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Performance of Cooperative Diversity for PCP OFDM Based Cognitive Relay Network

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ABSTRACT

In this paper**,** an adaptive Orthogonal Frequency Division Multiplexing (OFDM) system, with a precoded cyclic prefix (PCP), will be proposed to address the recent need of robust and flexible transmission technique in Cognitive Radio (CR) communications which is not clarified until now. Identification of PCP-OFDM signals is therefore of great importance for the design of fair spectrum sharing mechanism, particularly at very low signal-to-noise ratio (SNR) when synchronization is not achievable. The precoded cyclic prefix, multiplexed with the data-carrying OFDM signals, provides one unique and recognizable feature of PCP-OFDM signals. In this paper, the network consists of sender, a destination and a third station, which is used as a relay is analyzed. The data that is sent to the sender is considered to be OFDM with PCP. The analysis of this system will be made which is not clarified until now. The channels are modeled containing noise, Rayleigh fading and path loss. Moreover, different combining methods and diversity protocols are compared. To combine the incoming signals the channel quality should be estimated as well as possible. Amplify and Forward (AAF) will be applied in this system. Also, the effect of the positions of the relay will be studied.

Keywords: *Cyclic prefix, OFDM, Cooperative Diversity, relay, Diversity protocols, Combining methods, fading, path loss.*

I. INTRODUCTION

CR [1, 2] is a revolutionary technology that aims for remarkable improvements in efficiency of spectrum usage. The cognitive radio is normally defined as an intelligent wireless communication system that is aware of its environment and uses the methodology of “understanding-by-building” to learn from the environment and adapt to statistical variations in the input stimuli, with the efficient utilization of the radio spectrum as the primary objective. In [3], Precoded Cyclic Prefix (PCP) OFDM system is proposed to provide a flexible, robust, and efficient platform. For efficient spectrum utilization, CR networks will be used PCP-OFDM system for transmission which is not clarified until now. The analysis of this system will be made. In PCP-OFDM system, consists of two precoded Kasami sequences which are used as real and imaginary sequences. The transmission protocols used in this paper are Amplify and Forward. Basically three different types of combining methods are examined which differ in the knowledge of the channel quality. The effect of the positions of the relay will be studied. The organization of this paper will be made as follows: Section II, PCP-OFDM system will be described. System model will be investigated in Section III. Combining techniques will be studied in Section IV. Cooperative transmission protocols will be described in Section V. Simulations Results will be studied in Section VI. Finally Conclusions will be illustrated in Section VII.

II. PCP-OFDM SYSTEM

Consider the proposed frame structure for PCP OFDM system in Fig. 1, where each OFDM symbol is protected by two identical neighboring PCPs [3]. The new OFDM symbol basically is the same as that in a traditional OFDM system, except that the cyclic prefix is now replaced by a precoded sequence. In addition, the duration of each PCP-OFDM symbol becomes $N + P$ samples, where N is the size of the FFT and P is the duration of the cyclic prefix, respectively. Pseudo random sequences or all zero sequences have been used in OFDM as prefix and postfix to protect OFDM symbol from ISI [4], [5]. Our proposed PCP is combined from two Kasami sequences, precoded by the CR transmitter identification and system parameters. The real part of the PCP represents the transceiver identification and the imaginary part is precoded with the OFDM system parameters including the number of the subcarriers and the modulation/coding schemes used. In addition, the size of inverse fast Fourier transformation (IFFT) block, i.e. the number of subcarriers employed by the adaptive OFDM modulator, is also controlled by the spectrum sensing, Sharing and Controlling Unit (SSCU). The total number of the subcarriers in the OFDM signal and its carrier frequency depend on the information of the available spectrum from the spectrum sensing unit. The number of subcarriers, as well as the coding and modulation schemes, will be coded into different cyclic prefix. The same PCP is used as the cyclic prefix for all the forthcoming OFDM symbols unless there is a change in the transmission system parameters. The analysis of the system will be investigated as follows:

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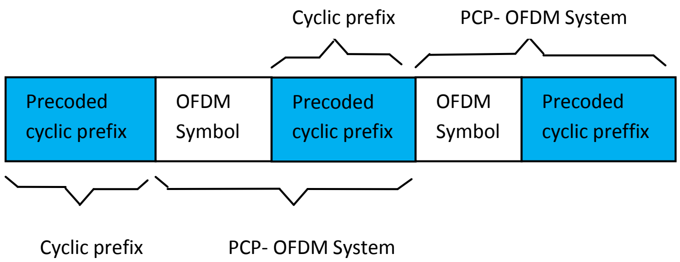

Fig.1: Frame structure of the proposed PCP-OFDM system.

