

Broadcast Cognitive Radio with Dirty Paper Coding over Nakagami- m Fading Channel

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Abstract—The symbol error rate (SER) performance analysis of a broadcast underlay cognitive radio (CR) network, under Nakagami- m fading channels is studied in this paper. Particularly, the underlay CR network is studied as a closed loop multiple antenna system, presented with dirty paper coding (DPC) approach with the aim to allowing the secondary user (SU) transmission to utilize the spectrum resources efficiently and avoid interference to the primary user (PU) receiver. The proposed approach is capable of achieving the same performance as that of the zero-forcing (ZF) algorithm over Nakagami- m fading channels at the SU receiver. We further show with the simulation results that the SER and bit error rate (BER) performances of the PU under Nakagami- m and Rician fading channels are significantly improved for the proposed study. Finally, we optimize the power allocation of the PU transmitter and approximately achieve 3 dB performance gain over Nakagami- m fading for the SU receiver.

Index Terms—bit error rate, broadcasting, cognitive radio, Nakagami distribution, performance analysis, Rician fading.

I. INTRODUCTION

The restricted frequency bandwidth and the inefficient usage for the radio spectrum require new communication principles to exploit the unused spectrum holes opportunistically for the current spectrum resources [1-3]. Cognitive radios (CR) have been proposed as new network systems for wireless communication to utilize the current frequency spectrum resources more efficient than the conventional models [1-2]. Spectrum utilization can be increased by allowing the unlicensed secondary users (SUs) to utilize the licensed band in the absence of the primary users (PUs). In the literature documented for CR, the primary user has the legacy rights to use the licensed spectrum. In addition, an unlicensed SU has lower priority to use the licensed frequency band and utilizes the idle spectrum holes opportunistically or sharing the same spectrum bands without interfering to the PU [2-10].

Dirty paper coding (DPC) and multi-input multi-output (MIMO) systems in CR networks are techniques that can utilize the spectrum resources efficiently [11-15]. The authors in [16-17] proposed a new scheme for a MIMO broadcasting system. The capacity of a channel with additive white Gaussian noise (AWGN) and power constraint input were evaluated in [18] with the aim of achieving optimal transmitter design. In [19-20], the authors analyzed the sum rate performance of a quantized channel state information (CSI) for multi-user MIMO transmission. The sum-rate maximization problem in multi-user multi-relay MIMO system was studied in [21] and the results on the precoding techniques for the source and the relay were

presented. In [22], the closed form expressions for the upper bound of the achievable sum-rate were derived for zero-forcing (ZF) beamforming.

Motivated by the above works, in this study, we consider a CR network as a broadcast scheme in which the SU's transmitter (SU_T) has perfect knowledge of the CSI of the link between PU transmitter (PU_T) and SU_T [23]. It is known that, using space division multiple access (SDMA) technique, it could be possible to separate spatially and transmit the signal from the PU_T to the PU receiver (PU_R) without any perturbation from the SU_T [16-17]. Nevertheless, SDMA suffers from the signal-to-interference plus noise ratio (SINR) degradation at each receiver. Thus, in this study, we present an interference avoidance method based on DPC, applicable for the quadrature amplitude modulation (QAM) signal constellations, resulting in a considerable improvement to SDMA system performance over Rayleigh (special case of Rician fading for $K=0$ [24] or Nakagami- m fading for $m=1$), Nakagami- m and Rician fading channels in the considered CR network.

Although the broadcast schemes for MIMO systems with CSI at the transmitter have been extensively studied (see [25-26]), comparison studies on the symbol error rate (SER) and bit error rate (BER) performance analyses and spectrum utilization for CR network transmission inspired by DPC over fading channels do not exist in the technical literature. In our study, we investigate the performance of the SER of the end-to-end signal-to-noise ratio (SNR) when all transmission links are subject to Nakagami- m and Rician distributions. Furthermore, we achieve better performance gain with power allocation among PU_T and SU_T for the SU receiver (SU_R).

The rest of the paper is organized as follows: The system model is described in Section 2 presenting a CR network as a broadcast scheme with CSI. The performance analysis of the proposed system model is discussed in Section 3. Section 4 provides the simulation results. Finally, Section 5 presents the concluding remarks.

