Interference-free Overlay Cognitive Radio Network based on Cooperative Space Time Coding

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***Abstract*—In this paper, we propose a two-phase overlay spectrum sharing protocol based on cooperative decode-and-forward relaying which allows the secondary system to gain spectrum access along with the primary system. In the proposed scheme, the secondary system operates simultaneously in the same frequency band as the primary system, which supports the relaying functionality. We show that by using a space time block code (STBC) design in two time phases in the secondary system, the subsequent interference from the secondary system to the primary system and vice versa can be completely removed. Consequently, it is possible to achieve spectrum access for secondary system without compromising on the performance of the primary system. Performance of the primary system and the secondary system is analyzed in terms of outage probability, and simulation results are shown to validate the efficiency of the proposed scheme.**

***Index Terms*—Spectrum sharing, cooperative decode-and-forward, STBC, outage probability.**

I. INTRODUCTION

With an exponential increase in the number of wireless applications in recent years, there is an insatiable demand for more radio spectrum. Perpetuating the problem further, most of the prime spectrum below 3GHz has already been allocated under the licensed band and is no longer available for new wireless systems [1]. In order to solve this spectrum scarcity problem, solutions in the form of cognitive radios [2] have been proposed. One of the key features of a cognitive radio is its ability to sense its ambient communication environment and consequently adapt its parameters to provide the best allowable quality of service to the unlicensed users with minimal interference to the licensed users [3].

In a cognitive radio framework, a secondary system (unlicensed user), comprising of secondary transmitter (ST) and secondary receiver (SR), is allowed to co-exist in the same frequency band as a primary system (licensed user), comprising of primary transmitter (PT) and primary receiver (PR). Based on the well known cognitive radio interweave technique [3], opportunistic transmissions by the secondary system are allowed whenever the signals from primary system are determined to be absent.

A variant of the above model, known as overlay cognitive radio network, has been proposed in [3]-[6]. In this case, the two systems operate on different levels of priority. Higher priority is given to the primary system and the secondary system operates on a lower priority with a constraint that its operation does not affect the performance of primary system. Although overlay techniques are one of the most promising techniques for cognitive radio network, these approaches are typically interference limited, i.e. the performance at PR and SR is limited by the interference from ST and PT respectively [5]-[8]. In [6], the overlay cognitive radio model was also extended to include multiple antennas (MIMO) at primary and secondary systems. An information theoretic approach is used to derive an achievable region for the Gaussian MIMO cognitive channel and an outer bound on the capacity region was obtained by assuming that ST has *a priori* knowledge of PT's message as well as full transmit channel state information (CSI).

In this paper, unlike [6]-[8], we propose a practical spectrum sharing scheme which exploits multiple antennas at ST with cooperative space time coding to effectively cancel out the interference from the secondary system to the primary system, and vice versa. Moreover, in the proposed scheme, all the message sharing is causal, no "genie added" information is required, and there is no requirement for transmit CSI.

Cooperation techniques to enhance the performance of a communication system in terms of diversity, coverage extension, etc, have been studied extensively in literature [9]. Control signalling for cooperation has also been proposed in [10]-[11]. Consequently in our proposed scheme, we presume that the primary system is an advanced system with relaying functionality like IEEE 802.16j [12] and it employs a practical handshake mechanism for cooperation that is similar to [11].

Consider a scenario in which the target rate between PT and PR drops below a particular threshold. PT will seek cooperation from neighboring terminals to enhance its transmission performance by broadcasting a cooperative right-to-send (CRTS) message which also indicates the target rate, R_{pt} for the primary system. PR responds to CRTS by transmitting a cooperative clear-to-send (CCTS) message. Upon overhearing CRTS and CCTS, ST estimates the channel gains of PT-ST and PR-ST links, and decides whether the R_{pt} requirement for the primary system can be met if it serves as a decode-and-forward (DF) relay for the primary system. If yes, ST responds

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by sending a cooperative clear to help (CCTH) message to PT and PR, and the primary system correspondingly switches to a two-phase DF relaying transmission mode, with ST as the relay terminal. However, if ST is not able to assist the primary system to achieve R_{pt}, it will simply remain silent and the primary system hence retains its original direct transmission from PT to PR.