A. Precoded Cyclic Prefix

Two Kasami sequences will be used to generate the precoded cyclic prefix according to

$$\mathbf{c}_P = \mathbf{c}_{P,r} + j\mathbf{c}_{P,i.} \quad (1)$$

Note here all elements in the pseudo random sequences in (1) take on values +1 or −1. This is to avoid any direct current (DC) component in the transmitted signal. The real part of the cyclic prefix, $\mathbf{c}_{P,i}$, will be used as the identification of cognitive radio, while the imaginary part $\mathbf{c}_{P,i}$ will be used to transmit the system parameters. The generator for such Kasami sequences can be found in [6]. When large set Kasami sequences with period of $2^n - 1$ are used, both the real and the imaginary parts of the PCP can have $M = 2^{n/2n+1}(2^n+1)$ different sequences. Here n is a nonnegative even integer. The real part of the cyclic prefix is uniquely assigned as the identification of the cognitive radio. Signals from each cognitive radio can then be easily traced back to its sourcing transmitter for spectrum monitoring and sharing purposes. With the M possible sequences for the imaginary part, it is therefore possible to transmit $\log_2 M \approx 1.5n$ bits for the cognitive radio parameters. This approach is similar to coded shift keying in [7]. The input data sequence is denoted as:

$$d = [d_0, d_1 \ldots d_{1.5n-1}], \quad (2)$$

Where $di \in \{0, 1\}$. Each data sequence of system parameters is thus associated with one unique Kasami sequence. For the sample Kasami sequence generator, it is possible to transmit nine bits of system information using Kasami sequence when $n = 6$.

B. PCP-OFDM Transceiver

Each OFDM symbol at transmitter side is specified by an N-point time-domain vector x obtained via an IFFT of the complex data vector X of size N. Without loss of generality, each OFDM symbol in time domain can be expressed in vector form as:

$$\mathrm{x} = \mathbf{F}_N^H \mathrm{X}, \quad (3)$$

Where $\mathbf{F}_N^H = \mathbf{F}_N^{-1}$ is the IFFT matrix with its (n, k)th entry $(exp\{j2\pi nk/N\}/\sqrt{N})$, $(.)^H$ being the vector/matrix transposes Operator. Before the transmission of the OFDM symbol in (3), the generated PCP sequence with length of P is inserted as its prefix. Note that in the proposed system, the beginning of the CR communication starts with one precoded cyclic prefix. This is equivalent to generating a new OFDM symbol of $N+2P$ samples with one pseudo random sequence as its last P samples and the other sequence as its cyclic prefix in the first P samples. Consequently, a cyclic structure for each PCP-OFDM symbol is produced, and this structure is similar to those seen in OFDM symbols that employ conventional cyclic prefix. Without loss of generality, consider the following signal vector for interference analysis and PCP-OFDM symbol demodulation as

$$\mathbf{x}' = [cP(0), cP(1), \ldots, cP(P-1), x(0), x(1), \ldots x(N-1), cp(0), cP(1), \ldots, cP(P-1)]^T \quad (4)$$

Now let $\mathbf{r}'$ be the received signal vector corresponding to one transmitted PCP-OFDM symbol. Unless otherwise stated, we assume an L-tap static complex channel $\mathbf{h} = [h_0, h_1 \ldots h_{L-1}]^T$ for signal propagation and interference analysis, where in the worst case $L = P + 1$. Then, $\mathbf{r}'$ can be expressed as:

$$\mathbf{r}' = \begin{bmatrix} h_{L-1} & . & . & . & . & h_0 & & & 0 \\ & h_{L-1} & . & . & . & . & h_0 & & \\ & & . & . & . & . & & & \\ & & & . & . & . & . & & \\ 0 & & & h_{L-1} & . & . & . & . & h \end{bmatrix} \mathbf{x}' + \mathbf{w}' \quad (5)$$