II. SYSTEM MODEL

In this section, we consider a CR system with M transmit and N receive antennas at the PU and SU sides, respectively. A certain assumption can be made without loss of generality that $M = N = 2$ as shown in Figure 1. The transmission links between the transmitter and the receiver sides are independent and identically distributed, and are subject to Nakagami- m and Rician fading, with channel coefficients h_{ij} from the i -th transmitter antenna

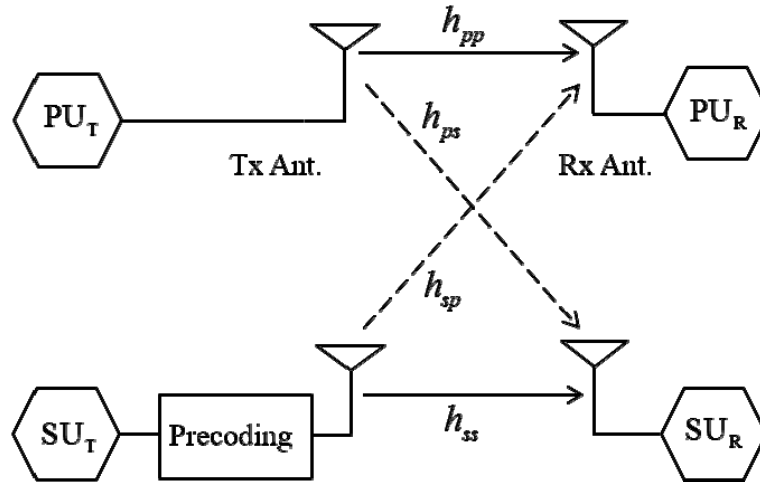


Figure 1. System model of the CR network as a broadcast scheme

$i = 1, 2, \dots, M$ to the j -th receiver antenna $j = 1, 2, \dots, N$, seen in the same figure above, in which h_{ij} is being used for modelling the $N \times M$ channel matrix \mathbf{H} [16-17]. In the system model, h_{pp} and h_{ss} are the direct links for the primary network and the secondary network, respectively. Besides, h_{ps} and h_{sp} are the transverse links between the primary and secondary networks. That it means, while $(i, j) = (1, 1)$ the fading channel corresponds to the primary network transmission. In addition, $(i, j) = (2, 2)$ represents the fading channel for the secondary network transmission. When the signal transmission for the PU_T is available, the signal at the receiver side, \mathbf{r}_t at time t can be given as follows:

$$\mathbf{r}_t = \mathbf{H}\mathbf{x}_t + \mathbf{n}_t. \quad (1)$$

In here, the $M \times 1$ transmit vector, namely \mathbf{x}_t , which is the transmitted signal represents the i -th antenna at time t . In the same manner, \mathbf{r}_t , which is the received signal vector displays the j -th antenna at time t [16]. In (1), \mathbf{n}_t is the AWGN term with zero mean and variance of σ^2 . We assume that the channel matrix \mathbf{H} is known at the SU_T that is to say perfect CSI is available at the SU_T [27].

In the ZF beamforming approach [28-29], the \mathbf{x}_t can be expressed as follows:

$$\mathbf{x}_t = \frac{\mathbf{H}^* (\mathbf{H}\mathbf{H}^*)^{-1} \mathbf{s}}{\sqrt{\text{tr}[(\mathbf{H}\mathbf{H}^*)^{-1}]}}. \quad (2)$$

In here, the conjugate transpose of \mathbf{H} is indicated with \mathbf{H}^* , while the original information at the transmitter side is depicted as \mathbf{s} , and tr is the trace of the matrix. Then the received signal in (1) is obtained as in [16-17]:

$$\mathbf{r}_t = \frac{\mathbf{s}}{\sqrt{\text{tr}[(\mathbf{H}\mathbf{H}^*)^{-1}]}} + \mathbf{n}_t. \quad (3)$$

We can model (3) as the scaled form of the transmitted signal. Therefore, ZF SDMA solution eliminates the interference from the received signal that is transferred from any other users in the transmitter side. However, $\left(\text{tr}[(\mathbf{H}\mathbf{H}^*)^{-1}] \right)^{1/2}$, which is the average power loss is still a problem for ZF model that means it performs poorly in low SNRs.

In this study, we utilize the approach developed in [11-17] while the proposed model is used for encoding, decoding and constellation scheme as shown in Fig. 1 and Fig. 2, respectively.

