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PERFORMANCE OF COOPERATIVE DIVERSITY IN COGNITIVE RELAY NETWORKS

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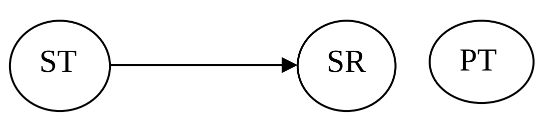
ABSTRACT

In a network with dynamic spectrum access, secondary users equipped with frequency-agile cognitive radios communicate with one another via spectrum that is not being used by the primary users or licensed users of the spectrum . We consider a scenario in which a secondary transmitter can communicate with a secondary receiver via a direct communication link or a relay channel. Cooperative relay communications or cooperative diversity has received a lot of attention in recent years. Two well known cooperative strategies are known as Amplify And Forward (AAF) and Decode And Forward (DAF). In this paper, the AAF strategy will be considered, which achieves diversity by using Maximal Ratio Combining (MRC) and Fixed Ratio Combining (FRC) which is not clarified until now. From simulation results, we can conclude that using both of the direct and relay channels, the transmissions performance of the secondary system can be improved significantly , Moreover, exploiting cooperative spectrum sensing technique for applications in a relay based cognitive radio network , it is seen that detection probability increases by using relay channel . The best performance was achieved when the relay is at equal distance from the sender and the destination or slightly closer to the sender.

Keywords: *Cognitive radio, Cooperative diversity, Relay*

1. INTRODUCTION

Cooperative relaying [1-2] is a promising technology for future wireless communications. It is mostly applicable to the small dimensional and limited power devices, which cannot use the conventional Multiple Input Multiple Output (MIMO) technology to obtain the advantages of MIMO. It can benefit most of the leverages of MIMO such as array gain, diversity gain, spatial multiplexing gain and interference reduction without using the conventional MIMO technology. Since the original signal is forwarded by relay nodes, the performance of relaying network depends on the relaying process of the relay nodes and fading characteristic of their links. Classifically, , relay network has three links Source-Destination (S-D) ,Source-Relay(S-R) and Relay-Destination(R-D) and the relaying processes are classified as Amplify and Forward (AF) and Decode and Forward (DF). In this paper we propose a cooperative communications strategy to maximize the transmission capacity of secondary users in a cognitive radio network. In Fig.1 (a), the secondary transmitter (ST) communicates directly with the secondary receiver (SR). However, in the scenario depicted in Fig.1 (b), ST communicates with SR via a relay channel. By using both of the direct and relay channels, the transmission performance of the secondary system can be improved significantly. Moreover, we propose a relay based cooperative spectrum sensing in cognitive radio networks. The idea is to utilize relay nodes to convey the signal transmitted from the primary user to a cognitive coordinator, which will make estimation of the presence or absence of primary activities. The cognitive coordinator use an energy detector to make the estimation. The rest of this paper is organized as follows .Cooperative relaying is described in Section 2. Combining techniques are explained in Section 3. Cooperative relaying with spectrum sensing will be introduced in Section 4 .The position of the relay is discussed in Section 5. Simulation results will be made in Section 6. Finally, conclusions will be done in Section 7.



(a) *Direct communication*

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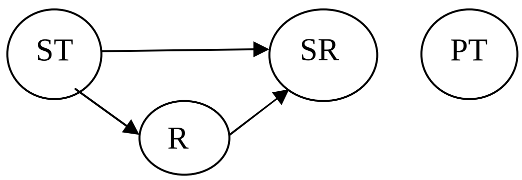

(b) Single relay cooperative communication

Fig.1. *Cooperative communication*

2. COOPERATIVE RELAYING

The received signal of a simple wireless channel model with fading and path loss is given by [3]

$$y = \delta\sqrt{\left(\frac{d_r}{d}\right)^{\alpha}}\, h\, S + n = \sqrt{p}\, h\, S + n$$

