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ENERGY EFFICIENT COMMUNICATION IN UNDERLAY MIMO COGNITIVE RADIO NETWORK

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ABSTRACT – In this paper, we consider efficient transmission for Orthogonal Frequency Division Multiplexing (OFDM) underlay MIMO (Multiple-Input Multiple – Output) Cognitive Radio (CR) networks. In particular, we consider the optimization to minimize overall energy consumption of single cell secondary network with multiple secondary users (SUs) using Energy Ratio (ER) algorithm and also reducing the synchronization errors using Constant Amplitude Zero Auto Correlation (CAZAC) technique since we have chosen OFDM as transmission medium. We also estimate Interference to Noise ratio and Packet Delivery Ratio (PDR). Simulation results shows that energy consumed per bit and interference to noise ratio is less for optimal time multiple stream than optimal time single stream and max rate transmission and Carrier Frequency Offset (CFO), Sampling Time Offset (STO) has been reduced using proposed algorithm.

INDEX TERMS – MIMO, energy consumption, interference to noise ratio, PDR, cognitive radio network, Energy Ratio algorithm, CFO, STO.

I.INTRODUCTION

Future wireless systems are evolving to support the exponentially increasing traffic demands which in most cases, is achieved at the expense of a higher energy consumption and a considerable impact on the environment. Energy-efficient transmission is of critical importance to reduce the carbon footprint and to prolong the battery lifetime of wireless devices. Studies of energy- efficient transmissions of MIMO networks fall into two classes: traditional MIMO networks [1], [8] and MIMO CR networks [4], [5]. For example, in the former class [1] investigated the energy consumption of a single MIMO/SISO link under different link distances. In [8], the authors considered power minimization through downlink transmit beam forming using semi definite programming (SDP) approach. In the latter class [4], [5] considered the energy/power minimization problem in MIMO CR networks. In this paper, we are interested in energy- efficient transmissions in a MIMO Cognitive Radio (CR) network.

We propose technique [2] called *Energy Ratio* (ER) which is a spectrum monitoring technique that is appropriate for OFDM based cognitive radios. Once the sensing phase is completed, it detects the reappearance of the PU while the SU continues transmission without scheduling any Quiet Periods (QP). The technique can be used in the frequency domain in which selective fading is converted to flat fading over OFDM sub-channels.The cognitive radio is to allow the Secondary Users (SUs) to opportunistically use the spectrum that is assigned to the licensed Primary Users (PUs) in order to alleviate spectrum scarcity. The MIMO techniques enables the SUs to coexist with the PUs without causing harmful interference to the primary links. Apart from the above advantage, performing energy-efficient transmissions among the SUs could also alleviate the interference to the primary system. . The key idea that enables the underlay mode in a CR network is that with multiple antennae, the SU can carefully design its pre-coding matrix so as to suppress the interference at the primary receivers. Such a technique normally requires Channel State Information (CSI).With the aid of MIMO techniques, it is possible that multiple SUs send uplink traffic to the secondary Base Station (BS) simultaneously with spatial multiplexing [6]. However, in a CR network, the interference power at each secondary receiver does not only come from the primary users but also from other SUs. The MIMO interference channel is well known to result in NP hard problems.

Therefore, in order to avoid excessive interference among the SUs, we focus on the case that the SUs send their traffic via OFDM [5].Orthogonal frequency division multiplexing is multi- carrier modulation (MCM) technique used for high data rate wireless applications that has large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels. Spectral efficiency and multipath immunity are two major advantages of OFDM technique. It is known that OFDM is sensitive to synchronization errors which may cause harmful ICI because of the Carrier Frequency Offset (CFO) and the Sampling Time Offset (STO).In this paper, we are also interested in reducing synchronization errors. CAZAC (Constant Amplitude Zero Auto Correlation) algorithm [3] is used in synchronization algorithms which in turn useful for estimation of channel and fast equalization. CAZAC sequences are widely used in fields of pulse radar compression, spread spectrum communication systems, OFDM systems. In this paper, we use CAZAC sequences as the pilot symbols to achieve the synchronization.

Observation shows that energy consumed per bit and interference to noise ratio is less for optimal time multiple stream than optimal time single stream and max rate transmission and Carrier Frequency Offset (CFO), Sampling Time Offset (STO) has been reduced using proposed algorithm.