Where the size of the channel matrix in (5) is $(N+P) \times (N+2P)$, and $\mathbf{w}'$ is an additive white Gaussian noise (AWGN) vector with the same size as $\mathbf{r}'$. Suppose the channel impulse response of the channel is known through channel estimation, a straightforward way to obtain the equalized signal $\tilde{\mathbf{x}}'$ with size of $(N + P)$ in time domain can be formulated as:

$$\tilde{\mathbf{x}}' = F_{N+p}^H \mathbf{D}^{-1} \mathbf{F}_{N+P} \mathbf{r}' + \tilde{\mathbf{w}}' \quad (6)$$

Where $\mathbf{D} = \text{diag}\{H'(0), H'(1), \ldots, H'(N+P-1)\}$ and $H'(k)$ is the kth entry of $\mathbf{F}N+P$ $[\mathbf{h}^T, \mathbf{0}]^T$. In other words, $\mathbf{D}$ is the diagonalized channel matrix for the frequency domain equalizer with the channel's frequency response as its diagonal elements.

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International Journal of Information and Communication Technology Research

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It is obvious that the desired equalized OFDM symbol $\tilde{\mathbf{x}}$ is the first N samples of $\tilde{\mathbf{x}}'$. The demodulation process is expressed as:

$$\tilde{\mathbf{X}} = \mathbf{F}_N\, \tilde{\mathbf{x}} + \tilde{\mathbf{W}}, \qquad (7)$$

Where $\tilde{\mathbf{W}}$ is the frequency-domain noise vector with size of N after the frequency domain equalization.

III. SYSTEM MODEL

In a wireless network, the data which is transferred from a sender to a receiver has to propagate through the air. During propagation, several phenomena will distort the signal such as noise, path loss and Rayleigh fading. Path loss and fading are multiplicative, noise is additive. The output of the transmitter after passing channel is expressed as:

$$y_d[n] = h_{s,d}[n] \,.\, x_s[n] + z_{s,d}[n] = d_{s,d} \,.\, \alpha_{s,d}[n] \,.\, x_s[n] + z_{s,d}[n]\,, \qquad (8)$$

where the suffixes s and d denote the sender and the destination, respectively. $x_s[n]$ is the transmitted symbol and $y_d[n]$ is the received symbol. $h_{s,d}[n]$ is attenuation and $d_{s,d}$ is path loss. $\alpha_{s,d}[n]$ is fading and $z_{s,d}[n]$ is noise.

There are several approaches to implement diversity in a wireless transmission [8], [9]. Multiple antennas can be used to achieve space and/or frequency diversity. But multiple antennas are not always available or the destination is just too far away to get good signal quality. To get diversity, an interesting approach might be to build an ad-hoc network using another mobile station as a relay. The model of such a system is illustrated in Fig.2. The sender S sends the data to the destination D, while the relay station R is used as a station. The relay sends this received data burst after processing to the destination as well, where the two received signals are combined. Orthogonal channels are used for the two transmissions. Without loss of generality, this can be achieved using time divided channels.

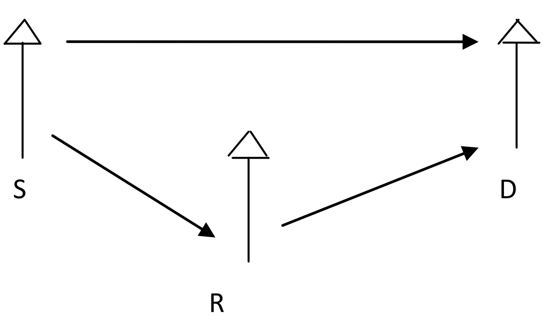

Fig.2: System Model.

