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Original Article

Outage Probability and Throughput Analysis of Cooperative NOMA System using Moving Relay

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Abstract - *The cell edge users suffer from low signal strength and interference from neighboring cells. Additionally, in a vehicular scenario, vehicle penetration loss (VPL) exacerbates and reduces signal strength badly at the cell edge, which results in poor coverage and low quality of service (QoS). Outage probability and throughput are important parameters that cell edge users need to analyze. Recent research shows that non-orthogonal multiple access (NOMA) and amplify and forward relaying based moving relay (MR) are promising techniques for handling these issues. The performance of decode forward relaying based MR has not been analyzed yet. In this paper, we propose a cooperative NOMA system with full duplex decode forward (FD-DF) relaying based MR on the roof of a vehicle for a downlink network to analyze the performance of cell edge vehicular users. We derive the outage probability capacity of vehicular cell edge and non vehicular users. We analyze vehicular users' outages and throughput performances in terms of transmit signal-to-noise ratio (SNR), power allocation coefficient, and residual interference levels. Simulation results show that FD-DFR based MR performs better than systems with half duplex decode forward (HD-DF) relaying based MR and without MR.*

Keywords - *Vehicular Penetration Loss (VPL), Non-Orthogonal Multiple Access (NOMA), Moving Relay (MR), Quality of service (QoS), Outage probability, Throughput*.

1. Introduction

Due to the rapid increase in the number of smartphone users, many now utilize wireless broadband when taking public transportation. On the other hand, vehicle penetration loss (VPL) significantly reduces radio signals, necessitating increased power to make up for it. This causes a smartphone energy drain. Thus, to fulfil QoS standards and reduce energy consumption for smartphone users in vehicles, the effect of VPL must be reduced [1]. By increasing network capacity and coverage, relays can mitigate the impact of VPL on wireless communication networks. Relaying has long been used in wireless communication networks to overcome signal fading difficulties and improve coverage and capacity. Relaying can be used directly or indirectly to relay signals to the base station. Moving relays (MRs) are a novel invention that improves passenger throughput in public transportation, particularly in rural locations where relay nodes are neither available nor cost-effective [2]. Moving Relay (MRs) comprise both external and internal antennas linked by wire to provide increased cellular service to vehicles. They can significantly reduce VPL, save energy, and improve coverage for vehicle users. According to measurements, VPL may reach 25 dB inside a minivan at 2.4 GHz [4, 5]. MRs can help improve group handover and collective channel status information input from users on public transportation. They can conserve device energy and outperform fixed relays when the VPL is moderate to high [6-8]. The idea of MRs was first introduced in LTE release-11 and is still under investigation for future LTE releases.

NOMA is a promising 5G technology that has the potential to replace current ones because of its higher spectrum efficiency, lower latency, and extensive connection [9]. In NOMA-based systems, users share the same resource at varying power levels depending on the channel. The Near-User (NU) with better channel status allotted less power than the Far-User (FU) with poor channel status. At the receiving end, NU performs the Successive Interference Cancellation (SIC) to decode the message of FU and detect its message [10]. The user with poor channel status perceives the other user's information as interference while decoding its message.

1.1. Related Work

In order to increase the system's transmission rate, coverage area, and connection, cooperative NOMA with a fixed relay is first investigated [9-13]. In [14], [15], the NOMA system using a relay with $\alpha - \mu$ and Nakagami-q fading channel is examined. The integration of MIMO with the NOMA system is examined in [16] and [17]. In [18], the bounded path loss model examines the outage probability of randomly dispersed NOMA users for downlink communication. For uplink cellular communication, the outage probability of NOMA based system with controlled power is examined in [19]. In [20], the rate coverage of multi-cell uplink NOMA users employing the Poisson cluster method was examined. SIC affects the NOMA system's performance and is a crucial term for decoding the multiplexed signal transmitted by the base station.