II.SYSTEM MODEL

The system model for Orthogonal frequency division multiplexing (OFDM) shown in Fig. 1.which is multi- carrier modulation technique for high data rate wireless applications that has large number of closely spaced orthogonal sub-carrier signals are used to carry data over several parallel channels. Spectral efficiency and multipath immunity are two major advantages of OFDM technique. It is known that OFDM is sensitive to synchronization errors which may cause harmful ICI because of the Carrier Frequency Offset (CFO) and the Sampling Time Offset (STO).

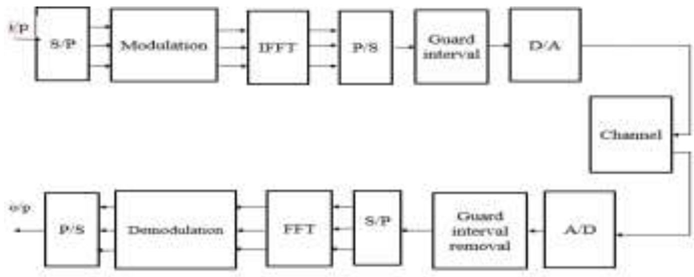

Fig. 1. System Model

The CFO is due to the difference between the carrier frequencies generated by the transmitter and receiver. It is commonly represented by the normalized CFO, $\varepsilon_C = \varepsilon_i + \varepsilon_f$, where ε_C is the ratio of the frequency offset to the sub- carrier spacing, ε_i the integer part of the normalized CFO, and ε_f is the fractional part [2]. The STO is caused by the mismatch in sampling frequencies between the transmitter and receiver. This can lead to serious degradation due to loss of orthogonality between subcarriers [2].The orthogonality can be completely maintained even though the signal passes through a fading channel by introducing a cyclic prefix.

The binary information is first grouped and converted from serial to parallel one because QAM modulation scheme accepts only parallel data streams. After inserting pilots either to all sub-carriers with a specific period between the input data sequence, IFFT transform block is used to transform the data sequence of length N {X(k)} into time domain signal {x(n)} ,where N represents FFT length. After conversion through D/A converter, this signal will be sent from the transmitter. The transmitted signal will pass through the fading channel with additive noise. At the receiver, through A/D and low pass filter, guard time is removed. Followed by FFT block in which the pilot signals are separated and the compressed channel for the data sub- channels is obtained in channel estimation block [7].

III.ENERGY RATIO ALGORITHM (ER)

ER is spectrum monitoring technique that is suitable for OFDM-based cognitive radio for energy consumption. In which once the sensing phase is completed, it detects the reappearance of the PU while the SU continues transmission without scheduling any Quiet Periods (QP). The technique can be used in the frequency domain in which selective fading is converted to flat fading over OFDM sub-channels [2].

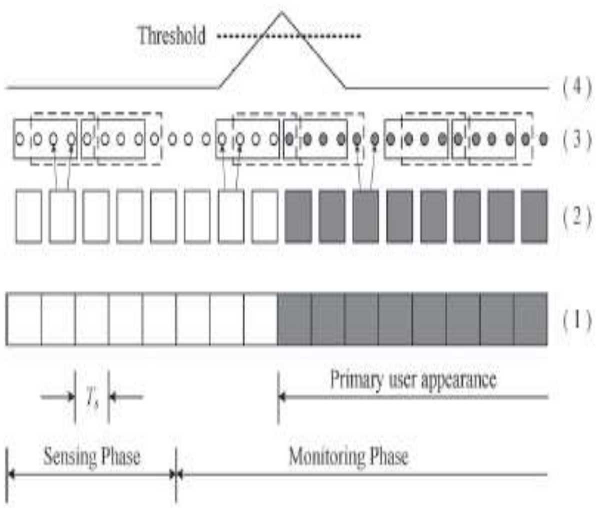

Fig. 2. Energy ratio processing details. (1) The time domain sequence for the OFDM blocks.
(2) Frequency domain samples. (3) Reserved tones processing with two sliding windows. (4) Decision making variable.

The overall algorithm is illustrated by Fig. 2. It is assumed that the primary signal appears during the monitoring phase. At the receiver, after CP removal and frequency domain processing on the received signal, the reserved tones from different OFDM symbols are combined to form one sequence of complex samples. Two consecutive equal- sized sliding windows are passed over the reserved tone sequence. The energy of the samples that fall in one window is evaluated and the ratio of the two energies is taken as the decision making variable. This is called ER algorithm.

