Antenna Selection in MIMO Cognitive AF Relay Networks with Mutual Interference and Limited Feedback

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***Abstract*—This paper studies antenna selection in amplify-and-forward (AF) multiple-input multiple-output (MIMO) cooperative cognitive radio system under mutual primary-secondary interference. Two power allocation methods are adopted at the secondary transmitters, assuming perfect and limited feedback from the primary receiver. For both methods, outage, error and ergodic capacity performance analysis is conducted, where simple, closed-form expressions are derived over Rayleigh fading channels. In addition, asymptotic analysis is performed to get insights about diversity gain and effects of key parameters including the primary receiver feedback and number of the antennas. Our analytical results, which are validated with simulations, show the effective impact of the proposed model on enhancing the overall system performance.**

***Index Terms*—Cognitive radio networks, Antenna Selection, Error Probability, Ergodic Capacity, Outage Probability**

I. INTRODUCTION

Recent reports have shown that the wireless spectrum is scarce and under-utilized [1]. As a consequence, cognitive radio (CR) has emerged as a paradigm to improve the utilization of the spectrum [1]. In CR systems, the spectrum is utilized through spectrum sharing, where the secondary users (SUs) share the spectrum with the primary users (PUs) opportunistically. Different schemes have been proposed for spectrum sharing, including interweave, underlay, and overlay schemes. In the underlay approach, which is arguably the most practical model, the SU is allowed to transmit concurrently with the PU using the PU's spectrum provided that the SU does not cause harmful interference to the PU receiver [2]. As a consequence, these power constraints may result in unstable transmission, lower reliability and limited coverage in secondary networks which drives demand for new transmission/reception techniques.

Cooperative relaying can be considered as one of the most important techniques that can help the SUs in terms of deployment, connectivity, and coverage, while minimizing the need for fixed infrastructures and reducing the total power consumption. In cooperative transmission, relay nodes can be considered as cooperative agents that receive the signal from the source and resend it to the destination after certain processing. The most common relaying schemes studied in literature are the amplify-and-forward (AF) relaying, and the decode-and-forward (DF) relaying. In the former, the relays simply transmit an amplified version of the received signal, while in the latter, the relays decode the received signal and then retransmit the detected signal. AF is widely used in the literature and is currently adopted in signal repeaters and other terrestrial communications due to its simplicity.

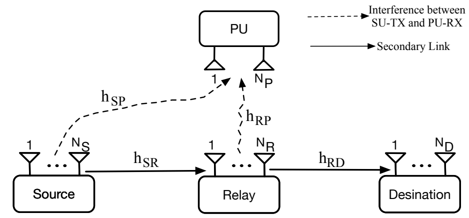

Fig. 1: Block diagram of cognitive spectrum sharing system with antenna selection and AF relaying.

Like cooperative relaying, antenna selection can be considered to be an important MIMO technique not only in 4G Long Term Evolution (LTE) systems [3] but also in the upcoming 5G systems due to its low hardware complexity. To leverage the advantages of cognitive relay networks, antenna selection has been considerably investigated in [4] - [6] and the references therein. In [4]- [5], generalized selection combining is studied on a DF cognitive radio system where outage and error probabilities are derived. Moreover, Yeoh et al. investigated transmit antenna selection (TAS) with different combining techniques in DF underlay systems in [6].

As can be seen from the aforementioned studies, the existing literature is limited with the analysis of antenna selection in DF cognitive relay systems. In addition, the majority of the works in MIMO cognitive relay systems considered only outage performance since the analysis of error probability and ergodic capacity is highly complicated. Motivated by the promising advantages of antenna selection and to fill-in the gap, in this work, we consider transmit-receive antenna selection in AF underlay cognitive relaying where simple expressions of outage, error probability and ergodic capacity are derived for Rayleigh fading channels.

The contributions of this paper are threefold; (1) assuming perfect channel state information (CSI) as well as limited CSI, closed form expressions of error and outage probability are derived based on an approximation of the signal to noise ratio (SNR) that is accurate for medium to high SNRs, (2) a simple ergodic capacity expression is derived, and (3) the asymptotic expressions of error and outage probabilities are obtained at high SNRs and fixed ratio of interference to transmit power.