NOMA systems were examined in [21]-[25] while taking perfect SIC into consideration. The user's end channel status information and base station power allocation control determine the SIC's efficiency [26]-[27]. A low Signal to Noice Ratio (SNR) signal experiences interference due to imperfect SIC, which leads to inaccurate decoding of a high SNR signal [28]. Recently, MR employing Half Duplex (HD) and Full Duplex (FD) Amplify and Forward (AF) relay in NOMA based system was studied in [3]. Thus, the impact of HD and FD Decode and Forward (DF) relay based MR with imperfect SIC needs to be examined for the suggested NOMA system model.

1.2. Motivation

Previous research has established a good foundation for cooperative NOMA with AF relaying based MR, but no study has been conducted on cooperative NOMA with DF relaying based MR. Previous study on MR employing AF relay have shown that MR decreases outage probability while improving system Quality of Service (QoS).

Roadside units were used for downlink analysis in [29] to determine the effectiveness of the NOMA system in vehicle communication. Using the orthogonal multiple access (OMA) approach for downlink communication, the performance of MR was examined in [30]. The HD-AF relay based MR is used in [3] to analyze the performance of vehicular user. The research work in [6], [29] and [30] therefore motivates us to make contributions in this area.

1.3. Contributions

The main contributions of this research work are as follows:

1. We derive the outage probability of both vehicular (FU) and non vehicular users (NU) with FD-DF relay based MR using the NOMA technique. Simulation results show that MR overcomes VPL's effect and significantly lower vehicular users' outage probability.
2. We analyze the outage probability of FU and show that it decreases with the power allocation coefficient and increases with the level of residual interference.
3. We compare the HD-DF MR with FD-DF MR and show that FD-DF MR outperforms the HD-DF MR.
4. We analyze the system throughput of the NOMA system with FD-DF MR and show that it outperforms the HD-DF MR at higher values of transmit SNR.

The remaining sections of this paper are organized as follows. Section II describes the system model. Section III shows the performance analysis of the suggested model. Section IV presents simulation results. Section V concludes the paper.

2. System Model

We consider a cooperative NOMA system with two users in which NU communicates directly with a base station (BS) and vehicular user, i.e. FU communicates via a moving relay. Here, we use the decode and forward protocol based moving relay.

BS sends the superimposed signal (s) to both NU and FU. The superimposed signal can be defined as

$$S(n) = \sqrt{P_{BS}a_1}x_1(n) + \sqrt{P_{BS}a_2}x_2(n) \tag{1}$$

Where, P_{BS} represent the power transmitted by BS, a_1 and a_2 are the power allocation coefficient for NU and FU, respectively, with conditions $a_1 < a_2$ and $a_1 + a_2 = 1$, x_1 and x_2 are message signals for NU and FU, respectively.

Now, the signal received at NU $(y_b^n(n))$ can be expressed as

$$y_b^n(n) = h_b^n S(n) + f_m^n \sqrt{P_r} x_2(n-\tau) + n_b^n \tag{2}$$

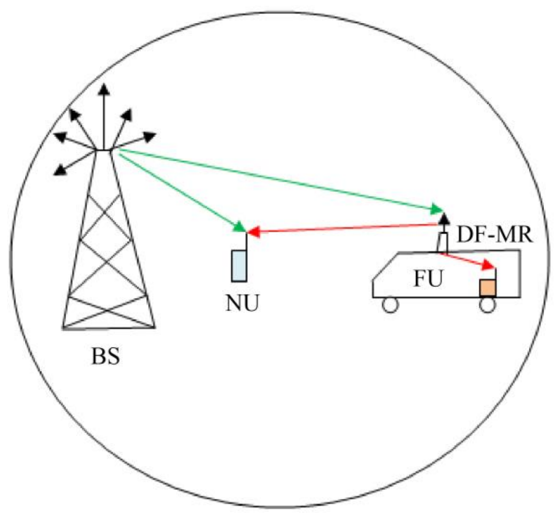

Fig. 1 System model for vehicular user

Where $h_b^n \sim \mathcal{CN}(0, \lambda_b^n)$ Represents the channel coefficient between the NU and BS. $n_b^n \sim CN(0, N_0)$ Is the additive white Gaussian noise (AWGN) at NU. $f_m^n \sim CN(0, \lambda_m^n)$ Represents the channel coefficient between the MR and NU.