Once ST is confirmed as a relay, secondary spectrum access is achieved by adopting the following two-phase transmission protocol. The system models for the 1st and 2nd phase are shown in Fig. 1 and Fig. 2 respectively. We denote the two antennas at ST as ST(1) and ST(2). In the 1st phase, the primary signal transmitted by PT to PR is also overheard by ST(1) and SR. Simultaneously, in the same phase, ST(2) transmits the secondary signal which is received by SR as well as PR. ST(1) attempts to decode and regenerate the primary signal it received in the first phase. If the decoding is successful[1], ST(1) and ST(2) transmits the complex conjugate of the secondary signal and negative complex conjugate of the primary signal in the 2nd transmission phase respectively. At PR, the combined received signals after the two-phase transmission are multiplied by an orthogonalization vector to cancel out the interference from secondary signal and retrieve the primary signal. The secondary signal is retrieved at SR in the same way.

The main advantages of the proposed scheme are summarized as follows.

- The proposed scheme is not interference-limited unlike the superposition coding techniques in [4], [5]. As a result, the performance of primary and secondary system is not limited by the interference from ST and PT respectively.
- The secondary user is able to achieve spectrum access as long as it is willing to increase its transmit power such that R_{pt} is met.
- The rate of primary as well as secondary transmission can be increased by just increasing the transmission power at ST. Consequently, there is no trade-off between the achievable performance of primary and secondary systems which is inherent in conventional overlay cognitive radio schemes.
- The proposed scheme also ensures that the performance of the secondary system can be maintained regardless of the availability of spectrum holes, thus making this scheme extremely attractive in dense urban areas where spectrum holes are hard to obtain.

The existence of the secondary system is transparent to the primary system as it is the onus of ST to "disguise" itself as a primary relay in exchange for the chance to access the spectrum. As a basic requirement for the proposed scheme, we assume that the primary system supports STBC [13] and the necessary CSI needed at the receiving terminals can be obtained through standard pilot symbol-aided channel estimation methods [14]. We analyze the proposed scheme by deriving the outage probability for the primary and secondary systems, and validate its efficiency through the simulation results. Throughout this paper, $\mathrm{E}[\cdot]$ denotes the expectation and a complex Gaussian random variable z with mean μ and variance σ^2 is denoted as $z \sim \mathcal{CN}(\mu, \sigma^2)$. An exponential distributed random variable x with mean $\frac{1}{\lambda}$ is denoted as $x \sim \varepsilon(\lambda)$. We denote the transpose and conjugate transpose of matrix $\boldsymbol{A}$ as $\boldsymbol{A}^T$ and $\boldsymbol{A}^H$, respectively.

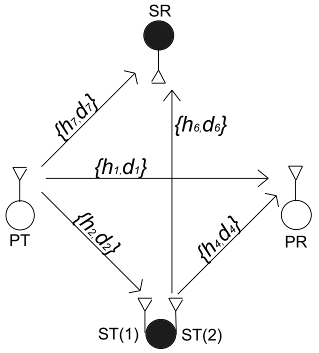

Fig. 1. Proposed scheme: Transmission phase 1.

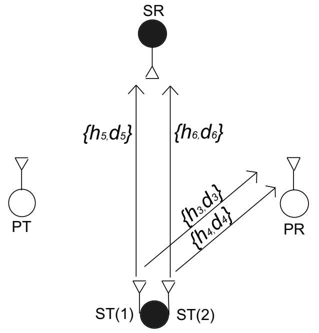

Fig. 2. Proposed scheme: Transmission phase 2.

II. System Model

The system model for the proposed scheme is shown in Fig. 1 and Fig. 2 for transmission phase 1 and phase 2 respectively. The channel between all the links i.e. PT-PR, PT-ST(1), ST(1)-PR, ST(2)-PR, ST(1)-SR, ST(2)-SR and PT-SR are modeled as Rayleigh flat fading with channel coefficients h_1, h_2, h_3, h_4, h_5, h_6 and h_7 respectively. The channel coefficients are given by $h_i \sim \mathcal{CN}(0, d_i^{-\nu})$, $i = 1,2,3,4,5,6,7$ where ν is the path loss component and d_i is the normalized distance between the respective transmitters and receivers. The normalization is done with respect to the link between PT and PR, i.e. $d_1 = 1$. Thus all the links can be characterized by the set of parameters $\{h_i, d_i\}$ as shown in the figures. The instantaneous channel gain of each link is denoted by $\gamma_i = |h_i|^2$. The primary and secondary signals are denoted by x_p and x_s respectively, have zero mean and $\mathrm{E}[x_p^* x_p] = 1$, $\mathrm{E}[x_s^* x_s] = 1$. P_p and P_s denote the transmit power at PT and ST respectively. In the following sections, we describe the communication protocols

