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ORIGINAL RESEARCH

Evaluation of antenna and relay scheme for cooperative non-orthogonal multiple access

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Abstract

An antenna selection followed by a relay selection scheme (ASRS) is proposed for cooperative non-orthogonal multiple access (NOMA)-based network. The proposed work selects an antenna to maximise the instantaneous rate of poor channel condition users while providing good quality of services (QoS). The outage probability performance of the proposed scheme is plotted for different antenna configuration while varying the SNR and distance with variable number of antennas and available relays. The fairness factor of the proposed work is also discussed, considering three different density areas. The proposed scheme is compared with novel schemes in literature for average sum rate and average energy efficiency to show its superiority.

KEYWORDS

5G mobile communication, bandwidth allocation, cooperative communication, MIMO communication, relay networks (telecommunication)

1 | INTRODUCTION

In the last 10 years, there is a significant growth in wireless communications. Relays are suitable solutions for increasing the coverage and QoS the users receive. Additionally, in the fifth generation (5G), multiple-input-multiple-output (MIMO), machine-to-machine (M2M) communication, augmented reality (VAR) and mobile broadband for high-speed entertainment etc are used. NOMA is one of the technologies which looks promising enough to improve the capacity of the 5G and beyond networks [1–3]. The use of cooperative NOMA allows degrees of freedom in the spatial domain while using a single antenna. The traditional orthogonal multiple access (OMA) assigns an orthogonal resource to a single user at any time. Due to this drawback, OMA is not sustained enough to ensure capacity for 5G and beyond networks. The different ways in which OMA schemes operate are frequency division multiple access (FDMA), code division multiple access (CDMA), and time division multiple access (TDMA). NOMA is classified into two: power and code domain [4]. The same resource block (RB) is used by NOMA for serving multiple users, and this leads to improved connectivity and better spectral efficiency. In NOMA, multiple users share the single frequency channel, which leads to better utilisation of spectrum, as the complete spectrum is available for all the users for transmission, which leads to better throughput, while orthogonal multiple access (OMA) divides the available bandwidth between users at any instant of time which limits their throughput. The work in this paper is focused on the power domain NOMA.

Superposition coding at the transmitter (base Station (BS) or relays) and successive interference cancelation (SIC) are used in NOMA, which proves it is better than OMA. The transmitter in NOMA superimposes signals of multiple users with different power coefficients using linear additions; this superimposed signal is transmitted using a single source [5]. The SIC is performed at the receiver, and the different signals at different signal strengths are decoded depending on their signal strength. The higher strength signal is decoded first and is used to decode subsequent signals. The process is repeated until all the signals are decoded. The weaker signal(s) are considered noise.

OMA uses orthogonal resources that are limited, hence the requirement of non-orthogonal resources arises for handling multiple users simultaneously. Another drawback with OMA is that it works on access request grants, which forces the user to make scheduling requests with BS, and they have to wait for the BS to send clear signals. This leads to higher latency in transmission. While on the other hand, NOMA does not use scheduling which results in lower latency during transmission [6]. NOMA, when used as cooperative communication, can provide better QoS to cell edge users in a cell with the help of relays, as direct communication of cell edge users suffers from poor QoS. The use of relays improves the reliability and spectral efficiency of cell edge users [7].

The signal in cooperative NOMA reaches to the cell users using two-hop communication, and the signals intended for cell edge users is send to relays and then relays transmit them to cell edge users. This leads to the saving of power of the BS for the transmission, which is suitable for greener communication.

1.1 | Work in literature

Many cooperative relaying systems uses NOMA for better QoS [8–11]. The work in Ref. [9] improves the spectral efficiency using NOMA cooperative relay network. The outage probability and sum capacity of NOMA using coordinated and direct relay transmission are better than non-coordinated relays [10]. The work in Ref. [11] examines the energy efficiency (EE) maximisation using power allocation schemes for cooperative NOMA. Fairness in providing resources to users in uplink is compared in Ref. [12] for OMA and NOMA. The sum rate of a two-user MIMO system is compared for OMA and NOMA in Ref. [13]. The work in Ref. [4] uses an equal degree of freedom (DoF) and random power coefficients to show the dominance of NOMA over OMA for MIMO systems, while work in Ref. [14] shows dominance of NOMA over OMA using equal DoF and equal power coefficients for single-input-single-output (SISO) systems. The work in Ref. [1] perform the optimal power allocation while maximising fairness which is done with data rate under full channel state information (CSI) and average CSI is used for outage probability [15]. In Ref. [16], the BS uses NOMA for securing connectivity, providing fairness to users and higher spectral efficiency for multiusers present in different channel conditions.

In Ref. [17], BS and users both have multiple antennas and use relaying to improve the performance of the system. In Ref. [18], decode and forward (DF) relays are equipped with multiple antennas and users use multiple antennas for better QoS in a cooperative NOMA system. The work in Refs. [19, 20] uses MIMO technology to enhance the performance of the system, and the results justified it. In Ref. [21], antenna selection (AS) is introduced to cooperative NOMA having multiple relays and the work proposes a method without having direct links and has benefits of both NOMA and MIMO. In Ref. [22], a coordinated direct and relay transmission (CDRT) scheme using selective DF is proposed which leads to reduction in error propagation. The traditional NOMA-DF scheme proposed in Ref. [23] has been improved in Ref. [24] with higher ergodic sum rate and improvement in outage probability. In Ref. [25], the advantage of cooperative NOMA using multiple relays, with users and relays equipped with multiple antennas, is discussed. The work in Ref. [26] focuses on errors in practical scenario which can result in imperfect SIC. The work uses a residual error of 10^{-2}, 10^{-3} and 10^{-4}, as the value of residual error increases the available capacity or in other words spectral efficiency decreases [27].

In this paper, motivated by the advantages of using multiple antennas for users and relays, the work is done to improve system performance. The paper considers two types of users: low-channel quality users (mainly at the edge of the cell) and good-channel quality users (near users). The work is summarised as follows:

(1) A MIMO relay system employing cooperative is used and a ASRS scheme is proposed which selects the best antenna of BS, relay node and antenna at relay for transmission with better QoS.
(2) The outage probability is simulated against SNR (dB), distance of users and variable number of antennas of BS with variable number of relays. In order to reduce the computational complexity and get a better understanding of outage, the lower bound of outage probability is used for simulations at high SNR.
(3) Users are clustered or grouped for scalability to do the performance analysis of sum rate, energy efficiency and fairness.

The remainder of the work is organised as follows. In Section II-III, the system model and selection of relay are described. In Section IV, simulations are presented and explained. The paper is concluded in section V.

2 | SYSTEM MODEL

The paper considers a single-cell network in which BS is placed at the centre. In the cellular network context for NOMA, both possibilities are there downlink and uplink. For the Vehicular ad hoc networks (VANET), roadside units (RSU) and vehicles are used in place of BS and users, respectively. In the downlink, vehicles reuse the same frequency through the superposition principle of signals, and in the uplink RSU does an interference cancellation. The work in this paper is on NOMA downlink only. The notation and subscripts used are given in Table 1. The network has total U users, including users in vehicles; the total number of users (including in vehicles) at a given instant of time which can serve as a relay are N denoted as r_n, $1 \le n \le N$. The r_n relays are considered to be distributed uniformly, as in the case of real time environment. The relays are used to provide coverage to vehicles or users in poor channel conditions. Let us assume that poor channel condition users (including vehicles) are Q and can be expressed as u_q, $1 \le q \le Q$. The users who can communicate directly with BS are L and can be expressed as u_l, $1 \le l \le L$, where $(N \cup Q \cup L) = U$. These poor channel vehicles or users can be in fading environment or at the edge of the cell, and the r_n relays are used to provide coverage to these users. There are three possible states of a vehicle: parked, stopped and moving. The

TABLE 1 Notations and subscripts.

