Cognitive Decode-and-Forward MIMO-RF/FSO Cooperative Relay Networks

Neeraj Varshney, *Student Member, IEEE*, and Aditya K. Jagannatham, *Member, IEEE*

***Abstract*— This letter considers decode-and-forward (DF) based mixed multiple-input multiple-output radio frequency/free space optical (MIMO-RF/FSO) cooperative relay systems for underlay cognitive radio scenarios. Subsequently, a performance analysis is presented and closed-form expressions are derived for the per-frame outage probability considering both orthogonal space-time block coded transmission and transmit antenna selection at the secondary user. The analysis assumes the RF links between the secondary user-relay and secondary user-primary user to be Nakagami-*m* fading in nature, while the FSO link between the relay and destination eNodeB is assumed to be affected by optical channel impairments, such as path loss, atmospheric turbulence, and pointing errors, thus incorporating the key characteristics of both the links. Further, the impact of primary user node mobility on the performance of the cognitive radio network is also analyzed. Results demonstrate an improved outage performance of the cognitive MIMO-RF/FSO DF cooperative relay system with multiple antennas in comparison to amplify-and-forward based single-input single-output systems proposed in the existing literature.**

***Index Terms*— Cognitive network, cooperative, decode-and-forward, MIMO, OSTBC, RF/FSO, transmit antenna selection.**

I. Introduction

MIXED radio frequency/free space optical (RF/FSO) relaying systems have recently attracted a significant research interest due to their ability to connect a large number of RF devices simultaneously to the last-mile access network using a single broadband FSO link. The low cost and rapid deployability of FSO systems together with their ability to support higher data-rates and use license free spectrum for operation make them ideally suited for such an architecture. More details about such systems and their several advantages can be found in [1] and the references therein. On the other hand, RF spectrum scarcity has become an important concern in cellular networks, due to the ever increasing number of users and data hungry applications. To alleviate this problem, the cognitive radio paradigm has been proposed for next generation wireless networks, wherein secondary users are allowed to opportunistically access spectrum that is allocated to the licensed primary users [2]. Thus, cognitive radio can be employed in conjunction with RF/FSO cooperative networks towards enhancing the overall network throughput, which forms the basis of this work.

Mixed cognitive RF and FSO fading channels have been initially proposed and analyzed in [3] and [4]. However, these works are limited to single antenna nodes and cannot be readily extended to multiple-input multiple-output (MIMO) systems, which additionally improve performance and data rate through multi-antenna diversity and spatial multiplexing respectively. Further, in contrast to the amplify-and-forward (AF) protocol considered in [3] and [4], decode-and-forward (DF) based cooperation, which is based on simple decoding at the relay, is better suited for cognitive mixed MIMO-RF/FSO cooperative relay systems [5].

This work therefore analyzes the end-to-end performance of an underlay cognitive mixed RF/FSO cooperative system with DF based cooperation. It can be noted that the transmit power of the cognitive radio system in underlay cognitive radio scenarios is strictly limited in order to restrict the interference to the primary receiver. This significantly affects the performance of cognitive transmission. Multiple antennas have been employed in this work at the cognitive source and relay to enhance the reliability of secondary communication, thereby improving the performance in comparison to the single antenna systems in [3] and [4], for the same transmit power. Closed form expressions are also derived for the per-frame outage probability to characterize the performance of underlay cognitive mixed MIMO-RF/FSO cooperative relay systems considering both orthogonal space-time block coded (OSTBC) transmission as well as transmit antenna selection (TAS) in (12), (13) respectively, whereas only single antenna systems have been considered in related works in existing literature. Note that OSTBC does not require channel state information (CSI) of the secondary user (SU)-relay link at the SU and is therefore ideally suited for implementation in practical wireless communication systems such as cellular networks. On the other hand, TAS requires a slightly higher complexity of implementation since the transmit antenna has to be chosen at the SU, which requires CSI of the SU-relay link. However, the complexity at the relay is $O(N_R)$ for both OSTBC and TAS. Simulation results are presented to verify the analytical results derived and also to yield insights into the outage performance of the system. Due to space limitations, analysis for the impact of PU node mobility on the cognitive network performance is presented in [6].