The received signal of a simple wireless channel model with fading and path loss is given by [10]

$$y = \delta\sqrt{\left(\frac{d}{d_r}\right)^{\alpha}}\, h\, s + n = \sqrt{p}\; h\, s + n \qquad (9)$$

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. $h \sim c\,N\,(0,\ \sigma_n^2)$ is a complex Gaussian random variable with variance σ_n^2 , $n \sim c\,N\,(0,\ N_o)$, S is the transmitted signal. In Equation (9), $p = \sigma^2 \left(\frac{d}{d_r}\right)^{\alpha}$ denotes the equivalent transmitted power after taking into account the effect of path loss, we also define as:

$$p_{o} = \delta^2 \left(\frac{d_r}{d_o}\right)^{\alpha} \qquad p_{1} = \delta^2 \left(\frac{d_r}{d_1}\right)^{\alpha}$$

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

As the equivalent transmitted powers from S to R, from R to D and S to D. d_o, d_1 and d_t denote the distances between the node pairs (S, R),(R, D)and (S, D), respectively. The received signal at a relay is the maximum ratio combining (MRC) sum of a repetition code over k_o time frames [11] as:

$$y_1 = \sum_{i=1}^{k_o} g_i * \left(g_i\sqrt{p_o}\, s + n_i\right)$$
$$= \tilde{g}\sqrt{p_o}\, s + x \qquad (10)$$

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

$$y_R = \sum_{j=1}^{k} h_j^* \left(\sqrt{p_1} h_j A\left(j\sqrt{p_o} S + n^{\sim}\right) + n_j\sqrt{p_o p_1} h^{\sim} A g^{\sim} S + nR\right) \qquad (11)$$

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

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

International Journal of Information and Communication Technology Research

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h_j is the channel gain between R and S 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 (S ⟶ R) channel model is

$$y_{ST} = f \sqrt{p_t}\, S + n_{ST} \quad (12)$$

Where *f* is the channel gain between *S* and *D*. *f*, h_j *and* g_i are constant over one time frame duration and independently identical distributed from one frame two another. At *S*, MRC is used to combine y_R and y_S. The noise variables n_R and n_S have different powers because n_R includes a noise contribution at the relay. For this reason, noise normalization is necessary for MRC of y_S and y_R [12]. The resulting SNR is

$$\gamma_w = |f|^2 \frac{p_t}{N_o} + |Ag^{\sim}h^{\sim}|^2 \frac{p_o p_1}{\sigma_R^2} = \gamma_t + \gamma_r \quad (13)$$

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

$$\gamma_t = |Ag^{\sim}h^{\sim}|^2 \frac{p_o p_1}{\sigma^2 R} = \frac{\gamma_0 \gamma_1}{\gamma_0 + \gamma_1 + 1} \quad (14)$$

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 *and* h_j are known at receiving end. The symbol error probability (SEP) conditioned on the instantaneous SNR γ_w is given by $p_e = Q(\sqrt{k\gamma_w})$ [12]. 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.

IV. COMBINING TECHNIQUES

a. Maximum Ratio Combining(MRC)

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 are perfectly known by the receiver.

$$y_d[n] = \sum_{l=1}^{R} h_{i,d}^* [n] \cdot y_{i,d}[n] \quad (15)$$

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

$$y_d[n] = h_{s,d}^*[n] y_{s,d}[n] + h_{r,d}^*[n] y_{r,d}[n] \quad (16)$$

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:

$$y_d[n] = \sum_{i=1}^{k} d_{i,d} \cdot y_{i,d}[n] \quad (17)$$

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

$$y_d[n] = d_{s,d} \cdot y_{s,d}[n] + d_{s,r,d} \cdot y_{r,d}[n] \quad (18)$$

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

V. COOPERATIVE TRANSMISSION PROTOCOLS

The cooperative transmission protocols used in the relay station are either Amplify and Forward (AAF) or Decode and Forward (DAF). These protocols describe how the received data is processed at the relay station before the data is sent to the destination. In this paper, we use Amplify and Forward protocol. This method is often used when the relay has only limited computing time/power available or the time delay, caused by the relay to decode and encode the message, has to be minimized. Of course when an analogue signal is transmitted, a DAF protocol cannot be used. The idea behind the AAF protocol is simple. The signal received by the relay was attenuated and needed to be amplified before it can be sent again. In doing so, the noise in the signal is amplified as well, which is the main downfall of this protocol. The incoming signal is amplified block wise. Assuming that the channel characteristic can be estimated perfectly, the gain for the amplification can be calculated as follows:

The power of the incoming signal (8) is given by,

$$E[|y_r^2|] = E[|hs,r|^2]\, E[|xs|^2] + E[|zs,r|^2] = |hs,r|^2 \xi + 2\sigma_{s,r}^2 ,$$

Volume 2 No. 7, July 2012 ISSN 2223-4985

International Journal of Information and Communication Technology Research

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Where(s) denotes the sender and(r) the relay. To send the data with the same power the sender did, the relay has to use a gain of

$$\beta = \sqrt{\xi / (\,|hs,r|^2\, \xi \,+\, 2\sigma_{s,r}^2)} \qquad (19)$$

This term has to be calculated for every block and therefore the channel characteristic of every single block needs to be estimated.

