to use spectrum cognitive radio system has to free that band from secondary user. In this case it might be possible secondary users are transmitting data on noncontiguous channels.

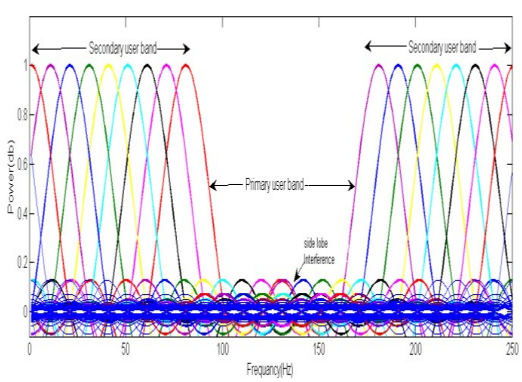

Fig. 4. Subcarrier Allocations

Fig.4. shows subcarrier allocation for NC-MC-CDMA where subcarriers in the band of primary user are null subcarrier as CR system transmission cannot be done in that band if we consider overlay mechanism. NC-MC-CDMA system will transmit data on present subcarriers only. Data will be spread using spreading sequence and IFFT method used to allocate the subcarrier, here spreading done in frequency domain for MC-CDMA system.

In MC-CDMA systems, the user"s data is spread onto $N_p$subcarriers. For user information discrimination at the receiver, the transmitter applies aunique orthogonal spreading code to each user"s data symbol. Walsh codes are most suitable orthogonal spreading code for MC-CDMA system. Spreading is performing in a frequency domain. Basic transmitter structure block diagram for MC-CDMA shown in fig: 5. For frequency domain spreading serial to parallel conversion is not necessary. Data bits are given as input using same as input data rate. U^{th} user data bits are spread using code $C_u= [C_u (0), C_u (1),$
..... $C_u (N_p -1)]$, where spreading sequence C_u will be generated by using Walsh code having length of number of subcarrier. Walsh code can accommodate $U=N_p$ users as Walsh matrix is a square matrix of the length N_p, Maximum N_p code can generate and as MC-CDMA uses a spreading based technique to differentiate the number of users [3].

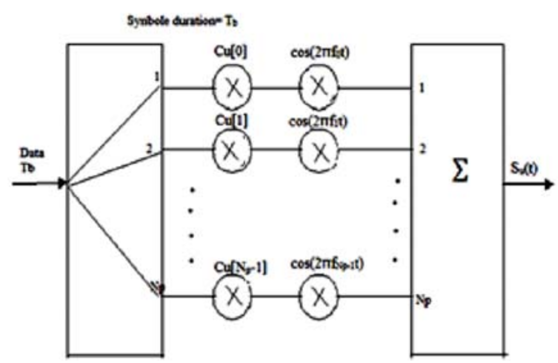

Fig.5. MC-CDMA transmitter block diagram

MC-CDMA transmitted signal for U^{th} user $S_u(t)$is given by (1).

$$s^u(\mathrm{t})= \sqrt{\frac{2P}{Np}} \sum_{n=0}^{Np-1} D^u\,(t) C_u[n] \cos(2\pi f_n t) \quad (1)$$

Where $D^u(t)$ is input data bits, $C_u[n]$ is spreading sequence for U^{th} user. $f_n$is the n^{th} subcarrier frequency in Eqn. (1).

In MC-CDMA based Cognitive radio few subcarriers are used by licensed user and so that for secondary users transmission become non-contiguous transmission. In this case subcarrier under primary user band is consider as null subcarriers .As efficiency of MC-CDMA are based on spreading code , Walsh code will not preserve its orthogonal property (cross correlation becomes nonzero) in non-contiguous transmission result in to multiuser interference.