U,N	Total users, users as a relay
r_n	Denotes a nth relay
u_q	Poor channel condition user
u_l	Good channel condition user
I,J,K	Number of BS, users and relays antennas
$H_{BS,n}$	Channel matrix between BS and nth relay node
$h^i_{BS,n}$	Channel vector of ith transmit antenna between BS and nth relay node
x,y	Transmit and receive signals
P_{BS}, P_{r_n}	Transmit power of BS and nth relay node.
α	Power coefficients
σ	Variance of the noise
γ	SINR
θ_n, $Đ_n$, ϑ_n and φ_n	nth relay beam width, beam direction, beam scanning and coordinate angle
C	Sum rate
EE	Energy efficiency
FF	Fairness factor

stopped vehicles are assumed to have zero speed for a particular time period denoted by t, $0 \le t \le 2$ min and parked vehicle speed is zero for time period greater than 2 min. The parked and stopped vehicle users are ideal for providing coverage to users with poor channel conditions. There is a threshold limit q' on the number of u_q users a relay r_n can serve and is limited by $\sum u_{q'} \le q^{th}$. The source BS, the vehicles or users which can serve as relays, and the users with high QoS are considered to be equipped with I,J and K antennas, respectively. The poor channel condition user due to obstacles or long distances cannot communicate directly with BS, and the relays will be used by these users. The network architecture is similar to that given in Ref. [28]. The wireless links use quasi-static Rayleigh fading and additive white Gaussian noise (AWGN).

In the initial phase BS selects an i^{th} transmit antenna to transmit the superimposed signals of users. In the second phase relays select the j^{th} transmit the decoded signal at the relay. The channel matrix between BS and n^{th} relay node is of the order $J \times I$ and is given as follows:

$$H_{BS,n} = \left[h^{BS}_{i,n}\right] = \left[h^{BS}_{1,n}, h^{BS}_{2,n} \ldots\ldots h^{BS}_{I,n}\right] \text{ where } 1 \le n \le N \text{ and } 1 \le i \le I \quad (1)$$

The channel vector linking ith transmit antenna of BS and nth relay node is given as follows:

$$h^i_{BS,n} = \left[h^i_{BS,n}(1), h^i_{BS,n}(2) \ldots\ldots h^i_{BS,n}(J)\right]^T, \text{where } 1 \le \text{i} \le \text{I} \quad (2)$$

The channel vector is modelled by the following:

$$h^i_{BS,n}(j) \sim CN\left(0, \Omega_{BS,r}\right), \text{where } 1 \le j \le J \quad (3)$$

In this paper, it is assumed that BS perceived all the channel matrices $H_{BS,n}$ and H_{BS,u_l} while nth the relay node is aware of $H_{BS,\left(u_q\|u_l\right)}$. The DF protocol is used for conventional downlink cooperative NOMA. The channel matrix between nth relay node and qth poor channel user of order $K \times I$ is given as follows:

$$h_{u_q,n} = \left[h^j_{u_q,n}\right] = \left[h^1_{u_q,n}, h^2_{u_q,n} \ldots\ldots h^J_{u_q,n}\right] \quad (4)$$

The channel vector linking jth transmit antenna of nth relay node and qth poor channel user is given as follows:

$$h^j_{u_q,n} = \left[h^j_{u_q,n}(1), h^j_{u_q,n}(2) \ldots\ldots h^j_{u_q,n}(K)\right]^T \quad (5)$$

The channel vector is modelled as follows:

$$h^j_{u_q,n}(k) \sim CN\left(0, \Omega_{r_n,u_q}\right), \text{where } 1 \le k \le K \quad (6)$$

In a similar way, the channel matrix between BS and lth near user is of order $J \times I$ and is given as follows:

$$H_{BS,u_l} = \left[h^{BS}_{i,u_l}\right] = \left[h^{BS}_{1,u_l}, h^{BS}_{2,u_l} \ldots\ldots h^{BS}_{I,u_l}\right] \text{ where } 1 \le i \le I \quad (7)$$

The channel vector linking ith transmit antenna of BS and lth relay node is given as follows:

$$h^i_{BS,u_l} = \left[h^i_{BS,u_l}(1), h^i_{BS,u_l}(2) \ldots\ldots h^i_{BS,u_l}(J)\right]^T, \text{where } 1 \le \text{i} \le \text{I} \quad (8)$$

The channel vector is modelled by the following:

$$h^i_{BS,u_l}(j) \sim CN\left(0, \Omega_{BS,u_l}\right), \text{where } 1 \le j \le J \quad (9)$$

Even though near users are not using relays for transmission by the very nature of wireless links and devices, in this paper, we considered that there is a channel matrix between relays and near users. The channel matrix is given as follows:

$$H_{u_l,n} = \left[h^j_{u_l,n}\right] = \left[h^1_{u_l,n}, h^2_{u_l,n} \ldots, h^J_{u_l,n}\right] \quad (10)$$

The channel vector between them is given as follows:

$$h^j_{u_l,n} = \left[h^j_{u_l,n}(1), h^j_{u_l,n}(2) \ldots\ldots, h^j_{u_l,n}(J)\right]^T \quad (11)$$

Each element of which is modelled by the following:

$$h^j_{u_l,n}(j) \sim CN(0, \Omega_{R,u_l}) \quad (12)$$

The paper uses two consecutive slots for the completion of the total transmission of information. The transmit power of BS and relays are P_{BS} and P_{r_n}, respectively. The maximal ratio combiner (MRC) is used at the receiver to maximise SNR and the diversity order [29].

The BS will select the ith antenna for transmission of superimposed signals of u_l and u_q users. The signal is given as follows:

$$x_{BS} = \sqrt{\alpha_l P_{BS}} x_l + \sqrt{\alpha_q P_{BS}} x_q \quad (13)$$

Where α_l and x_l represents power coefficients and signals of near users. α_q and x_q represents power coefficients and signals of poor channel users. Also, $\sum_{l=1}^{L} \alpha_l + \sum_{q=1}^{Q} \alpha_q = 1$.

The signal received at nth relay is given as follows:

$$y^i_{r_n} = h^i_{BS,n} x_{BS} + w_n \quad (14)$$

Using MRC, the signal is given as follows:

$$\tilde{y}^i_{r_n} = \frac{h^i_{BS,n}\left[h^i_{BS,n}\right]^H x_{BS} + \left[h^i_{BS,n}\right]^H w_n}{\left\|h^i_{BS,n}\right\|} \quad (15)$$

$$= \frac{\sqrt{\alpha_l P_{BS}} x_l(t_1) h^i_{BS,n}\left[h^i_{BS,n}\right]^H + \sqrt{\alpha_q P_{BS}} x_q h^i_{BS,n}\left[h^i_{BS,n}\right]^H + \left[h^i_{BS,n}\right]^H w_n}{\left\|h^i_{BS,n}\right\|} \quad (16)$$

For simplification, let $P_{BS} = P_{r_n} = P$, $\sigma^2_{r_n} = \sigma^2$.

The instantaneous SINR by nth relay node to decode x_q

$$\gamma^i_n = \frac{\alpha_q P \sum_{j=1}^{J} \left|h^i_{BS,n}(j)\right|^2}{\alpha_l P \sum_{j=1}^{J} \left|h^i_{BS,n}(i)\right|^2 + \sigma^2} \quad (17)$$

If we consider only one near user and one poor channel user, the above expression will be

$$\gamma^i_n = \frac{(1-\alpha_l)\gamma \sum_{j=1}^{J} \left|h^i_{BS,n}(j)\right|^2}{\alpha_l \gamma \sum_{j=1}^{J} \left|h^i_{BS,n}(i)\right|^2 + 1} \quad (18)$$

Where the average SNR of the system is $\gamma \triangleq \frac{P}{\sigma^2}$ and $\alpha_l + \alpha_q = 1$

The signal received at lth user is given as follows:

$$y^i_{u_l} = h^i_{BS,u_l} x_{BS} + w_{u_l} \quad (19)$$

Using the MRC signal will be

$$\tilde{y}^i_{u_l} = \frac{h^i_{BS,u_l}\left[h^i_{BS,u_l}\right]^H x_{BS} + \left[h^i_{BS,u_l}\right]^H w_{u_l}}{\left\|h^i_{BS,u_l}\right\|} \quad (20)$$

The instantaneous SINR for nth relay node to decode x_l and x_q after applying, SIC is given as follows:

$$\gamma^i_l[t_1] = \alpha_l \gamma \sum_{k=1}^{K} \left|h^i_{BS,u_l}(k)\right|^2 \quad (21)$$

$$\gamma^i_{l,q} = \frac{\alpha_q P \sum_{k=1}^{K} \left|h^i_{BS,u_l}(k)\right|^2}{\alpha_l P \sum_{k=1}^{K} \left|h^i_{BS,u_l}(l)\right|^2 + \sigma^2} \quad (22)$$

The n^{th} relay node will select the j^{th} antenna to transmit decoded signal(s) x_q. In the meantime, BS will be transmitting the signals x_l for u_l users.

