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Energy Efficient Cooperative Spectrum Sensing and Sharing Strategy Selection for Cognitive MIMO Sensor Networks

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***Abstract*—The continuing demand of wireless communication requires a more efficient use of the limited spectrum resources. Cognitive radio (CR) is an intelligent technology for enhancing the utilization of the precious spectrum resources. In CR , the spectrum to be shared in a flexible way. Multiple-input and Multiple-output (MIMO) communication technology has gained significant attention as it is a powerful scheme to improve spectral efficiency. In this paper the important task is to develop energy efficient cooperative spectrum sensing and sharing strategy for multi-Input Multi-Output (MIMO) sensors. The cooperative spectrum sensing techniques were proposed to improve performances of signal sensing with the background of two decision techniques Hard Decision and Soft Decision.CR channel SNR has a major impact on the performance of a wireless connection. In this paper, it is explained that how MIMO sensor can efficiently do the spectrum sensing and use the channel even if the SNR value is lower than a specified threshold value.**

***Keywords*—Cognitive Radio, MIMO, Sensor Network, Spectrum Sensing, Energy Efficiency, SNR ,Capacity**

I: INTRODUCTION

Recently, in Wireless Communication, Cognitive Radio (CR) has been adapted for using the unused spectrum bands effectively[1]. The Cognitive Radio and MIMO Technology jointly have received great attention in recent years. The former is the key enabling technology for spectrum utilization [2]and the later has already proved itself as a powerful signal processing technique to improve spectral efficiency. The basic strategy for CR network is dynamical locate unused spectrum which dedicated to licensed users[3]. Secondary Users(SU) should detect the Primary User (PU) signal in order to avoid interference with them[4].

Spectrum sensing is a technique in CR network to determine the white spectrums. Cooperative spectrum sensing was proposed to tackle the problem of fading, noise, uncertainty, shadowing, and even hidden node of primary users (PUs)[5].

In Cooperative spectrum sensing different sensors share their statistic information to find the PU. Wireless Cognitive networks employ sensors have limited batteries due to the cost factors . One of the challenges is how to minimize energy consumption so that the sensors can last for a long time[5].

In this paper, an energy efficient cooperative spectrum sensing based on MIMO sensors is proposed[6]. MIMO sensor is a promising solution versus using more sensors. In MIMO cooperative spectrum sensing, diversity helps that multi-antenna sensors behave virtually same as multi-sensors systems.

II: SYSTEM MODEL

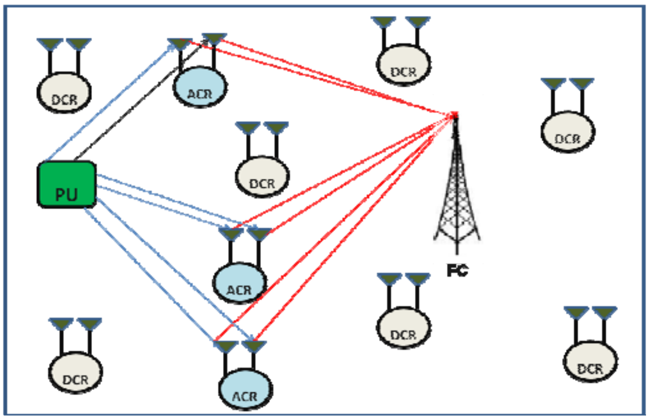

Fig:1: Cooperative Spectrum Sensing by MIMO Sensors

As a preliminary, we set up a network with 'S' numbers of SUs, one PU and a fusion centre (FC). It is indicated in Fig.1. ACR means Activated Cognitive Radio and DCR means Deactivated Cognitive Radio. In the section-A the equations based on SISO sensors are explained and then in section B the equations are extended to MIMO sensors.

A: Conventional sensor network with single antenna:

Each sensor decides which channel is busy or idle based on samples of its receiving signal, that is, $y_i[n]$=1......S, and n is a sample index. Therefore, there are two hypotheses about receive signal, Hypothesis H_1 refer to PU's presence and Hypothesis H_0 means that PU is not present .

$$H_1 : y_i[n] = h_i[n]x[n] + z_i[n] \quad (1)$$
$$H_0 : y_i[n] = z_i[n] \quad (2)$$

Where , x[n]- is nth sample of transmitted signal from PU. , $z_i[n]$ - is independent and identically distributed Gaussian noise with Zero mean and σ_z^2 is the variance received by sensor. , $h_i[n]$ is channel gain between ith sensor and PU, it has model as follows:

$$h_i=10^{\frac{-PL_i}{20}} \cdot g_i \quad (3)$$

Where g_i is a zero mean complex-valued Gaussian process with unit variance for a Raleigh fading channel and PL_i has two parts:

$$PL_i=20\log\left(\frac{d_{pi}4\pi f_c}{c}\right)+n_i \quad (4)$$

Where the first term which is path loss part involves:

d_{pi} : distance of every sensor from PU

f_c : carrier frequency and

c : speed of light

The second term is a zero mean real Gaussian random variable.