II. SYSTEM MODEL

As shown in Fig. 1, the secondary network (SN) consists of a source (S) and destination (D) having N_S and N_D antennas

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communicating with the relay (R) having N_R antennas in the presence of a primary user (PU) having N_P antennas. The direct link between S to D is assumed to be unavailable e.g., due to heavy shadowing and all transmit-receive antenna channels between $S \rightarrow R$ and $R \rightarrow D$ hops are modeled as independent and identically distributed (i.i.d) Rayleigh fading. In the proposed structure, SN shares the same frequency spectrum with the PN as long as the interference between SN and PN is limited with a predetermined threshold $\mathcal{Q}_p$. The communication between S to D takes place in two time slots. In the first time slot, S transmits its signal x_s through the selected k-th $\left(1 \leq k \leq N_S\right)$ and j-th $\left(1 \leq j \leq N_R\right)$ antennas. The received signal at the R can be expressed as $y_r = \sqrt{P_S} h_{S,R}^{(k,j)} x_s + n_r$. In the second time slot, R amplifies the received signal with gain G and forwards to the D through the selected j-th and l-th $(1 \leq l \leq N_D)$ antennas. The received signal at the D can be written as

$$y_d = \sqrt{P_R} h_{R,D}^{(j,l)} G y_r + n_d, \tag{1}$$

where $h_{S,R}^{(k,j)} \sim \mathcal{CN}(0, \sigma_{S,R}^{2(k,j)})$ and $h_{R,D}^{(j,l)} \sim \mathcal{CN}(0, \sigma_{R,D}^{2(j,l)})$ are the selected channel coefficients between $S \rightarrow R$ and $R \rightarrow D$ paths and $n_r, n_d \sim \mathcal{CN}(0, N_0)$ represent the additive white Gaussian noise. As we assume all paths have perfect channel knowledge, the scaling factor G is given as $G = \sqrt{P_R / (P_S |h_{S,R}^{(k,j)}|^2 + N_0)}$.

To meet the interference power constraints of the PN, the transmit power at the S and R are set to $P_S = \min\{\mathcal{Q}_P / |h_{S,P}^{(k,p)}|^2, P_{\max}\}$, and $P_R = \min\{\mathcal{Q}_P / |h_{R,P}^{(j,p)}|^2, P_{\max}\}$ respectively [8], where $P_{\max}$ is the total transmit power available in the network, $h_{S,P}^{(k,p)} \sim \mathcal{CN}(0, \sigma_{S,P}^{2(k,p)})$ and $h_{R,P}^{(j,p)} \sim \mathcal{CN}(0, \sigma_{R,P}^{2(j,p)})$ are the channel coefficients between $S \rightarrow P$ and $R \rightarrow P$ paths. By substituting G in (1) and after a few manipulations, e2e SNR can be expressed as $\gamma_{e2e} = \frac{\gamma_{S,R}\gamma_{R,D}}{\gamma_{S,R}+\gamma_{R,D}+1}$. As best antenna pairs are selected based on the maximization of received SNR, $\gamma_{S,R}$ and $\gamma_{R,D}$ can be expressed as

$$\gamma_{S,R} = \min\left\{ \frac{\bar{\mathcal{Q}}_p}{\max\limits_{\substack{1 \leq k \leq N_S \\ 1 \leq p \leq N_P}} |h_{S,P}^{(k,p)}|^2}, \bar{P}_{\max} \right\} \max_{\substack{1 \leq k \leq N_S \\ 1 \leq j \leq N_R}} |h_{S,R}^{(k,j)}|^2,$$

$$\gamma_{R,D} = \min\left\{ \frac{\bar{\mathcal{Q}}_p}{\max\limits_{\substack{1 \leq j \leq N_R \\ 1 \leq p \leq N_P}} |h_{R,P}^{(j,p)}|^2}, \bar{P}_{\max} \right\} \max_{\substack{1 \leq j \leq N_R \\ 1 \leq l \leq N_D}} |h_{R,D}^{(j,l)}|^2, \tag{2}$$

where $\bar{\mathcal{Q}}_p = \mathcal{Q}_p / N_0$ and $\bar{P}_{\max} = P_{\max} / N_0$. As $\gamma_{S,R}$ and $\gamma_{R,D}$ are theoretically complicated, obtaining the statistics of the e2e SNR will not be possible. Thereby, we use the well-known upper bound [7] to simplify the analysis as

$$\gamma_{e2e} \leq \gamma_{up} = \min\left(\gamma_{S,R}, \gamma_{R,D}\right). \tag{3}$$

It is important to note that this approximation is accurate at medium and high SNR values [7].

