

Spectrum Sensing Algorithm in Cognitive Radio & Channel Capacity

Mr. Kishor G. Khune

Dept. of Electronics and
Telecommunication Engineering STES's
Sinhgad Institute of Technology,
Lonavala, University of Pune, India

Dr. Tanuja S. Dhope

Dept. of Electronics and
Telecommunication Engineering STES's
Sinhgad Institute of Technology,
Lonavala, University of Pune, India

Prof. Vijaya. G. Rajeshwarkar

Dept. of Electronics and
Telecommunication Engineering STES's
Sinhgad Institute of Technology,
Lonavala, University of Pune, India

Abstract – Spectrum sensing is one of the most important tasks in cognitive radio operation, for increasing spectrum efficiency one have to concentrate on the spectrum sensing. We know the frequency spectrum available is limited, as compare to wireless users. This increases the important of spectrum sensing. Increasing efficiency of the spectrum usage is an urgent need as a key result of the increasing demand for higher data rates, better quality of services and higher capacity.

In this thesis we go through several spectrum sensing techniques for cognitive radio based systems like Energy detection and cooperative spectrum sensing, with some practical challenges and drawbacks in these techniques. This thesis gives idea about the Multiple Input Multiple Output (MIMO) concept. Actually in MIMO more than one antenna are placed at transmitter and receiver side.

We are also going to see that, how with MIMO system effectively converted into benefit for communication system. The probability of spectrum detection increases and the probability of false alarm decreases with help of channel capacity.

Here we concentrate on the theoretical study of spectrum sensing and comparative study of channel capacity of correlated and non-correlated channels.

Keywords – Cognitive Radio, Spectrum Hole, Spectrum Sensing, MIMO, Correlated, Uncorrelated.

I. INTRODUCTION

Licensed users are primary users having higher priority while using a part of spectrum, secondary users are unlicensed users. Federal Communication Commission (FCC) has issued a Notice of Proposed Rulemaking concerning cognitive radio that requires rethinking of the wireless communication architecture so that mounting radios can share spectrum with primary users without causing interference to them [1] [5]. The word 'Cognition' means mental process of obtaining knowledge by its brain, experience and the minds. Main two operation of Cognitive radio enabled user to conclude portion of the spectrum available and discover the presence of licensed user while primary user operates in licensed bands. Four main tasks cognitive radio have to carry:

- Spectrum sensing,
- Spectrum sharing,
- Spectrum mobility,
- Spectrum management.

Each of these tasks has its own important as explained follow: Spectrum sensing targets to determine spectrum availability and the existence of the licensed users. Spectrum management is to guess how long the spectrum

holes are likely to remain accessible for use to the unlicensed users. Spectrum sharing is to allocate the spectrum holes properly among the secondary users bearing in mind usage cost. Spectrum mobility is to maintain continuous communication requirements during the transition to better spectrum. [2] [7]

Spectrum sensing is key element in cognitive radio to get a feel for its environment by detecting spectrum holes. Actually spectrum holes are band of frequencies licensed to primary user but at a particular time and specific geographical location that bands is not utilized by primary user. Several spectrum sensing methods are proposed in literature among them we will focus on few like energy Detector, Periodogram, Welch's periodogram, cooperative and multiple antenna spectrum sensing methods.

II. VARIOUS SPECTRUM SENSING METHODS

Ideal features of Cognitive Radio are: intelligence, reliability, alertness, adaptability, efficiency and tremendous quality of service. To improve the detection probability, signal detection methods can be used in spectrum sensing. Signal processing is concerned with improving the quality of signal at the top of measurement systems and its main aim is to decrease the noise in the signal that has not been reduced by careful design of measurement system. With the improvement in signal processing, we are able to think about cognitive radio technology. In this sector, we give an outline of some familiar spectrum sensing techniques. [7]

1) Energy detection

If the previous knowledge of the primary user signal is mysterious, the energy detection method is optimal for detecting the presence of Primary user. In this approach, the radio frequency (RF) energy in the channel or the received signal strength indicator is measured to define the channel status i.e. idle or busy. The detection is based on some function of the received samples which is compared to a predetermined threshold level. If the threshold is beaten, it is decided that signal is present otherwise it is absent. However, this method is prone to false detections since it only measures the signal power. When the signal is greatly oscillated, it becomes challenging to distinguish between the absence and the presence of the signal. If previous knowledge of primary user signal is unknown, the energy detection method is optimal for identifying any zero mean constellation signals.