II. System Model

Consider a cognitive mixed MIMO-RF/FSO DF cooperative relay network in which a multi-antenna SU communicates with the destination eNodeB through an intermediate relay node in the presence of a multi-antenna primary user (PU) receiver with N_p antennas as shown in Fig. 1. The communication channel between the SU and the relay node is a Nakagami-*m*, $m \geq \frac{1}{2}$, fading RF MIMO link, with the SU and relay nodes equipped with N_S transmit and N_R receive antennas respectively. In contrast to AF protocol [3], [4], the relay first decodes the symbols transmitted during the first phase and retransmits it to the destination eNodeB through an FSO link in the subsequent phase. To enable point-to-point FSO communication, the relay and destination eNodeB are assumed to be equipped with a single photo-aperture

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The authors are with the Department of Electrical Engineering, IIT Kanpur, Kanpur 208016, India (e-mail: neerajv@iitk.ac.in; adityaj@iitk.ac.in).

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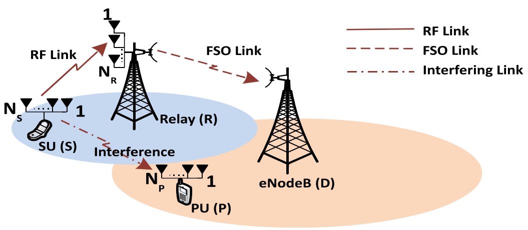

Fig. 1. Schematic diagram of a cognitive mixed RF/FSO DF cooperative relay network.

transmitter and a single photo-detector respectively. Similar to the work in [1], it is assumed that there is no RF link available between the SU and destination for direct communication.

A. OSTBC Based Transmission Over the SU-Relay RF Link

The received codeword $\mathbf{Y}_{SR}^{(k)} \in \mathbb{C}^{N_R \times T}$ at the relay corresponding to the transmission of an orthogonal space-time coded block $\mathbf{X}_{SR}^{(k)} \in \mathbb{C}^{N_S \times T}$, where T denotes the block length and k represents the k^{th} coded block in a frame of N_b codeword matrices, is given as

$$\mathbf{Y}_{SR}^{(k)} = \sqrt{P_S^k/(R_c N_S)}\mathbf{H}_{SR}^{(k)}\mathbf{X}_{SR}^{(k)} + \mathbf{W}_{SR}^{(k)} \tag{1}$$

where R_c denotes the rate of the OSTBC and P_S^k is the source transmit power. The SU-relay (SU-R) MIMO channel matrix $\mathbf{H}_{SR}^{(k)} \in \mathbb{C}^{N_R \times N_S}$ comprises of entries $h_{SR}^{(k)}[l,m]$, $1 \leq l \leq N_S$, $1 \leq m \leq N_R$ that are independent and identically distributed (i.i.d.) Nakagami-m random channel coefficients with variance δ_{SR}^2 and severity parameter m_{SR} each. The entries of the additive white noise matrix $\mathbf{W}_{SR}^{(k)} \in \mathbb{C}^{N_R \times T}$ are i.i.d. symmetric complex Gaussian with power η_0. To limit the interference at the PU to a given threshold P_A, the transmit power at the SU is regulated as $P_S^k = \frac{P_A}{||\mathbf{H}_{SP}^{(k)}||_F^2}$ [7], [8], where $\mathbf{H}_{SP}^{(k)} \in \mathbb{C}^{N_P \times N_S}$ denotes the MIMO channel matrix between the SU and PU, and comprises of entries $h_{SP}^{(k)}[l,n]$ that are i.i.d. Nakagami-m distributed with variance δ_{SP}^2 and severity parameter m_{SP}. Therefore, the instantaneous SNR per symbol corresponding to SU-R transmission of a codeword matrix $\mathbf{X}_{SR}^{(k)}$ can be written as [9]