We obtain the optimal Neyman-Person test that state decision metric for energy detector

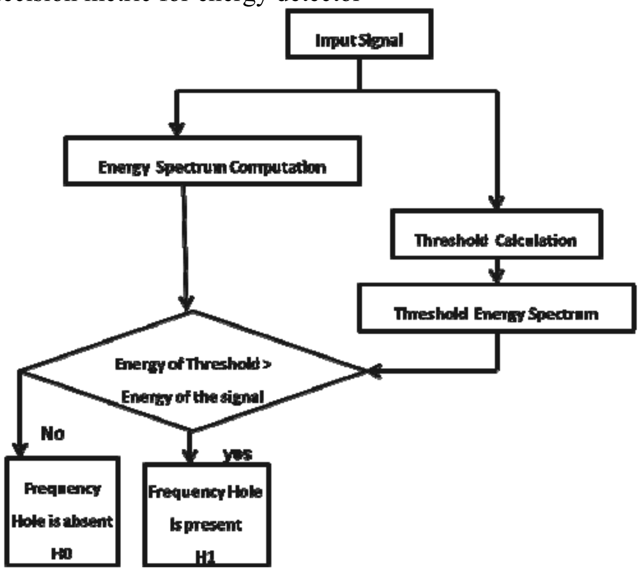

Fig:2 Flow for Energy detection method

$$E_{di}=\frac{1}{N}\sum_{n=1}^{N} y_i^2\,[n] \quad (5)$$

Where N- Number of samples which integrated for reliable decision, E_{di} - Decision metric for energy detector and T- Detection threshold .

The detection performance can be considered from two aspects:

i) P_{di} local probability of detection and

ii) P_{fi} local probability of false alarm

P_{di} is the probability of detecting signal when PU is present (hypothesis H_1) ,

P_{fi} is probability of detecting signal when PU is not present (hypothesis H_0)

$$P_{di} = P(E_{di}>T|H_1)$$

$$= Q(\left(\frac{T}{\sigma_z^2}-snr_i-1\right)\sqrt{\frac{N}{2snr_i+1}}) \quad (6)$$

$$P_{fi} = P(E_{di}>T|H_o) = Q(\left(\frac{T}{\sigma_z^2}-1\right)\sqrt{N}) \quad (7)$$

Where snr_i is signal to noise ratio in ith sensor when PU is present. Based on hypothesis testing, each sensor sends one bit decision to FC, as a busy channel and as an idle channel. In this case global probability of detection and global probability of false alarm are as follows:

$$P_d = 1-\prod_{i=1}^{S}(1-\rho_i P_{di}) \quad (8)$$

$$P_f = 1-\prod_{i=1}^{S}(1-\rho_i P_{fi}) \quad (9)$$

Where $\rho_i \in \{0,1\}$ is the assignment index,"0" indicates that sensor node is on sleeping mode (is not selected for sensing) and "1" indicates that sensor is on sensing mode.

It is found that, when more sensors are distributed in the network, then due to multi sensor diversity and less distance between some sensors and primary user, we can achieve superior performance. But increasing number of sensors has a significant implementation of cost. So, MIMO sensors can be implemented in the network with rational cost and give a better performance against multiple sensors. As a promising design, we can use MIMO sensors versus using multiple sensors. MIMO sensor network design is more cost efficient.

B. ***Promising Sensor Network With MIMO Sensors:***

Two strategies can be applied to use diversity advantages in MIMO sensors. The first strategy, as named hard decision and second strategy is soft decision[7].

Hard decision is the one in which the each secondary user detects independently and gives the one-bit decision regarding the existence of the primary user. The two simple rules of hard decision are OR and AND rule. In second strategy as named soft decision, signals are combined then detection is performed on the combined signal. SC and EGC are used as combination schemes.

Similar to single antenna sensors, two hypothesis can be assumed for received signal in each antenna.

$$H_1 : y_{i,l}[n] = h_{i,l}[n]x[n] + z_{i,l}[n] \quad (10)$$

$$H_0 : y_{i,l}[n] = z_{i,l}[n] \quad (11)$$

Where , $y_{i,l}[n]$ - denotes nth sample of received signal at lth antenna of ith sensor and $h_{i,l}[n]$ is a channel gain between the lth antenna of sensor and PU, it has model as follows:

$$h_{i,l}=10^{\frac{-PL_i}{20}}.g_{i,l} \quad (12)$$

Where $g_{i,l}$ is a zero mean complex-valued Gaussian process with unit variance for a Raleigh fading channel between lth antenna of sensor i and PU.