VI. SIMULATION RESULTS

a. Simulation Conditions

In this section, we investigate the performance of cooperative relaying in cognitive radio networks in terms of the average signal to noise ratio (SNR). The results were obtained using a computer simulation in MATLAB. We assume that primary network uses OFDM signal with PCP, and modulation with 64 QAM and N=512 subcarriers. 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.

b. Simulation results

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 and show also improvement using PCP and relay channel.

Figure 4 shows the cooperative relaying over fading channel. We conclude that the improvement using PCP and relay channel with cooperative scheme is better than the case of not using PCP.

Figure 5 illustrates the effects of different weighting for FRC. The best performance using FRC is achieved with a ratio 2:1, and also illustrates that performance change obviously with big change in weighting for FRC.

Figure 6 illustrates the effects of different weighting for FRC. The best performance using FRC is achieved with a ratio 2:1, and also illustrates that performance change slightly with small change in weighting for FRC.

Figure 7 shows the effect on the performance for the different combining types using an AAF protocol. It is seen that the Maximum Ratio Combining (MRC) is much better than the one using FRC due to diversity gain.

Figures 8 and 9 demonstrate the effect of the position of the 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 .

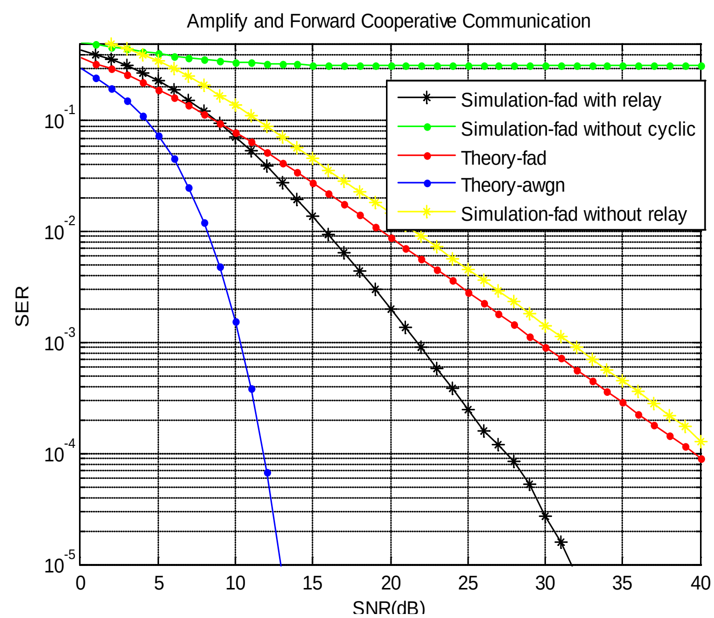

Fig.3 Comparisons of SEP for cooperative relaying with or without relay channel.

