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Modified Greedy Algorithm for Cognitive DS-CDMA System

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Abstract: Since appearance of cognitive radio systems, users 'access to wireless communication systems has become based on certain constraints. In this paper we tried to minimize MAI caused by multiplexing users in DS- CDMA system. By applying interference limitation algorithm denoted by modified *Greedy algorithm*, number of activated users will vary at each signalling interval based on pre-determined interference threshold. Simulation of proposed cognitive CDMA system using software tools showed that acceptable bit error rate level could be obtained at receiving end at low value of signal- to-noise ratio when compared to traditional CDMA system without Greedy algorithm.

Keywords: DS-CDMA, MAI, CRN, Greedy algorithm.

I. INTRODUCTION

The radio spectrum is a scarce natural resource. The regulation of this resource is often a task made by government agencies. For example, the Canadian Radio-television and Telecommunications Commission (CRTC) in Canada and the Federal Communications Commission (FCC) in USA are responsible for allocating spectrum frequencies to different coexisting wireless networks in order to prevent interference among them [1]. However, since the license assignment is done in a static manner, it leads to an underutilization of scarce radio spectrum which can be as high as 85%. [2].

The radio spectrum, which is needed for wireless communication systems, is a naturally limited resource. To support various wireless applications and services in a non-interfering basis, the fixed spectrum access (FSA) policy has traditionally been adopted by spectrum regulators, which assign each piece of spectrum with certain bandwidth to one or more dedicated users. By doing so, only the assigned (licensed) users have the right to exploit the allocated spectrum, and other users are not allowed to use it, regardless of whether the licensed users are using it. With the proliferation of wireless services in the last couple of decades, in several countries, most of the available spectrum has fully been occupied, which results in the spectrum scarcity problem. On the other hand, recent studies on the actual spectrum utilization measurements have revealed that a large portion of the licensed spectrum experiences low utilization [3]. These studies also indicate that it is the inefficient and inflexible spectrum allocation policy that strongly contributes to spectrum scarcity and, perhaps, even more than the physical shortage of the spectrum. To maintain sustainable development of the wireless communication industry, novel solutions should be developed to enhance the utilization efficiency of the radio spectrum. [4] Hence, dynamic spectrum sharing among the existing wireless networks receives an increasing research interest aiming to enhance the spectrum utilization. Cognitive radio networks (CRN) are wireless networks where unlicensed secondary users can communicate over the same frequency bands initially allocated to existing licensed primary users.

Code division multiple access (CDMA) scheme plays a crucial role in third generation mobile systems. Universal mobile telecommunication system (UMTS) is an important standard for third generation mobile system, based on wideband- CDMA (W-CDMA) as its multiple access technique. CDMA has numerous attributes that distinguish it from other techniques such as time-division multiple-access (TDMA) and frequency- division multiple-access (FDMA). [5]

Each of the above access techniques has its advantages and disadvantages. For example, TDM requires accurate time synchronization between transmitter and receiver for monitoring which users are supported in which time slot. Another disadvantage for TDM technology is ISI caused by fading channel distortion. The benefit of this technique is the ability of cochannel interference control. By contrast, an advantage of DS-CDMA is the ability of resolving multipath components with aid of a RAKE receiver. More specifically, the RAKE- fingers coherently combine the differently delayed, attenuated and phase- rotated signal components, hence achieving a diversity gain. Actually nothing is perfect, where in DS-CDMA technology if PN codes are not perfectly orthogonal, transmitted data by all multiplexing

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users will form interference source to each other known by multiple access interference MAI. Many techniques have been introduced for reducing MAI more than conventional DS-SDMA receiver. [6]

The ability to offer greater capacity and multi-rate transmission with backward compatibility, seamless integration, and easier migration path to 3G cellular systems has fuelled the widespread deployment of CDMA systems all over the world. But the principal attraction has always been the increased capacity over TDMA and FDMA systems, which explains multitudes of research devoted to study capacity of CDMA systems. And since CDMA capacity is limited by interference [7], most researches applied on CDMA systems were aimed to minimize multiple access interference (MAI).