The signal received by poor channel users will be

$$y^j_{u_q} = \sqrt{P_{r_n}} h^j_{u_q,r_n} x_q + w_{u_q} \quad (23)$$

Using MRC, the signal at u_q will be

$$\tilde{y}^j_{u_q} = \frac{\sqrt{P_{r_n}} h^j_{u_q,r_n}\left[h^j_{u_q,r_n}\right]^H x_{BS} + \left[h^j_{u_q,r_n}\right]^H w_{u_q}}{\left\|h^j_{u_q,r_n}\right\|} \quad (24)$$

For u_q to decode x_q, the instantaneous SINR is given as follows:

$$\gamma^j_{u_q} = \frac{P}{\sigma^2} \sum_{k=1}^{K} \left|h^j_{u_q,r_n}(k)\right|^2 \quad (25)$$

In this condition, the signal received at u_l users is given as follows:

$$y^{i,j}_{u_l} = \sqrt{\alpha_l P_{BS}} h^i_{BS,u_l} x_l + \sqrt{P_{r_n}} h^j_{u_p,r_n} x_q + w'_{u_l} \quad (26)$$

After decoding, u_l can remove the signal of x_q which is an interfering signal. This is possible only if,

$$R_{u_q} \le log_2\left(1 + \gamma^i_{u_l,u_q}\right) \quad (27)$$

Where is R_{u_q} is the target data rate of the user u_q.

When Equation (27) holds true, and the channel estimation is done correctly, the SINR for x_q detection is given as follows:

$$\gamma^i_{u_l}[t_2] = \frac{\alpha_1 P}{\sigma^2} \sum_{k=1}^{K} \left|h^i_{BS,u_l}(k)\right|^2 \quad (28)$$

The achievable data rate of u_l is given as follows:

$$C_{u_l} = \frac{1}{2}\, log_2\{1+\gamma_l^i[t_1]\} + \frac{1}{2}\, log_2\left\{1+\gamma_{u_l}^i[t_2]\right\} \quad (29)$$

Using SIC, it needs to be ensured that u_l the targeted data rate is achieved, which depends on the following two conditions:

$R_{u_l} \le C_{u_l}$ and Equation (27) is satisfied.

Further, we can select antennas β which ensure transmission between BS and near users, keeping this in mind, we assume that $\gamma_l^i[t_1] = \gamma_{u_l}^i[t_2] = \gamma_{u_l}^i$ and putting in Equations (21) and (28), we get the following:

$$C_{u_l} = log_2\left\{1+\gamma_{u_l}^i\right\} \quad (30)$$

$$\sum_{k=1}^{K} \left|h_{BS,u_l}^i(k)\right|^2 > max\left\{\frac{2^{2R_{u_l}}-1}{\alpha_l\gamma}, \frac{2^{2R_{u_q}}-1}{\gamma\left(1-\left(1-\alpha_q\right)2^{2R_{u_q}}\right)}\right\} = w \quad (31)$$

To ensure transmission between BS and poor channel users,

$$C_{u_q} = \max_{\substack{1\le n\le N\\ i\in\beta\\ 1\le j\le J}} \left\{min\left\{\frac{1}{2}log_2\{1+\gamma_l^i[t_1]\} + \frac{1}{2}log_2\left\{1+\gamma_{u_l}^i[t_2]\right\}\right\}\right\} \quad (32)$$

3 | OUTAGE PROBABILITY

For u_l users, when the BS antennas not able to meet the requirements of the rate, the transmission will be outage. The outage probability of u_l will be

$$P_{u_l} = \prod_{i=1}^{I} P\left(\sum_{k=1}^{K}\left|h_{BS,u_l}^i(k)\right|^2 < w\right) \quad (33)$$

Using the work given in [30, 31], the cumulative density function (CDF) of $\left|h_{BS,u_l}^i(k)\right|^2$ will be

$$CDF(z) = 1 - exp\left(\frac{-z}{\Omega_{BS,u_l}}\right)\sum_{p=0}^{K-1}\frac{1}{p!}\left(\frac{z}{\Omega_{BS,u_l}}\right)^p \quad (34)$$

Using above P_{u_l} will be calculated as follows:

$$P_{u_l} = \left[1 - exp\left(\frac{-w}{\Omega_{BS,u_l}}\right)\sum_{p=0}^{K-1}\frac{1}{p!}\left(\frac{w}{\Omega_{BS,u_l}}\right)^p\right]^I \quad (35)$$

In order to obtain system diversity gain, the lower bound of outage probability approximated for higher SNR. For higher SNR,

$$\lim_{\gamma\to\infty} P_{u_l} = \left(\frac{u_l^K}{K!\left(\Omega_{BS,u_l}\right)^K\gamma^K}\right)^I \quad (36)$$

Equation (3) reduces to $\frac{1}{\gamma^{IK}}$.

Using Equation (31), $max\left\{\frac{2^{2R_{u_l}}-1}{\alpha_l\gamma}, \frac{2^{2R_{u_q}}-1}{\gamma\left(1-\left(1-\alpha_q\right)2^{2R_{u_q}}\right)}\right\} = w$

$$w_l = \gamma w = max\left\{\frac{2^{2R_{u_l}}-1}{\alpha_l}, \frac{2^{2R_{u_q}}-1}{\left(1-\left(1-\alpha_q\right)2^{2R_{u_q}}\right)}\right\} \quad (37)$$

This gives diversity order of u_l as $g_l = IK$ (38)

The outage probability for any t antennas used by BS for transmission is given as follows:

$$P_{u_l}{}^t \cong \binom{I}{t}\left(\frac{u_l^K}{K!\left(\Omega_{BS,u_l}\right)^K\gamma^K}\right)^{I-t} \quad (39)$$

If n is the relay node and u_q user is not able to decode its information correctly even in presence of many antennas. The outage probability of P_{u_q} is given as follows:

$$P_{u_q} = P_{u_l} + P(r_n) \quad (40)$$

Finding the CDF and probability density function (PDF) using [31], the outage probability of relay node is given as follows:

$$\begin{aligned} P(r_n) = \sum_{t=1}^{I}\Bigg(&\left[1 - exp\left(\frac{2^{2R_{u_q}}-1}{\gamma\Omega_{r_n,u_q}}\right)\sum_{p=0}^{K-1}\frac{1}{p!}\left(\frac{w}{\Omega_{r_n,u_q}}\right)^p\right]^J \\ &+\left[1 - exp\left(\frac{2^{2R_{u_q}}-1}{\gamma\left(1-\left(1-\alpha_q\right)2^{2R_{u_q}}\right)\Omega_{BS,r_n}}\right)\sum_{p=0}^{J-1}\frac{1}{p!}\left(\frac{w}{\Omega_{BS,r_n}}\right)^p\right]^t - \left[1 - exp\left(\frac{2^{2R_{u_q}}-1}{\gamma\Omega_{r_n,u_q}}\right)\sum_{p=0}^{K-1}\frac{1}{p!}\left(\frac{w}{\Omega_{r_n,u_q}}\right)^p\right]^W \\ &\times\left[1 - exp\left(\frac{2^{2R_{u_q}}-1}{\gamma\left(1-\left(1-\alpha_q\right)2^{2R_{u_q}}\right)\Omega_{BS,r_n}}\right)\sum_{p=0}^{J-1}\frac{1}{p!}\left(\frac{w}{\Omega_{BS,r_n}}\right)^p\right]^t\Bigg)^N \\ &\times\left[1 - exp\left(\frac{-w}{\Omega_{BS,u_l}}\right)\sum_{p=0}^{K-1}\frac{1}{p!}\left(\frac{w}{\Omega_{BS,u_l}}\right)^p\right]^{I-t} \times exp\left(\frac{-tw}{\Omega_{BS,u_l}}\right)\binom{I}{t}\left(\sum_{p=0}^{K-1}\frac{1}{p!}\left(\frac{w}{\Omega_{BS,u_l}}\right)^p\right)^t \end{aligned} \quad (41)$$