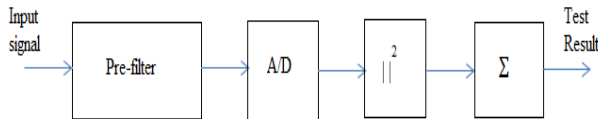


Fig.1. Energy detection with pre-filter

As shown in figure (2), pre-filter block contains the band-pass filter to select the bandwidth of interest and then output of this block is converted to digital from analog state. Further this signal is squared and integrated over the observation interval. The output is paralleled to a previously calculated threshold to infer the presence of the primary user signal.

Though the energy detection method has advantage of implementation of itself without any previous knowledge of primary user signal but still it has some weakness:

- i) The first limitation is that it has poor performance under low SNR conditions. At low SNR noise variance is not accurately known so this problem arrives, and noise uncertainty may explain the energy detection is useless.
- ii) Energy detection uses the threshold which depends on the noise variance and small noise power estimation errors can result in significant performance.

2) Periodogram Method

This is a non-parametric method of spectral estimation in which the power spectral density is projected directly from the signal itself. The power spectral density of the signal can be valued by finding the fast Fourier transform of the samples & taking the magnitude square of the result. In this method, we consider a finite length sequence. It is alike to multiplying the signal with a rectangular window in time domain. This sudden change introduces the undesired side lobes in the frequency response, leading to a spectral leakage. The variance of estimated power spectral density does not decrease with increase in number of samples considered. The formulae for periodogram method is as follows, [8]

$$X(k) = \sum_{n=1}^N x(n)e^{-j2\pi(k-1)(n-1)/N} \quad \text{where} \quad 1 \leq k \leq N$$

Here, $x(n)$ is the discrete received signal, N is the FFT size. Then we apply $X(k)$ to an energy detector as follows:

$$\Xi_{\text{periodogram}} = \frac{1}{N} \sum_{k=1}^N |X(k)|^2$$

As seen in this equation, we sum N components of the output of square law device when $X(k)$ is applied to, hence the alteration of the statistics fluctuates with respect to FFT size. In order to moderate this fluctuation, we divide the statistics with FFT number in order to hold the variance constant. Refer figure (3).

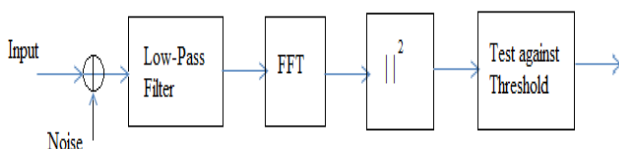


Fig.2. Spectrum sensing using Periodogram method

The main drawback of periodogram is the spectral leakage.

1) Welch's method

The method involves dividing the time series data into overlapping segments, calculating a modified periodogram of each segment, and then averaging the power spectral density estimates. The result is Welch's Power Spectral Density (PSD) estimate. The length of the applied window controls the trade-off between bias and difference of the resulting power spectral density (PSD). By default, the data is divided into eight segments with 50% overlap between them. A Hamming window is used to calculate the modified periodogram of each segment. The averaging of improved periodograms tends to decrease the variance of the estimate relative to a single periodogram evaluation of the total data record. Although overlap between segments tends to existing redundant information, this effect is weakened by the use of a nonrectangular window, which decreases the status or weight given to the end samples of segments (the samples that overlap) [9]. However, as mentioned above, the combined use of short data records and nonrectangular windows results in compact resolution of the estimator. In short, there is adjustment between variance reduction and resolution. One can drive the parameters in Welch's method to obtain improved estimates relative to the periodogram, especially when the signal noise ratio is small.

