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Spectrum Sensing from Smart City Perceptive

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Abstract - Frequency availability while developing a city as smart city is a crucial task as the spectrum is scarce resource. We propose the use of cognitive radio for checking spectrum availability via spectrum sensing technique. We propose the use of multiple antenna technique for improving detection probability of the primary users. The detection performance is evaluated using different techniques based on energy detection method. This paper shows the unique way to detect the license user in spite of its fast moving. For performance comparison various parameters like number of sample, signal- to- noise ratio, probability of detection and multipath fading are taken into considerations.

Keywords:smart cities, spectrum sensing,multiple antenna

I. INTRODUCTION

With the fast expansion of the city, an augmented request of resources likes energy,water,good sanitation, education and healthcare needs to be fulfilled. This imposes the necessity to utilize all of these resources in an 'intelligent' / 'smart' way to accomplish the expectations of city residents[1]. The applications like an intelligent-buildings, mobility & transport, water infrastructure, waste management, healthcare and education are based on the frequency availability in the spectrum band. Since the spectrum is scarce resource, it is very difficult to allocate new frequencies for the new applications as mentioned above. Cognitive Radio (CR) can be used to solve the frequency allocation problem of smart cities viz the dynamic allocation of frequency by continuous checking of spectrum utilized by primary/licensed user (PU) and if detected as idle, it is allocated to unlicensed /secondary users (SU) [2][3]-[7].Various applications of CR can be found in [8].

There are various algorithms used to check the presence of licensed primary users viz general likelihood ratio test (GLRT), match filtering (MF), energy detection (ED), cyclostationary, eigenvalue based detection and covariance based detection [2][3]. Each of the methods has advantages and disadvantages. GLRT is the finest method but it entails exact channel information and distribution of noise and source signal. MF based detector necessitates perfect understanding of the channel response from PU to the receiver and precise synchronization. Multiple antenna techniques i.e. Multiple Input Multiple Output (MIMO) are presently utilized for consistent signal transmission, effective communication and improvement in bit-error rate. In this paper we have utilized multiple antenna techniques in conjunction with energy detectors (EDs) in order to improve PU detection performance in a CR using single carrier. In [9], improvement in hardware requirement and sensing time is accomplished through 2-stage sensing with multiple antennas. In [10] and [11], the spectrum sensing using ED for unknown deterministic signal and Rayleigh fading has been evaluated. Overall, the multiple antenna method expands system performance and upturns spectrum efficiency. Multiple antennas different techniques with mathematical derivations are described in [12]. GLRT with multiple antennas has been studied and GLRT with multiple antenna outperforms even at SNR=-24dB [13].

The organization of paper is the following: section II briefs about different spectrum sensing techniques based on ED and gives detailed idea about multiple antenna techniques, section III describes proposed system. Section IV evaluates the simulation results. Section V gives conclusion.

Neyman–Pearson (NP) criteria defines that sensing a spectrum is a binary hypothesis problem and given by:

$$H0: \quad Y(n) = w(n) \quad \text{: absence of Signal} \qquad (1)$$
$$H1: \quad Y(n) = x(n)hr(n) + w(n) \text{ : presence of signal}$$

where x(n)=input signal,$hr(n)$= gain of the channel, $w(n)$is the white noise with mean zero and variance σ_w^2.Two metrics are used for analysing the perfromance of spectrum sensingalgorithm: P_d is the probability of algorithm accuratelydiscovering the presence of PU andP_{fa}defines the probability of algorithm mistakenly declaring the presence of PU.P_{md} is the probability of missed detection, I.e. 1-P_d.