The outage probability of u_q is given as follows:

$$P_{u_q} \cong P_{u_l} + \sum_{t=1}^{I} \left[\left\{ \left(\frac{2^{2R_{u_q}} - 1}{\gamma\left(1 - \left(1 - \alpha_q\right) 2^{2R_{u_q}}\right) \Omega_{BS,r}} \right)^{J} \times \frac{1}{J!} \right\}^{t} + \left(\frac{\left(2^{2R_{u_q}} - 1\right)^{K}}{K!\left(\Omega_{r_n,u_q}\right)^{K} \gamma^{K}} \right)^{J} \right]^{N} \times \binom{I}{t} \left(\frac{u_l^K}{K!\left(\Omega_{BS,u_l}\right)^{K} \gamma^{K}} \right)^{I-t} \tag{42}$$

For finding the diversity order of u_q, find variables A and B such that

$$A = \min_{t \geq K, 1 \leq t \leq I} \{K(I + NJ - t)\} \tag{43}$$

$$B = \min_{t \leq K, 1 \leq t \leq I} \{K(I + t(N-1))\} \tag{44}$$

The values of A and B will be used to find the diversity of u_q

$$g_q = min\{\min(A, B), IK\} \tag{45}$$

4 | SELECTION OF RELAY

The poor channel user(s) u_l distance from the relay decides which relay will be used for transmission. In this literature while deciding the relay for transmission antenna, its parameters are not taken into account to calculate the distance or more specifically coverage area. Also, they considered antennas to be omnidirectional, which results in increased interference. While some scheme uses the direction and directive beam width of the antenna [32]. The *nth* relay beam width and beam direction are denoted by θ_n and $Đ_n$ degrees, respectively. The beam scanning and coordinate angle of *nth* relay is denoted by ϑ_n and φ_n

$$Đ_n = |\varphi_n \pm \vartheta_n| \tag{46}$$

Also, $\vartheta_n < \frac{|180° - \theta_n|}{2}$

The work in this paper considers both the distance and angle of poor channel users with the relay, before the selection of a relay for cooperative communication. A poor channel user, when served by any relay, will receive interference from adjacent relays when their beam extends into each other. The poor channel might be due to attenuation, multipath fading and interference from nearby relays and users, and for considering the effect of these factors in this paper, a quasi-static Rayleigh fading is used. The fading then is constant within the blocks. While considering interference, the work in this paper considers the effect of interference from other users utilising the same relay for transmission with BS; this affects SIC considerably. These factors decide the strength of the signal received by the receiver of the poor channel user and decide the carrier to noise and interference ratio (*CNIR*). Using Shannon's capacity theorem,

$$C = B \times log_2 (1 + CNIR) \tag{47}$$

The *CNIR* in dB can be calculated using the following:

$$CNIR = 10\, log_{10} \left(\frac{P_{r_n}}{\sum_{n' \neq n} P_{r_{n'}}} \right) \tag{48}$$

Let P_{r_n} is power of *nth* serving relay and $P_{r_{min}}$ is the minimum power required for good QoS, then $P_{r_n} \geq P_{r_{min}}$. $\sum_{n' \neq n} P_{r_{n'}}$ is the sum of the power of the interfering relay with *nth* serving relay.

The P_{r_n} in dB at a distance "?" from the serving *nth* relay can be calculated as follows:

$$P_{r_n}(d) = P_t(d) - P_L(d) \tag{49}$$

Where P_t denotes the transmitter power and P_L denotes path loss factors [33]. The minimum received power required in dB for good QoS is denoted by $P_{r_{min}}$ and, therefore, the algorithm for antenna selection at BS followed by relay selection (ASRS) is explained as follows:

Algorithm

1. First of all, create the subset of antennas at the base Station for successful transmission in BS-u_l channel

$$A = \left\{ i : 1 \leq i \leq I, \left\| h_{BS,u_l} \right\|^2 > \sum_{k=1}^{K} \left\| h_{BS,u_l}^{i}(k) \right\|^2 \right\} \tag{50}$$

2. Selection of relay for poor channel users, which maximises the instantaneous rate of BS-u_q channel. Poisson distribution is considered for the distribution of the users and with the implementation of quasi-static Rayleigh fading.

for $n=1:N$
for $u_q=1:u_Q$
Find the angle between n^{th} relay and a poor channel user.

$$\Phi_{r_n,u_q} = \left|Ð_{r_n} - \varphi_{uq}\right| \tag{51}$$

Find all relays and poor channel users with $\Phi_{r_n,u_q} \le \frac{\theta}{2}$. Let the number of relays that satisfies this condition are n_ϕ, $n_\phi \subseteq$N.
Calculate $P_{r_{n_\phi}}$.

$$P_{r_{n_\phi}} \ge P_{r_{min}}, \forall n_\phi \tag{52}$$

For all relays, find the relay which has

$$\begin{aligned} &max\left\{min\left\{\left|h^i_{BS,n_\phi}\right|^2, \left|h^i_{n_\phi,u_l}\right|^2, \left|h^j_{n_\phi,u_q}\right|^2\right\}\right\} \\ &max\left\{min\left\{\left|h^i_{BS,n_\phi}\right|^2, \left|h^i_{n_\phi,u_l}\right|^2, \left|h^j_{n_\phi,u_q}\right|^2\right\}\right\} \end{aligned} \tag{53}$$

This n_ϕ relay will be used by poor channel user for transmission. The flowchart is shown in Figure 1.