(1) Where δ is the free space signal power attenuation factor between the source and a reference distance d_r ,d is the distance between the source and destination, and α is the propagation exponent. $h \sim c\, N(0, \sigma_h^2)$ is a complex Gaussian random variable with variance σ_h^2, $n \sim cN(0, N_0)$,S is the transmitted signal . in equation (1), $p = \sigma^2\left(\frac{d_r}{d}\right)^{\alpha}$ denotes the equivalent transmitted power after taking into account the effect of path loss ,we also define

$$p_0 = \delta^2\left(\frac{d_r}{d_0}\right)^{\alpha} \quad p_1 = \delta^2\left(\frac{d_r}{d_1}\right)^{\alpha}$$

$$p_t = \delta^2\left(\frac{d_r}{d_t}\right)^{\alpha}$$

as the equivalent transmitted powers from ST to R , from R to SR and ST to SR . d_o ,d_1 ,d_t denote the distances between the node pairs (ST, R),(R, SR)and (ST, SR). The received signal at a relay is the maximum ratio combining (MRC) sum of a repetition code over k_o time frames [4]:

$$y_1 = \sum_{i=1}^{k_0} g_i^*(g_i\sqrt{p_o}S + n_i) = g^\sim\sqrt{p_o}S + n^\sim$$

(2)

Where $g^\sim = \sum_{i=1}^{k_0}|g_i|^2$ and $n^\sim = \sum_{i=1}^{k_0} g_i^* n_i$, S is the transmitted symbol, $|s|^2 = 1$ and g_i is the channel gain between ST and R during time frame I . The received signal at SR due to relay R is

$$y_R = \sum_{j=1}^{k} h_j^* \left(\sqrt{p_1} h_j A\left(j\sqrt{p_o}S + n^\sim\right) + n_j\sqrt{p_o p_1}\, h^\sim A g^\sim S + nR\right)$$

(3)

Where $h^\sim = \sum_{j=1}^{k_1}|h_j|^2$, $A = \sqrt{\frac{1}{p_o g^{\sim 2} + N_o g^\sim}}$

$$n_R = \sum_{j=1}^{k_1}\left(|h_j|^2 A\sqrt{p_1}\, n^\sim + h_j^*\, n_j\right)$$

h_j is the channel gain between R and SR during time frame j. Here, A is the amplification factor which is chosen to maintain average constant power output at R. The noise variance of y_R , $\sigma_R^2 = A^2 p_1 g^\sim h^2 N_o + h^\sim N_o$ where $h^\sim = \sum_{j=1}^{k_1}|h_j|^2$.

The direct transmission (ST ⟶ SR) channel model is

$$y_{ST} = f\ \sqrt{p_t}\, S + n_{ST} \qquad (4)$$

Where f is the channel gain between ST and SR f, h_j , g_i are constant over one time frame duration and independently identical distributed from one frame two another. At SR , MRC is used to combine y_R and y_{ST}. The noise variables n_R and n_{ST} have different powers because n_R includes a noise contribution at the relay .For this reason, noise normalization is necessary for MRC of y_{ST} and y_R [5].
The resulting SNR is

$$\gamma_w = |f|^2\frac{p_t}{N_o} + |Ag^\sim h^\sim\ |^2\frac{p_o p_1}{\sigma_R^2} = \gamma_t + \gamma_r \qquad (5)$$

Where $\gamma_t = |f|^2\frac{p_t}{N_o}$ and

$$\gamma_t = |Ag^\sim h^\sim|^2\frac{p_0 p_1}{\sigma^2 R} = \frac{\gamma_0\gamma_1}{\gamma_0 + \gamma_1 + 1} \qquad (6)$$

With $\gamma_o = \frac{g^\sim p_o}{N_o}$ and $\gamma_1 = \frac{h^\sim p_1}{N_o}$ .We assume that f, g_i ,h_j are known at receiving end .The symbol error probability (SEP) conditioned on the instantaneous SNR γ_w is given by $p_e = Q(\sqrt{k\gamma_w})$ [5]. Where k is a constant that depends on the type of modulation and $Q(x) = \sqrt{\frac{1}{2\pi}}\int_x^\infty e^{-t^2/2}\, d_t$ is the standard Q-function.