III. MULTIPLE ANTENNA TECHNIQUES

Multiple-input, multiple-output (MIMO) describes a system with a transmitter with multiple antennas transmitting through the propagation environment to a receiver with multiple receive antennas. Even when a wireless channel with high channel capacity is given, we still need to find good techniques to achieve high-speed data transmission or high reliability. Multiple antenna techniques can be broadly classified into two categories: diversity techniques and spatial-multiplexing techniques. The diversity techniques intend to receive the same information-bearing signals in the multiple antennas or to transmit them from multiple antennas, thereby improving the transmission reliability. A basic idea of the diversity techniques is to convert Rayleigh fading wireless channel into more stable AWGN-like channel without any catastrophic signal fading. In the spatial-multiplexing techniques, on the other hand, the multiple independent data streams are simultaneously transmitted by the multiple transmit antennas, thereby achieving a higher transmission speed. When the spatial-multiplexing techniques are used, the maximum achievable transmission speed can be the same as the capacity of the MIMO channel; however, when the diversity techniques are used, the achievable transmission speed can be much lower than the capacity of the MIMO channel. [1][7]

A. Random MIMO Channel Capacity:

For a MIMO system with N_T transmit and N_R receive antennas as shown in figure, a narrowband time-invariant wireless channel can be represented by $N_R \times N_T$ matrix H of $N_R \times N_T$, H is a random matrix, which means that its

channel capacity is also randomly time-varying. Consider a transmitted symbol vector \mathbf{X} of $N_T \times 1$ dimensions which is composed of N_T independent input symbols $x_1; x_2; \dots; x_{N_T}$. Then, the received signal y of $N_R \times 1$ dimensions can be rewritten in a matrix form as follows:

$$y = \sqrt{\frac{E_x}{N_T}} Hx + z \quad (1)$$

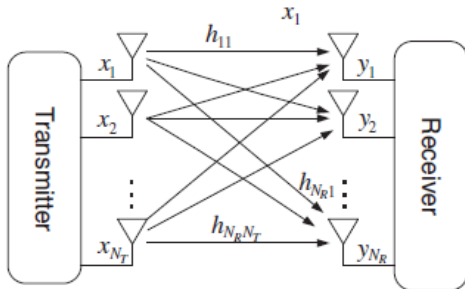


Fig.3. $N_R \times N_T$ MIMO system

Where $z=(z_1, z_2, \dots, z_{N_R})$ of $N_R \times 1$ noise vector which is zero mean circular symmetric complex Gaussian. The auto-correlation of transmitted signal vector is given by:

$$R_{xx} = E\{xx^H\} \quad (2)$$

The MIMO channel capacity can be given by its time average. In practice, we assume that the random channel is an ergodic process [2]. Then, we should consider the following statistical notion of the MIMO channel capacity: The channel capacity of random uncorrelated MIMO channels is given by

$$C_{iid} = \log_2 \det(I_{N_R} + \frac{E_x}{N_T N_0} H R_{xx} H^H) \text{ bps/Hz} \quad (3)$$

Where C_{iid} is channel capacity of uncorrelated MIMO channels, $\frac{E_x}{N_0}$ is Signal to noise ratio in linear scale, $N_T =$ no of transmitting antennas, $I_{N_R} =$ identity matrix of $N_R \times N_R$ dimensions, H is a iid matrix.

In general, the MIMO channel gains are not independent and identically distributed (iid.). The channel correlation is closely related to the capacity of the MIMO channel. The capacity of the MIMO channel when the channel gains between transmit and received antennas are correlated [1].

B. Correlated channel model:

$$H = R_r^{1/2} H_w R_t^{1/2} \quad (4)$$

Where R_t is correlation matrix, reflecting the correlations between transmit antennas, R_r is correlation matrix, reflecting the correlations between receiving antennas [1]. H_w , Denotes the iid Rayleigh fading channel gain matrix. The diagonal entries of R_t and R_r are constrained to be a unity [5].

The channel capacity for correlated MIMO is given by [5]:

$$C_{correlated} = \log_2 \det(I_{N_R} + \frac{E_x}{N_T N_0} R_r^{1/2} H_w R_t H_w^H R_r^{1/2}) \quad (5)$$