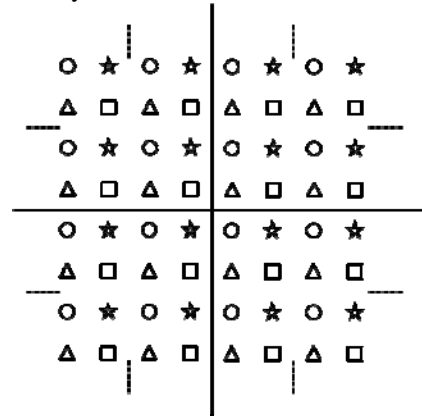


Figure 2. 4-QAM signal constellations [17]

III. PERFORMANCE ANALYSIS OF THE PROPOSED SYSTEM MODEL

We consider the SER performance analysis of the proposed system model for Nakagami- m and Rician fading channels. The channel matrix, \mathbf{H} is given by

$$\mathbf{H} = \begin{bmatrix} h_{pp} & h_{ps} \\ h_{sp} & h_{ss} \end{bmatrix} \quad (4)$$

where h_{ij} is the channel fading coefficient from the i -th transmitter antenna to the j -th receiver antenna [30]. By assuming without loss of generality that, $\mathbf{H} \neq 0$ and $\alpha = \sqrt{|h_{pp}|^2 + |h_{ps}|^2} \neq 0$. Then the \mathbf{H} matrix can be re-

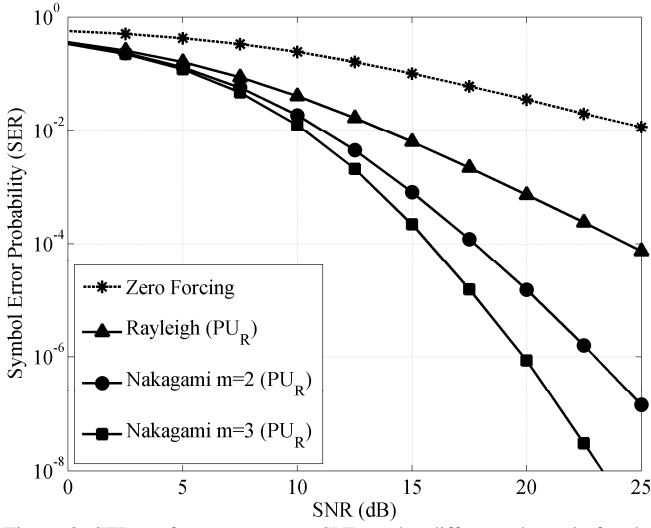


Figure 3. SER performance versus SNR under different channels for the PU_R perspective

expressed as [16-17] $\mathbf{H} = \mathbf{Z}\mathbf{W}$ where

$$\mathbf{Z} = \frac{1}{\alpha} \begin{bmatrix} \alpha^2 & 0 \\ h_{sp}h_{pp}^* + h_{ss}h_{ps}^* & -h_{sp}h_{ps} + h_{ss}h_{pp} \end{bmatrix} \quad (5)$$

$$\mathbf{W} = \frac{1}{\alpha} \begin{bmatrix} h_{pp} & h_{ps} \\ -h_{ps}^* & h_{pp}^* \end{bmatrix}.$$

The SU_T transmits the signal $\tilde{\mathbf{x}}_t = \mathbf{W}_t \mathbf{x}_t$ instead of \mathbf{x}_t in order not to generate any interference for the PU_R . Assume that $\mathbf{x}_t = \mathbf{W}^* \mathbf{c}_t$, where \mathbf{c}_t is the $M \times 1$ new transmit vector, then the received signals at PU_R and SU_R sides are given by

$$r_1 = \alpha c_1 + n_1$$

$$r_2 = \frac{1}{\alpha} \left((h_{sp}h_{pp}^* + h_{ss}h_{ps}^*) c_1 + (-h_{sp}h_{ps} + h_{ss}h_{pp}) c_2 \right) + n_2, \quad (6)$$