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[1] If the decoding at ST(1) is unsuccessful, an outage is declared for the primary as well as secondary system.

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for the above scheme and obtain the outage probability for the primary as well as the secondary system.

III. OUTAGE PERFORMANCE OF PRIMARY SYSTEM

A. Transmission Phase 1

In the 1st transmission phase shown in Fig. 1, the primary signal x_p is transmitted by PT and secondary signal x_s is transmitted by ST(2) simultaneously. Denoting the signal received by PR, SR and ST(1) as $y_{pr}^{(1)}$, $y_{sr}^{(1)}$ and y_{st} respectively, we have[2]

$$y_{pr}^{(1)} = \sqrt{P_p} h_1 x_p + \sqrt{P_s} h_4 x_s + n_{11} \tag{1}$$

$$y_{sr}^{(1)} = \sqrt{P_p} h_7 x_p + \sqrt{P_s} h_6 x_s + n_{12} \tag{2}$$

$$y_{st} = \sqrt{P_p} h_2 x_p + n_{13}. \tag{3}$$

Here $n_{1j} \sim \mathcal{CN}(0, \sigma^2)$, $j = 1, 2, 3$ is the additive white Gaussian noise (AWGN) at the respective receivers for the 1st transmission phase. The achievable rate between PT and ST(1) is thus given by $R_1 = \frac{1}{2}\log_2\left(1 + \frac{P_p \gamma_2}{\sigma^2}\right)$, where the factor $\frac{1}{2}$ accounts for the fact that the overall transmission is being split into two phases.

B. Transmission Phase 2

After reception of x_p in the 1st transmission phase, ST(1) attempts to decode x_p. If the decoding is successful, ST(1) regenerates x_p. Let $z_s^{(21)}$ and $z_s^{(22)}$ be the transmitted signals from ST(1) and ST(2) during the 2nd phase respectively. The transmitted signal in the 2nd phase from ST can then be written as

$$\boldsymbol{z}_s = \sqrt{\frac{P_s}{2}} \boldsymbol{x}_{st} \tag{4}$$

where $\boldsymbol{z}_s = \begin{bmatrix} z_s^{(21)} & z_s^{(22)} \end{bmatrix}^T$, $\boldsymbol{x}_{st} = \begin{bmatrix} x_s^* & -x_p^* \end{bmatrix}^T$. The signal received at the primary receiver in the 2nd phase is thus,

$$y_{pr}^{(2)} = \boldsymbol{h}_s \boldsymbol{z}_s + n_{21} \tag{5}$$

where $\boldsymbol{h}_s = \begin{bmatrix} h_3 & h_4 \end{bmatrix}$ and $n_{21} \sim \mathcal{CN}(0, \sigma^2)$ is the AWGN. Taking the complex conjugate of the above signal we obtain,

$$y_{pr}^{(2)*} = (\boldsymbol{h}_s \boldsymbol{z}_s)^* + n_{21}^* = \sqrt{\frac{P_s}{2}} h_3^* x_s - \sqrt{\frac{P_s}{2}} h_4^* x_p + n_{21}^*. \tag{6}$$

Thus the signal at PR after the two-phase transmission can be written as

$$\boldsymbol{y} = \boldsymbol{H}_p \boldsymbol{x} + \boldsymbol{n} \tag{7}$$

where $\boldsymbol{y} = \begin{bmatrix} y_{pr}^{(1)} & y_{pr}^{(2)*} \end{bmatrix}^T$, $\boldsymbol{x} = \begin{bmatrix} x_p & x_s \end{bmatrix}^T$, $\boldsymbol{n} = \begin{bmatrix} n_{11} & n_{21}^* \end{bmatrix}^T$ and

$$\boldsymbol{H}_p = \begin{bmatrix} \sqrt{P_p} h_1 & \sqrt{P_s} h_4 \\ -\sqrt{P_s/2} h_4^* & \sqrt{P_s/2} h_3^* \end{bmatrix}. \tag{8}$$