In NOMA based system, NU performs SIC in which first NU decodes the message of FU, and then it detects its own message. In the proposed system, we consider the realistic situation by considering imperfect SIC due to residual interference. Therefore, the received signal at NU can be modified as

$$y_b^n(n) = h_b^n S(n) + \hat{f_m^n}\sqrt{P_r}x_2(n-\tau) + n_b^n \quad (3)$$

Where $\hat{f_m^n} \sim CN(0, k_1\lambda_m^n)$ is the residual self-interference channel coefficient, and k_1 is the level of residual interference and $k_1 = 0$ is the case of perfect interference cancellation. P_rDoes MR transmit the power.

The signal to interference pulse noise ratio (SINR) of NU to decode the message of FU (γ_n^f) can be defined using Equation(1) and Equation (3) as

$$\gamma_n^f = \frac{|h_b^n|^2 P_{BS} a_2}{|h_b^n|^2 P_{BS} a_1 + \left|\hat{f_m^n}\right|^2 P_r + N_0} \quad (4)$$

$$\gamma_n^f = \frac{|h_b^n|^2 a_2 \rho_s}{|h_b^n|^2 \rho_s a_1 + \left|\hat{f_m^n}\right|^2 \rho_r + 1} \quad (5)$$

Where $\boldsymbol{\rho_s} = \frac{\mathbf{P_{BS}}}{\mathbf{N_0}}$ and $\rho_r = \frac{P_r}{N_0}$

Further, SINR of NU to decode its own message with imperfect SIC (γ_n^n) can be defined using Equation(1) and Equation (3) as

$$\gamma_n^n = \frac{|h_b^n|^2 a_1 \rho_s}{\mu_1 |h_b^n|^2 \rho_s a_2 + \left|\hat{f_m^n}\right|^2 \rho_r + 1} \quad (6)$$

Now, the signal received at FU without MR.

$$y_b^{f,v}(n) = h_b^f \left\{\sqrt{(P_{BS}a_1 - \gamma)}x_1(n) + \sqrt{(P_{BS}a_2 - \gamma)}x_2(n)\right\} + n_b^f \quad (7)$$

$$\gamma_b^{f,v} = \frac{\left|h_b^f\right|^2 (P_{BS}a_2 - \gamma)}{\left|h_b^f\right|^2 (P_{BS}a_1 - \gamma) + N_0} \quad (8)$$

Now, the signal received at MR from BS $(y_b^m(n))$ can be expressed as

$$y_b^m(n) = h_b^m S(n) + h_r^r \sqrt{P_r}x_2(n-\tau) + n_b^m \quad (9)$$

Where $h_r^r \sim \mathcal{C}N(0, \lambda_r^r)$ represents the channel coefficient for the MR self-interference channel and $n_b^m \sim \mathcal{C}N(0, N_0)$ Is the AWGN at MR. Now, after taking interference cancellation $y_b^m(n)$ can be modified as

$$y_b^n(n) = h_b^m S(n) + \hat{h_r^r}\sqrt{P_r}x_2(n-\tau) + n_b^m \quad (10)$$

Where $\hat{h_r^r} \sim \mathcal{C}N(0, k_2\lambda_r^r)$ Is the residual self-interference for FD-DF MR. Hence, the SINR at MR to decode the message of FU (γ_b^m) using Equation(10) and Equation(1) can be defined as

$$\gamma_b^m = \frac{|h_b^m|^2 a_2 \rho_s}{|h_b^m|^2 \rho_s a_1 + \left|\hat{h_r^r}\right|^2 \rho_r + 1} \quad (11)$$