$$\gamma_{SR}^{(k)\dagger} = \frac{P_S^k ||\mathbf{H}_{SR}^{(k)}||_F^2}{R_c N_S \eta_0} = \frac{P_A ||\mathbf{H}_{SR}^{(k)}||_F^2}{R_c N_S \eta_0 ||\mathbf{H}_{SP}^{(k)}||_F^2} = \frac{P_A G_{SR}^{(k)}}{R_c N_S \eta_0 G_{SP}^{(k)}} \tag{2}$$

where $G_{SR}^{(k)} = ||\mathbf{H}_{SR}^{(k)}||_F^2 = \sum_{l=1}^{N_S}\sum_{m=1}^{N_R} |h_{SR}^{(k)}[l,m]|^2$ and $G_{SP}^{(k)} = ||\mathbf{H}_{SP}^{(k)}||_F^2 = \sum_{l=1}^{N_S}\sum_{n=1}^{N_P} |h_{SP}^{(k)}[l,n]|^2$. The cumulative distribution function (CDF) of $\gamma_{SR}^{(k)\dagger}$ for the cognitive secondary user (SU), with transmit power P_S^k constrained as above, is given as

$$F_{\gamma_{SR}^{(k)\dagger}}(x) = 1 - \frac{\xi_2^{\tau_2}}{\Gamma(\tau_2)} \sum_{l=0}^{\tau_1 - 1} \frac{\Gamma(\tau_2 + l)(\xi_1 x)^l}{\Gamma(l+1)(\xi_2 + \xi_1 x)^{\tau_2 + l}} \tag{3}$$

where $\tau_1 = N_S N_R m_{SR}$, $\tau_2 = N_S N_P m_{SP}$, $\xi_1 = \frac{R_c N_S \eta_0 m_{SR}}{P_A \delta_{SR}^2}$, $\xi_2 = \frac{m_{SP}}{\delta_{SP}^2}$, and $\Gamma(x)$ denotes the Gamma function [10]. The detailed derivation of the above CDF is given in [6, Appendix A]. This key result is subsequently employed to derive the net per-frame outage probability for the system with OSTBC in (12).

B. Transmit Antenna Selection (TAS) at the SU

To contrast performance with that of OSTBC, TAS, which significantly reduces the hardware complexity since it requires only one RF chain for transmission while achieving the full diversity, is also considered at the SU. The instantaneous SNR at the relay corresponding to the transmission of a symbol $x_{SR}^{(k)}$ using the i^{th} SU antenna is given as, $\gamma_{SR}^{(k)\ddagger}[i] = \frac{P_S ||\mathbf{h}_{SR}^{(k)}[i]||_F^2}{\eta_0}$ where $i = 1, 2, \cdots, N_S$ and $\mathbf{h}_{SR}^{(k)}[i] \in \mathbb{C}^{N_R \times 1}$ denotes the channel vector between the relay and i^{th} SU antenna. Similar to OSTBC based transmission, the transmit power at the SU is limited as $P_S^k = \frac{P_A}{||\mathbf{h}_{SP}^{(k)}[i]||_F^2}$ to prevent the PU receiver from being interfered beyond an acceptable level P_A, where $\mathbf{h}_{SP}^{(k)}[i] \in \mathbb{C}^{N_P \times 1}$ denotes the channel vector between the PU and i^{th} SU antenna. Substituting $P_S^k = \frac{P_A}{||\mathbf{h}_{SP}^{(k)}[i]||_F^2}$, the instantaneous SNR $\gamma_{SR}^{(k)\ddagger}[i]$ can be rewritten as, $\gamma_{SR}^{(k)\ddagger}[i] = \frac{P_A ||\mathbf{h}_{SR}^{(k)}[i]||_F^2}{\eta_0 ||\mathbf{h}_{SP}^{(k)}[i]||_F^2}$. One can obtain a higher instantaneous SNR $\gamma_{SR}^{(k)\ddagger}[i]$ at the relay through TAS at the SU. The metric employed for antenna selection is given as

$$G_m^{(k)} = \max_{1 \leq i \leq N_S} \left\{ \frac{||\mathbf{h}_{SR}^{(k)}[i]||_F^2}{||\mathbf{h}_{SP}^{(k)}[i]||_F^2} \right\} = \max_{1 \leq i \leq N_S} \left\{ \frac{G_{SR}^{(k)}[i]}{G_{SP}^{(k)}[i]} \right\} \tag{4}$$