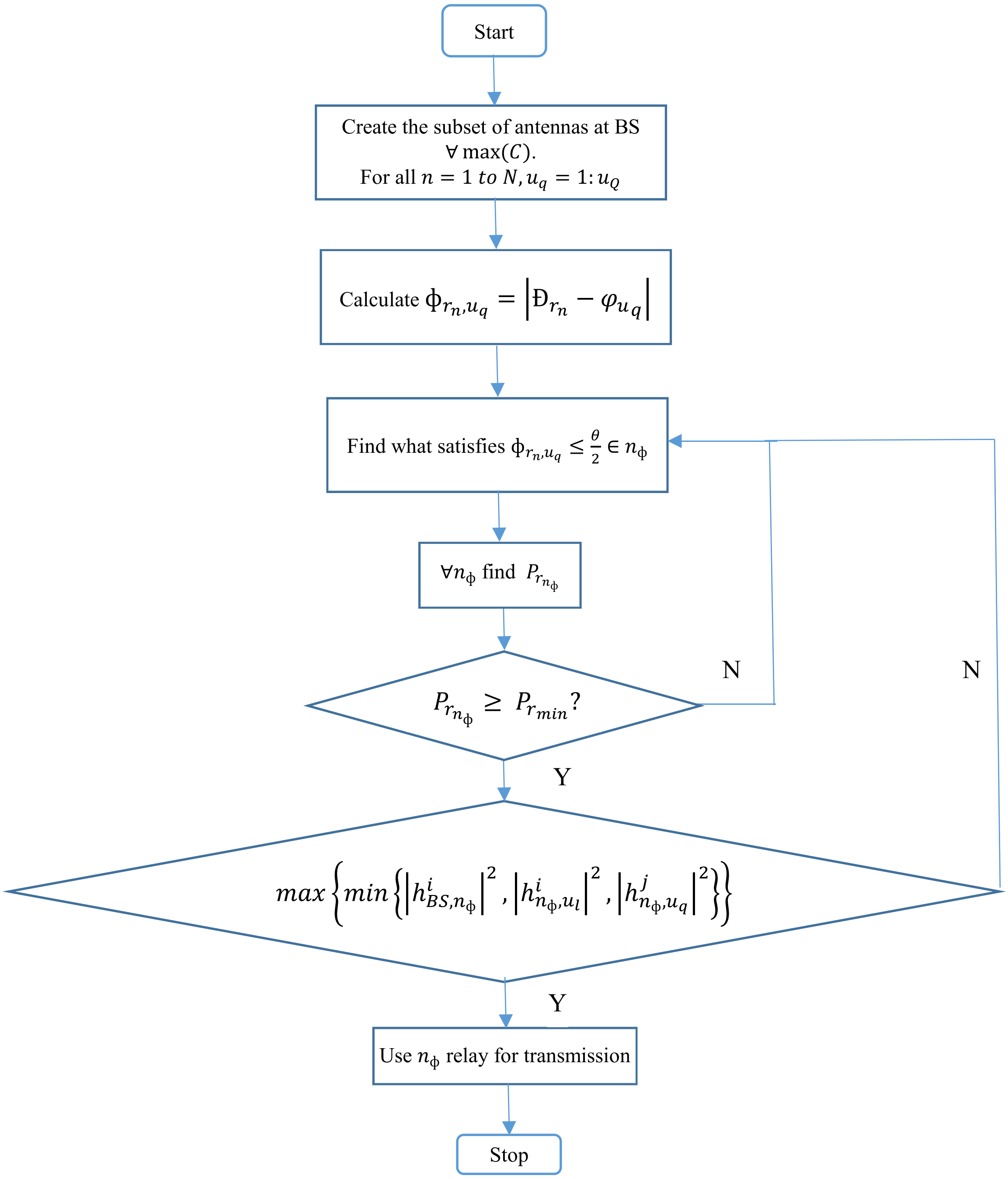

FIGURE 1 Flowchart of the proposed work.

In cooperative NOMA, the devices or users which are used as relays are not fixed [28]. The relays will be used either for one-hop or two-hop communication. The number of antennas, power levels, and processor capability of a relay decide its ability to work. Depending upon the capability of the user or vehicle, it can be in any of these modes.

a. Relays will not perform SIC for users.
b. Relay will perform SIC for users.

5 | SYSTEM ANALYSIS

For the simulations MATLAB is used and all the results are average of 5 simulations.

5.1 | Sum rate

For any q'^{th} user after application of SIC, the data rate that can be achieved in time subslot t is given as follows:

$$C_{q',n} = t \times log_2\left(1 + \min\left(SNR_{q'} + SINR_{q'}\right)\right) \tag{54}$$

The system data rate of the system when the relays will not perform SIC for users, mode (a) is used will be given as follows:

$$C_{total,n} = \sum_{q'} C_{q'} \tag{55}$$

The system data rate of the system when the relays perform SIC for users, mode (b) is used will be given as follows:

$$C_{total,n} = C_{r_n} + \sum_{q'} C_{q'} \tag{56}$$

Where $C_{r_n} = t \times log_2(1 + SNR), SNR = \frac{P_{q'+1}P_{r_n}|h_{r_n}|^2}{\sigma^2}$, C_{r_n}: relay data rate. With $C_{r_n} > C_{q',n}$.

5.2 | Energy efficiency

The optimisation of energy efficiency (EE) is one of the important objectives of the 5G network. The EE for cooperative NOMA [26, 27] depends on data rate of the user and the power consumption of the relay to achieve it. The EE of any q' user at the time signal is received given by the following:

$$EE_{q'} = \frac{C_{q',n}}{P_{utilization}} \tag{57}$$

$P_{utilization}$: power utilisation of n^{th} relay for sending a message to q' user.

The energy efficiency of the system for all q' users using nth relay is given as follows:

$$EE_{total,n} = \frac{C_{total,n}}{\sum_{q'} P_{utilization}} \tag{58}$$

5.3 | Fairness factor

$$FF_{total} = \frac{\left(\sum_{q'} C_{q',n}\right)^2}{q' \times \sum_{q'} \left(C_{q',n}\right)^2} \tag{59}$$

The maximum fairness factor is 1, the higher the value of FF, the better the quality of service user receives.

6 | RESULTS AND SIMULATIONS

For the purpose of simulation, the parameters [28, 34] used are carrier frequency in THz is 0.34, bandwidth at BS is 10 GHz, cell radius for the high-density area is 500m, the medium-density area is 1300 m and for the low-density area is 1700m. The outage probability of u_l is analysed with respect to SNR and its position in Figures 2 and 3, respectively. It can be seen from Figure 4, that the outage probability is almost equal to 1 when one antenna is used for BS and user, the outage probability is high up to SNR = 15 dB and decreases slightly from SNR 15–30 when $I = 2$, $K = 2$. The outage probability starts decreasing for low SNR when $I = 3$, $K = 2/3$ as the number of antenna increases the probability of outage is almost negligible for SNR = 18 dB.

In Figure 3, the curves of the outage probability are plotted with respect to the position of u_l^{th} user for the different number of BS and user antennas. It is clearly evident from the curves for different antenna configurations that as distance increases from BS, the outage probability of the u_l^{th} user increases. The outage probability is close to one for all antenna configurations when they are far from BS. This clearly indicates that the channel conditions are poor when a user is far from BS, and there is no much influence of having more antenna with BS and user.

In Figure 4, the curves of the outage probability are plotted with respect to the SNR of u_q^{th} user with different antenna configurations of BS and number of relay and user antenna fixed to 2. The number of relays is fixed at 3. From the result, it is evident that increasing the number of BS antennas reduces the chances of outage considerably and becomes almost negligible at SNR = 27 dB for the number of BS antennas = 4.

The fairness factor (*FF*) defined in equation (46) for U users is $\frac{1}{U} \leq FF \leq 1$, where $FF_{max} = 1$. As the number of users in the system increases the fairness decreases. The FF indicates how the resources are shared among users. In Figure 5, FF is compared for three different scenarios for a maximum, when

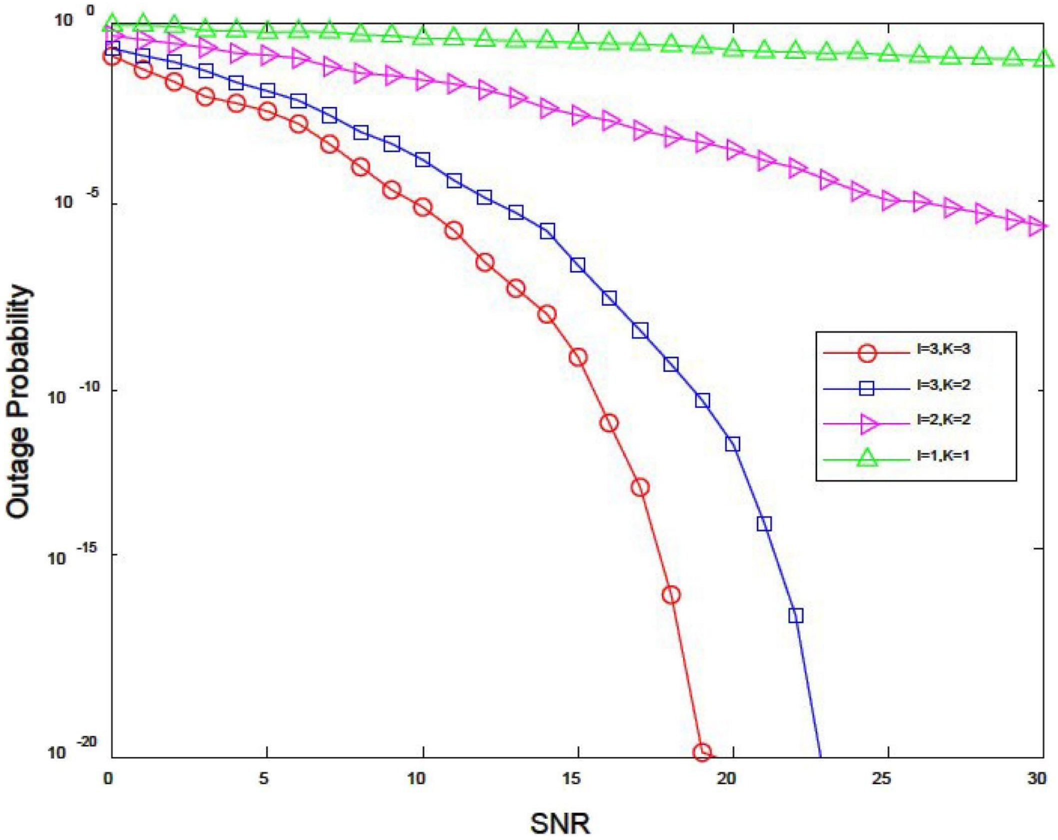

FIGURE 2 Illustration for outage probability versus SNR for u_l user for different antenna configuration for BS and user.