Now, the signal received at FU from MR $\left(y_m^f(n)\right)$ can be defined

$$y_m^f(n) = h_m^f \sqrt{P_r}x_2(n-\tau) + n_m^f \quad (12)$$

Where $h_m^f \sim \mathcal{C}N\left(0, \lambda_m^f\right)$ represents the channel coefficient between FU and MR and $n_m^f \sim \mathcal{C}N(0, N_0)$ is the AWGN at FU. Now, the SINR at FU to decode its message (γ_m^f) using Equation(12) can be defined as

$$\gamma_m^f = \left|h_m^f\right|^2 \rho \quad (13)$$

3. Performance Analysis

3.1. Outage Probability

3.1.1. Outage probability of NU

The outage probability (OP) of NU (P_o^n) can be written as

$$P_o^n = 1 - \left[P\left(\log_2\left(1+\gamma_n^f\right) > R_2\right)\right] \times \left[P\left(\left(\log_2\left(1+\gamma_n^n\right) > R_1\right)\right] \quad (14)$$

Where $P\ (.)$ denotes the probability

$$P_o^n = 1 - \left[P\left(\gamma_n^f > x_2\right)\right] \times \left[P\left(\gamma_n^n > x_1\right)\right] \quad (15)$$

Where $2^{R_2} - 1 = x_2$ and $2^{R_1} - 1 = x_1$

Now, Equation(15) can be modified by substituting γ_n^f from Equation (5) and γ_n^n from Equation (6) as

$$P_o^n = 1 - \left[P\left(\frac{|h_b^n|^2 a_2 \rho_s}{x_2} > |h_b^n|^2 \rho_s a_1 + \left|\hat{f_m^n}\right|^2 \rho_r + 1\right)\right] \times \left[P\left(\frac{|h_b^n|^2 a_1 \rho_s}{x_1} > \mu_1 |h_b^n|^2 \rho_s a_2 + \left|\hat{f_m^n}\right|^2 \rho_r + 1\right)\right] \quad (16)$$

$$P_o^n = 1 - \left[P\left(\phi |h_b^n|^2 \rho_s > \left|\hat{f_m^n}\right|^2 \rho_r + 1\right)\right] \times \left[P\left(\Psi |h_b^n|^2 \rho_s > \left|\hat{f_m^n}\right|^2 \rho_r + 1\right)\right] \quad (17)$$

Where $\phi = \left(\frac{a_2 - x_2 a_1}{x_2}\right)$ and $\Psi = \left(\frac{a_1 - \mu_1 x_1 a_2}{x_1}\right)$

$$P_o^n = 1 - \left[P\left(|h_b^n|^2 > \frac{\left|\hat{f_m^n}\right|^2 \rho_r + 1}{\phi \rho_s}\right)\right] \times \left[P\left(|h_b^n|^2 > \frac{\left|\hat{f_m^n}\right|^2 \rho_r + 1}{\Psi \rho_s}\right)\right] \quad (18)$$

Furthermore, Equation (18) can be modified as

$$P_o^n = 1 - \left[\mathbb{E}_{\left|\hat{f_m^n}\right|^2}\left\{e^{-\frac{\left|\hat{f_m^n}\right|^2 \rho_r + 1}{\phi \rho_s \lambda_b^n}}\right\}\right] \times \left[\mathbb{E}_{\left|\hat{f_m^n}\right|^2}\left\{e^{-\frac{\left|\hat{f_m^n}\right|^2 \rho_r + 1}{\Psi \rho_s \lambda_b^n}}\right\}\right] \quad (19)$$

$$P_o^n = 1 - \left[\int_0^\infty e^{-\frac{|\hat{f}_m^n|^2\rho_r}{\phi\rho_s\lambda_b^n}} e^{-\frac{1}{\phi\rho_s\lambda_b^n}} \frac{1}{k_1\lambda_m^n} e^{-\frac{|\hat{f}_m^n|^2}{k_1\lambda_m^n}} d|\hat{f}_{r,1}|^2\right] \times \left[\int_0^\infty e^{-\frac{|\hat{f}_m^n|^2\rho_r}{\Psi\rho_s\lambda_b^n}} e^{-\frac{1}{\Psi\rho_s\lambda_b^n}} \frac{1}{k_1\lambda_m^n} e^{-\frac{|\hat{f}_m^n|^2}{k_1\lambda_m^n}} d|\hat{f}_{r,1}|^2\right] \quad (20)$$