II. ANALYSIS OF ED AND MIMO BASED TECHNIQUESS

Time Domain ED, Periodogram based ED and Welch periodogram based ED is very well discussed in [6],[7],[14],[15] The energy of received signal in time domain is :

$$\epsilon_{\text{time}} = \sum_{n=1}^{N} |X(n)|^2 \text{where N=samples} \qquad (2)$$

And finally test static is compared with threshold (τ) to evaluate $H0$ or $H1$

$\tau \lesseqgtr \epsilon_{\text{time}}$ (3)

If $\tau > \epsilon_{\text{time}}$, presence of PU otherwise PU is absent. $P_d and P_{fa}$ for ED are given by[6]:

$$P_{fa} = P\left\{Y \middle| \frac{\tau}{H_0}\right\} = Q_m(\sqrt{2y}, \sqrt{\tau}\,) \quad (4)$$

$$P_d = P\left\{Y \middle| \frac{\tau}{H_1}\right\} = \Gamma(\,n, \tfrac{\tau}{2}\ \,)/\Gamma(n) \quad (5)$$

For Periodogram$\epsilon_{\text{periodogram}}$ is calculated as :

$$X(k) = \sum_{n=1}^{N} X(n) e^{-j2\pi(k-1)(n-1)/N} (6)$$

Where $1 \le k \le N$, N point FFT,received signal is $X(n)$

X(k)is applied to ED as :

$$\epsilon_{\text{periodogram}} = \frac{1}{N} \sum_{k=1}^{N} |X(k)|^2 \quad (7)$$

For Welch periodogramϵ_{welch} is calculated as

$$\boldsymbol{x = [x_1, x_2, \ldots\ldots x_M(l)]} \quad (8)$$

$$\boldsymbol{x_1(\rho) = \sum_{l=1}^{N} x_1(l) e^{-j2(Y-1)(l-1)/N}} \quad (9)$$

$$\epsilon_{welch} = \sum_{Y=1}^{L} \sum_{l=1}^{M} \frac{1}{N} |\, x_1(\rho)|^2 \quad (10)$$

To provide higher data rates,better sensing result compared to single antenna multiple antenna techniques used. As name suggest-multiple antennas, the communication system will have multiple transmitting and multiple receiving antennas [7][16].Multiple Antenna Techniques i.e.MIMO based on ED are as follows:

A. *Selection Combining*

In this method, channel state information must be known by CR, hence selects the branch with the highest channel gain, receives the data from that antennaand fed to an ED.see figure 1.

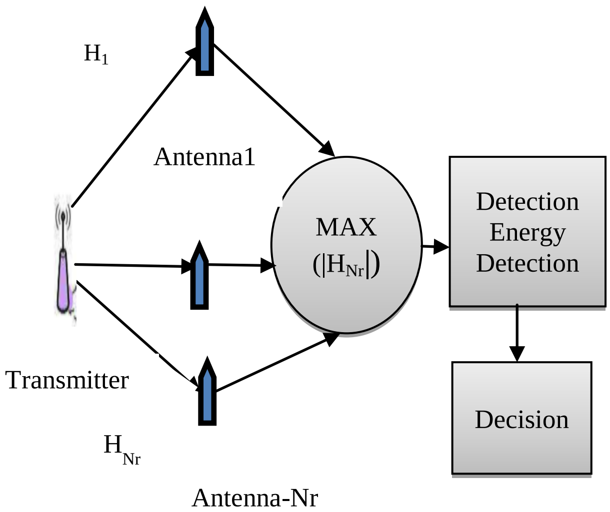

Figure1: Selection Combining

$$s_j(t) = x(t)h_j + w(t) where j = 1,2, \ldots\ldots N_r (11)$$

whereN_r is the number of antenna at receiver side, $s_j$is the received signal at j[th]antenna. $h_j$is the channel gain at j[th] antenna.

$$j_{max} = \max\ (|h_j\,|) \quad (12)$$

Then the received signal at Jmaxth antenna is applied to the energy detector equation 13.$P_{fa(SC)}$is given by equation 14.

$$\epsilon_{sc} = \sum_{l=1}^{N} |s_{jmax}(l)\,|2 \text{ where N=symbollength} \quad (13)$$

$$P_{fa(SC)} = \frac{\Gamma(N, 2\sigma_W^2)}{\Gamma(N)}) \quad (14)$$

B. *Maximum Ratio Combining*

In this method,channel state information must be known by CR.CR receives data from each antenna, multiplies them with the conjugate of each channel gain and summing all the multiplied data which is then applied it to ED .see figure 2.