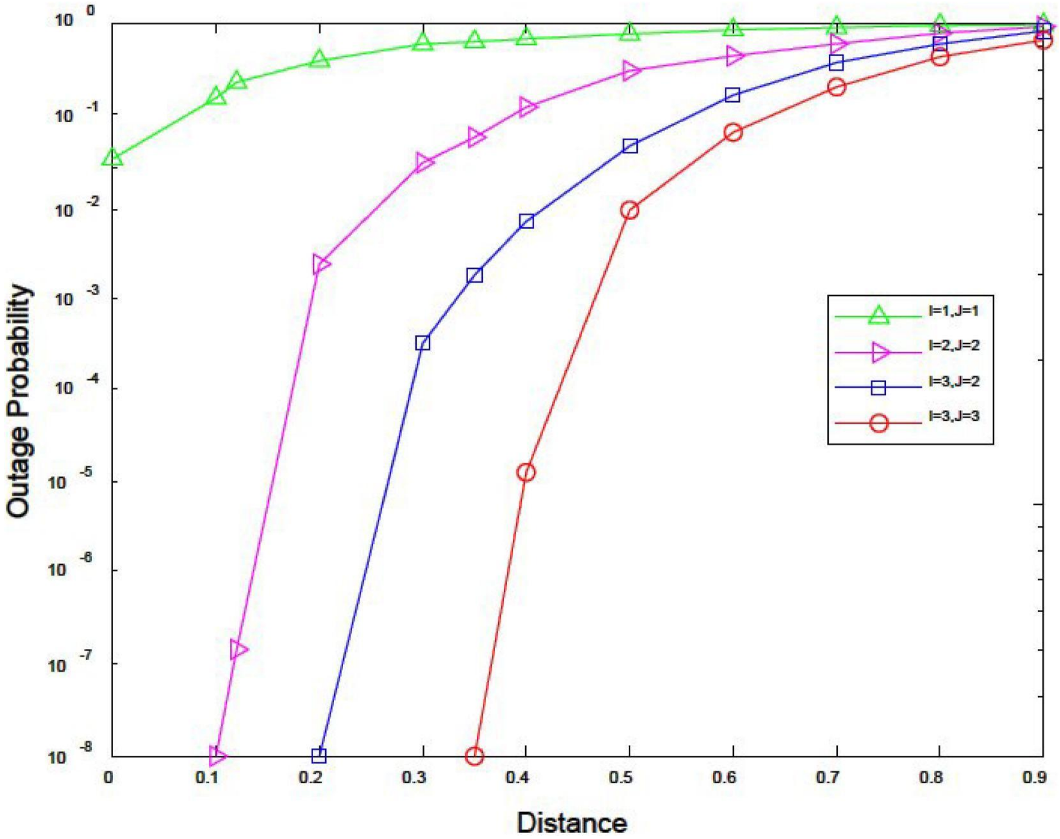

FIGURE 3 Illustration for outage probability versus SNR for u_l user for different antenna configuration for BS and user and position from BS.

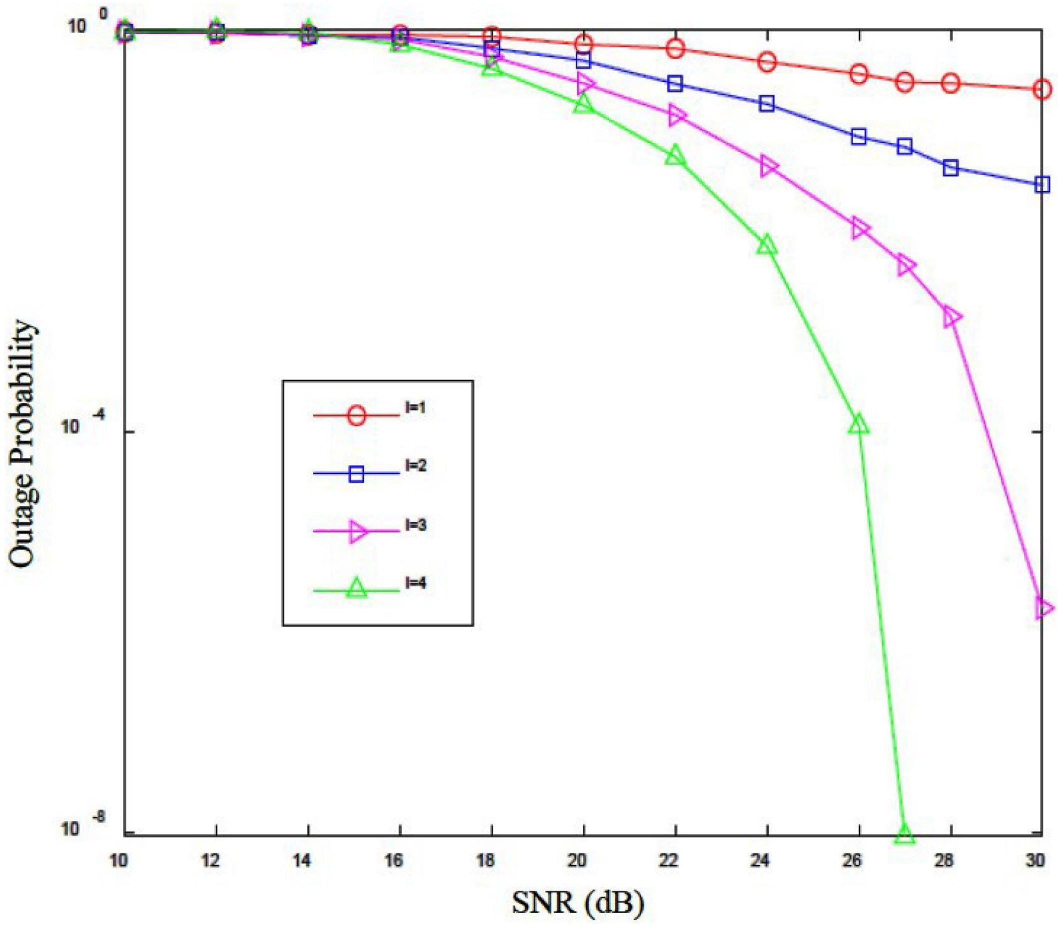

FIGURE 4 Illustration for outage probability versus SNR for u_q user for different antenna configuration for BS.

cell density in terms of location city, suburbs and rural areas. In low and medium-density areas, due to the availability of resources due to fewer users, more resources can be assigned to users with poor channel conditions, therefore fairness decreases for these two scenarios. Also, channel quality is affected due to distributed users.

In Figure 6, the curves of the average sum rate of the users are plotted versus the number of users in the cell. The maximum number of users considered are 500. The proposed ASRS scheme is compared with the CNCS, ANCS, CNAS and ANAS explained in Ref. [25]. As the number of users increase, the average sum rate for all schemes increases. The ASRS scheme performs better than other schemes as it employs antenna and relay selection to ensure good channel quality for poor channel condition users.

In Figure 7, the average energy efficiency (*EE*) of the system is analysed in the presence of users varying from 150 to 500. The average energy efficiency of the system is a variable of data rate of the system at any instant of time or is a variable of the data rate of poor channel users. The ASRS scheme improves it as it uses the relays for transmission to poor channel users, which are least crowded, and selects an antenna which maximises the instantaneous rate. This leads to lesser interference and SIC requirements at the relay.