IV.CONSTANT AMPLITUDE ZERO AUTO CORRELATION (CAZAC)

OFDM is sensitive to synchronization errors which may cause harmful ICI because of the Carrier Frequency Offset (CFO) and the Sampling Time Offset (STO). CAZAC (Constant Amplitude Zero Auto Correlation) sequences are used in synchronization algorithms which are useful for channel estimation and fast start-up equalization. CAZAC sequences are widely used in fields of pulse radar compression, spread spectrum communication systems, OFDM systems. In this paper, we use CAZAC sequences as the pilot symbols to achieve the synchronization. This sequences have the fine natures of constant envelope and zero auto-correlation function. Therefore, using CAZAC sequences can reduce the linearity requirements of the RF amplifier and synchronization performance is improved [3].

Estimation can be done in 3 steps

- Power detection
- Coarse timing synchronization- This estimates the start of the OFDM frame over an approximate range of samples. It can be estimated using maximum-likelihood estimation.
- Fine timing synchronization- needed to obtain start of the OFDM frame to within a few samples. It can be obtained by cross-correlating the receive samples with the transmitted sequence.

V.SIMULATION RESULTS

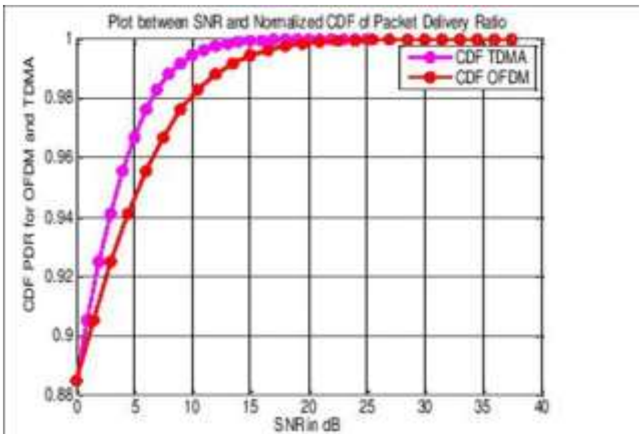

Fig. 1 PDR Comparison for OFDM and TDMA

Fig. 1. shows PDR Vs. SNR. PDR is the ratio of

the total number of packets delivered to the destination to the total number of packets sent from the source.

PDR=Total number of packet delivered at the receiver / Total number of packet sent from the transmitter.

Greater the packet delivery ratio, better the performance of the system. In this fig, OFDM has 40 dB SNR which is greater than 25dB of SNR performance of TDMA.

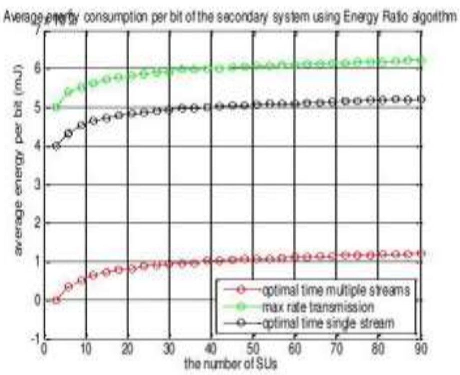

Fig. 2. Average energy consumption per bit of the secondary system

The energy consumption per bit of the SUs in the statistical CSI scenario, named "optimal time single, optimal time multiple streams and max rate transmission", is shown in Fig. 2. In this graph, average energy consumption is done using Energy Ratio(ER) algorithm. Energy consumed per bit will be lesser for optimal time multiple streams is about 1.2mJ compared with optimal time single stream about 5.2mJ and max rate transmission about 6.2mJ since multiple streams of data is transmitted over channel.