III. Performance Analysis

In this section, we evaluate the performance of cognitive cooperative network in terms of outage probability, error probability and ergodic capacity.

A. Statistical Properties of the SNR

By using (3), the CDF of γ_{up} can be expressed as

$$\begin{aligned} F_{\gamma_{up}}(\gamma) &= \Pr\left[\min\left(\gamma_{S,R}, \gamma_{R,D}\right) \leq \gamma_{th} \right] \\ &= F_{\gamma_{S,R}}(\gamma) + F_{\gamma_{R,D}}(\gamma) - F_{\gamma_{S,R}}(\gamma) F_{\gamma_{R,D}}(\gamma). \end{aligned} \tag{4}$$

By using (4) and with the help of [8], $F_{\gamma_{S,R}}(\gamma)$ can be expressed as can be seen in (5) at the top of the next page.

With the help of order statistics [9], and by using binomial expansion, $F_{|h_{S,R}^{(k,j)}|^2}(x)$ and $f_{|h_{S,P}^{(k,p)}|^2}(x)$ can be expressed as $F_{|h_{S,R}^{(k,j)}|^2}(x) = \sum_{t=0}^{N_S N_R} \binom{N_S N_R}{t} (-1)^t e^{-tx}$ and $f_{|h_{S,P}^{(k,p)}|^2}(x) = N_S N_P \sum_{m=0}^{N_S N_P - 1} \binom{N_S N_P - 1}{m} (-1)^m e^{-(m+1)x}$. By substituting $F_{|h_{S,R}^{(k,j)}|^2}(x)$ and $f_{|h_{S,P}^{(k,p)}|^2}(x)$ into (5) and after a few manipulations, $F_{\gamma_{S,R}}(\gamma)$ can be expressed as given in (6). $F_{\gamma_{R,D}}(\gamma)$ can be obtained similarly by replacing subscript $\{S, R\}$ with $\{R, D\}$ and $\{N_S, N_R\}$ with $\{N_R, N_D\}$. Note that, $\eta_{S,R}$ is given as $\eta_{S,R} = \bar{\mathcal{Q}}_p \sigma_{S,R}^{2(k,j)} / \sigma_{S,P}^{2(k,p)}$ and $\eta_{R,D}$ can be expressed as $\eta_{R,D} = \bar{\mathcal{Q}}_p \sigma_{R,D}^{2(j,l)} / \sigma_{R,P}^{2(j,p)}$.

By substituting $F_{\gamma_{S,R}}(\gamma)$ and $F_{\gamma_{R,D}}(\gamma)$ into (4), $F_{\gamma_{up}}(\gamma)$ can be obtained. Hence, outage probability can be found as $P_{out} = F_{\gamma_{up}}(2^{2\mathcal{R}} - 1)$, where $\mathcal{R}$ denotes the data rate.

B. Average Error Probability

Average error probability is an important performance indicator in wireless communications and it can be derived by using the CDF of the e2e SNR as given below [9]

$$P_s(e) = \frac{a\sqrt{b}}{2\sqrt{\pi}} \int_0^\infty \gamma^{-1/2} e^{-b\gamma} F_{\gamma_{up}}(\gamma) d\gamma, \tag{7}$$

where a and b denotes modulation coefficients. i.e., $\{a = 1, b = 1\}$ for binary phase shift keying (BPSK) modulation. By substituting (6) into (7), average error probability can be obtained. To the best of our knowledge, the above integral can not be evaluated in closed-form. To solve this problem, we first simplify the CDF of γ_{up} as $F_{\gamma_{up}}(\gamma) \approx F_{\gamma_{S,R}}(\gamma) + F_{\gamma_{R,D}}(\gamma)$. To obtain a simple error probability expression, we assume S and R are not power-limited terminals i.e., $P_{\max} = \infty$ [8], then after changing the variables in the integral as $\psi_{S,R} = 1 + m + \frac{t\gamma}{\eta_{S,R}}$ and $\psi_{R,D} = 1 + m + \frac{t\gamma}{\eta_{R,D}}$, the error probability expression can be written in a more tractable form as can be seen in (8).