$$P_o^n = 1 - \left[e^{-\frac{1}{\phi\rho_s\lambda_b^n}}\left(\frac{k_1\lambda_m^n\rho_r + \phi\rho_s\lambda_b^n}{\phi\rho_s\lambda_b^n}\right)^{-1}\right] \times \left[e^{-\frac{1}{\Psi\rho_s\lambda_b^n}}\left(\frac{k_1\lambda_m^n\rho_r + \Psi\rho_s\lambda_b^n}{\Psi\rho_s\lambda_b^n}\right)^{-1}\right] \quad (21)$$

$$P_o^n = 1 - \left[e^{-\frac{1}{\phi\rho_s\lambda_b^n}}\left(1 + \frac{k_1\lambda_m^n\rho_r}{\phi\rho_s\lambda_b^n}\right)^{-1}\right] \times \left[e^{-\frac{1}{\Psi\rho_s\lambda_b^n}}\left(1 + \frac{k_1\lambda_m^n\rho_r}{\Psi\rho_s\lambda_b^n}\right)^{-1}\right] \quad (22)$$

3.1.2. Outage probability of NU

The OP of FU (P_o^f) can be written as

$$P_o^f = 1 - [P(\log_2(1+\gamma_b^m) > R_2)] \times [P((\log_2(1+\gamma_m^f) > R_2)] \quad (23)$$

$$P_o^f = 1 - [P(\gamma_b^m > x_2)] \times [P(\gamma_m^f > x_2)] \quad (24)$$

$$P_o^f = 1 - \left[P\left(\frac{|h_b^m|^2\rho_s a_2}{x_2} - |h_b^m|^2\rho_s a_1 > |\hat{h_r^r}|^2\rho_r + 1\right)\right] \times \left[P\left(|h_m^f|^2 > \frac{x_2}{\rho_r}\right)\right] \quad (25)$$

$$P_o^f = 1 - \left[P\left(|h_b^m|^2 > \frac{|\hat{h_r^r}|^2\rho_r + 1}{\rho_s\phi}\right)\right] \times \left[P\left(|h_m^f|^2 > \frac{x_2}{\rho_r}\right)\right] \quad (26)$$

Where $\phi = \left(\frac{a_2 - x_2 a_1}{x_2}\right)$

$$P_o^f = 1 - \left[P\left(|h_b^m|^2 > \frac{|\hat{h_r^r}|^2\rho_r + 1}{\rho_s\phi}\right)\right] \times \left[P\left(|h_m^f|^2 > \frac{x_2}{\rho_r}\right)\right] \quad (27)$$

$$P_o^f = 1 - \left[E_{|\hat{h_r^r}|^2}\left\{e^{-\frac{|\hat{h_r^r}|^2\rho_r + 1}{\phi\rho_s\lambda_m^b}}\right\}\right] \times \left[e^{-\frac{x_2}{\lambda_m^f\rho_r}}\right] \quad (28)$$

$$P_o^f = 1 - \left[\int_0^\infty e^{-\frac{|\hat{h_r^r}|^2\rho_r}{\phi\rho_s\lambda_m^b} - \frac{1}{\phi\rho_s\lambda_m^b}} \frac{1}{k_2\lambda_r^r} e^{-\frac{|\hat{h_r^r}|^2}{k_2\lambda_r^r}} d|\hat{h_r^r}|^2\right] \times \left[e^{-\frac{x_2}{\lambda_m^f\rho_r}}\right] \quad (29)$$

$$P_o^f = 1 - \left[\frac{e^{-\frac{1}{\phi\rho_s\lambda_m^b}}}{k_2\lambda_r^r}\int_0^\infty e^{\left[-\frac{\rho_r k_2\lambda_r^r + \phi\rho_s\lambda_r^r}{k_2\phi\rho_s\lambda_m^b\lambda_r^r}\right]|\hat{h_r^r}|^2} d|\hat{h_r^r}|^2\right] \times \left[e^{-\frac{x_2}{\lambda_m^f\rho_r}}\right] \quad (30)$$