Multiplying $\boldsymbol{y}$ by the orthogonalization vector $\boldsymbol{w}_p = \begin{bmatrix} \sqrt{P_s/2} h_3^* & -\sqrt{P_s} h_4 \end{bmatrix}$, we obtain,

$$\begin{aligned} \boldsymbol{w}_p \boldsymbol{y} = &\left(\sqrt{\frac{P_s}{2}} \sqrt{P_p} h_3^* h_1 + \frac{P_s |h_4|^2}{\sqrt{2}} \right) x_p \\ &+ \sqrt{\frac{P_s}{2}} h_3^* n_{11} - \sqrt{P_s} h_4 n_{21}^*. \end{aligned} \tag{9}$$

It is clear that the secondary signal x_s has been completely removed. Thus the signal received at PR experiences no interference from the secondary transmission. The achievable rate between PT and PR, conditioned on the successful decoding at ST, can be written as

$$R_2 = \frac{1}{2} \log_2 (1 + \mathrm{SNR}^{\mathrm{PRI}}) \tag{10}$$

where $\mathrm{SNR}^{\mathrm{PRI}}$ is the instantaneous Signal to Noise Ratio (SNR) at PR after the two phase transmission which is given by

$$\begin{aligned} \mathrm{SNR}^{\mathrm{PRI}} &= \frac{\left| h_3^* \sqrt{P_s/2} \sqrt{P_p} h_1 + P_s |h_4|^2 / \sqrt{2} \right|^2}{\mathrm{E}\left[\left| \sqrt{P_s/2} h_3^* n_{11} - \sqrt{P_s} h_4 n_{21}^* \right|^2 \right]} \\ &= \frac{P_p \gamma_3 \gamma_1 + P_s \gamma_4^2 + 2\sqrt{P_s P_p} Re(h_3^* h_1) \gamma_4}{(\gamma_3 + 2\gamma_4)\sigma^2}. \end{aligned} \tag{11}$$

The achievable rate between PT and PR is thus $R_p = \min(R_1, R_2)$. The $\min(\cdot)$ operator implies that if ST(1) is not able to decode x_p, an outage is declared for the primary system. The outage probability of the primary transmission with a target rate of R_{pt} is thus given as

$$\begin{aligned} P_{out}^p &= \Pr\{R_p < R_{pt}\} \\ &= 1 - \Pr\{R_1 > R_{pt}\} \Pr\{R_2 > R_{pt}\}. \end{aligned} \tag{12}$$

Since $\gamma_2 \sim \varepsilon(d_2^\nu)$,

$$\Pr\{R_1 > R_{pt}\} = \Pr\left\{ \gamma_2 > \frac{\sigma^2 \rho_1}{P_p} \right\} = \exp\left(- d_2^\nu \frac{\sigma^2 \rho_1}{P_p} \right) \tag{13}$$

where $\rho_1 = 2^{2R_{pt}} - 1$.

$$\begin{aligned} \Pr\{R_2 > R_{pt}\} &= \Pr\{\mathrm{SNR}^{\mathrm{PRI}} > \rho_1\} \\ &= \int\int\int \mathrm{SNR}^{\mathrm{PRI}} p_{\boldsymbol{\gamma_1}}(\gamma_1) p_{\boldsymbol{\gamma_3}}(\gamma_3) p_{\boldsymbol{\gamma_4}}(\gamma_4) \\ &\qquad d\gamma_1 d\gamma_3 d\gamma_4 \end{aligned} \tag{14}$$

where $p_{\boldsymbol{\gamma_1}}(\gamma_1)$, $p_{\boldsymbol{\gamma_3}}(\gamma_3)$ and $p_{\boldsymbol{\gamma_4}}(\gamma_4)$ are the probability density functions of γ_1, γ_3 and γ_4 respectively.