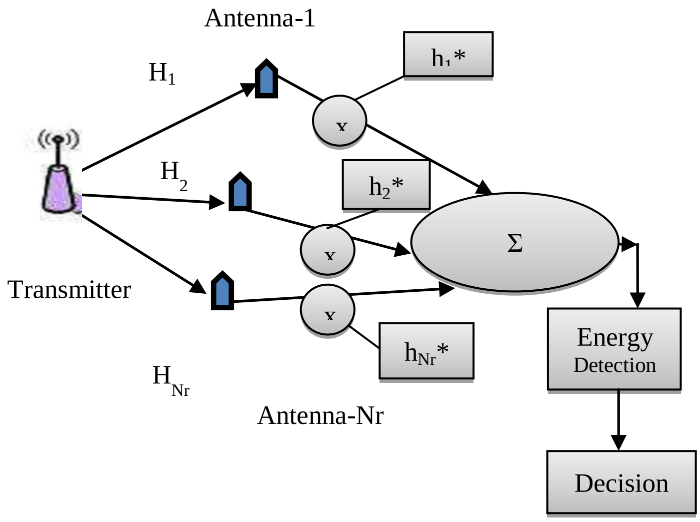

Figure 2:Maximum Ratio Combining

The received data at each antenna is multiplied with the conjugate of the channel gain and summation of all is applied to an energy detector as follows

$$\epsilon_{MRC} = \sum_{l=1}^{N} \sum_{j=1}^{Nr} |\, s_j(l) * h_j(l)|^2 \quad (15)$$

$P_{fa(MRC)}$is given by equation 11.

$$P_{fa(MRC)} = \frac{\Gamma(\frac{N}{2}, \frac{\tau}{2\sum_{j=1}^{Nr}(h_j^{*2})\sigma_W^2})}{\Gamma(\frac{N}{2})} \quad (16)$$

C. *Equal Gain Combining*

In Equal Gain Combining normalized data which is multiplied with the conjugate of the channel gain and then divided by its absolute valueapplied to only one energy detector. See Figure 3.

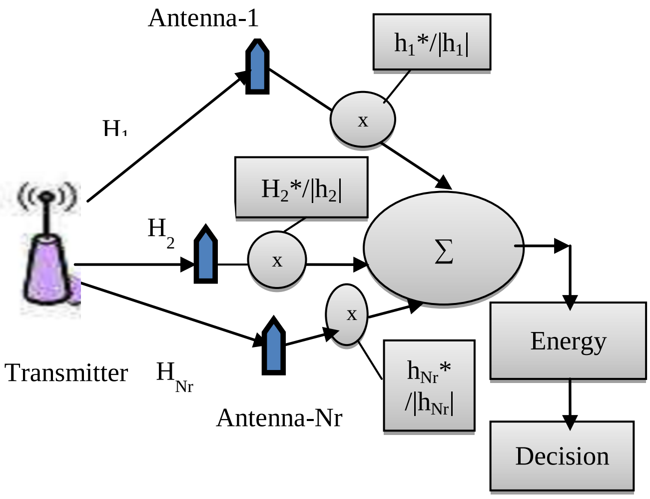

Figure 3:Equal Gain Combining

$\in_{EGC}$ is calculated in equation 17 .$P_{fa(EGC)}$is calculated using equation 18.

$$\in_{EGC}=\sum_{l=1}^{N}|(\sum_{j=1}^{Nr}|\, s_j(l).\frac{h_j^{*}}{h_j})|^2 \qquad (17)$$

$$P_{fa(EGC)} = \frac{\Gamma(\frac{N}{2}, \frac{\tau}{2\sum_{j=1}^{Nr}(h_j^{*2}/|h_j^2|\sigma_w^2})}{\Gamma(\frac{N}{2})} \qquad (18)$$