where $G_{SR}^{(k)}[i] = ||\mathbf{h}_{SR}^{(k)}[i]||_F^2$ and $G_{SP}^{(k)}[i] = ||\mathbf{h}_{SP}^{(k)}[i]||_F^2$. Further, the instantaneous SNR for the SU-relay link with TAS is

$$\gamma_{SR}^{(k)\ddagger} = \frac{P_A}{\eta_0} \max_{1 \leq i \leq N_S} \left\{ \frac{G_{SR}^{(k)}(i)}{G_{SP}^{(k)}(i)} \right\} = \frac{P_A}{\eta_0} G_m^{(k)} \tag{5}$$

and the CDF of $\gamma_{SR}^{(k)\ddagger}$, for the cognitive secondary user with TAS as shown in [6, Appendix B], is obtained as

$$F_{\gamma_{SR}^{(k)\ddagger}}(x) = \left[1 - \frac{\xi_2^{\widetilde{\tau}_2}}{\Gamma(\widetilde{\tau}_2)} \sum_{l=0}^{\widetilde{\tau}_1 - 1} \frac{\Gamma(\widetilde{\tau}_2 + l)(\widetilde{\xi}_1 x)^l}{\Gamma(l+1)(\xi_2 + \widetilde{\xi}_1 x)^{\widetilde{\tau}_2 + l}} \right]^{N_S} \tag{6}$$

where $\widetilde{\tau}_1 = N_R m_{SR}$, $\widetilde{\tau}_2 = N_P m_{SP}$, $\widetilde{\xi}_1 = \frac{\eta_0 m_{SR}}{P_A \delta_{SR}^2}$, and $\xi_2 = \frac{m_{SP}}{\delta_{SP}^2}$. Equation (6) is employed to derive the desired outage probability for the mixed MIMO-RF/FSO system with TAS.

On the other hand, the optical channel for the FSO link between the relay and destination eNodeB at the k^{th} instant can be modeled as $H_{RD}^{(k)} = H_l H_a H_p$, where H_l accounts for the path loss [11], H_a represents the atmospheric turbulence-induced fading modeled using the Gamma-Gamma distribution [12, eq. (13)], and H_p represents the misalignment fading (pointing errors) [11, eq. (11)]. The corresponding PDF of the optical channel is given as [13, eq. (12)]

$$f_{H_{RD}^{(k)}}(h) = \frac{\alpha\beta\xi^2}{A_0 H_l \Gamma(\alpha)\Gamma(\beta)} G_{1,3}^{3,0}\left(\frac{\alpha\beta h}{A_0 H_l} \,\middle|\, \begin{matrix} \xi^2 \\ \xi^2 - 1, \alpha - 1, \beta - 1 \end{matrix} \right) \tag{7}$$

where H_l is the path loss, A_0 is the fraction of the collected power at $r = 0$, r being the radial displacement due to pointing errors. The quantity ξ is defined as $\xi = w_e/2\sigma_s$, where w_e is the equivalent beam-width radius and σ_s is the standard deviation of the pointing error displacement at the receiver. Further, $G^{m,n}_{p,q}(x|\, {}^{a_1,\ldots,a_p}_{b_1,\ldots,b_q})$ is the Meijer's G-function [14, eq. (8.2.1.1)], α and β are the large-scale and small-scale scintillation parameters, respectively that depend on the Rytov variance $\sigma_R^2 = 1.23C_n^2k^{7/6}L^{11/6}$, where k, C_n^2, and L denote the optical wave number, refractive index structure constant, and link distance respectively.

Employing a coherent optical receiver with heterodyne detection at the eNodeB, the instantaneous SNR of the relay-destination FSO link is given as [15, eq. (2)]

$$\gamma_{RD}^{(k)} \approx \frac{\Re A}{q \triangle f} H_{RD}^{(k)} \tag{8}$$

where $\Re$ is the responsivity of the photodetector, A is the photodetector area, q is the electronic charge, and $\triangle f$ denotes the noise equivalent bandwidth of the receiver.