To preserve the orthogonality of spreading sequence in noncontiguous transmission, Carrier Interferometry (CI) codes are introduced. Over a Walsh code whose code length is restricted to 2^n having bits +1 or -1, CI codes are complex orthogonal codes. CI codes generate spreading sequence of any length of *N*. and thus CI /MC-CDMA provide the flexibity of supporting *U>N* users by providing phase shift (π/N) without expansion of bandwidth. Using CI code for MC-CDMA spreading sequence for U^{th} user is given in Eqn.(2).

$$C^u(t)= \sum_{i=0}^{Np-1} \beta_i^u e^{j2\pi i\Delta ft} \quad (2)$$

where, β_i^u= is the U^{th} user complex spreading sequence for i=0,
1,…Np-1.

$$\beta_i^u= \beta_0^u ,\beta_1^u , \beta_2^u ,……., \beta_{Np-1}^u \quad (3)$$

$$\beta_i^u= e^{j(2\pi/A)u0}, e^{j(2\pi/A)u1}, ……… e^{j(2\pi/A)uNp-1} \quad (4)$$

Where *A=Np-m*, *Np*= number of subcarrier, *m*=no.of null subcarriers in Eqn.(4). Here $\Delta f = \frac{1}{T_b}$ where T_b is symbol duration. For Hadamard code β_i^u is -1,+1 . However, when CI codes are used,‟s are complex phases corresponding to Eqn.
(3) can be written as

$$\beta_i^u= 1,e^{j\Delta\theta u},e^{j2\Delta\theta u}, … … … . , e^{j(Np-1)\Delta\theta u} \quad (5)$$

Where $\Delta\theta_u = \frac{2\pi}{N} * u$ where u=1,2,….N_p-1 and (6)

$$\Delta\theta_u = \frac{2\pi}{N} * u + \frac{\pi}{N} \quad \text{Where } u = N_p, N_p+1,….2N_p \quad (7)$$

In this way from Eqn.(6) and (7) *2N* users are supported on codes of length *N* with minimal performance degradation as the number of users increase from *N* to *2N*.The transmitted signal for the user *U* for CI/MC-CDMA is given byEqn. (8).

$$S^u(t)=\sum_U^{U-1} \sum_{i=0}^{Np-1} AD^u\beta_i^u \, e^{j2\pi f_c t} e^{j2\pi i\Delta ft} \quad (8)$$

Where $D^u(t)$ is input data bits, U=Total nuber of users, *A*=Amplitude in Eqn. (8) .For non-contiguous transmission let consider, total subcarriers are 16. For U^{th} SU if vector Y represent the noncontiguous subcarrier allocation to the user. Y=[1110011010001101] where „0‟ indicate null subcarrier.
Then $C^u(t)$is given by

$$e^{j2\pi\Delta f0t} . e^{j0U2\pi/9} + e^{j2\pi\Delta f1t} . e^{j1U2\pi/9} + e^{j2\pi\Delta f2t} . e^{j2U2\pi/9} + e^{j2\pi\Delta f5t} . e^{j3U2\pi/9} + e^{j2\pi\Delta f6t} . e^{j4U2\pi/9} + e^{j2\pi\Delta f8t} . e^{j5U2\pi/9} + e^{j2\pi\Delta f12t} . e^{j6U2\pi/9} + e^{j2\pi\Delta f13t} . e^{j7U2\pi/9} + e^{j2\pi\Delta f15t} . e^{j8U2\pi/9} \quad (9)$$

Spreading sequence in Eqn.(9), is a complex sequence using CI concept for the NC transmission we can note here code generated for noncontiguous subcarriers will preserve its orthogonal property. Orthogonality of Walsh and CI code is observed for non-contiguous transmission where number of subcarriers may not be remain in power of 2 and so cross co relation of user i and user *j* for the case of Walsh become non zero shows that Walsh code not preserve its orthogonality where in the case using CI code cross correlation is zero result into orthogonal code in noncontiguous transmission.

It is observed that the cross correlation of two user spreading sequence, the first set of N_p*-1* equally spaced zeros in cross correlation indicates that a CI/MC-CDMA system can simultaneously support *Np* orthogonal signature waveforms (and, hence, N orthogonal users). The existence of a second set of zeros, equally spaced by time separation (1/ ((Np-1) f)), indicates that we can place an additional (N-1) signature waveforms at highly (but pseudo) orthogonal locations. [The first set of N orthogonal signature waveforms and the second set of N-1 signature waveforms are nearly orthogonal (pseudo orthogonal)]. Hence, a CI/MC-CDMA system can support N orthogonal users and, additionally, if more users are to be accommodated, it can support these users pseudo-orthogonally by assigning N-1 up to pseudo-orthogonal signature waveforms. This flexibility is not found in the MC-CDMA codes available to date, where codes are chosen to support orthogonal users [4]-[6].