In (8), $\mathcal{A} = a/2\big(N_S N_P \sum_{m=0}^{N_S N_P - 1} \binom{N_S N_P - 1}{m} (-1)^m \frac{1}{1+m} + N_R N_P \sum_{m=0}^{N_R N_P - 1} \binom{N_R N_P - 1}{m} (-1)^m \frac{1}{1+m}\big)$. A closed form solution can be found by using [10, eqn. 3.383.4] which is given as (9). Note that, $\mathcal{W}_{\cdot,\cdot}(\cdot)$ denotes the Whittaker function [10, eqn. 9.222.1].

C. Ergodic Capacity

Ergodic capacity can be specified as the expectation of information rate in the wireless systems. Mathematically, it can be expressed as $\mathbb{C} = \frac{1}{2}\mathbb{E}\left[\log_2(1 + \gamma_{e2e})\right]$, where $\mathbb{E}[\cdot]$ denotes the expectation operation and $1/2$ shows that transmission occurs in two time slots. To the best of our knowledge, there is no closed form solution for $\mathbb{C}$. Nevertheless, a tight upper bound on the ergodic capacity can be obtained by using Jensen's inequality [9].

$$\begin{aligned} \mathbb{C} &= \frac{1}{2}\mathbb{E}\left[\log_2(1 + \gamma_{e2e})\right] \leq \frac{1}{2}\log_2(1 + \mathbb{E}[\gamma_{e2e}]) \\ &\approx \frac{1}{2}\log_2\left(\frac{\min\left(\frac{\bar{\mathcal{Q}}_p}{\sigma_{S,P}^{2(k,p)}}, \bar{P}_{\max}\right)\sigma_{S,R}^{2(k,j)} \times \min\left(\frac{\bar{\mathcal{Q}}_p}{\sigma_{R,P}^{2(j,p)}}, \bar{P}_{\max}\right)\sigma_{R,D}^{2(j,l)}}{\min\left(\frac{\bar{\mathcal{Q}}_p}{\sigma_{S,P}^{2(k,p)}}, \bar{P}_{\max}\right)\sigma_{S,R}^{2(k,j)} + \min\left(\frac{\bar{\mathcal{Q}}_p}{\sigma_{R,P}^{2(j,p)}}, \bar{P}_{\max}\right)\sigma_{R,D}^{2(j,l)} + 1} \right). \end{aligned} \tag{10}$$

As can be seen from (10), ergodic capacity depends only on the channel variances. Specifically, when $\sigma_{S,R}^2, \sigma_{R,D}^2 >$

$$F_{\gamma_{S,R}}(\gamma)=F_{|h_{S,P}^{(k,p)}|^2}\left(\frac{\bar{\mathcal{Q}}_p}{\bar{P}_{\max}}\right)F_{|h_{S,R}^{(k,j)}|^2}\left(\frac{\gamma}{\bar{P}_{\max}}\right)+\int_{\frac{\bar{\mathcal{Q}}_p}{\bar{P}_{\max}}}^{\infty}F_{|h_{S,R}^{(k,j)}|^2}\left(\frac{x\gamma}{\eta_{S,R}}\right)f_{|h_{S,P}^{(k,p)}|^2}(x)dx. \quad (5)$$

$$F_{\gamma_{S,R}}(\gamma)=\sum_{t=0}^{N_SN_R}\sum_{m=0}^{N_SN_P}\binom{N_SN_R}{t}\binom{N_SN_P}{m}(-1)^{t+m}e^{-\frac{m\bar{\mathcal{Q}}_P+t\gamma}{\bar{P}_{\max}}}+N_SN_P\sum_{t=0}^{N_SN_R}\sum_{m=0}^{N_SN_P-1}\binom{N_SN_R}{t}\binom{N_SN_P-1}{m}(-1)^{t+m}$$
$$\times\left(\frac{e^{-\frac{\bar{\mathcal{Q}}_P}{\bar{P}_{\max}}(1+m+\frac{t\gamma}{\eta_{S,R}})}}{1+m+\frac{t\gamma}{\eta_{S,R}}}\right). \quad (6)$$