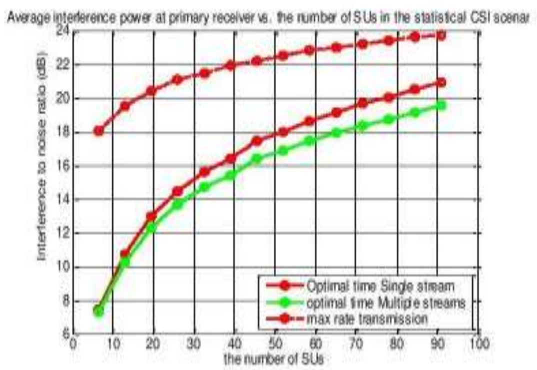

Fig. 3. Interference to noise ratio Vs number of SUs

Fig. 3. shows the average interference power from the SUs to the primary receivers in the statistical CSI scenario, which is measured by the interference-to-noise ratio (in dB). In the "max-rate" scheme, the average interference- to-noise ratio is smaller than the required 24dB. This is because the secondary transmitter needs to satisfy the interference constraint at both primary receivers in each simulated network. Therefore, the interference-to-noise ratio at each primary receiver is smaller than 24dB in many simulation runs. The interference to the primary system is also alleviated in the "optimal time single stream", "optimal time multiple streams "and "max rate transmission". The interference power to the primary system adapts to the traffic load of the secondary system. Moreover, we can observe that in the "optimal time multiple streams" scheme, the interference to noise ratio reduced compared with the other schemes. From Fig Interference to noise ratio is about

Optimal time multiple streams: 19dB Optimal time single stream : 21dB Max rate transmission : 24 dB

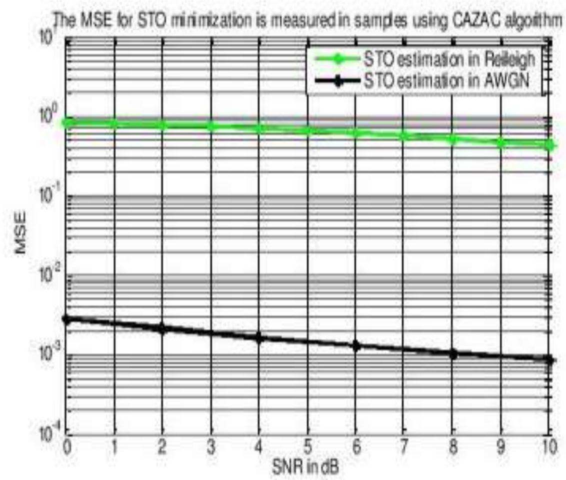

Fig. 4. STO minimization using CAZAC

Sampling Time Offset (STO) has been estimated and minimized using CAZAC algorithm is shown in Fig. 4. STO is estimated for both fading (Rayleigh) and non- fading (AWGN) channel. The Mean Square Error (MSE) is reduced about 10−2.9 for AWGN channel since it has uniform spectrum throughout the channel which is lesser than 10−0.6 for Rayleigh channel.

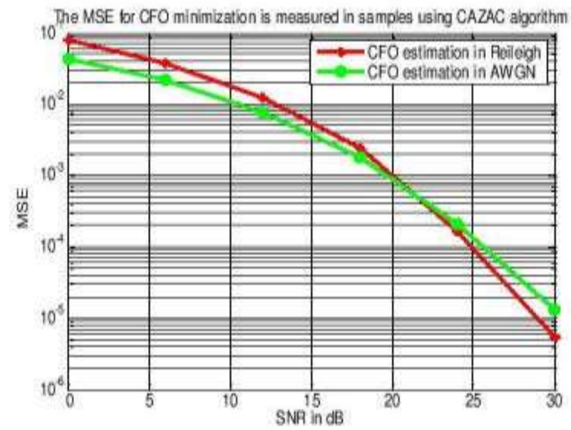

Fig. 5. CFO minimization using CAZAC

Carrier Frequency Offset (CFO) has been estimated and minimized using CAZAC algorithm is shown in Fig. 5. CFO is estimated for both fading (Rayleigh) and non- fading (AWGN) channel. The Mean Square Error (MSE) is reduced about 10−1.6 for AWGN channel since it has uniform spectrum throughout the channel which is lesser than 10−1.2 for Rayleigh channel.

VI.CONCLUSION AND FUTURE WORK

We calculated energy consumed per bit, interference to noise ratio over single, multiple stream and max rate transmission. Packet Delivery Ratio (PDR) is calculated for both TDMA and OFDM. We estimated and reduced the STO and CFO for Rayleigh and AWGN channel. Simulation results shows that energy consumed per bit and interference to noise ratio is less for optimal time multiple stream than optimal time single stream and max rate transmission. SNR performance is increased for OFDM than TDMA. Mean Square Error (MSE) is reduced for AWGN channel than Rayleigh channel. Spectrum efficiency can be further improved if the SUs send simultaneous uplink transmissions with spatial multiplexing. Considering the diversity gain and the spatial multiplexing gain trade-off for energy-efficient MIMO CR networks is left for future studies.

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