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3. COMBINING TECHNIQUES

a. Maximum Ratio Combining

The Maximum Ratio Combining (MRC) achieves the best possible performance by multiplying each input signal with its corresponding conjugated channel gain . this assumes that the channels' phase shift and attenuation is perfectly known by the receiver .

$$y_d[n] = \sum_{l=1}^{R} h_{i,d}^* [n] \cdot y_{i,d}[n] \quad (7)$$

Using a one relay system , this equation can be rewritten as

$$y_d[n] = h_{s,d}^*[n] y_{s,d}[n] + h_{r,d}^*[n] y_{r,d}[n] \quad (8)$$

b. Fixed Ratio Combining (FRC)

Instead of just adding up the incoming signals, they are weighted with a constant ratio, which will not change a lot during the whole communication. The ratio should represent the average channel quality and therefore should not take account of temporary influences on the channel due to fading or other effects .The FRC can be expressed as.

$$y_d[n] = \sum_{i=1}^{k} d_{i,d} \cdot y_{i,d}[n] \quad (9)$$

Where $d_{i,d}$ denotes weighting of the incoming signal $y_{i,d}$. Using one relay station ,the equation simplifies to

$$y_d[n] = d_{s,d} \cdot y_{s,d}[n] + d_{s,r,d} \cdot y_{r,d}[n] \quad (10)$$

Where $d_{s,d}$ denotes the weight of the direct link and $d_{s,r,d}$ gives the one of the multi-hop link.

4. COOPERATIVE RELAYING WITH SPECTRUM SENSING

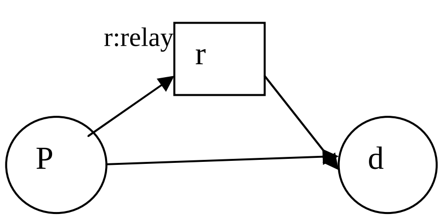

Fig.2. Illustration of a cooperative network with cognitive relays

We consider a relay-based spectrum sensing [9-10-11] by using one relay channel is added in cognitive radio. As the primary user starts using the band, cognitive radios receive the signal of the primary user. Instead of making individual hard decision about the presence or absence of the primary user, relay –based cognitive radios simply amplify and retransmit the noisy version of the received signals to the cognitive coordinator. The cognitive coordinator is equipped with the energy detector which compares the received signal strength with a pre-defined threshold. Based on the decision, the cognitive coordinator informs the cognitive radios the presence or absence of primary user's activities

We have three nodes ,i.e., the primary user, the cognitive relay and the cognitive coordinator. The cognitive relay continuously monitors the signal received from the primary user. The received signal by the cognitive relay ,denoted by y_{pr} is given by

$$y_{pr} = \theta \, X h_{pr} + w_r \quad (11)$$

Where θ denotes the primary activity indicator ,which is equal to 1 at the presence of primary activity ,or equal to 0 .Otherwise , X is the transmitted signal from the primary user, h_{pr} is the channel gain of channel between the primary user and relay and w_r is the noise signal at the cognitive

relay .The cognitive relay act as amplify and forward (AF) relaying mode.

The received signal at the cognitive coordinator, denoted y_{rd} ,is given by

$$y_{rd} = \sqrt{A} y_{rd} h_{rd} + w_d = \theta \sqrt{A} h_{pr} h_{rd} X + \sqrt{A} h_{rd} w_r + w_d = \theta h X + w \quad (12)$$

Where h_{rd} is the channel gain of channel between relay and cognitive coordinator and w_d is the noise signal at the cognitive coordinator. $h = \sqrt{A} h_{pr} h_{rd}$ and $w = \sqrt{A}\, h_{rd} w_r + w_d$ is the total effective noise at the cognitive coordinator ,which can be modeled as $w] \sim c\, N(0, A|h_{rd}|^2 + 1) N_0)$.

The received signal at the cognitive coordinator follows a binary hypothesis as :

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$$y_d = \begin{cases} w & : H_0 \quad \theta = 0 \\ hx + w & : H_1 \quad \theta = 1 \end{cases} \qquad (13)$$

As described in [6-7], the received signal is first pre filtered by an ideal band pass filter with center frequency f_c and bandwidth w in order to normalize the noise variance . The output of integrator, denoted by y, acts as test statistic . The pdf of y is given by,

$$f_y(y) = \begin{cases} \frac{1}{2^u \Gamma(u)} y^{u-1} \quad e^{-y^2/2} & : H_0 \\ \frac{1}{2}\left(\frac{y}{2\gamma}\right)^{\frac{u-1}{2}} e^{-2\gamma+y/2} I_{u-1}(\sqrt{2}\gamma y) & : H_1 \end{cases} \qquad (14)$$

Where Γ(.) is the gamma function ,$I_n(.)$ is the nth order modified Bessel function of the first order, and u=TW where T and W are chosen to restrict u to an integer value