respectively [31]. In (6), c_1 and c_2 are the information sent from the PU_T and SU_T , successively. Here, $(\cdot)^*$ is the complex conjugation. From the expression for r_1 , it is observed that the performance of the PU_R is similar with the Alamouti scheme, which is employed for 2 transmit and 1 receive antennas [32]. We choose $c_2 = v - u$, where $u = c_1 \left((h_{sp}h_{pp}^* + h_{ss}h_{ps}^*) / (-h_{sp}h_{ps} + h_{ss}h_{pp}) \right)$ and v is the nearest QAM symbol to the u in the signal constellation map, which is the desired symbol transmitted from the SU_T . The 4-QAM signal constellation map which is used in the proposed system model is shown in Fig. 2. In this way, the first part of r_2 in (6), $\alpha^{-1} c_1 (h_{sp}h_{pp}^* + h_{ss}h_{ps}^*)$ can be ignored and rewritten as in the following equation, proving that r_2 performance is almost the same with \tilde{r}_2 [16-17],

$$\tilde{r}_2 = \frac{1}{\alpha} \left((-h_{sp}h_{ps} + h_{ss}h_{pp}) c_2 \right) + n_2. \quad (7)$$

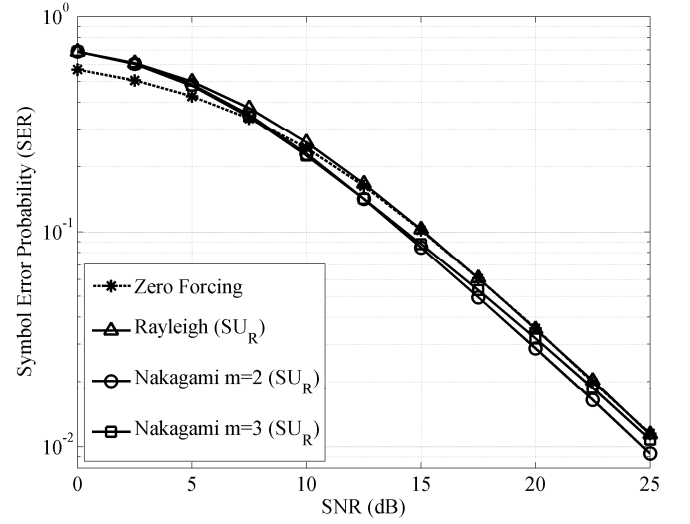


Figure 4. SER performance versus SNR under different channels for the SU_R perspective

While PU_T has the transmit power of $(P/2)$, we observe from the numerical results that the mean average power for SU_T (P_{SU_T}) is exactly equal to $(2P/3)$, which can be derived from the below equation with the help of the QAM constellation map as

$$P_{SU_T} = P \int_0^1 \int_0^1 \left(\sqrt{P_x^2 + P_y^2} \right)^2 dx dy \quad (8)$$

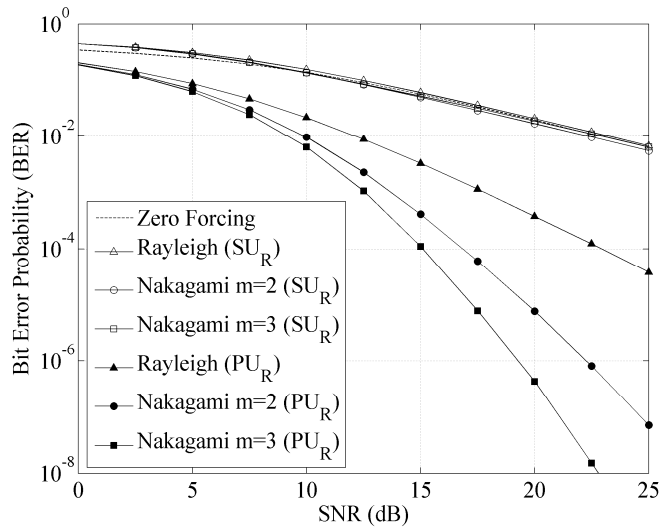
where P is the total power of the transmitters, P_x and P_y are the real and the imaginary parts of the 4-QAM symbols, respectively. It is analyzed that the performance of the SU_R is exactly the same as with the BLAST scheme [33], equipped with 2 transmit and 2 receive antennas.

