Maximizing Reliability of Multihop Cognitive Radio Network

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Abstract— In this paper, Performance of a cognitive radio with the help of a multi-antenna based cognitive relay (CR) is proposed. The best relay selection strategy is analyzed in presence of Rayleigh fading channel. The hybrid combining (SC/MRC) employs at the output, the signals received from multiple receiving antenna via cognitive relay (CR), The relay received and forwards the signal to secondary user destination (D) using some relay strategy like: Decode Amplify-and-Forward (DAF) for dual hop system and Decode Amplify-and-Forward (DAF) and then Amplify-and-Forward (AF) strategy for more than two hop relaying network. In multi-hop environment comparison of BER has been evaluated, between dual hop (DAF) vs three hop (DAF and AF), and also between hybrid combining (SC/MRC) and Maximal ratio combiner.

Key words: Cognitive Relay (CR), Decode Amplify-and-Forward (DAF), Decode-And-Forward (DF), Hybrid Combiner (SC/MRC)

I. INTRODUCTION

The demand for the radio spectrum is dramatically increasing and is estimated to rise rapidly in the near future with context to the rapid development of different wireless applications, Leads to the scarcity of free space radio spectrum. Several studies have shown that the spectrum (license band) is not in use most of the time; these licensed bands are idle for this period of time, which considered as a wasting of resources. The mentioned studies confirmed that there are unused spaces in the allocated spectrum theses spaces seem to be as spectrum holes. Cognitive Radio is characterized by the fact that it can adapt, according to the environment, by changing its transmitting parameters, such as modulation, frequency, frame format, etc.

II. SYSTEM MODEL

A. *Link Reliability Enhancement*

In conventional communication architecture, there is only Base Station (Source or BS) which is directly connected with Mobile Station (Destination or MS) now apart from Source and destination there is the relay station. Relay Station (RS) is placed between BS and MS. The main advantage of RS is increase the coverage of BS and also reduces the distance of MS from BS, path loss is also reduces. The installation of RS is less than a BS. Deep fade region is also covered by The RS. To improve link performance or reliability in this paper multi-hop relay strategy is used here. In 3 hop relay network Decode, Amplify and Forward (DAF) [12] and Amplify and Forward (AF) as well as in 2 hop relay network is Decode, Amplify and Forward.

We consider a wireless relay network consisting of one source, N relay and one destination operating over Rayleigh fading channels. The source (S) communicates with the destination (D) via relay nodes. The relay terminals perform hard decisions on the received symbols before forwarding them to their respective successor node.

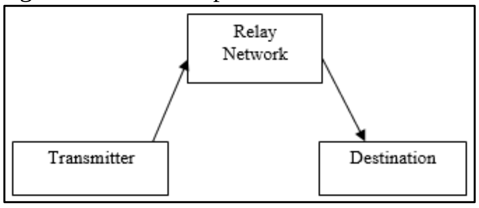

Fig. 1: Basic Idea of Cooperative Communication

Amplify and Forward (AF) - Amplify and Forward is work like repeater. It is also known as non regenerative repeater. By this strategy relay simply amplify the received signal and forward it to destination.

$$X_r(s) = X_t(s)*\beta$$

Where, $\beta = \sqrt{\frac{\varepsilon}{|\mathbf{h}_{(s,r)}|^2\varepsilon + 2\sigma^2_{(s,r)}}}$,

Decode and Forward (DF) - The relays which has ability of regeneration of the data use DF strategy for modeling of a wireless system. In DF strategy relay first decodes the received data then it re-encodes using specific encoding scheme and then re-transmits toward destination.

B. *Better Receiver Diversity*

In this paper, we discussed a Hybrid combiner which is a combination of L branch selection combiner and M branch maximal ratio combiner.