D. Square-Law Combining

The energy detectors' outputs are combined, comparedwith a threshold for $P_{fa(SLC)}$.

$$\in_j=\sum_{n=1}^{N}|Xj(n)|^2 \qquad (19)$$

$$\in_{SLC}=\sum_{j=1}^{Nr}\in_j \qquad (20)$$

$$P_{fa(SLC)} = \frac{\Gamma(Nr.\frac{N}{2}, \frac{\tau}{2\sigma_W^2})}{\Gamma(Nr.\frac{N}{2})} \qquad (21)$$

III. PROPOSED SYSTEM

In order to make a city as Smart City for various applications as mentioned in section I, the proposed system is as shown in figure 4.

Every person has been given the facility to activate the spectrum sensing on demand basis through his/her smartphone. The spectrum sensing hardware starts seeking for available frequencies within the specified frequency band as per the program embedded in it.so that if the frequency band is found to be free ,it can be utilized for various smart cities related applications as discussed in section I. The spectrum sensing results are displayed through webserver on Web dashboard and through cloud the user can come to the availability of particular frequency for its own applications. The spectrum sensing hardware consists of National instruments USRP (Universal Software Defined Peripheral Board) with MIMO antennas. Various spectrum sensing algorithms like ED in time domain, periodogram, Welch periodogram and different multiple antenna techniques based on ED are running on USRP board. The detailed explanation of spectrum sensing algorithms is described in section II.

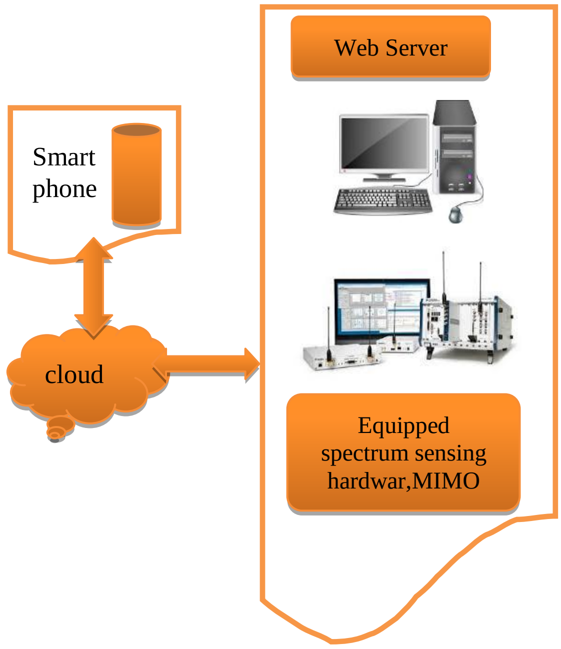

Figure 4:Proposed System

Every person has been given the facility to activate the spectrum sensing on demand basis through his/her smartphone. The spectrum sensing hardware starts seeking for available frequencies within the specified frequency band as per the program embedded in it.so that if the frequency band is found to be free ,it can be utilized for various smart cities related applications as discussed in section I.

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IV. SIMULATION RESULT

While evaluating performance of MIMO using ED based different techniques, we have considered Binary Phase -shift keying (BPSK) and Quadrature Phase-shift keying (QPSK) modulated wireless voice signal as PU signal and PU signal encountered two types of fading Additive -White Gaussian Noise(AWGN) and Rayleigh fading. The time-varying Jakes model is used in Rayleigh fading.

The simulation is carried for time domain ED, periodogram,Welch periodogram and different multiple antenna techniques.

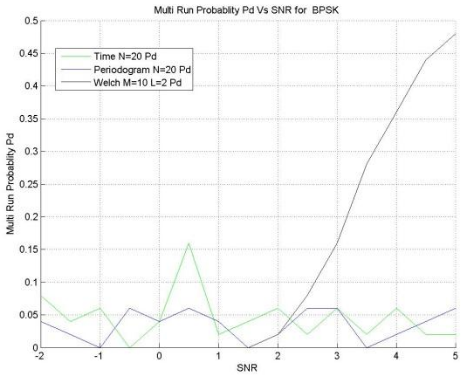

Figure 5 : Probability of detection BPSK versus SNR for P_{fa} =0.01 for N=10

Figure 5 shows that Welch periodogram with M=10,L=2 is performing well compared to time domain ED and periodogram.