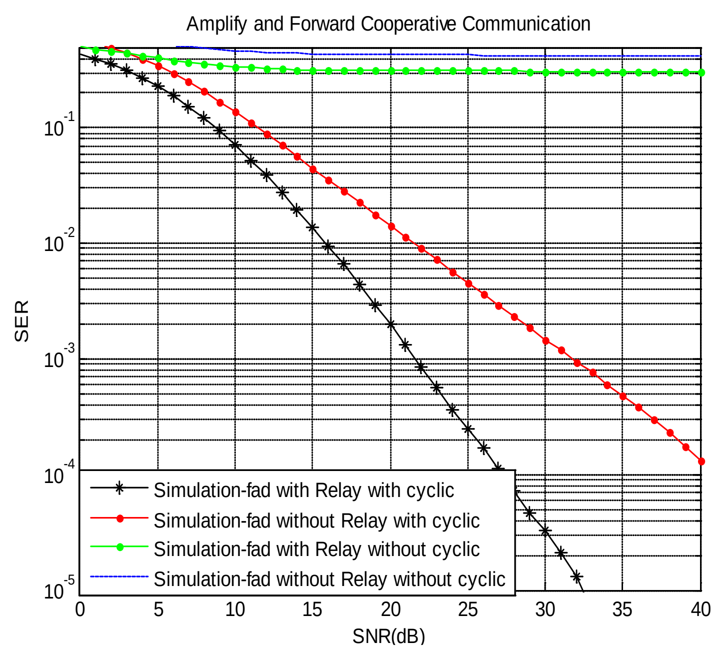

Fig.4: Comparisons of SEP for Cooperative with or without Relay and with and without PCP.

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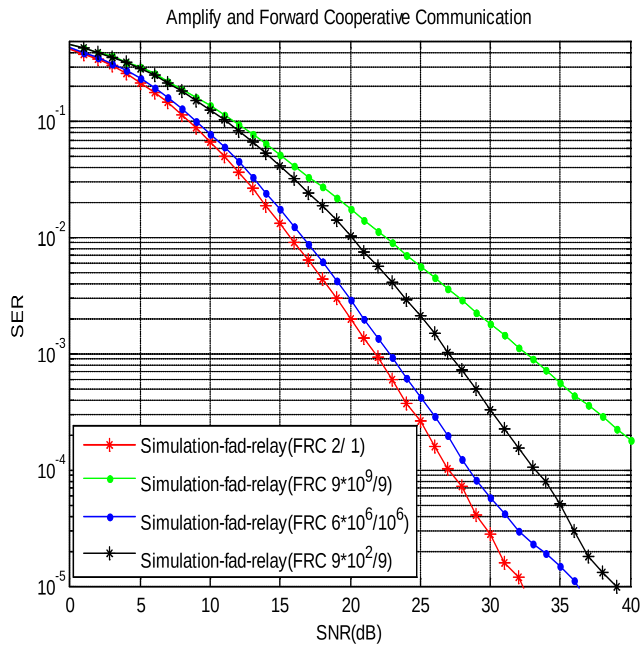

Fig.5: Comparisons of SEP for Different Ratios of FRC other with Big Change in Weight of FRC.

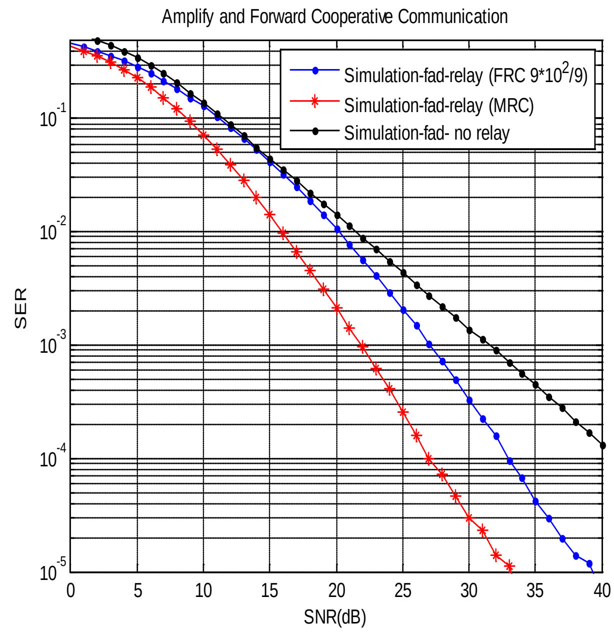

Fig.7 SER vs. SNR(dB) under using Different Combining Types.