1) *Selection Combiner*

Consider a SC that chooses the 1 of its L input branches with the largest SNR. The branch SNR is modeled as random variables let a_1, a_2 …………a_L denoted the increasing order of set of which has average power $\mathcal{E}_p$. we define the instantaneous SNR per bit for each channel with $\gamma_{(.)}$.

$$\gamma_l = a^2 E_b/N_0, \quad l = 1,2,3.......,L \qquad (1)$$

(E_b/N_0 is bit energy to Gaussian noise spectral density ratio), a is instantaneous gain. the corresponding average SNR per bit each channel as

$$\overline{\gamma} l = \overline{a^2}\, E_b/N_0 = \mathcal{E}_p\, E_b/N_0,$$

$$P_e = \frac{1}{2}\sum_{k=0}^{N}(-1)^k N_k \left(1 + \frac{k}{(E_b/N_0)}\right)^{-\frac{1}{2}} \quad (2)$$

2) *Maximal Ratio Combiner*

For MRC diversity, the conditional SNR is again given by,

$$\gamma_{(l)} = (x+a)^n = \sum_{l=1}^{L} \gamma(l),$$

Where now the $\gamma_{(l)}$'s correspond to a randomly chosen subset of the received branches including the possibility of all the branches. The chi-squared distribution for random variable

$$F_G(g) = \frac{1}{(L-1)!} g^{L-1} e^{-g},$$

Where g $= ||\overline{h}||^2$, is a chi-squared random variable with 2L degree of freedom.

$$\overline{w}_{opt} = \frac{\overline{h}}{||\overline{h}||}$$

The optimal receiver output is $\overline{w}_{opt}$, $\overline{h}$ is fading co-efficient vector.

The value of SNR

$$SNR= ||\bar{h}|| \frac{\varepsilon_p}{\sigma^2}$$

The bit error rate expression for

$$P_e = \frac{1}{2}\left[1 - \sqrt{\frac{E_b/N_0(E_b/N_0+2)}{E_b/N_0+1}}\right] \qquad (3)$$

The Hybrid combiner is an amalgamation of two combiners which is simulated on MIMO system. And the performance is analyzed by BER calculations.

There are several approaches to sense the vacant frequency spectrum, Energy detection technique is one of them. In energy detection technique relay node cooperatively sense the presence or absence of PU through pre-defined threshold value. Combine the outputs selected from the all antennas using hybrid SC/MRC combiner. Calculate the bit error rate by comparing the transmitted and received bits.

The following steps of the hybrid technique is to understand the algorithm that has been designed to select the number of antennas and how one by one hybrid SC/MRC combiner is work.

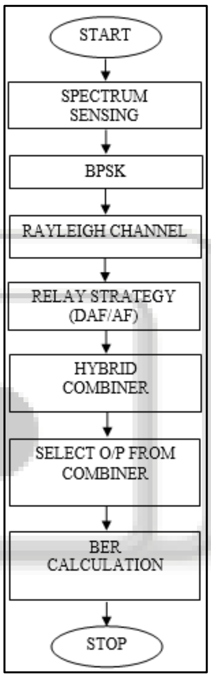

Fig. 2: Flow Chart for Proposed Work

The above steps are the basic steps that are used to enhance the link reliability through relay strategies and to get better receiver diversity. The hybrid SC/MRC is used to select the best output from the total number of the received antennas and hence neglect the uncertain signals having massive noise and selecting the signals with high SNR. In this way this proposed algorithm helps in increasing the throughput of the system. A simulation environment has been developed in MATLAB 2016a to assess the impact of number of relay antennas and relays on the outage performance of the antenna. Our simulated results demonstrate that the deployment of multi-antennas at the relays can reduce the required number of relay.