$$P_s(e)=\mathcal{A}+$$
$$\frac{a\sqrt{b}}{2\sqrt{\pi}}\Bigg\{N_SN_P\sum_{t=1}^{N_SN_R}\sum_{m=0}^{N_SN_P-1}\binom{N_SN_R}{t}\binom{N_SN_P-1}{m}(-1)^{t+m}\left(\frac{\eta_{S,R}}{t}\right)^{\frac{1}{2}}e^{\frac{b\eta_{S,R}(m+1)}{t}}\int_{m+1}^{\infty}e^{\frac{-b\eta_{S,R}\psi_{S,R}}{t}}\psi_{S,R}^{-1}(\psi_{S,R}-m-1)^{-\frac{1}{2}}d\psi_{S,R}$$
$$+N_RN_P\sum_{t=1}^{N_RN_D}\sum_{m=0}^{N_RN_P-1}\binom{N_RN_D}{t}\binom{N_RN_P-1}{m}(-1)^{t+m}\left(\frac{\eta_{R,D}}{t}\right)^{\frac{1}{2}}e^{\frac{b\eta_{R,D}(m+1)}{t}}\int_{m+1}^{\infty}e^{\frac{-b\eta_{R,D}\psi_{R,D}}{t}}\psi_{R,D}^{-1}(\psi_{R,D}-m-1)^{-\frac{1}{2}}d\psi_{R,D}\Bigg\}. \quad (8)$$

$$P_s(e)=\mathcal{A}+\frac{a}{2}\Bigg\{N_S\sum_{t=1}^{N_SN_R}\sum_{m=0}^{N_S-1}\binom{N_SN_R}{t}\binom{N_S-1}{m}(-1)^{t+m}\left(\frac{b\eta_{S,R}}{t}\right)^{1/4}e^{\frac{b\eta_{S,R}(m+1)}{2t}}(m+1)^{-3/4}\mathcal{W}_{-\frac{1}{4},\frac{1}{4}}\left(\frac{b\eta_{S,R}(m+1)}{t}\right)$$
$$+N_R\sum_{t=1}^{N_RN_D}\sum_{m=0}^{N_R-1}\binom{N_RN_D}{t}\binom{N_R-1}{m}(-1)^{t+m}\left(\frac{b\eta_{R,D}}{t}\right)^{1/4}e^{\frac{b\eta_{R,D}(m+1)}{2t}}(m+1)^{-3/4}\mathcal{W}_{-\frac{1}{4},\frac{1}{4}}\left(\frac{b\eta_{R,D}(m+1)}{t}\right)\Bigg\}. \quad (9)$$

$\sigma_{S,P}^2,\sigma_{R,P}^2$, ergodic capacity increases. On the other hand, when $\sigma_{S,R}^2,\sigma_{R,D}^2<\sigma_{S,P}^2,\sigma_{R,P}^2$, ergodic capacity degrades.

D. Asymptotic Analysis

At high SNR, $F_{\gamma_{up}}^{\infty}(\gamma)$ can be written as $F_{\gamma_{up}}^{\infty}(\gamma)=F_{\gamma_{S,R}}(\gamma)+F_{\gamma_{R,D}}(\gamma)$. By substituting $\exp(-x/a)^{x\to 0}\approx 1-x/a$ in (5), with the help of [10, eqn. 3.351.2] and after few manipulations, $F_{\gamma_{up}}^{\infty}(\gamma)$ can be expressed as

$$F_{\gamma_{up}}^{\infty}(\gamma)=\mathcal{Z}\left(\frac{\gamma}{\bar{\gamma}}\right)^{\mathcal{G}_d}+\mathcal{O}(\bar{\gamma}^{-\mathcal{G}_d}). \quad (11)$$

In (11), we assume $\bar{\gamma}=\kappa_1\bar{\mathcal{Q}}_p=\kappa_2\bar{P}_{\max}$, where κ_1 and κ_2 are positive constants, $\bar{\gamma}$ stands for the average SNR and $\mathcal{Z}$ is

$$\mathcal{Z}=\begin{cases}\Delta_{S,R}, & N_SN_R<N_RN_D\\ \Delta_{S,R}+\Delta_{R,D}, & N_SN_R=N_RN_D.\\ \Delta_{R,D}, & N_SN_R>N_RN_D\end{cases} \quad (12)$$