On the other hand, the instantaneous SNR of the relay-destination FSO link with intensity modulation/direct detection (IM/DD) is given as [15, eq. (4)]

$$\gamma_{RD}^{(k)} = \frac{(\Re A\zeta)^2}{2\triangle f(q\Re A I_b + 2k_bT_kF_n/R_L)}\left(H_{RD}^{(k)}\right)^2 \tag{9}$$

where I_b is the background light irradiance, k_b is Boltzmann's constant, T_k is the temperature in Kelvin, ζ is the modulation index, F_n represents a thermal noise enhancement factor due to amplifier noise, and R_L is the load resistance. The CDF of $\gamma_{RD}^{(k)}$ is given as [16, eq. (5)]

$$F_{\gamma_{RD}^{(k)}}(x) = \Theta_1 G^{3\theta,1}_{\theta+1,3\theta+1}\left(\frac{\Theta_2}{\mu_\theta}x \,\middle|\, {}^{1,\Theta_3}_{\Theta_4,0}\right) \tag{10}$$

where θ defines the type of detection technique used at the destination, i.e., $\theta = 1$ represents heterodyne detection and $\theta = 2$ represents IM/DD, and μ_θ is the average electrical SNR [16]. Moreover, the various quantities in (10) are defined as, $\Theta_1 = \frac{\theta^{\alpha+\beta-2}\xi^2}{(2\pi)^{\theta-1}\Gamma(\alpha)\Gamma(\beta)}$, $\Theta_2 = \frac{(\alpha\beta)^\theta}{\theta^{2\theta}}$, $\Theta_3 = \frac{\xi^2+1}{\theta},\ldots,\frac{\xi^2+\theta}{\theta}$ comprises of θ terms, and $\Theta_4 = \frac{\xi^2}{\theta},\ldots,\frac{\xi^2+\theta-1}{\theta},\frac{\alpha}{\theta},\ldots,\frac{\alpha+\theta-1}{\theta},\ \frac{\beta}{\theta},\ldots,\frac{\beta+\theta-1}{\theta}$ comprises of 3θ terms.

III. Outage Probability Analysis

Let γ_{th} denote the threshold for SNR outage at the destination node and $\epsilon(\gamma_{\text{th}})$ denote the corresponding outage event. Therefore, the net per-frame outage probability $\Pr(\epsilon(\gamma_{\text{th}}))$ corresponding to the transmission of a frame of length N_b in cognitive mixed MIMO-RF/FSO DF cooperative relay network can be expressed as

$$\Pr(\epsilon(\gamma_{\text{th}})) = \frac{1}{N_b}\sum_{k=1}^{N_b}\Pr(\gamma_{\min}^{(k)} \le \gamma_{\text{th}}) = \frac{1}{N_b}\sum_{k=1}^{N_b}F_{\gamma_{\min}^{(k)}}(\gamma_{\text{th}})$$

where $\gamma_{\min}^{(k)} = \min\{\gamma_{SR}^{(k)}, \gamma_{RD}^{(k)}\}$ denotes the end-to-end SNR and $F_{\gamma_{\min}^{(k)}}(\cdot)$ represents the CDF of $\gamma_{\min}^{(k)}$ given below

$$F_{\gamma_{\min}^{(k)}}(x) = 1 - (1 - F_{\gamma_{SR}^{(k)}}(x))(1 - F_{\gamma_{RD}^{(k)}}(x)) \tag{11}$$

where $F_{\gamma_{SR}^{(k)}}(x)$ and $F_{\gamma_{RD}^{(k)}}(x)$ denote the CDFs of the SNRs for the SU-relay and relay-eNodeB links respectively. Finally, substituting the expressions for $F_{\gamma_{SR}^{(k)}}(x)$, $F_{\gamma_{RD}^{(k)}}(x)$ from (3), (10) respectively in the above equation, the net per-frame outage probability for the scenario with OSTBC transmission is given by

$$\Pr(\epsilon(\gamma_{\text{th}}))\big|_{\text{OSTBC}} = 1 - \left(\frac{\xi_2^{\tau_2}}{\Gamma(\tau_2)}\sum_{l=0}^{\tau_1-1}\frac{\Gamma(\tau_2+l)(\xi_1\gamma_{\text{th}})^l}{\Gamma(l+1)(\xi_2+\xi_1\gamma_{\text{th}})^{\tau_2+l}}\right) \times \left(1 - \Theta_1 G^{3\theta,1}_{\theta+1,3\theta+1}\left(\frac{\Theta_2}{\mu_\theta}\gamma_{\text{th}} \,\middle|\, {}^{1,\,\Theta_3}_{\Theta_4,\,0}\right)\right). \tag{12}$$