IV. DIRECT TRANSMISSION WITHOUT SECONDARY SYSTEM

Without the secondary system, the achievable rate between PT and PR is given by $R_d = \log_2(1 + \frac{P_p \gamma_1}{\sigma^2})$. Thus the outage probability of the primary signal transmission with target rate R_{pt} is

$$P_{out}^d = \Pr\{R_d < R_{pt}\} = 1 - \exp\left(\frac{-\sigma^2}{P_p} \rho_2 \right) \tag{15}$$

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[2] In the 1st phase, ST(1) also receives the signal x_s from ST(2) but since *a priori* knowledge of x_s is available at ST, it can be canceled out easily.

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where $\rho_2 = 2^{R_{pt}} - 1$. To satisfy the priority condition, we ensure that the outage probability under the proposed scheme is equal or less than the outage probability without spectrum sharing, i.e.

$$P_{out}^{p} \leq P_{out}^{d}. \tag{16}$$

V. OUTAGE PERFORMANCE OF SECONDARY SYSTEM

A. *Transmission Phase 1*

In transmission phase 1, the signal received at SR is given by (2).

B. *Transmission Phase 2*

Let $y_{sr}^{(2)}$ be the signal received at the secondary receiver in the 2nd phase such that

$$y_{sr}^{(2)} = \boldsymbol{g}\boldsymbol{z}_s + n_{22} \tag{17}$$

where $\boldsymbol{g} = \begin{bmatrix} h_5 & h_6 \end{bmatrix}$ and $n_{22} \sim \mathcal{CN}(0, \sigma^2)$ is the AWGN. Taking the complex conjugate of the above signal, we obtain

$$y_{sr}^{(2)*} = \sqrt{\frac{P_s}{2}} h_5^* x_s - \sqrt{\frac{P_s}{2}} h_6^* x_p + n_{22}^*. \tag{18}$$

Thus the signal at SR after the two-phase transmission can be written as

$$\boldsymbol{u} = \boldsymbol{G}_s \boldsymbol{x} + \boldsymbol{n}_s \tag{19}$$

where $\boldsymbol{u} = \begin{bmatrix} y_{sr}^{(1)} & y_{sr}^{(2)*} \end{bmatrix}^T$, $\boldsymbol{n}_s = \begin{bmatrix} n_{12} & n_{22}^* \end{bmatrix}^T$ and

$$\boldsymbol{G}_s = \begin{bmatrix} \sqrt{P_p} h_7 & \sqrt{P_s} h_6 \\ -h_6^* \sqrt{P_s/2} & h_5^* \sqrt{P_s/2} \end{bmatrix}. \tag{20}$$

Multiplying $\boldsymbol{u}$ with an orthogonalization vector $\boldsymbol{w}_s = \begin{bmatrix} \sqrt{P_s/2} h_6^* & \sqrt{P_p} h_7 \end{bmatrix}$, we obtain,

$$\begin{aligned} \boldsymbol{w}_s \boldsymbol{u} = & \left(\sqrt{\frac{P_s}{2}} \sqrt{P_p} h_5^* h_7 + \frac{P_s |h_6|^2}{\sqrt{2}} \right) x_s \\ & + \sqrt{\frac{P_s}{2}} h_6^* n_{12} - \sqrt{P_p} h_7 n_{22}^*. \end{aligned} \tag{21}$$

From (21), we can observe that the primary signal x_p has been completely removed. Therefore ST does not experience any interference from the primary transmission. Thus the achievable rate between ST and SR, assuming successful decoding of x_p at ST in the 1st transmission phase, is given as

$$R_3 = \frac{1}{2} \log_2 (1 + \mathrm{SNR}^{\mathrm{SEC}}) \tag{22}$$

where $\mathrm{SNR}^{\mathrm{SEC}}$ is the instantaneous SNR at SR after the two phase transmission and is given by

$$\begin{aligned} \mathrm{SNR}^{\mathrm{SEC}} = & \frac{\left| h_5^* \sqrt{P_s/2} \sqrt{P_p} h_7 + P_s |h_6|^2 / \sqrt{2} \right|^2}{\mathrm{E}\left[\left| \sqrt{P_s/2} h_6^* n_{12} - \sqrt{P_p} h_7 n_{22}^* \right|^2 \right]} \\ = & \frac{P_s \gamma_5 P_p \gamma_7 + {P_s}^2 \gamma_6^2 + 2\sqrt{P_s P_p} Re(h_5^* h_7) \gamma_6}{(P_s \gamma_6 + 2 P_p \gamma_7) \sigma^2}. \end{aligned} \tag{23}$$