Figure 6 shows the probability of detection for QPSK and BPSK signal using ED and periodogram with no. of segments=20 in AWGN channel. Figure 6 shows that periodogram gives betterP_d results as compared to time domain ED even for poor values of SNR.

As SNR increases the P_d also increases.

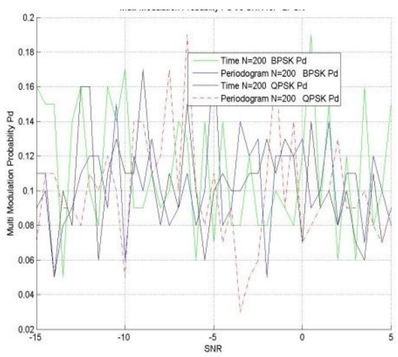

Figure 6:$P_d$for QPSK and BPSK using ED using ED for N=200 using single antenna in AWGN channel keeping Pfa =0.01

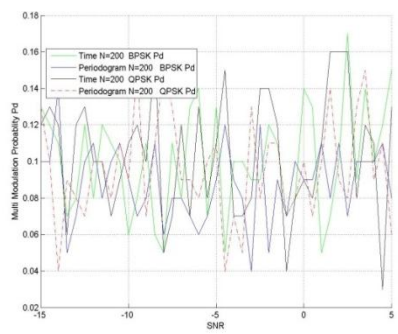

Figure 7:P_d for QPSK and BPSK using ED for N=200 using single antenna in Rayleigh fading channel keeping Pfa =0.01

Figure 7 shows the probability of detection for QPSK and BPSK signal using ED and Periodogram with no. of segments=20 in Rayleigh fading channel. For Rayleigh fading, time varying Jakes model is used. The figure 7 shows that periodogram gives better results as compared to time domain ED even for poor values of SNR.

Performance of BPSK is compared with various MIMO techniques for time domain based ED in figure 8 , periodogram based ED in figure 9 and Welch periodogram based in figure 10 with 0.9800, 0.9700, 0.9000, 0.8700 as antenna channel gains. For selection combining; antenna -01 with channel gain 0.98 has been selected. As shown in Figure 8 , For time domain ED and SNR=0.05dB MRC and EGC gives P_d =1 compared to P_d =0.05 and 0 respectively provided by SC,SLC.

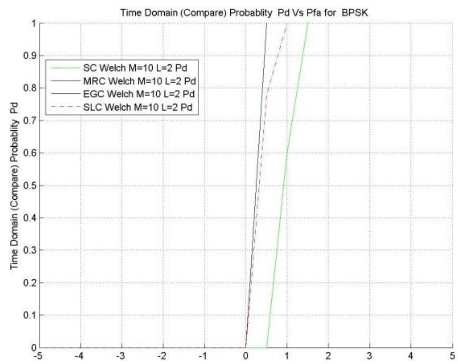

Figure 8: MIMO techniques viz SC, EGC, MRC, SLC using Time domain ED with N=20, M=10 ,L=2 $P_d$vs SNR for BPSK for Pfa=0.01 for various values of SNR

Performance of BPSK is compared with various MIMO techniques for time domain based ED in figure 8 , periodogram based ED in figure 9 and Welch periodogram based in figure 10 with 0.9800, 0.9700, 0.9000, 0.8700 as antenna channel gains. For selection combining; antenna -01 with channel gain 0.98 has been selected.