One of the principal characteristics of a CDMA network is that the capacity of the system is a function of total interference experienced by the network, and is upper bounded by the cell experiencing the most interference. Thus, it is imminent to characterize total inter-cell interference seen by a single cell in terms of the user distribution in every other cell for determining capacity in that single cell. Traditionally, the total interference contributed by a cell has been viewed as an approximation, determined by simply multiplying the number of users in that cell by the average interference offered by that cell [7]. In other words, a user placed anywhere within a cell generated the same amount of interference.

User positions were varied over time, but the number of users was kept constant [8]. In this paper, we use a model where interference is calculated independent on distances between uses but only on channel coefficients time variation. Computer simulations of a CDMA network are carried out in order to study effect of some system parameters on bit error rate (BER) performance. Selected systems parameters studied in this paper are interference threshold, processing gain, modulation type, total number of users and number of active users. Sections of this paper are organized as follows. In section 2, characteristics of cognitive radio network will be discussed. In section 3, proposed system model will be explained. In section 4, simulation results of proposed cognitive CDMA system will be displayed and analysed. Finally in section 5, conclusion for proposed system performance is given.

II. Cognitive Radio Network Characteristics

The components of the CRN architecture can be classified in two groups or networks: primary and secondary networks. In the secondary network, secondary users must have the capability of adapting their transmission parameters to operate in multiple frequency bands and hence exploit the spectrum opportunities in both time and space. This ability can be granted using the software defined radio technology [9]. However, despite the possibility of maximizing the spectrum resources utilization offered by the CRN, the co-existence of the primary and secondary users is a very challenging problem. The secondary users can access the portion of radio spectrum initially reserved to primary users using one of the following techniques: spectrum overlay or spectrum underlay [10], [11].

In spectrum overlay, the unlicensed users can transmit in the spectrum belonging to users of a primary network if these users are not accessing their spectrum resources. On the other hand, for the spectrum underlay technique, the secondary users can access the spectrum owned by a primary network even if there are primary users using the same spectrum at the same time.

Anyhow, the secondary transmitters must not violate an interference level that has to be maintained at the receiving points of the primary transmissions. The authors in [12] study the capacity limits for spectrum sharing in a CRN where a secondary user respects an interference temperature in order to protect a primary transmission. Their study assumes two types of interference-power constraints, average and peak. The proposed model does not guarantee any protection to the primary users. Since it does not allow more than one user to transmit in each available frequency band, the studied objective functions cannot be optimized. In this paper, we propose an efficient novel spectrum sharing based on interference control algorithm among uses sharing same resources (in time or frequency domain) [2].

In the proposed interference control algorithm, little modifications have been applied to greedy algorithm with very low computational complexity in order to choose the secondary transmissions to be activated in the current time slot (TS). This algorithm allows the secondary transmissions causing a minimum of mutual interference to be activated in the same frequency band.
The capabilities of cognitive radio may provide many of the current wireless systems with adaptability to existing spectrum allocation in the deployment field, and hence improve overall spectrum utilization. Among many others, these features can also be used to meet many of the unique requirements and challenges of wireless sensor networks (WSN), which are, traditionally, assumed to employ fixed spectrum allocation and characterized by resource constraints in terms of communication and processing capabilities of low-end sensor nodes. [13]

III. Proposed Cognitive CDMA System

Consider the uplink of a single-cell CDMA network. Assume data transmission of all users (primary and

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secondary) is done in synchronous manner. We do not model the inter-cell interference due to frequency reuse. Inter-cell interference significantly adds to the complexity of the optimization problem, and shall be dealt with as a separate issue on its own right. The throughput of uplink transmission is typically limited due to the power constraint of primary users (Pus). Thus it is better suited to employ cooperation. A number of secondary users (SUs) are located in the cell and perform cooperative transmission for PUs to access the primary spectrum. We model the fading environment by large scale path loss and shadowing, along with fast Rayleigh fading. We assume techniques for channel estimation are employed and full channel side-information (CSI) is available, which enhances BER performance of CDMA cognitive system. Such assumptions about the fading environment and CSI are commonly used as in. Noises are modelled as complex Gaussian noises with zero mean and unity variance.