The achievable rate at ST after the two-phase transmission will be $R_s = \min(R_1, R_3)$. The outage probability of the secondary transmission with target rate R_{st} is thus[3],

$$\begin{aligned} P_{out}^{s} &= \Pr\{R_s < R_{st}\} \\ &= 1 - \Pr\{R_1 > R_{pt}\} \Pr\{R_3 > R_{st}\}, \end{aligned} \tag{24}$$

where

$$\Pr\{R_1 > R_{pt}\} = \Pr\left\{ \gamma_2 > \frac{\sigma^2 \rho_1}{P_p} \right\} = \exp\left(- d_2^{\nu} \frac{\sigma^2 \rho_1}{P_p} \right), \tag{25}$$

$$\begin{aligned} \Pr\{R_3 > R_{st}\} &= \Pr\{\mathrm{SNR}^{\mathrm{SEC}} > \rho_3\} \\ &= \int\int\int \mathrm{SNR}^{\mathrm{SEC}} p_{\boldsymbol{\gamma_5}}(\gamma_5) p_{\boldsymbol{\gamma_6}}(\gamma_6) p_{\boldsymbol{\gamma_7}}(\gamma_7) \\ &\qquad d\gamma_5 d\gamma_6 d\gamma_7, \end{aligned} \tag{26}$$

$\rho_3 = 2^{2R_{st}} - 1$ and $p_{\boldsymbol{\gamma_5}}(\gamma_5)$, $p_{\boldsymbol{\gamma_6}}(\gamma_6)$, $p_{\boldsymbol{\gamma_7}}(\gamma_7)$ are the probability density functions of γ_5, γ_6 and γ_7 respectively.

VI. SIMULATION RESULTS AND DISCUSSION

In this section, we compare our proposed spectrum sharing scheme with direct transmission without the secondary system. We consider the outage probabilities of the primary and secondary systems under different conditions for the above scheme. The chosen target rates are $R_{pt} = R_{st} = 1$ and the path loss component is chosen as $\nu = 4$. For simplicity, we consider the scenario where PT, PR, ST and SR are collinear with SR in the middle of PT and ST as shown in Fig. 3, and the distance between the two antennas of ST is much smaller than the distance between the nodes. Thus, $d_1 = 1, 0 \leq d_2 \leq 1$, $d_3 \approx d_4 = 1 - d_2$, $d_5 \approx d_6 = d_2/2$ and $d_7 = d_2/2$. In Fig. 4, we show the outage probability for the proposed scheme for different d_2 and $\frac{P_s}{\sigma^2}$, keeping $\frac{P_p}{\sigma^2} = 10$dB. As observed from Fig. 4, for a fixed value of $\frac{P_p}{\sigma^2}$, when $\frac{P_s}{\sigma^2}$ increases, the outage probability of the primary system (P_{out}^{p}) decreases. For $d_2 \leq 0.75$, $\frac{P_s}{\sigma^2} = \{20, 30\}$dB, the requirement in (16) is satisfied and thus we can have secondary spectrum access along with the primary transmission.

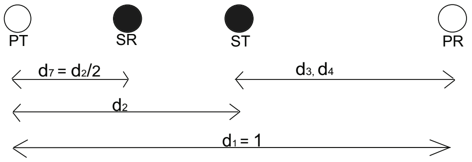

Fig. 3. Simulation scenario.

Another point to note is that P_{out}^{p} is dependent on d_2, which in turn determines the successful decoding of x_p in the 1st phase (Eq. 13). If ST is too far away from PT ($d_2 \geq 0.75$), then P_{out}^{p} increases, thus limiting the possibility of spectrum access for the secondary system. For $\frac{P_s}{\sigma^2} = 10$dB and $d_2 \leq 0.4$, P_{out}^{p} is limited by the link between ST and PR (d_3, d_4), which determines the successful decoding of x_p in the 2nd phase (Eq. 14).