When hard decision is used, local probability of detection and local probability of false alarm can be obtained by:

1)OR Rule: In OR rule, if any one of individual user's decision is right, or logic ONE, the final decision in Fusion Center is marked by logic ONE. Therefore, the cooperative probability of detection and false alarm in case of OR rule can be written:

$$P_{d.OR} = 1-\prod_{i=1}^{S}(1-\rho_i P_{di}) \quad (13)$$

$$P_{f.OR} = 1-\prod_{i=1}^{S}(1-\rho_i P_{fi}) \quad (14)$$

2)AND Rule: In this scheme, if all of the local decisions are ONEs, the final decision is marked ONE at the Fusion Center. At the same way, the cooperative probability of detection and false alarm in AND rule can be written:

$$P_{d.AND}= \prod_{i=1}^{S}\rho_i P_{di} \quad (15)$$

$$P_{f.AND}= \prod_{i=1}^{S}\rho_i P_{fi} \quad (16)$$

Where ,$P_{di} = 1-\prod_{i=1}^{L}(1-\rho_i P_{di,l}) \quad (17)$

$P_{fi} = 1-\prod_{i=1}^{L}(1-\rho_i P_{fi,l}) \quad (18)$

Where $P_{di,l}$ and $P_{fi,l}$ are probability of detection and probability of false alarm of lth antenna in ith sensor, respectively and L is number of antennas.

$P_{di,l} = Q\left(\left(\frac{T}{\sigma_z^2} - snr_{i,l} - 1\right)\sqrt{\frac{N}{2snr_{i,l}+1}}\right)$ (19)

$P_{fi,l} = Q\left(\left(\frac{T}{\sigma_z^2} - 1\right)\sqrt{N}\right)$ (20)

When soft decision is used, local probability of detection and local probability of false alarm can be obtained by:

1)Selection Combining (SC): In this scheme, the FC make final decision by comparing SNR, of all *L* branches. The branch with maximum SNR will be selected.

$snr_{i,sc} = \max(snr_{i,1}, snr_{i,2}, \dots \dots, snr_{i,L})$ (21)

Effective noise variance, $\delta_{sc}^2 = \delta_z^2$ (22)

2)Equal Gain Combining (EGC): It is easily realized that we must estimate channel coefficients for choosing the best branch in SC. In EGC, however, the channel estimation module is no longer needed. The decision of EGC is based on the sum of all statistic cognitive users information. SNR of EGC, snr_{EGC}, is the sum of all SNRs of other users.

$snr_{i,EGC} = \sum_{l=1}^{L} snr_l$ (23)

Effective noise variance, $\delta_{EGC}^2 = L\delta_z^2$ (24)

Local probability of detection and local probability of false alarm can be calculated by replacing effective SNR and effective noise variance in eq (6) and (7).

III. Total Energy Consumption And Selection Of Maximum Number Of Sensors

The important issue in cooperative sensing is energy consumption[9].

Energy consumed by each sensor,

$C_{tot} = \sum_{i=1}^{S} \rho_i [\sum_{l=1}^{L} C_{s_{i,l}} + C_{t_i}]$ (25)

Where $C_{s_{i,l}}$ is the energy consumed in listening and collecting the H_0 observation samples, as well as the energy required for making a local decision. we assume $C_{s_{i,l}}$is same for all sensors and all antenna and denote by C_s . The transmission energy C_{t_i} is the energy required to transmit the 1-bit local decision to the FC.

$C_{t_i} = Transmitter\ electronics\ energy + amplification\ to\ receiver\ sensitivity\ level$

For energy efficient spectrum sensing we have to properly calculate the number of sensors participate in sensing. Sensor selection should be based on optimizing energy consumption while satisfying global detection constrains: $P_d \geq \alpha$ and $P_f \leq \beta$,

$min_{(\rho_i)} C_{tot} = \sum_{i=1}^{S} \rho_i [L C_s + C_{t_i}]$ (26)

ρ_i's can be interpreted as a priority parameter so that higher value of ρ_i's indicates that higher priority of sensor in sensor selection.

$\sum_{i=1}^{S} \rho_i \leq S_{max}$ (27)

Where,$S_{max} = \left[\frac{\ln(1-\beta)}{\ln(1-P_{fi})}\right]$ is the maximum number sensors can be selected for spectrum sensing.