$$P_o^f = 1 - \left[e^{-\frac{1}{\phi\rho_s\lambda_m^b}}\frac{\phi\rho_s\lambda_m^b}{\rho_r k_2\lambda_r^r + \phi\rho_s\lambda_m^b}\right] \times \left[e^{-\frac{x_2}{\lambda_m^f\rho_r}}\right] \quad (31)$$

3.2. Throughput of the Proposed System

This model assumes a case in which the macrocell transmits data at a certain rate and that the probability of an outage impacts the system's throughput. The system's throughput can be defined as

$$T = (1 - P_o^n) * R_1 + (1 - P_o^f) * R_2 \quad (32)$$

Where R_1 and R_2 are the target rates for near users and cell edge users, respectively, and P_o^n and P_o^f are the outage probabilities of near user and cell edge users, respectively.

Table 1. Simulation parameters

Parameter	Values
R_1	1 bps/Hz
R_2	1 bps Hz
ρ_s	0-40 dB
a_1	0.05-0.5
a_2	0.5-0.95
ρ_r	0-20 dB
μ_1	0.1-0.9
λ_b^n	1
$\lambda_m^n = \lambda_b^m = \lambda_b^f = \lambda_m^f$	0.5
λ_r^r	0.3
k_1	-15-15 dB
k_2	-20 -20 dB

4. Results

This section presents and analyzes the simulation findings of the proposed cooperative NOMA system with decode and forward MR for downlink communication. The proposed system model includes a vehicle, one decoded and forwarded

MR on top of a vehicle, and a macrocell serving as a BS. We apply the Monte Carlo simulation (MS) to verify the results obtained from Analytical simulation (AS). The parameters that are taken in the simulation are displayed in Table 1.

Figure 2 shows the graphs between OP and transmit SNR for both end users with and without employing MR. It is observed that using MR decreases the OP of vehicular users by up to 90 % at 30 dB transmit SNR.

Figure 3 plots the OP of NU and FU using HD-DF and FD-DF MR against transmitting SNR. Plots show that, with the given simulation parameters, FD-DF MR has a lower OP than HD-DF MR. So, FD-DF MR outperforms the HD-DF MR.

Figure 4 shows the graphs between OP and the power allocation coefficient of FU, i.e., the vehicular user employing MR at different values of transmit SNRs. It is observed from the plots that as the values of the power allocation coefficient increase, the OP of the FU user decreases. It is also observed that OP decreases as the value of transmit SNR increases at a given power allocation coefficient.

Figure 5 shows the graphs between OP and the level of residual interference due to MR for FU, i.e., vehicular users employing MR at different values of transmit SNRs. It is observed from the plots that as the values of the level of residual interference increase, the OP of the FU user increases. It is also observed that OP decreases as the value of transmit SNR increases at a given level of residual interference.

Figure 6 shows the graphs between system throughput and transmit SNR employing HD-DF MR and FD-DF MR. It is observed from the plots that as the values of transmit SNR increase, system throughput increases. Moreover, it is also observed that at higher values of transmit SNR, FD-DF MR has higher throughput than HD-DF MR.

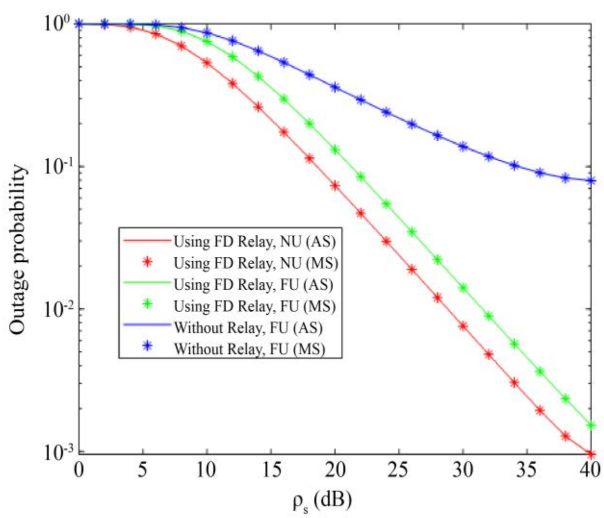

Fig. 2 OP vs transmit SNR (with and without FDDF MR)