In Figure 8, the outage probability versus SNR for u_q user for the varying number of the relay are shown. Increase in the number of relays will decrease the outage probability. The outage probability is mainly affected by the accessibility of near users after a certain number of relays (1–4) are available in the network. In general, the number of available relays and the poor channel condition user, which can pair with near user, improves the system capacity.

In Figure 9, the outage probability versus SNR for u_q user for the varying number of relays and antennas is shown. It is evident from Figure 8, that increasing relays has little impact after relays increase to a certain degree. In order to reduce the outage probability number of antennas of BS, relays and users required to be varied. The gain in performance from a multiple antenna network is evident from Figure 9 when compared with a single antenna and single relay configuration.

7 | CONCLUSION

In this paper, an ASRS scheme is proposed for cooperative NOMA. The scheme makes the selection of antenna and relay for poor channel condition users. The antenna selection is based on maximising the instantaneous rate, and the relay selected is

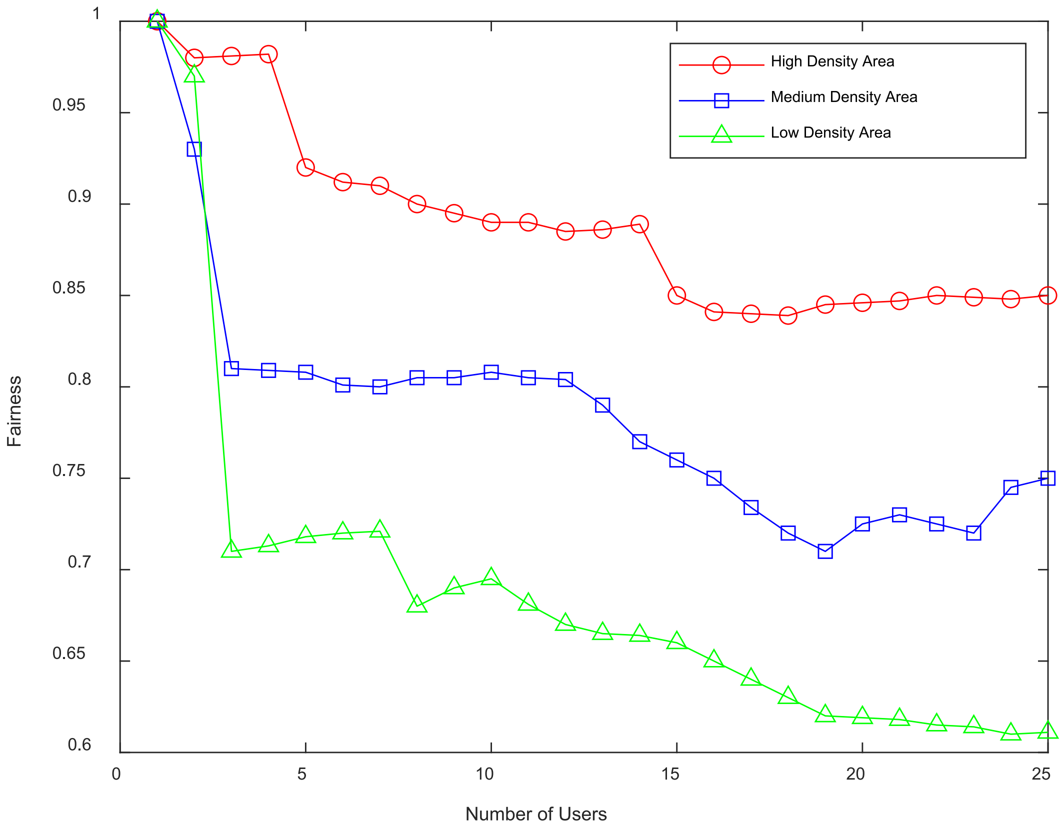

FIGURE 5 Fairness comparison for different density of users.

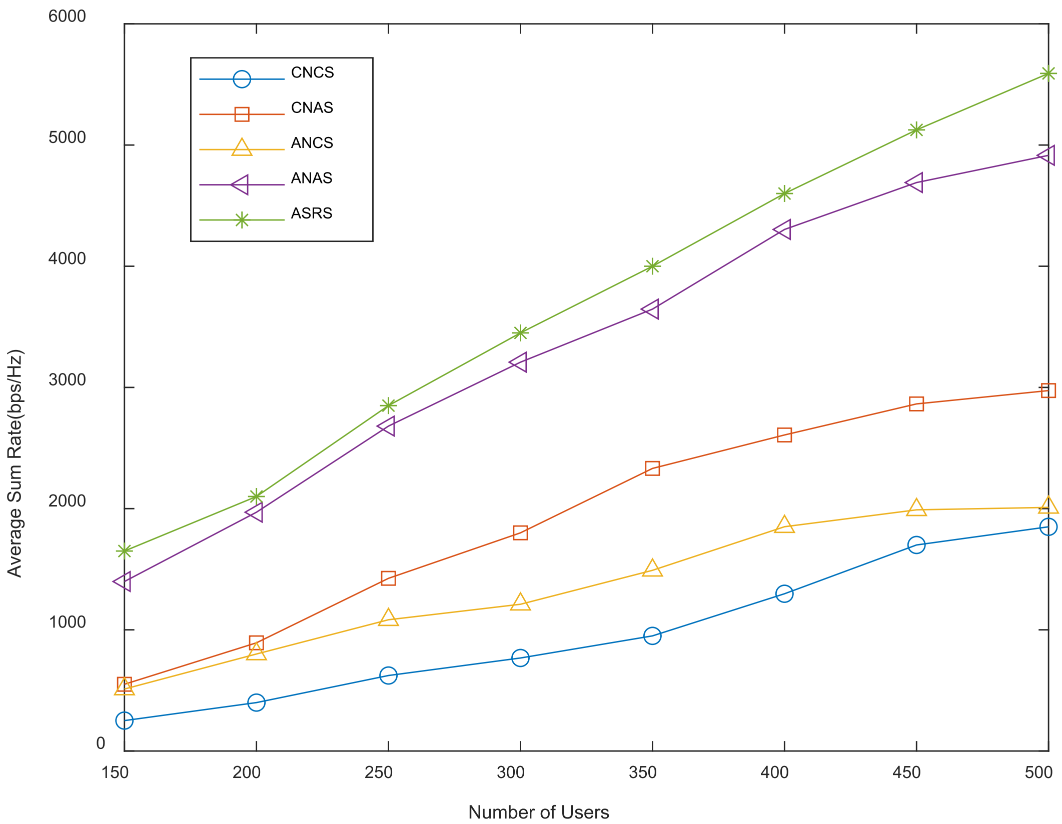

FIGURE 6 Illustration of average sum rate for different user's configurations for different schemes.