A. CDMA Transceiver Parameters:

There are K users including both Pus and SUs where K represents also number of transmission channels (complex channel coefficients with Rayleigh distribution H and fast time varying in addition to additive white Gaussian noise AWGN N). Proposed cognitive CDMA transmitter contains traditional stages as illustrated in figure (1) except in the process of active users' number determination which is based on modified Greedy algorithm to be explained in coming subsections.

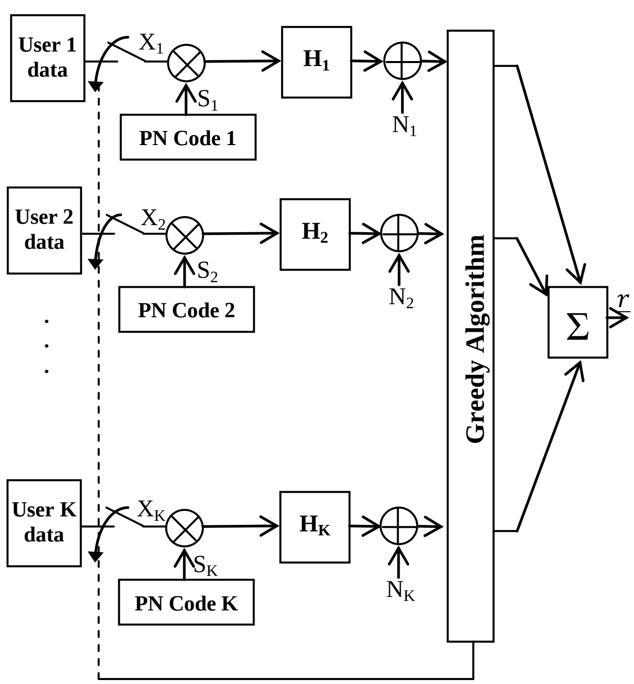

Fig. 1 "Cognitive CDMA Transmitter"

Received signal equation could be given as follows:

$$r(t) = \sum_{k=1}^{K} A_k X_k \sum_{n=0}^{N_c-1} S_k(t - nN_c)\, H_{n,k} + N_k \qquad (1)$$

Where:

- A_k: is the amplitude per data symbol for user number k.
- X_k: is data symbol of user number k which depends on modulation type. For example in case of BPSK $X_k \in \{\pm 1\}$ whereas in QPSK case $X_k \in \{\pm 1 \ \pm j\}$.
- $S_k(t)$: is the signature waveform of user k with chip duration T_c and number of chips = N_c.
- $H_{n,k}$: is the channel coefficient corresponding to chip number n and user k with Rayleigh distribution.
- N_k: is AWGN component with zero mean and unity variance.

For signal analysis simplifying, we will represent received signal in matrix form as follows:

$$\underline{r} = [r_1 \ r_2 \ \dots \ r_{N_c}]^T$$
$$= SH.A.X.+N \qquad \dots (2)$$

Where:

- $SH = \begin{bmatrix} S_{1,1}H_{1,1}P_1 & S_{1,2}H_{1,2}P_2 & \dots & S_{1,K}H_{1,K}P_K \\ S_{2,1}H_{2,1}P_1 & S_{2,2}H_{2,2}P_2 & \dots & S_{2,K}H_{2,K}P_K \\ & & \vdots & \\ S_{N_c,1}H_{N_c,2}P_1 & S_{N_c,2}H_{N_c,2}P_2 & \dots & S_{N_c,K}H_{N_c,K}P_K \end{bmatrix}$

Where, Pi is active users' matrix containing 1 or 0 depending on greedy algorithm result which will be explained in the next subsection.