IV: Efficient Transmission By Mimo Sensors In Low Snr

SNR directly affects the performance of a wireless communication[9]. A higher SNR value means there is a better signal(meaningful information) level than the noise (unwanted signal) level. A higher SNR value gives a higher data rates and fewer retransmissions. So it can offer a reliable transmission. Obviously the reverse is also true. A lower SNR value impacts the transmission of a wireless communication and gives a lower data rate, which decreases spectral efficiency.

In the previous observations, it is clear that by using MIMO sensors we can sense the spectrum more energy efficiently. The main goal of CR is to utilize the unused spectrums. So, by using MIMO sensors not only we can sense the spectrum more cost effectively but also we can use that channel even if the SNR is less than the required value and can efficiently transmit our data.

Comparison of MIMO(Multiple-In and Multiple-Out) with SISO(Single-In and Single-Out) :

The capacity of a channel, which is the maximum error-free transmission rate is defined as the number of bits transmitted per second per Hz(bits/s/Hz)[10].

The main concept of MIMO is one of channel capacity. Capacity of a simple RF channel, as per Shanon's capacity theorem:

$C_s = B log_2(1 + \rho)$ (28)

where C_s= capacity (bits/s/Hz), *B*=bandwidth (Hz), ρ =*S/N*= signal to noise ratio for a SISO system.

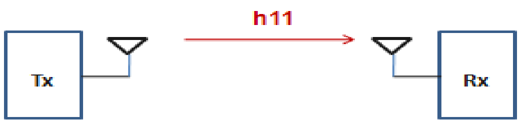

Fig:3 SISO System

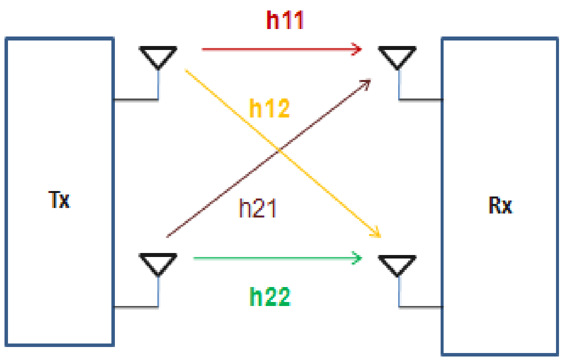

Fig:4 MIMO System

MIMO channel is represented by a N×M antennas(N-Transmit antennas and M-Receive antennas). From each transmit antenna i to each receive antenna k, the complex throughput correlation matrix(with amplitude and phase) is defined as H-matrix [H_{ik}]. The new capacity equation for MIMO systems is

$C_M = \sum_{i=1}^{p} B \log_2(1 + \frac{S_i}{N} \sigma_i^2(H))$ (29)

where, p= number of independent transmit/receive paths which should not be greater than min(N,M). So the number of sufficiently uncorrelated path in the network can be defined as 'p' . In the network, p is defined as the rank of the matrix H and is also referred to as the rank of the channel in LTE. S_i is the signal power in channel i, N is the noise power, and $\sigma_i^2(H)$ are singular values of the H matrix.

The capacity of a SISO System is a slow increase because it is a log function of the SNR. In a SISO system to increase the capacity by any considerable factor takes an huge amount of power. MIMO brings a different concept in channel capacity.

Without increasing the power and just by using multiple antennas at the transmitter and receiver side, the same performance can be achieved as increasing the power in SISO. Quite remarkable, and worth investigative closely.

In MIMO, by using multiple antennas we can increase the capacity linearly with the number of antennas, where as in SISO/SIMO/MISO systems capacity increases logarithmically(slow increase).

VI Observation And Result Analysis

For this study the number of sensors considered varies from five to forty-five and are distributed randomly.