On the other hand, substituting the expressions (6), (10) in (11), the closed-form expression for the net per-frame outage probability with transmit antenna selection is given by

$$\Pr(\epsilon(\gamma_{\text{th}}))\big|_{\text{TAS}} = 1 - \left(1 - \left[1 - \frac{\xi_2^{\widetilde{\tau}_2}}{\Gamma(\widetilde{\tau}_2)}\sum_{l=0}^{\widetilde{\tau}_1-1}\frac{\Gamma(\widetilde{\tau}_2+l)(\widetilde{\xi}_1\gamma_{\text{th}})^l}{\Gamma(l+1)(\xi_2+\widetilde{\xi}_1\gamma_{\text{th}})^{\widetilde{\tau}_2+l}}\right]^{N_S}\right) \times \left(1 - \Theta_1 G^{3\theta,1}_{\theta+1,3\theta+1}\left(\frac{\Theta_2}{\mu_\theta}\gamma_{\text{th}} \,\middle|\, {}^{1,\,\Theta_3}_{\Theta_4,\,0}\right)\right). \tag{13}$$

It can also be noted that the CDF of the individual links derived in (3), (6), (10) can also be employed to derive the performance of a heterogeneous multi-hop mixed RF/ FSO cooperative DF relaying system.

IV. Numerical Results

This section presents simulation results to demonstrate the outage performance of the cognitive mixed RF/FSO DF cooperative system and also, to validate the analytical expressions derived. The simulation scenario comprises of Nakagami-m faded RF links with severity parameters $m_{SR} = m_{SP} = m \in \{1.5, 2, 2.5, 3.5\}$, average gains $\delta_{SR}^2 = \delta_{SP}^2 = 1$, number of antennas $N_S \in \{2, 3\}$, $N_R = N_P = 2$, SNR outage threshold $\gamma_{\text{th}} = 5$ dB, and noise power $\eta_0 = 1$. Further, it is assumed that the FSO link experiences atmospheric turbulence with $C_n^2 \in \{3\times10^{-14}, 1\times10^{-13}\}$ m$^{-2/3}$, link length $L \in \{1, 2\}$ km, aperture radius $a = 0.1$ m, and laser wavelength $\lambda = 1.55 \times 10^{-6}$ m. Under these conditions, the various parameters for the FSO link with moderate and strong atmospheric turbulence are set as, ($\alpha = 5.4181, \beta = 3.7916, H_l = 0.9033, \xi = 1.6758$) and ($\alpha = 5.0711, \beta = 1.1547, H_l = 0.8159, \xi = 1.6885$) respectively.

Fig. 2(a) shows the outage probability versus the received power limit P_A at the PU-receiver for different values of the average relay-destination SNR $\bar{\gamma}_{RD}$ and $m_{SR} = m_{SP} = 2$. Firstly, it can be observed from Fig. 2 that the analytical outage values obtained using (12) and (13) for the rate $R_c = \frac{1}{2}$ OSTBC $\mathcal{G}_c^3$ based transmission [17] and TAS respectively coincide with the simulated ones, validating the analytical results derived. Fig. 2(a) shows that the asymptotic performance of the system under consideration, with both OSTBC transmission and TAS is limited by an asymptotic outage floor i.e., $\lim_{P_A\to\infty}\Pr(\epsilon(\gamma_{\text{th}})) = F_{\gamma_{RD}^{(k)}}(\gamma_{\text{th}})$. This interesting result is owing to the fact that the end-to-end performance of the system at high SNR is dominated by the weaker FSO link due to fixed transmit power at the relay. Further, since the transmit power of the secondary user is limited, the asymptotic performance of the system is considered for