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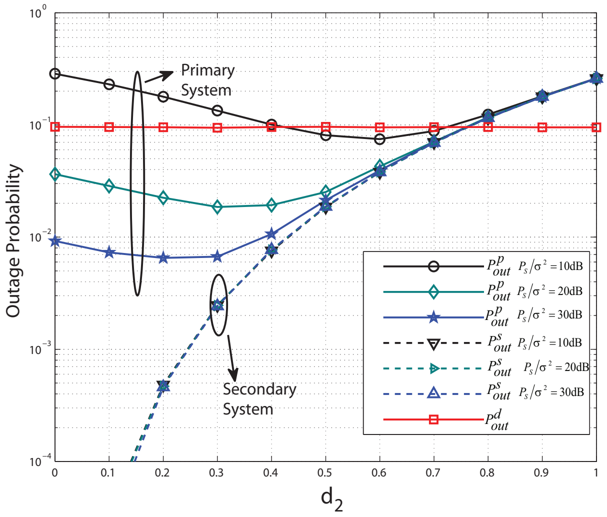

Fig. 4. Outage probability comparison for different d_2 and $\frac{P_p}{\sigma^2} = 10$dB.

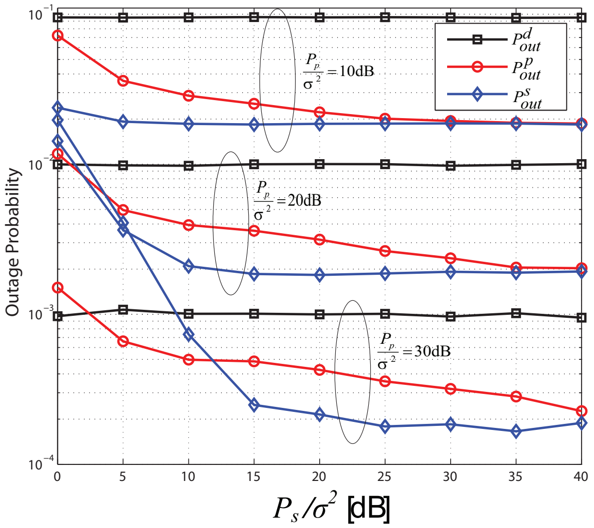

Fig. 5. Outage probability comparison for different $\frac{P_s}{\sigma^2}$ [dB].

For the secondary system, no significant variation is seen in P_{out}^{s} for $\frac{P_s}{\sigma^2} = \{10, 20, 30\}$dB and the performance is only limited by the successful decoding of x_p in the 1st phase (Eq. 25) which is dependent on d_2 as can be seen from Fig. 4.

Fig. 5 shows the outage probability performance of the proposed scheme for different $\frac{P_s}{\sigma^2}$ and $\frac{P_p}{\sigma^2}$ while $d_2 = 0.5$. It is quite obvious from Fig. 5 that the outage probability of primary as well as secondary transmission decreases with an increase in $\frac{P_s}{\sigma^2}$. This validates our conjecture that the secondary transmission does not interfere with the primary transmission as long as $\frac{P_s}{\sigma^2}$ is large enough. In fact the proposed scheme contributes to an improvement in the performance of the primary transmission. Another observation that can be made from Fig. 5 is that spectrum access for the secondary system is possible even for very high values of $\frac{P_p}{\sigma^2}$ as long as ST is willing to increase $\frac{P_s}{\sigma^2}$ so that the priority condition in (16) is met. The floor in the outage probability for high values of $\frac{P_s}{\sigma^2}$ is due to the limitation of DF relaying in the 1st phase (PT-ST link).

VII. CONCLUSIONS

We proposed an interference-free spectrum sharing scheme for an overlay cognitive radio network based on cooperative DF relaying, where the secondary transmitter employs an STBC design to transmit the primary signal along with its own secondary signal. We showed that by using the proposed scheme, the primary and secondary systems can transmit simultaneously in the same frequency. Furthermore, the likelihood of spectrum access for the secondary user increases with an increase in its transmit power.

We quantified the performance of primary and secondary systems in terms of outage probability and showed that the primary user can improve its QoS (target outage rate) by receiving assistance from ST while allowing spectrum access by the secondary system. Simulation results were also shown to validate the effectiveness of the proposed scheme.

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[3] Note that if ST is not able to decode x_p in the 1st phase, an outage is declared for the secondary system.

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