- $A = \mathrm{diag}[A_1 \ A_2 \ \dots \ A_K]$
- $X = [X_1 \ X_2 \ \dots \ X_K]^T$
- $N = [N_1 P_1 \ N_2 P_2 \ \dots \ N_K P_K]^T$

Stages of cognitive CDMA receiver are compatible stages to cognitive CDMA transmitter block diagram but in reverse order. Figure 2 illustrates stages of cognitive CDMA receiver.

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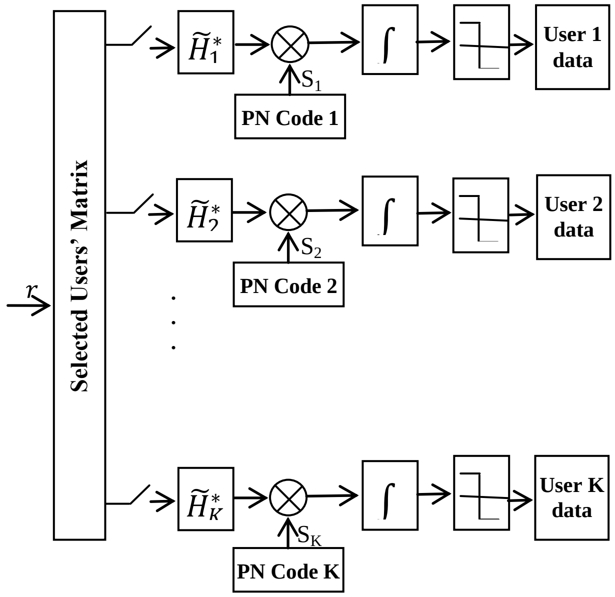

Fig. 2 "Cognitive CDMA Receiver"

B. Modified Greedy Algorithm:

In the proposed cognitive CDMA system, not all the K users are activated at each signalling interval (i.e. data symbol interval) but a group of users are selected using modified greedy algorithm. The difference between algorithm mentioned in [2] and our algorithm is that the modified algorithm suits CDMA technique by the aid of channel parameters knowledge. Steps of proposed greedy algorithm are given as follows:

1. At each signalling interval, consider that channel coefficients matrix H is perfectly known at transmitter. Users' signatures matrix S is assumed to contain Walsh PN codes of CDMA multiplexing users.
2. Decide required interference threshold I_{th}.
3. Calculate interference parameter Ci caused by each user as follows:

   $C_i = \sum_{n=1}^{N_c} S_{n,i} H_{n,i}$ . . . . (3)
4. If $C_i < I_{th}$ then put 1 in active users' matrix P, otherwise put 0.
5. Repeat steps 3 and 4 for the rest users i.e. $1 \leq i \leq K$

Figure 3 displays steps of proposed greedy algorithm but in form of flow chart.

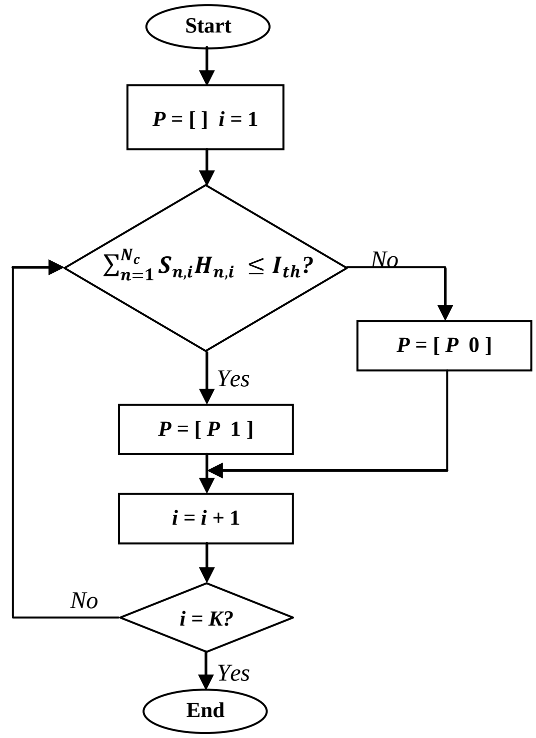

Fig. 3 "Proposed Greedy Algorithm Flow Chart"