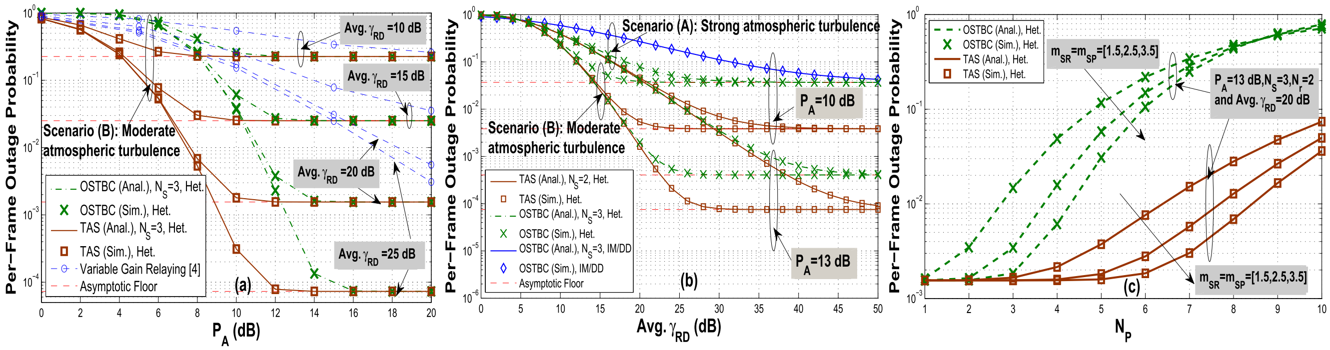

Fig. 2. Outage Performance of a cognitive mixed RF/FSO DF cooperative system for both OSTBC based transmission and TAS at the SU.

increasing interference threshold P_A. One can also observe that the MIMO SU-R link with TAS and DF based cooperation significantly improves the performance in comparison to the SISO system with variable gain relaying considered in [4]. However, in comparison with [4], the system performance with OSTBC is marginally worse in the low SNR regime due to power normalization by the factor $R_C N_S$ where $R_c = 1/2$ and $N_S = 3$.

Fig. 2(b) demonstrates the outage probability versus relay-destination SNR for strong and moderate atmospheric turbulence conditions as well as for different values of the received power limit P_A at the PU-receiver with $m_{SR} = m_{SP} = 2$. The simulation curves therein show that the outage performance severely degrades for low values of P_A since it reduces the SU transmit power, while a significant performance improvement can be achieved by increasing the received power limit P_A at the PU-receiver. Further, one can also observe in Fig. 2(b) that in contrast to moderate atmospheric turbulence, strong atmospheric turbulence significantly degrades the performance in the low and moderate SNR regimes. However, in the high SNR regime, the system outage probability experiences an identical asymptotic limit i.e., $\lim_{\bar{\gamma}_{RD}\to\infty} \Pr(\epsilon(\gamma_{\text{th}})) = F_{\gamma_{SR}^{(k)}}(\gamma_{\text{th}})$ under both the atmospheric turbulence conditions. Furthermore, performance of the IM/DD scheme is also demonstrated therein, which can be seen to result in significantly higher outage values in comparison to heterodyne detection.

Fig. 2(c) shows the impact of the number of antennas N_P at the PU-receiver on the performance of the cognitive radio system. It can be seen that while the outage performance for both TAS and OSTBC transmission severely degrades as N_P increases, OSTBC suffers from higher outage levels in comparison to TAS, for a fixed value of N_P. This is due to the interference power constraint, which results in a higher reduction in the SU transmit power for OSTBC.

V. Conclusion

This work analyzes the outage performance of an underlay cognitive DF MIMO-RF/FSO cooperative relay system considering TAS and OSTBC based RF transmission to enhance the reliability of secondary communication. Moreover, the impact of PU node mobility on the cognitive network performance is also demonstrated. Simulation results demonstrate an improved performance in comparison to single antenna RF/FSO AF cooperative systems proposed in literature.

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