The joint probability density functions (PDF) of the L_c largest of the $\overline{\gamma l}$ is then given by

$$P_{(\gamma_r,\ldots,\gamma_{Lc})}= L_c!\binom{M}{L}\left[P_\gamma(\gamma_L)\right]^{M-L_c}\prod_{l=1}^{L} P_\gamma(\gamma_l),\quad \gamma_1\geq \ldots\gamma_L\geq 0$$

Where $P_\gamma(\gamma)$ is the PDF of γ, and $P_\gamma(\gamma)=\int_0^{\gamma} P_\gamma(\gamma)\,d\gamma$ is the corresponding cumulative distribution function (CDF).

C. *Average BER of SC/MRC-L/M Binary Receivers*

For binary signals and a receiver that using the hybrid SC/MRC scheme with and (i.e., MRC combining of the strongest two of the three received branches), the BER conditioned on the fading amplitudes is given by

$$P_b(\gamma_t)=Q(\sqrt{2g\gamma_t})$$

Where Q, represents Gaussian function,

$$Q(x) = \frac{1}{\pi}\int_0^{\frac{\pi}{2}} e^{\frac{-x^2}{2\sin^2\phi}}d\phi, \qquad x\geq 0 \quad (5)$$

The value of g is 1 for coherent Binary PSK, 1/2 for coherent orthogonal Binary FSK, and $\gamma_t = \gamma_t + \gamma_t$ shows the total SNR. The average BER is calculated by

$$P_b(E)=\int_0^{\infty} Q(\sqrt{2g\gamma_t})P_{\gamma t}(\gamma_t)\,d\gamma_t.$$

III. Simulation and Results

Figure 1 and figure 2 show the plots of the performance of BPSK transmission link having 2-hop network with relay using DAF relay strategy and 3-Hop network using DAF and AF relay strategy. As shown in figure 1, the 3-hop network having DAF and AF relays has better performance than the 2-hop using DAF protocol in the case when transmitter has two and receiver have four antennas.

In figure 2, we decrease the number of receiving antennas (Rx) to 2 for both 3-hop and 2-hop relay networks. Again, the performance of 3-hop (DAF&AF) is better than 2-hop (DF) and the BER value decreased when number of receiving antenna is increased. A Hybrid SC/MRC system has illustrated in Figure 3. The signals in all the M number of branches are Selection diversity combined. The signals in all the L number of branches are Maximal ratio combined to obtain the final output for Rayleigh fading channel. At the first combining stage, the three branches with SNR greater than threshold SNR chosen. The outputs of first combining stage are given as inputs to second combining stage. In second combining stage the dual Maximal ratio combining is carried out. The signals in two branches are co-phased and weighted by different weights. The signals are then summed up. The performance of this system is evaluated in terms of bit error rate (BER). Figure 5 shows that when the transmitted bits are moderate then the Hybrid SC/MRC combiner is giving better performance than classical MRC when the SNR is low. And also in other values of SNR the Hybrid SC/MRC techniques is giving better performance comparison to classical approach.