In the above, $\Delta_{S,R}$ can be expressed as

$$\Delta_{S,R}=\kappa_2^{N_SN_R}\sum_{m=0}^{N_SN_P}\binom{N_SN_P}{m}(-1)^m e^{-m\frac{\kappa_2}{\kappa_1}}$$
$$+\frac{N_SN_P\sigma_{S,R}^{2(k,j)}}{\kappa_1\sigma_{S,P}^{2(k)}}\sum_{m=0}^{N_SN_P-1}\binom{N_SN_P-1}{m}(-1)^m$$
$$\times\left(\frac{1}{1+m}\right)^{N_SN_R+1}\Gamma\left(N_SN_R+1,(m+1)\frac{\kappa_2}{\kappa_1}\right), \quad (13)$$

where $\Gamma(\cdot,\cdot)$ is the lower incomplete Gamma function [10, eqn. 8.350.2]. $\Delta_{R,D}$ can be obtained similarly by replacing subscript $\{S,R\}$ with $\{R,D\}$ and $\{N_S,N_R\}$ with $\{N_R,N_D\}$. At high SNR, P_{out}^{∞} can be expressed as $P_{out}^{\infty}=F_{\gamma_{up}}^{\infty}(\gamma_{th})=(\mathcal{G}_a\gamma_{th})^{\mathcal{G}_d}$, therefore diversity gain can be obtained as $\mathcal{G}_d=\min(N_SN_R,N_RN_D)$ and array gain becomes $\mathcal{G}_a=(\mathcal{Z}\gamma_{th})^{-1/\mathcal{G}_d}$. By substituting (11) in (7), asymptotic error probability can be obtained as

$$P_s^{\infty}(e)=\frac{a\mathcal{Z}\Gamma(\mathcal{G}_d+1/2)}{2\sqrt{\pi}(b\bar{\gamma})^{\mathcal{G}_d}}. \quad (14)$$

This result shows that the diversity gain of the SN is independent from the number of PU's antennas.

E. Impact of Limited Feedback

In CR networks, the primary receiver is generally assumed to know the interference channel gain (or its estimate). Therefore, it can calculate the mean value (MV) of this gain. Then, the estimated arithmetic MV (a constant) is fed back to the secondary source. Consequently, the adoption of the MV-power allocation can considerably reduce the feedback burden when compared to the scheme which requires instantaneous CSI feedback on every symbol unit or block of symbols [11]. In the presence of limited feedback, the transmit powers at the S and R are set to $\hat{P}_S=\min\{\bar{\mathcal{Q}}_P/\sigma_{S,P}^{2(k,p)},\bar{P}_{\max}\}$ and $\hat{P}_R=\min\{\bar{\mathcal{Q}}_P/\sigma_{R,P}^{2(j,p)},\bar{P}_{\max}\}$, respectively. By substituting $\hat{P}_S$ and $\hat{P}_R$ in (4) and with the help of binomial expansion $\hat{F}_{\gamma_{up}}(\gamma)$ can be obtained as

$$\hat{F}_{\gamma_{up}}(\gamma)$$
$$=\sum_{t=0}^{N_SN_R}\binom{N_SN_R}{t}(-1)^t e^{-t\gamma/\left\{\min\{\bar{\mathcal{Q}}_P/\{\sigma_{S,P}^{2(k,p)},\bar{P}_{\max}\}\sigma_{S,R}^{2(k,j)}\right\}}$$
$$+\sum_{t=0}^{N_RN_D}\binom{N_RN_D}{t}(-1)^t e^{-t\gamma/\left\{\min\{\bar{\mathcal{Q}}_P/\{\sigma_{R,P}^{2(j,p)},\bar{P}_{\max}\}\sigma_{R,D}^{2(j,l)}\right\}}. \quad (15)$$

By substituting (15) into (5), with the help of [10, eqn. 3.351.3], the average error probability in the presence of

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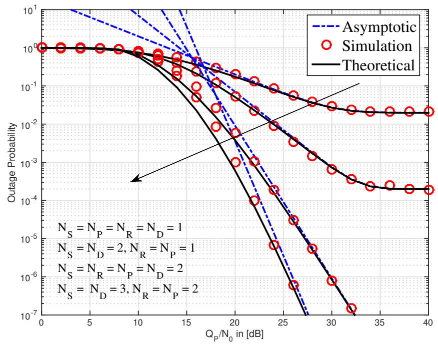

Fig. 2: Outage probability vs $\bar{\mathcal{Q}}_p$ for different number of antennas.

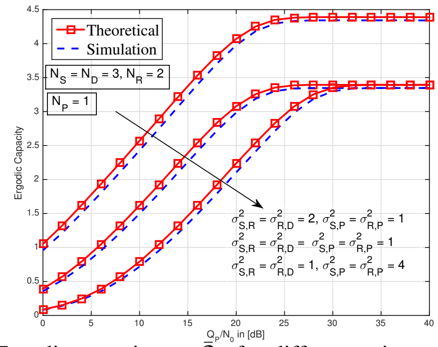

Fig. 3: Ergodic capacity vs $\bar{\mathcal{Q}}_p$ for different primary-secondary channel variances.