IV. SYSTEM SIMULATION

In this section a group of figures will be displayed and analysed in order to explain practical effect of modified Greedy algorithm on CDMA system efficiency. Usually bit error rate (BER) measured at receiving end in terms of SNR is considered main method of performance measurement at any mobile communication system. MATLAB code is used for software simulation of proposed cognitive CDMA system in order to study effect of many system parameters on BER level.

The first set of curves shown in figure 4 displays BER performance versus variation in SNR measured at receiving end in dB with system parameters set as follows: 10 users' data are proposed to be multiplexed using DS- CDMA technique with QPSK as modulation method and PN Walsh code length = 64 chips. The main objective of this figure is to illustrate the effect of interference threshold value on the proposed CDMA system performance from BER point of view.

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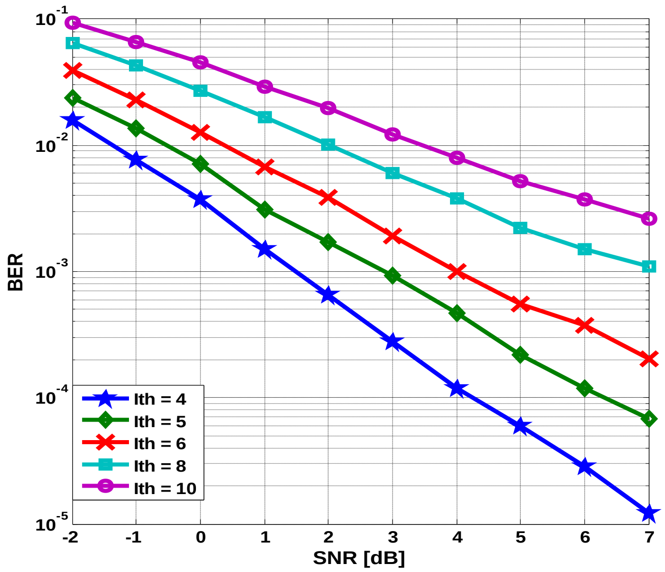

Fig. 4 "BER performance of proposed cognitive CDMA transceiver with K = 10, N = 64, and QPSK at different values of interference threshold values"

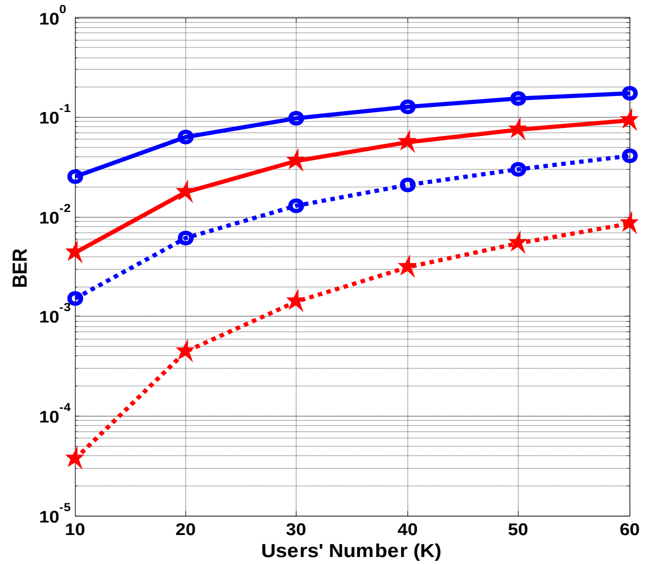

Fig. 5 "BER performance of proposed cognitive CDMA transceiver with I^{th} = 2 and SNR = -2dB using different modulation techniques (QPSK and BPSK) and different values for processing gains N. Solid line is for N = 64 and dashed line is for N = 128"

Five values of interference threshold (I_{th}) have been examined in this stage; I_{th} = 10, 8, 6, 5, and 4 whereas rest system parameters remain fixed with values mentioned in previous paragraph. Let's remember, threshold of interference represents allowed MAI level of power. Simulation results showed that by decreasing interference threshold, lower BER level could be obtained at receiving end. The reason explaining this result is the reduction happens in the allowed number of users resulted from interference threshold reduction which will be proved in coming results.