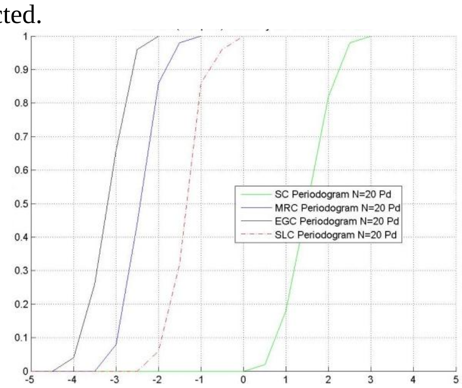

Figure 9:MIMO techniques viz SC, EGC, MRC, SLC using periodogram with N=20, M=10 ,L=2 $P_d$vs SNR for BPSK for Pfa=0.01

As shown in Figure 8 , For time domain ED and SNR=0.05dB MRC and EGC gives P_d =1 compared to P_d =0.05 and 0 respectively provided by SC,SLC.

As shown in Figure 9, For periodogram with SNR= -2dB, N=20 MRC and EGC provides P_d as 1, 0.87 respectively compared to SLC, SC as 0.05and 0 respectively. As shown in Figure 10, MRC and EGC outperforms the SC and SLC techniques.

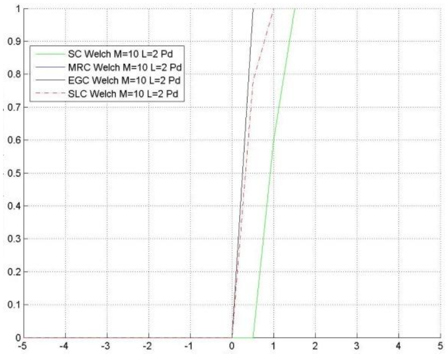

Figure 10:MIMO techniques viz SC, EGC, MRC, SLC using Welch periodogram with N=20, M=10 ,L=2 $P_d$vs SNR for BPSK.

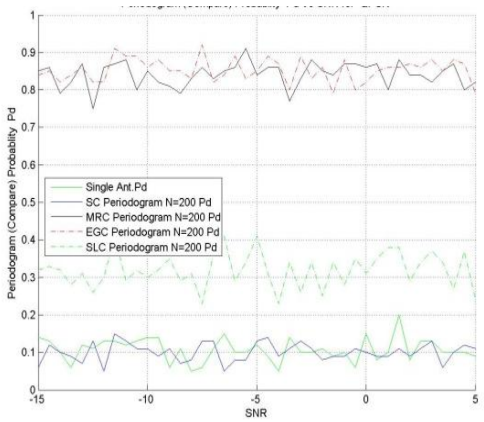

Figure 11: MIMO techniques QPSK viz SC, EGC, MRC, SLC using periodogram with M=20 a) $P_d$vs SNR b) P_d vs SNR with N=200

Figure 11 shows the comparison of P_d vs SNR for QPSK signal among various MIMO techniques viz SC,EGC,MRC,SLC using periodogram with no. of segments with single antenna using periodogram. The simulation is carried for SNR -15dB to 5dB, P_{fa}=0.01, N=200 with 0.9800, 0.9700, 0.9000, 0.8700 as antenna channel gains. For selection combining; antenna -01 with channel gain 0.98 has been selected. For SNR =-15dB MRC, EGC provides P_d as 0.88 and 0.87 respectively when compared to SC and SLC which provides P_d as 0.08 and 0.14 respectively**.** Results show that MRC and EGC outperform the other two methods for poor SNR values. Figure 8 to 11 reflect that as number of samples increases probability of detection also increases.

V. CONCLUSIONS

In this paper dynamic spectrum sensing using cognitive radio for effective utilization of available spectrum for making a city as 'Smart City' have been studied. The performance of various MIMO techniques based on energy detection has been evaluated compared with single antenna. The simulation results shows that in AWGN channel the time domain energy detection and periodogram methods for BPSK and QPSK based PU signal outperforms the Rayleigh channel for single antenna.

The simulation results demonstrate considerable detection performance gain for MIMO based techniques compared to single antenna. Even though the signal undergoes through fading the detection performance of MRC and EGC does not deteriorate. Among the multiple antenna techniques the MRC and EGC outperforms the SC and SLC techniques.

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