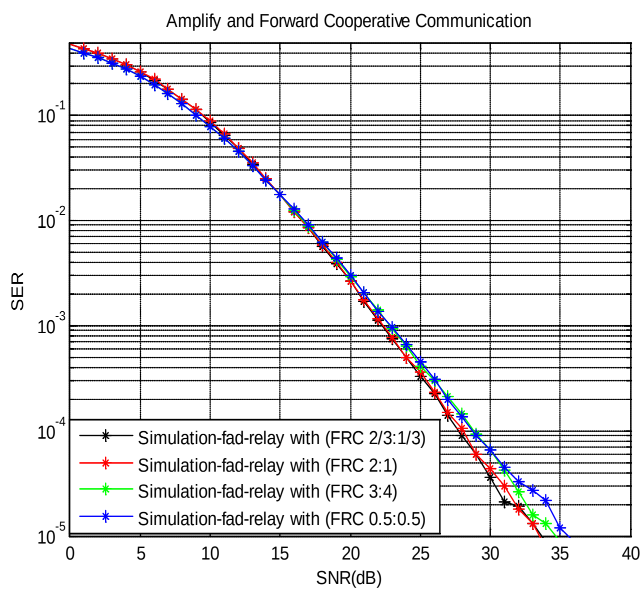

Fig.6: Comparisons of SEP for Different Ratios of FRC with Small Change in Weight of FRC.

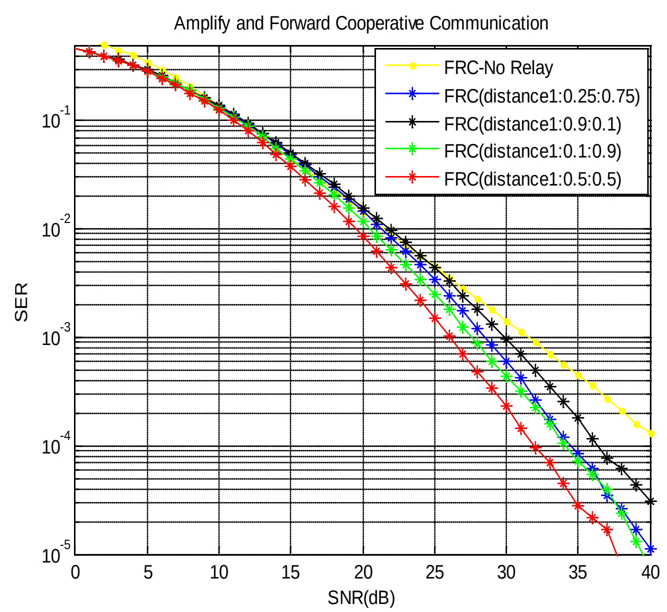

Fig.8: Comparisons of SEP for FRC when the Relay is located between Sender and Destination.

Volume 2 No. 7, July 2012 ISSN 2223-4985

International Journal of Information and Communication Technology Research

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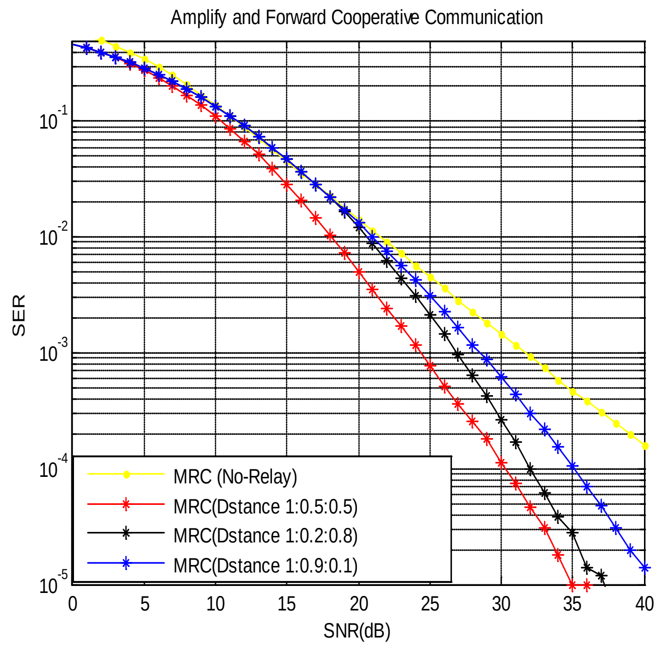

Fig.9: Comparisons of SEP for MRC when the Relay is located between Sender and Destination.

VII. CONCLUSIONS

In this paper, we have discussed the concept of cooperation diversity in cognitive relay networks in PCP-OFDM system which is not clarified until now. It is seen that SEP with relay channel is better than SEP without relay channel. Moreover, it is shown that the 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. Moreover, the analysis for using OFDM signal with and without PCP and relay channel is made.

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