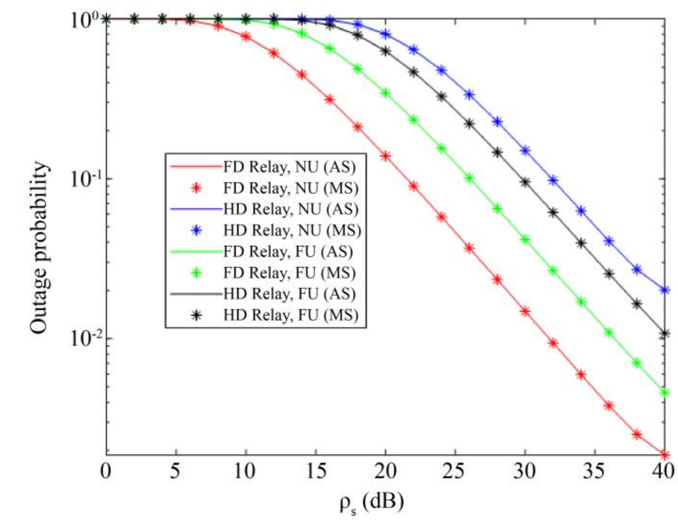

Fig. 3 OP vs transmit SNR (Comparison of HD and FD MR)

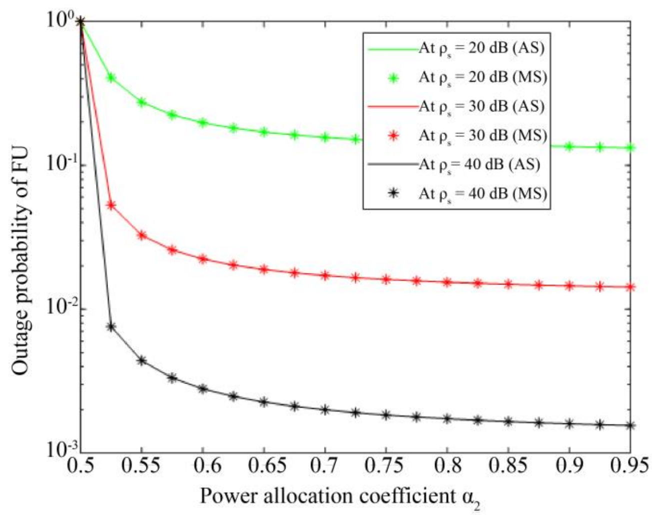

Fig. 4 OP of FU vs power allocation coefficient

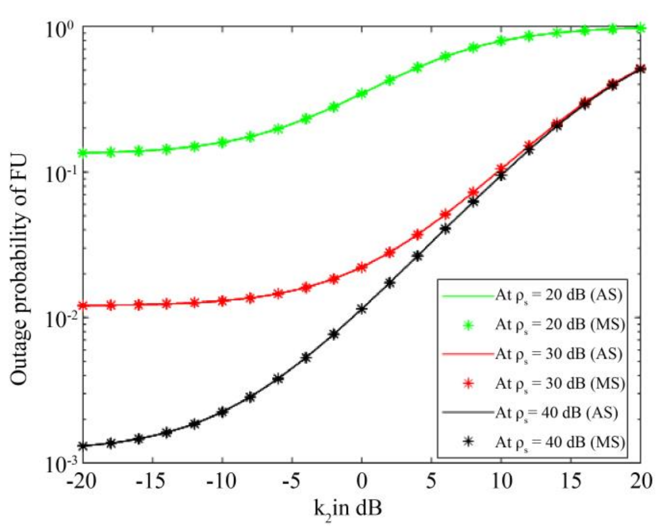

Fig. 5 OP of FU vs level of residual interference

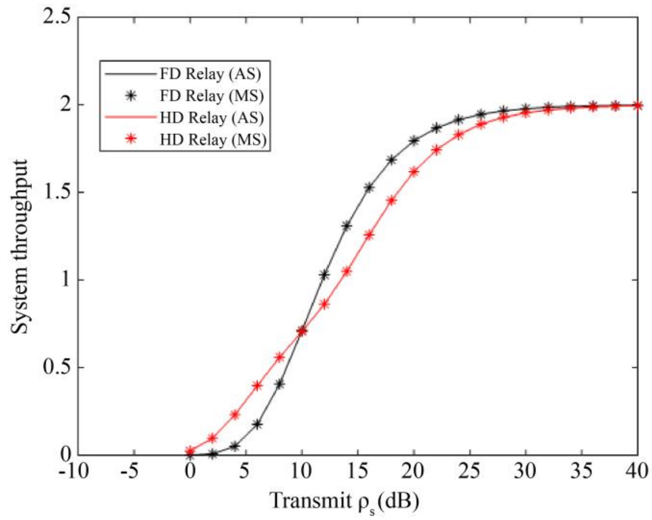

Fig. 6 Throughput vs transmit SNR (Comparison of HD and FD MR)

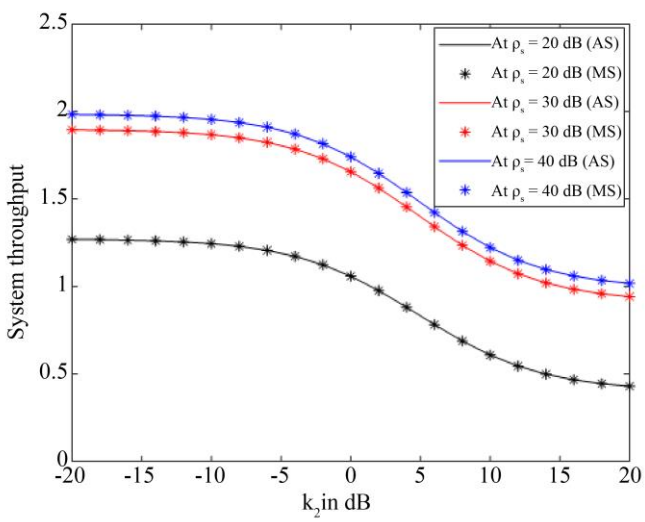

Fig. 7 Throughput vs level of residual interference

Figure 7 shows the graphs between system throughput and level of residual interference with employing FD-DF MR. It is observed from the plots that as the values of the level of residual interference increase, system throughput decreases. Furthermore, it is also observed that system throughput increases as the values of transmit SNR increase at a given level of residual interference.

5. Results

This paper uses imperfect IC to present the performance analysis of the vehicular NOMA system employing FD-DF MR over the Rayleigh fading channel. We first derive the OP of the vehicular user when there is no direct link between the macrocell BS and the vehicular user. We show that in comparison to HD-DF MR and without MR, FD-DF MR has lower outage probability for both users. Additionally, the OP of cooperative NOMA depends on the power allocation coefficient and the level of residual interference and outage of vehicular users reduces as the power allocation coefficient increases.

Second, we examine the throughput of the suggested vehicular NOMA system and find that it reduces the amount of residual self-interference. Therefore, placing FD-DF MR on the roof of the vehicle in the NOMA system outperforms the cooperative NOMA system with HD-DF MR, and MR overcomes the effect of VPL, supporting group handover for vehicular users and lowering the OP of vehicular cell edge users. Relay diversity can be used for the suggested system model in the future.

Declarations

Authors' Contribution

The First Author handles the conceptualizes the manuscript, simulations and drafting. The remaining authors reviewed the manuscript.

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