IV. SIMULATION RESULTS

In this section, the numerical results are presented through the receiver operating characteristics (ROC) curves. SER performance of the proposed system based on 4-QAM with Gray coding is shown in Fig. 3 with different fading channel approaches for the PU_R . The performance over Rayleigh (special case of Nakagami- m fading for $m=1$) and Nakagami- m fading channels for both $m=2$ and $m=3$ are displayed for different values of the SNR. We also apply ZF scheme for the comparison purposes with the implemented scenario. As it is shown in the same figure the performance of the system improves, as the value of the shape factor, m increases. It is clear that the system performance for the proposed scenario over both the Rayleigh and Nakagami- m fading channels outperforms the ZF algorithm.

In Fig. 4, we present the SER results under consideration for the SU_R over the same fading channels. We observe that our approach achieves the same performance bound over both Rayleigh and Nakagami- m fading channels.

In Fig. 5, we compare the BER performance of the PU_R and SU_R in the presence of Rayleigh and Nakagami- m fading channels for both $m=2$ and $m=3$.

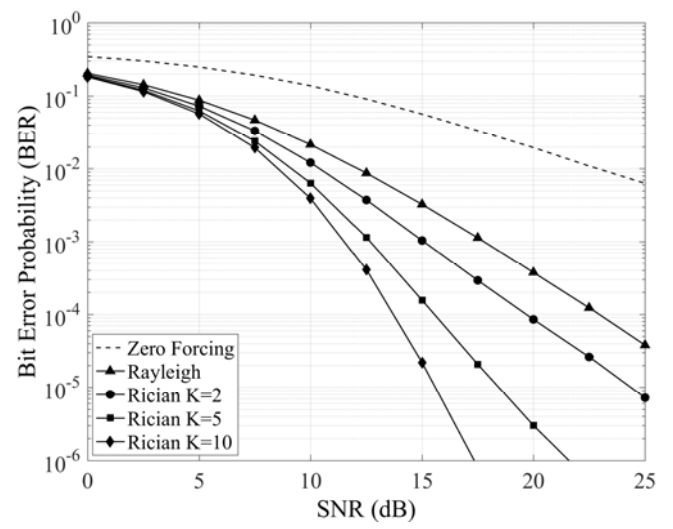
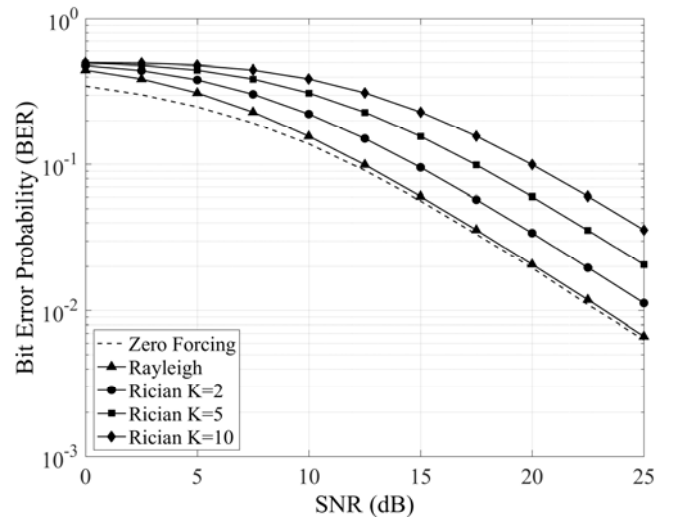
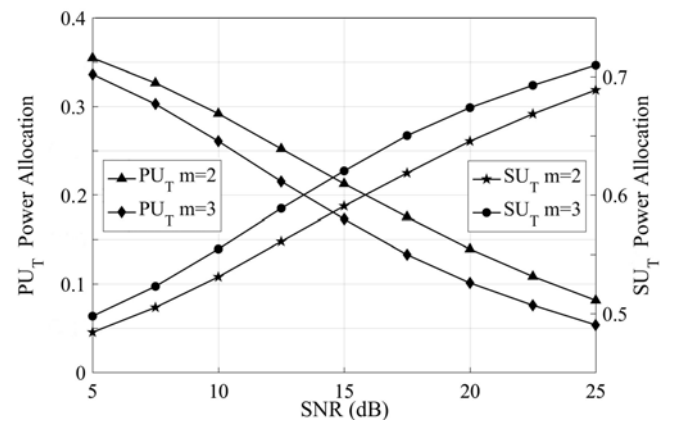
Figure 5. BER performance of the PU_R and SU_R

The performance over Rician fading channels with the value of Rician K-factor, ($K=2$, $K=5$, $K=10$) are displayed for different values of the SNRs in Fig. 6. As it is expected, the system performance improves while the value of Rician K-factor increases. It is noted that the BER performance for the proposed scenario over the Rician fading channel outperforms the ZF algorithm.