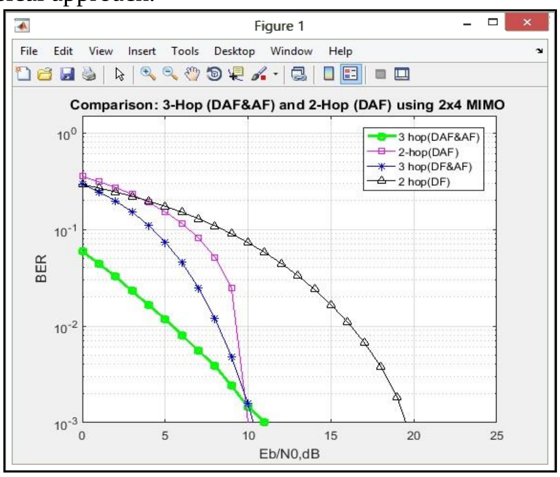

Fig. 3: Comparison of 3 hop (DAF&AF), 3 hop(DF and AF) in 2X4 MIMO

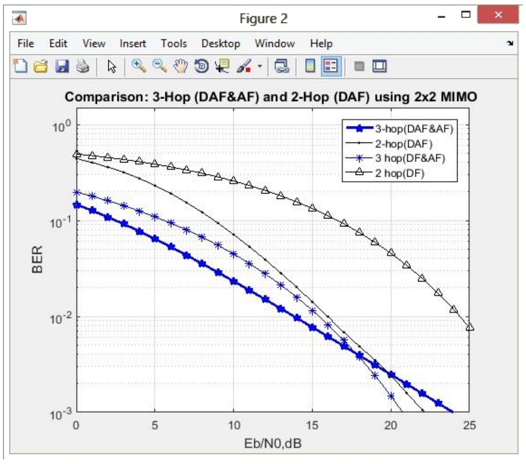

Fig. 4: Comparison of 3 hop (DAF&AF), 3 hop (DF and AF) in 2X2 MIMO

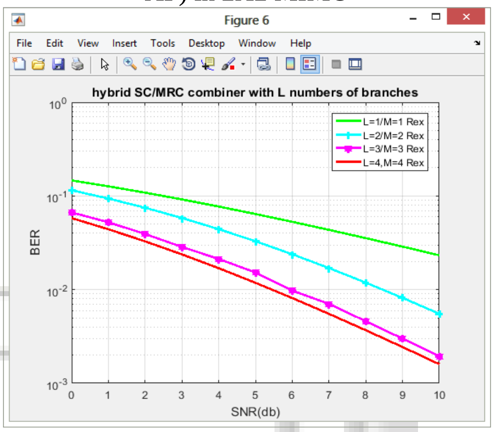

Fig. 5: Hybrid SC/MRC combiner with different L/M branches

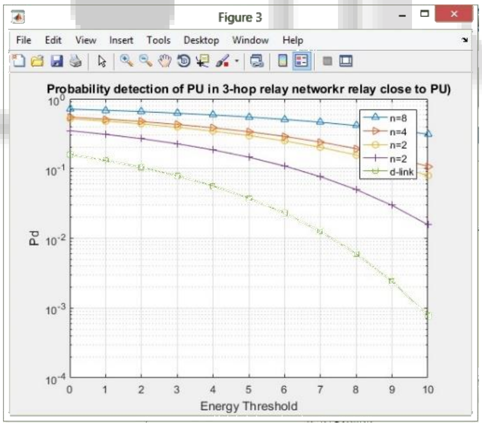

Fig. 6: Probability detection of PU when relay is close to PU in 3 hop relay network.

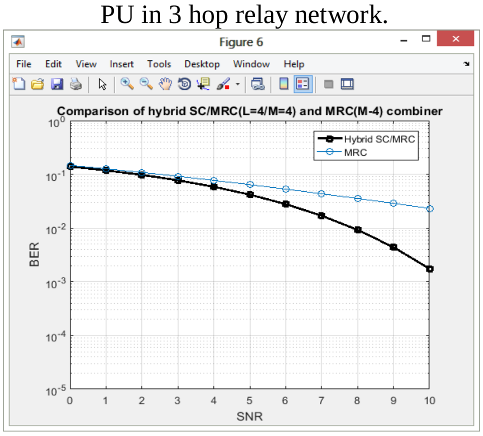

Fig. 7: Comparison between hybrid combiner and MRC

IV. Conclusion

In conventional communication, when the distance between the source and destinations is large the regenerative repeaters are used to keep the signal strength above the significant threshold. In cognitive radio network relay not only used to amplify the signal level but also do the spectrum sensing (To detect the presence of PU) and encoding and decoding of the signal (by relay strategy like DAF, AF, DF etc) and then transmit it to the secondary destination. In this paper, It has been seen that multi-hop relay strategy is key aspect for link reliability is enhancement and by using the Hybrid L/M branch SC/MRC Diversity Combiner at a low SNR values, the Bit Error Rate (BER) obtained is very less as compared to already existing standalone diversity combining techniques.

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