In the next set of curves shown in figure 5, we will focus on the effect of two parameters on BER level obtained at receiving end; the number of multiplexed users K in CDMA system and processing gain N representing PN code length. As well known, increment in users' number usually results in degradation in BER performance as a result of MAI increment. But actually, in the proposed cognitive CDMA system, increment in users' number resulted in small increment in BER.

Table 1 displays an example for BER obtained when 10 users cooperating cognitive CDMA system using different modulation techniques and different processing gains:

Table 1: "BER picked from figure 5 at K =10"

N = 64	QPSK	0.0252
	BPSK	0.0044
N = 128	QPSK	0.0015
	BPSK	3.7569 x 10^{-5}

As appeared in figure 5 and table 1, when applying BPSK as modulation technique, lower BER could be obtained at receiving end when compared with QPSK technique and this conclusion is well known but actually in the proposed cognitive CDMA system the difference between BPSK and QPSK techniques is becoming wider especially when large value of processing gain is applied. In order to explain this idea more clear let's display numeric example confirming this conclusion. When N = 64, BPSK requires less SNR by 15 dB w.r.t. QPSK in order to achieve the same BER. Whereas, when N = 128, BPSK requires less SNR by 20 dB w.r.t. QPSK in order to achieve the same BER.

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In the coming set of curves shown in figure 6, we will display how the number of active users is affected by interference threshold I_{th} and processing gain N. Two cases are handled in this figure, when N = 64 and 128. Although previous results have shown that processing gain increment resulting in BER reduction but actually in the proposed system, when results is considered for certain number of users K, you should know that not all users are allowed to access the system, but based on interference threshold condition mentioned before.

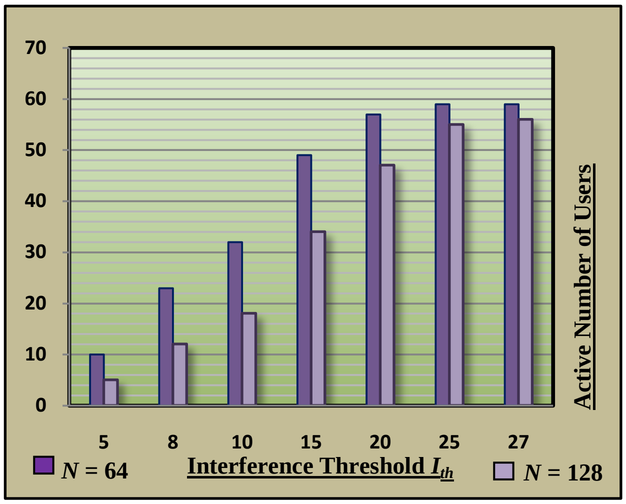

Fig. 6 "Performance of active users' number versus variation in interference threshold I_{th} and processing gain N"

V. CONCLUSIONS

Multiple access interference was considered first enemy of DS- CDMA since appearance of this techniques. In the proposed cognitive DS- CDMA system, modified Greedy algorithm was applied in order to decrease MAI caused by multiplexing users to each other. Acceptable BER could be obtained using this algorithm where at SNR = 3 dB, obtained BER at receiver will be order of 10-4. But there is one drawback of this proposed system is the limitation happens in the number of activated users in order to achieve this result. Where in order to obtain BER level mentioned before, 10 users are assumed to access the system but actually only 8 of them will be activated.

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