In Fig. 7, we present the BER results under consideration for the SUR over the Rayleigh and Rician distributions. It illustrates the Rayleigh distribution which is slightly similar to ZF approach, outperforms the Rician channel model. The same plot shows that the BER performance degradation with the increasing values of K-factor for Rician fading. The reason of this result is basically related with the coefficient of c_2 in (7).

In Rician fading channels, while the K-factor increases, the variance of c_2 coefficient ($-h_{sp}h_{ps} + h_{ss}h_{pp}$) decreases. In addition, the mean value of the c_2 coefficient becomes zero due to minus sign. Then this coefficient leads the signal level of c_2 to the noise level, hence BER degradation occurs. In other words, if the Rician K-factor increases, the interference from the PUT is higher at the SUR. It is clearly analysed that better BER performance over Nakagami-m fading channel is achieved with the increase of the fading parameter, m . Consequently, the interference is very critical in degrading the BER performance of the SUR even if the direct link SUT-SUR is getting improved. On the other hand, this performance degradation under Nakagami-m and Rician distribution can be easily eliminated by the power allocation among both the PUT and SUT.

In Fig. 8, we depict the power allocations for PUT and SUT over Nakagami-m fading distributions for both $m=2$ and $m=3$. In this figure, ensuring that the SER performance for the PUR remains in Rayleigh bound, while decreasing the PUT power, and increasing the SUT power at the same time, then we try to improve the SER performance for the SUR.

Figure 6. BER performance versus SNR under different channels for the PU_R perspectiveFigure 7. BER performance versus SNR under different channels for the SU_R perspectiveFigure 8. Power allocation for both PU_T and SU_T over Nakagami-m fading channel

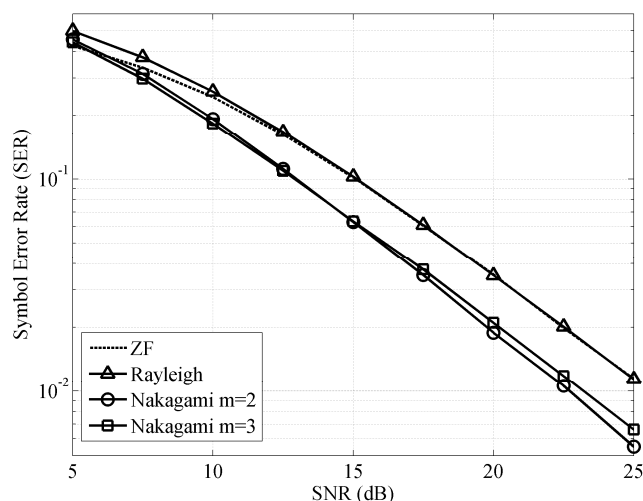


Figure 9. SER performance of the SU_R with power allocation

The SER performance analysis of the ZF algorithm is depicted in Fig. 9. Besides, the performance for the proposed power allocation scheme over both the Nakagami- m and Rayleigh fading distributions are shown in the same figure. It is clearly analysed that the same error performance over Rayleigh fading is achieved with the ZF algorithm. The performance for the power allocation scenario over Nakagami- m fading ($m = 2, 3$) is approximately 3 dB better, compared to the results shown in Fig. 4, for the SU_R , while all SER values for the PU_R satisfy the Rayleigh bound.

V. CONCLUSION

In this paper, we have studied a broadcast underlay cognitive radio network as a closed loop multiple antenna system with dirty paper coding scheme under Nakagami- m and Rician fading channels. We have provided strictly accurate and intensive data for the SER and BER analyses of the primary user and secondary user receivers. In the proposed study, we achieved SER and BER performance improvements for the PU under Nakagami- m and Rician fading channels compared to the Rayleigh distribution, while all fading channels outperform ZF algorithm. We have also demonstrated that the performance for the SU is almost the same with the well-known zero forcing scheme over Nakagami- m distribution while achieving a low computational complexity. Moreover, we optimized the power allocation among the PUT and SUT. In this way approximately 3 dB performance gain is achieved over Nakagami- m fading for the SUR.

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