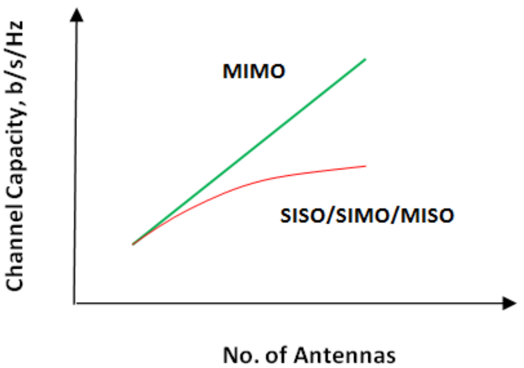

Fig:5 MIMO System capacity increases without increasing power

V. Simulation Results

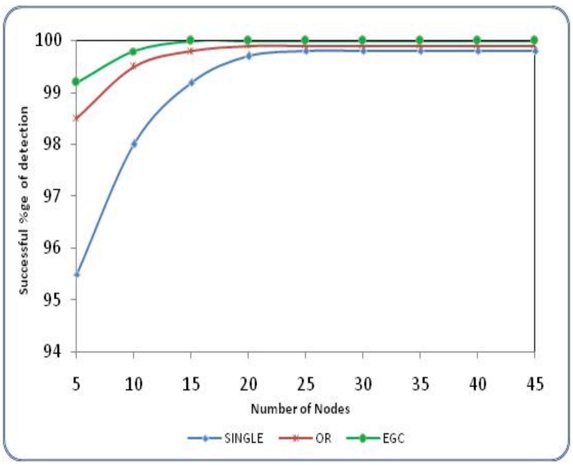

Fig: 6 Successful percent of detection in network dimension of 300 meters

We simulate the spectrum detection in two network dimensions :

i)Fig:6: Network dimension of 300 meters: It is observed that in small dimension network SISO sensors provide better spectrum sensing than MIMO.

ii)Fig:7: Network dimension of 1100 meters: When network dimension increases it is observed that MIMO sensors achieves better energy efficient spectrum sensing compare to SISO. The soft decision, EGC combination obtains optimum result in large environments.

It is observed that in large dimension area even by using 45 single antenna sensors, desired detection performance cannot be exceeded more than 30%, whereas with 30 MIMO sensors, the detection performance reaches 90%.

iii)Fig:8: It explains, with addition of more number of antennas the capacity of the MIMO system further enhanced but to avoid complexity the no of antennas limited to four both at transmitter and receiver. Capacity of 15 bits/s/Hz for a SNR of 15 dB is really significant compared to a capacity of less than 4 bits/s/Hz in case of SISO with same SNR which establishes its energy and spectral efficiency capability.

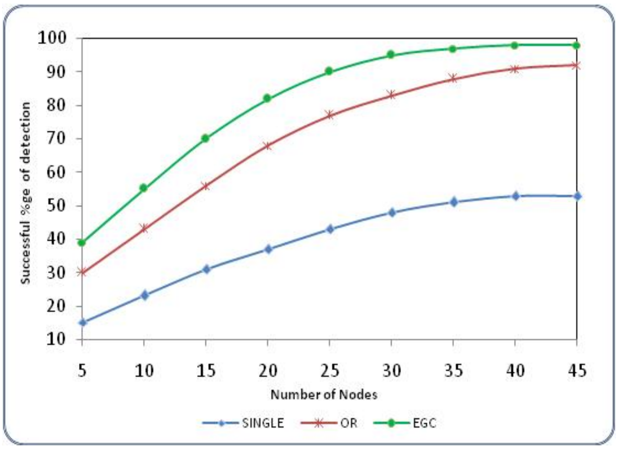

Fig: 7 Successful percent of detection in network dimension of 1100 meters

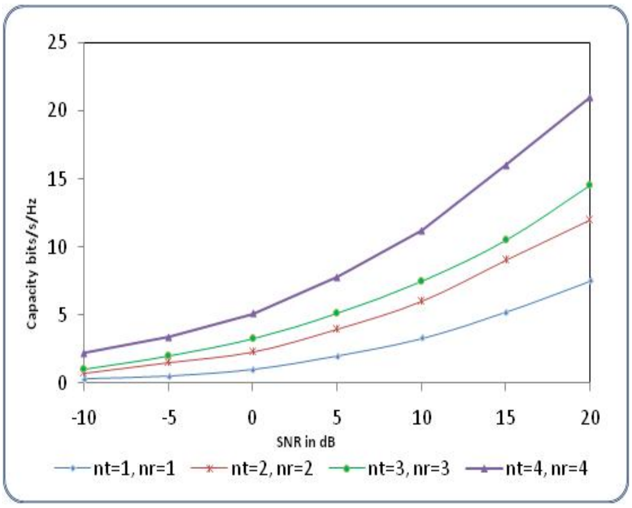

Fig:8 Comparing capacity of MIMO systems over SISO systems

VII CONCLUSION

Proper utilization of radio frequency spectrum is very essential due to the rapid growth of wireless communication. MIMO sensors improve energy consumption for cooperative spectrum sensing. Simulation results show that in small Network dimension SISO sensors give a better result than MIMO, but in large dimension environments MIMO sensors give a superior result with less number of sensors and have minimum energy consumption. The soft decision, EGC combination even suggests much better result in large dimension environments and more efficient data transmission can be achieved with MIMO sensor Network by defining a clear edge over SISO sensor Network.

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