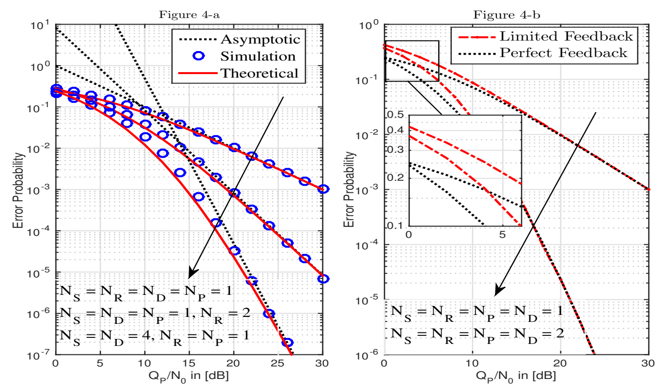

Fig. 4: Error probability performance for perfect and limited feedback.

limited feedback can be obtained as

$$\hat{P}_s(e) = \frac{a\sqrt{b}}{2}\Bigg\{\sum_{t=0}^{N_S N_R}\binom{N_S N_R}{t}(-1)^t\Bigg(b+\frac{t\gamma}{\min\Big\{\frac{\bar{\mathcal{Q}}_P}{\sigma^{2(k,p)}_{S,P}},\bar{P}_{\max}\Big\}\sigma^{2(k,j)}_{S,R}}\Bigg)^{-\frac{1}{2}} + \sum_{t=0}^{N_R N_D}\binom{N_R N_D}{t}(-1)^t\Bigg(b+\frac{t\gamma}{\min\Big\{\frac{\bar{\mathcal{Q}}_P}{\sigma^{2(j,p)}_{R,P}},\bar{P}_{\max}\Big\}\sigma^{2(j,l)}_{R,D}}\Bigg)^{-\frac{1}{2}}\Bigg\}. \quad (16)$$

IV. Numerical Results

In this section, Monte-Carlo simulations are carried out to demonstrate the accuracy of the theoretical derivations. In the simulations, high SNRs are used to verify the analytical findings and to demonstrate the impacts of mutual interference and total transmit power available in the network.

Fig. 2 depicts the outage probability of the proposed scenario for different number of antennas and when $\sigma^2_{S,R} = \sigma^2_{R,D} = \sigma^2_{S,P} = \sigma^2_{R,P} = 1$. We assume the rate is $\mathcal{R} = 1.75$ bits/channel and $P_{\max}$ is set to 30 dB. As can be seen, theoretical curves match perfectly with the simulations and as the total number of antennas increase, the outage performance improves substantially. An outage floor is also noticed as $\mathcal{Q}_p$ reaches to the maximum power i.e. 30 dB.

Fig. 3 shows the impact of different channel variances on the performance of ergodic capacity. The figure shows that when $\sigma^2_{S,R}, \sigma^2_{R,D} > \sigma^2_{S,P}, \sigma^2_{R,P}$, ergodic capacity increases, however ergodic capacity degrades when $\sigma^2_{S,R}, \sigma^2_{R,D} < \sigma^2_{S,P}, \sigma^2_{R,P}$ as expected from (15). Moreover, the theoretical curves give a tight upper bound to the simulations.

In Fig. 4, error probability is depicted for BPSK signalling. In this figure, we compare perfect feedback scenario with the limited feedback one for $\sigma^2_{S,R} = \sigma^2_{R,D} = 2, \sigma^2_{S,P} = \sigma^2_{R,P} = 4$. Different from the previous figures, there is no error floor in Fig. 4 since the SUs are assumed to be not power-limited terminals i.e., $P_{\max} = \infty$. In addition, Fig. 4-b shows that there is 2 dB difference between perfect feedback case with the limited one at 0 to 10 dB. However, at medium to high SNRs, limited feedback curves match perfectly with the perfect feedback.

V. Conclusions

In this work, we investigated the outage, error and capacity performance of transmit-receive antenna selection of a cooperative AF spectrum sharing system under primary-secondary interference. By using these simple expressions, the system designer can get a quick idea about the performance without the need for simulations or prototyping.

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