The total end to end signal to noise ratio (SNR), denoted γ, is given[8] by

$$\gamma = \frac{\gamma_{pr}\gamma_{rd}}{\gamma_{pr}+\gamma_{rd}+1} \qquad (15)$$

Where $\gamma_{pr} = |h_{pr}|^2 E_p/N_o$ and $\gamma_{rd} = |h_{rd}|^2 E_r/N_o$ are SNRS of the links from the primary users to cognitive relay to the cognitive coordinator, respectively

5. POSITION OF THE RELAY

So Fars, the three stations was positioned equidistantly and therefore the three channels had all the same average signal to noise ratio. In this section the effect is shown when the relay station is moved .for the following simulations the AAF diversity protocol is used and the incoming signals at the destination are combined using FRC and MRC.

6. SIMULATIONS RESULTS

a. Simulation condition

In this section ,we investigate the performance of cooperative relaying in cognitive radio networks in terms of the average symbol error probability (SEP) .the results in fig. 3-9 were obtained using a computer simulation in MATLAB . we assume that primary network uses OFDM modulation with 64 QAM and N=512 subcarriers . Energy detector is used to detect the presence or absence of the primary user signal.

b. Simulation result

Figure 3 shows the cooperative relaying over fading channel and AWGN channels .We conclude that the improvement using relay channel with cooperative scheme is better than the case of not using relay channel

Figure 4 shows the effect on the performance for the different combining types using a AAF protocol can be seen .it is seen that the Maximum Ratio Combining (MRC) is much better than the one using FRC

Figure 5 illustrates the effects of different weighting for FRC .the best performance using FRC is achieved with a ratio 2/3:1/3

Figure 6, 7 demonstrates the effect position relay between sender and destination on performance of cooperative relaying in the case of MRC and FRC .It is shown that the best performance is achieved ,when the relay is situated in the middle between the sender and the destination ,or slightly closer to the sending station .

Figure 8 shows performance results of relay based cooperative spectrum sensing .It is seen that the probability of missed detection is greatly reduced by using relay channel for a given probability of false alarm

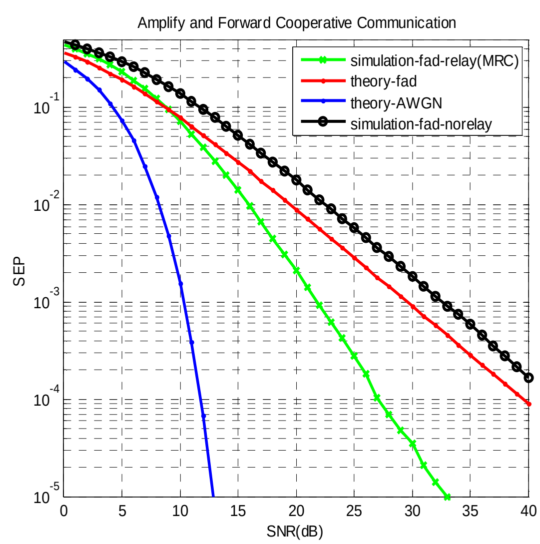

Fig.3. Comparison of SEP for cooperative relaying with or without relay channel

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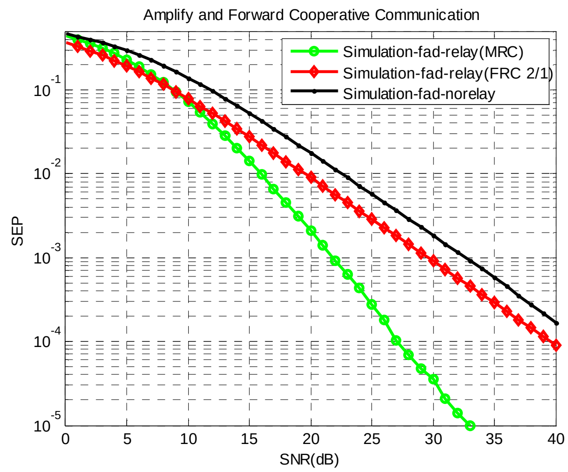

Fig.4. The different combining types are compared with each other.