V. CHANNEL MODEL

The channel model for proposed work considers frequency selective channel having L multipath for a multipath Rayleigh fading. Channel amplitudes assumed to be statically independent random variable having PDF of Rayleigh distribution. Phase and path delays are uniformly distributed. The channel is assumed to be time-variant. Consequently, during a symbol period, the discrete time channel impulse response is given by Eqn. (10).

$$h(n,\tau)=\sum_{l=1}^{L} h_l(n)\delta(n-\tau_l) \qquad (10)$$

If L multipath impulse responses is considered for each user for Rayleigh fading channel can be given as Eqn. (11).

$$h_u(t)=\sum_{l=1}^{L} \alpha_l^u\, \delta(t-\tau_l)e^{j\psi_l^u} \qquad (11)$$

Where in Eqn. (11) l is index for multipath. α, ψ, and τ are the amplitude phase and delay for that multipath [7]. We can consider that all the subcarrier are having same delay. Amplitude, phase and delay variable are mutually independent. Amplitude is following Rayleigh distribution having mean *0* and variance *1*, phase of different paths are to be distributed random variables in *[0 2π]*. Delay for path for any user *U* are uniformly distributed *[0 Ts]* [8]. With Rayleigh fading multipath effect and Doppler Effect are to be considered. One can analyze the NC-MC-CDMA performance with Doppler Effect with the frequency selective Rayleigh fading channel with the consideration of velocity and distance of the secondary user. If we assume equal power distribution for all the users than the received signal at base station can be written as Eqn. (12).

$$r(t)=\sum_{u=1}^{U}\sum_{j=1}^{N_p-1}\sqrt{\frac{2P}{N}}\alpha_j^u D_j^u C_u[j-1]PT_s(t-nT_s-\zeta_u)\cos\left(2\pi f_j t+\phi_j^u\right)+n(t) \qquad (12)$$

Up on receiving signal (12) for U^{th} user ,where $\alpha$is the gain, an amplitude following Rayleigh pdf . The φ is phase offset in the j^{th} subcarrier due to the channel, U is the total number of users utilizing the system and *n(t)* represents additive white Gaussian noise (AWGN) [3].

VI. ANALYSIS OF NC-MC-CDMA AND CI/NC-MC-CDMA

The system describes above using MC-CDMA technique implemented using Walsh and CI spreading code. Considering correlation property of PN, Gold, Walsh and CI it is found that CI and Walsh are more compatible so in proposed work done with Walsh and CI code. MATLAB tool used for the simulation of the system. For all the simulations we have considered QPSK modulation in AWGN and Rayleigh channel theoretical BER are respectively in Eqn. (13) and (14) expressed as

$$p_e=\frac{1}{2}erfc\sqrt{\frac{E_b/N_0}{2}} \qquad (13)$$

$$p_e=\frac{1}{2}*\left(1-\sqrt{\frac{E_b/N_0}{E_b/N_0+1}}\right) \qquad (14)$$

In fig. 6.Simulation result for single user is shown where parameters used for simulation are given as Table 1.

Number of user	1
Number of subcarrier	16
Number of Rayleigh multipath	04
Spreading code	Walsh, CI

Table: 1 Parameters for single user

Number of user	2
Number of subcarrier	16
Number of Rayleigh multipath	04
Spreading code	Walsh, CI

Table: 2 parameters for two users

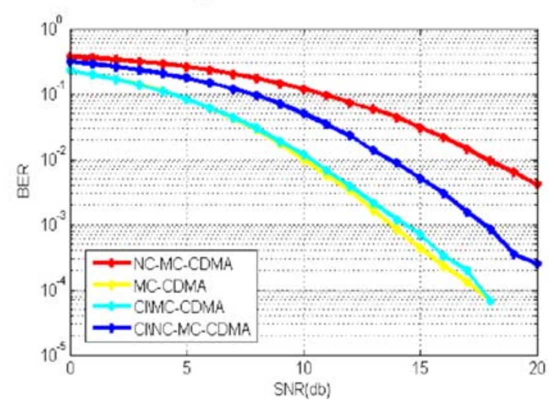

Fig. 6. BER performance of single user using CI and Walsh code.