IV. OUTPUT

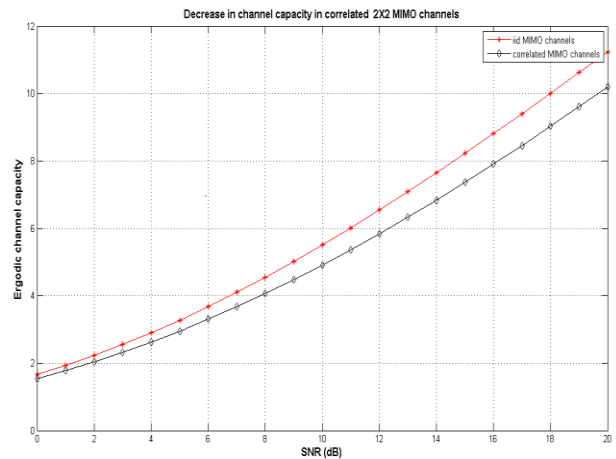


Fig.4. Ergodic_capacity calculation in case of correlated and uncorrelated 2*2 MIMO

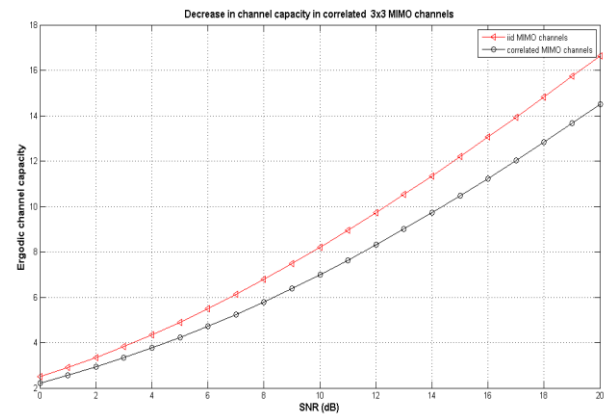


Fig.5. Ergodic_capacity calculation in case of correlated and uncorrelated 3*3 MIMO

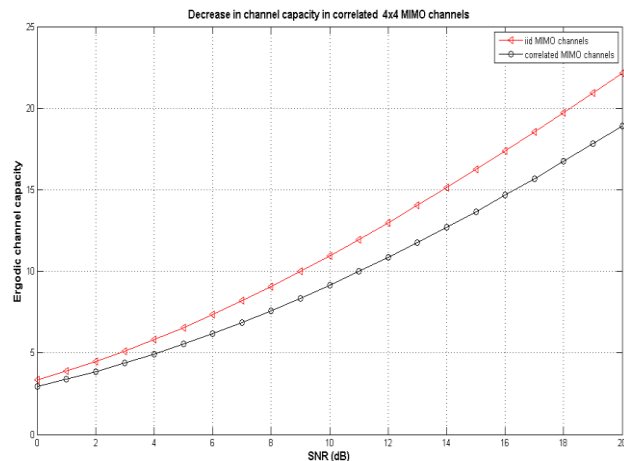


Fig.6. Ergodic_capacity calculation in case of correlated and uncorrelated 4*4 MIMO

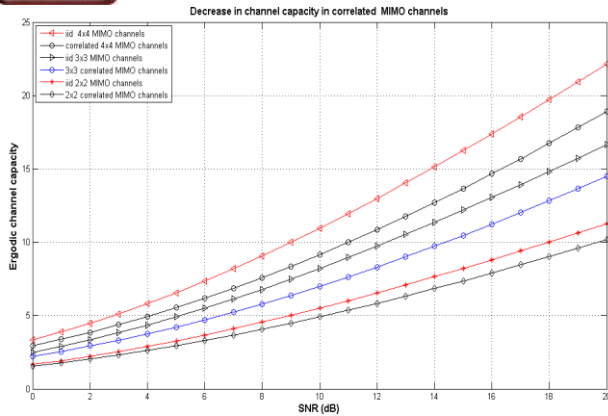


Figure (7) Egrodic_capacity calculation in case of correlated and uncorrelated MIMO

So figure (4), figure (5), figure (6), figure (7) shows respectively correlated and uncorrelated channel ergodic_capacity for 2*2, 3*3, 4*4 and comparative study of all.

V. CONCLUSION

In this paper, we get the brief idea about spectrum sensing and comparative study between the correlated and uncorrelated. The simulation results figure (7) show that as numbers of transmitting and receiving antennas are increased the channel capacity is also increased. Comparing channel capacity for uncorrelated and correlated MIMO channels, it clearly reveals that there is drastic reduction in channel capacity for correlated channels figure (4), figure (5) and figure (6).

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