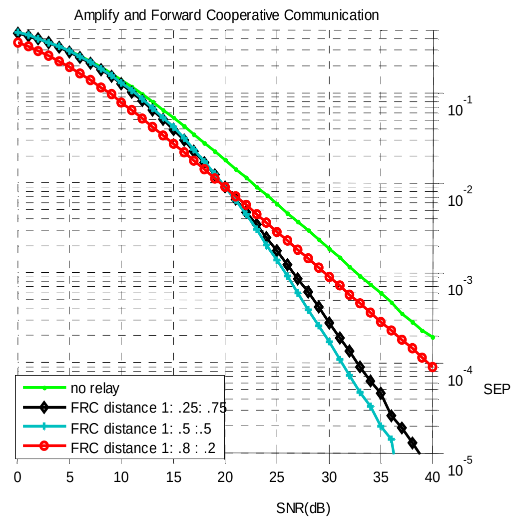

Fig.6. Comparison of SEP for FRC when the relay is located between sender and destination

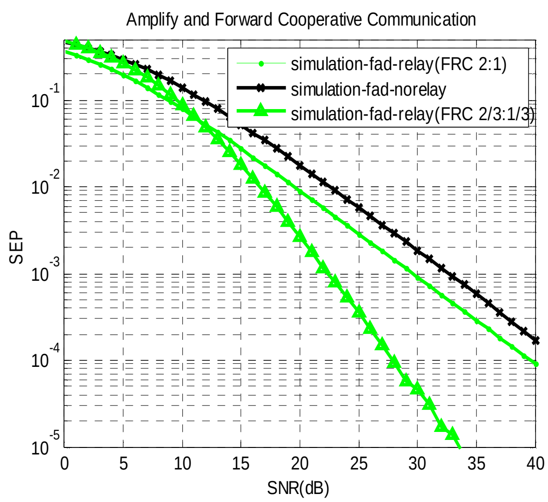

Fig.5. Comparison of SEP for different ratios of FRC

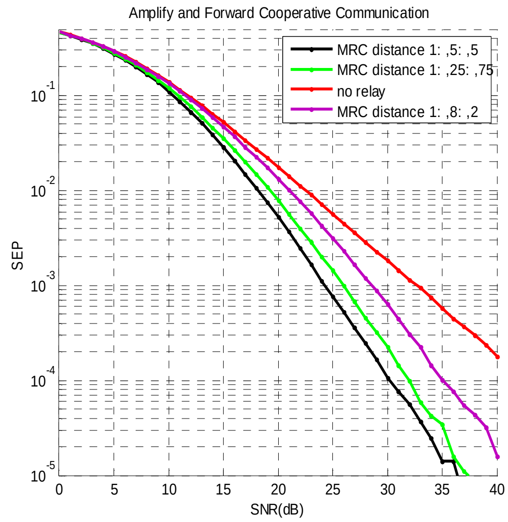

Fig.7. comparison of SEP for MRC when the relay is located between sender and destination

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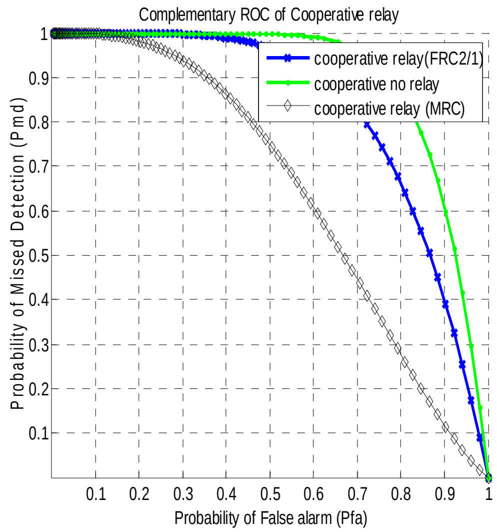

Fig.8. comparison of performance for relay based cooperative spectrum sensing

7. CONCLUSIONS

In this paper ,we have discussed the concept of cooperation diversity in cognitive relay networks. It is seen that symbol error probability (SEP) with relay channel is better than SEP without relay channel. Moreover, it is shown that position of the relay effects on the performance of cooperative relaying where the best performance is achieved when the relay is situated in the middle between the sender and the destination. The relay based spectrum sensing with an energy detector for a cognitive radio network with Rayleigh fading channels has been investigated. The analysis for the detection probability and the false alarm probability has been made . It is seen that the detection probability increases by using relay channel.

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