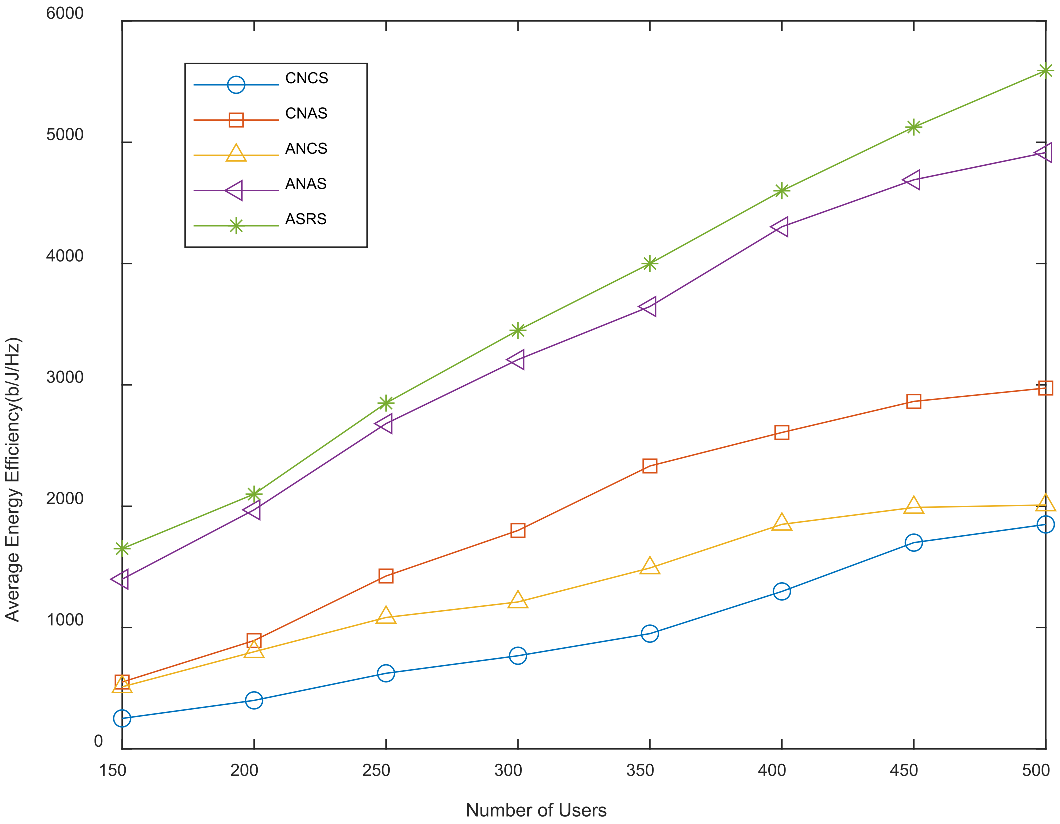

FIGURE 7 Illustration of average energy efficiency for different user configurations for different schemes.

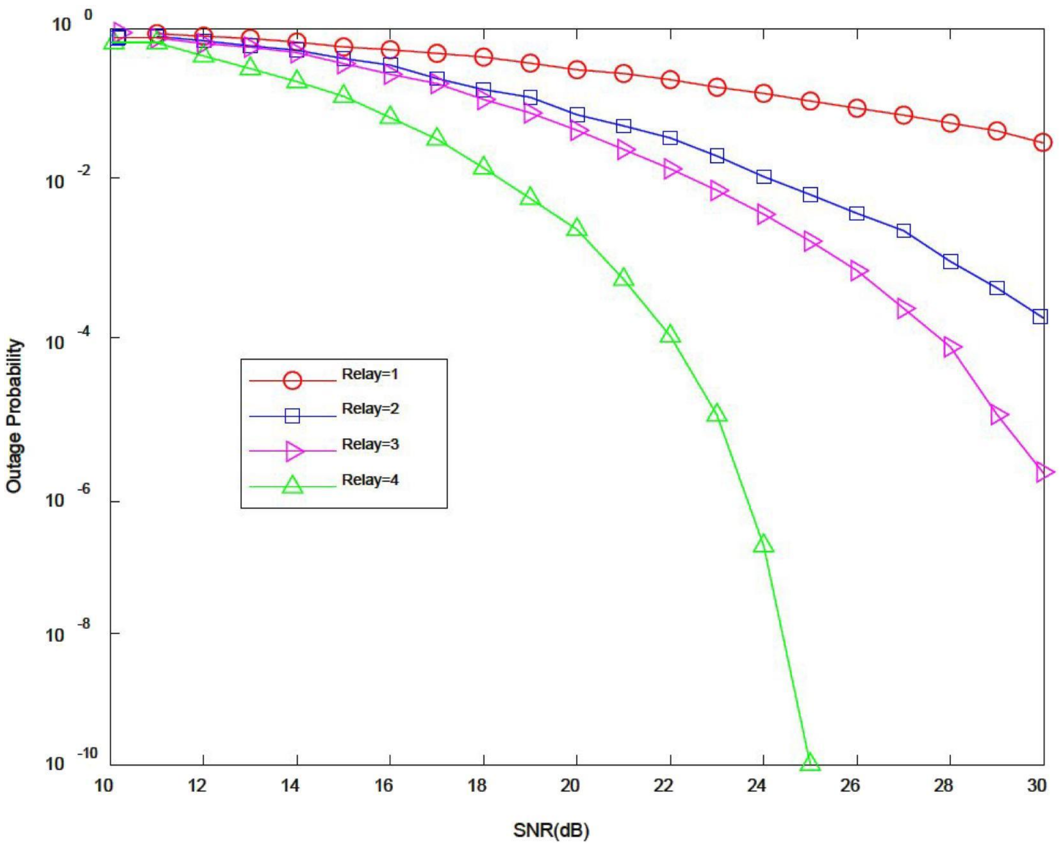

FIGURE 8 Illustration for outage probability versus SNR for u_q user for varying number of relays.

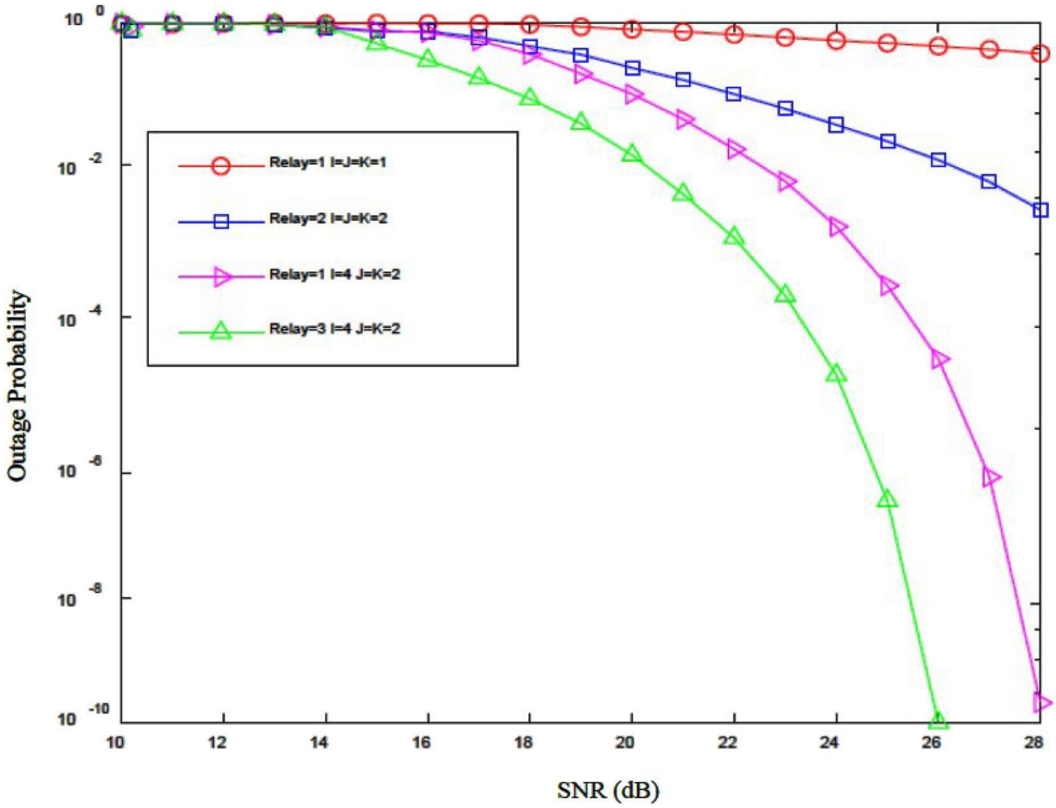

FIGURE 9 Illustration for outage probability versus SNR for $u_q$user for varying number of relays and antennas.

one that is least crowded. The outage probability of the users is plotted for different antenna configurations, and the proposed scheme is compared with other works in the literature to show its accuracy. Simulated results verified the proposed work findings. In the future, work will be done to find the suitability of the proposed ASRS scheme for imperfect SIC in a practical scenario regarding data rate and spectral efficiency.

AUTHOR CONTRIBUTIONS

Vipin balyan: Conceptualisation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Writing – original draft; Writing – review & editing.

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CONFLICT OF INTEREST STATEMENT

The author declares there are no conflicts of interest with respect to submission and publication of this paper.

DATA AVAILABILITY STATEMENT

Research data is not shared. The author will use data for research in the future and cannot be made available. Data will be made available to others providing proper motivation.

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