It can be observed in fig. 7. for MC-CDMA BER is poor but for the case of CI code BER performance increase as more diversity is provided and for the case NC-MC-CDMA it is observed from simulation CI environment become prominent because of orthognality is preserved.

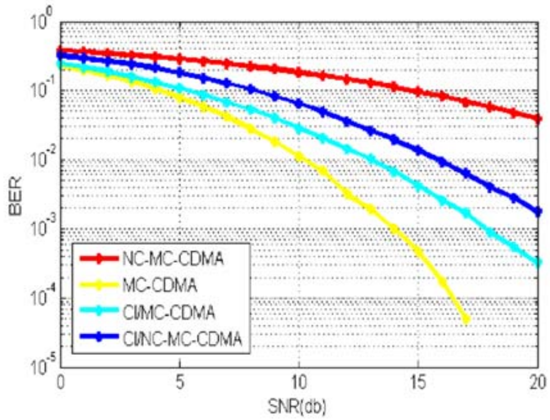

Fig. 7. BER performance of two user using CI and Walsh code

Number of user	4
Number of subcarrier	16
Number of Rayleigh multipath	04
Spreading code	Walsh, CI

Table:3 parameters for four users

It can be observed here in above fig. 8. for four users MCCDMA BER is poor but for the case of CI code BER performance increase and for the case NC-MC-CDMA It is observed from simulation CI environment become prominent here closer response of simulation result shown less number of user data bits.

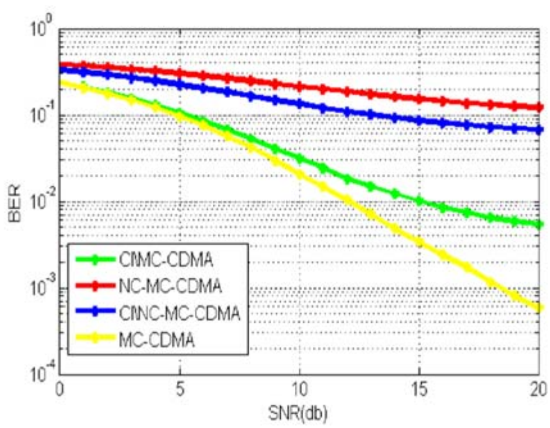

Fig. 8. BER performance of four user using CI and Walsh code.

System simulation performance with different number of subcarriers for same user shown in fig. 9. We uses 16 and 32 number of subcarriers for MC-CDMA , NC-MC-CDMA with higher number of subcarrier CI provide more diversity and so BER improved.Fig.9. Simulation also conclude that increasing number of subcarrier provide more diversity.

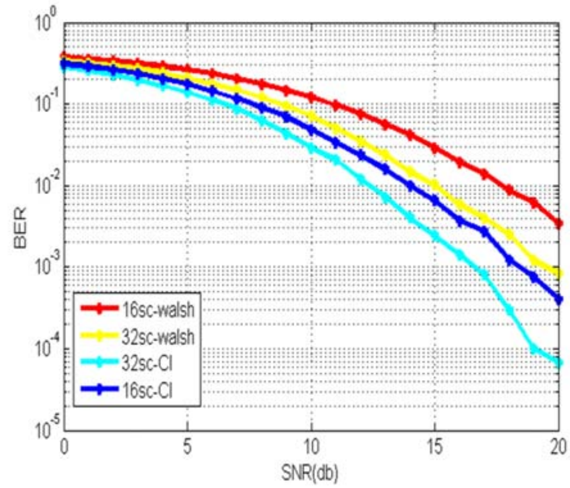

Fig. 9. BER performance of single user using CI and Walsh code with different subcarrier.

VII. CONCLUSION

In this paper the BER performance for MC-CDMA and NCMC-CDMA using CI and Walsh code for single user and up to four users are carried out. It is apparent from the simulation results that CI code performed well than other orthogonal codes like Walsh Hadamard. Here the orthogonality of spreading codes is violated in case of Walsh Hadamard code at cognitive environment due to sub-carrier nulling but in this environment CI codes maintain their orthogonality and give better performance.

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