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Hybrid Relaying Cooperative NOMA with Adaptive and Opportunistic Resource Allocation for Downlink Optimization in B5G Networks

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Abstract: This research investigates the optimization of downlink performance metrics, including spectral efficiency, data rates, and coverage, for cell-edge user equipment (UE) in Beyond 5G (B5G) networks using a hybrid relaying Cooperative Non-Orthogonal Multiple Access (CNOMA) framework. The system architecture consists of a gNodeB (gNB) located at the cell center, serving both an intra-cell cluster (ICC) near the gNB and a cell-edge cluster (CEC) positioned farther away. To address the challenges faced by UEs in these clusters, particularly random signal strength deprivation due to deep Rayleigh fading, two novel resource allocation strategies are proposed: Channel-Aware Adaptive Fair (CAAF) Power Allocation and Resource-Free Best Positioned Opportunistic Relay Selection (RFBP-ORS). The CAAF method ensures fair and dynamic power allocation by leveraging real-time channel state information (CSI), while RFBP-ORS selects the optimal relay based on resource availability and spatial positioning, thereby maintaining uninterrupted connectivity. Simulation results reveal that the proposed methodologies significantly enhance the achievable data rates by up to 140% compared to conventional CNOMA, reaching 5.8 bps/Hz at 12.5 dB SINR. They also improve energy efficiency to 1 Gb/J and achieve a 10 times reduction in outage probability for cell-edge users at 12.5 dB SINR, thereby demonstrating strong suitability for B5G deployment requirements. The proposed CNOMA-based hybrid relaying scheme outperforms conventional resource allocation approaches, offering a reliable and efficient communication framework for B5G networks, particularly benefiting UEs near the cell edge. These findings underline the potential of CNOMA-based adaptive and opportunistic resource allocation in addressing the evolving demands of next-generation wireless networks.

Keywords: B5G networks; cell-edge optimization; cooperative NOMA; hybrid relaying; resource allocation

1 INTRODUCTION

Proliferation of connected devices and exponential growth of mobile data traffic demanded a paradigm shift in multiple access techniques of cellular networks beyond 5G for peak data rate improvement, efficient resource utilization, massive connectivity and enhanced ultra-reliability. Traditionally, wireless networks have been using Orthogonal Multiple Access (OMA) methods that reserve different resources to users so that they do not interfere with each other. OMA was fine for previous generations but has problems in satisfying the demands of dense and data-intensive networks.

Non-Orthogonal Multiple Access (NOMA) is a promising approach that will enable simultaneous transmission to multiple users on the same resources. Significantly enhances both spectrum and spectral efficiency and provides for additional increased network coverage through leverage over power-domain multiplexing, making it key enablement for B5G, but the advantages with the use of NOMA pose challenges in some manners too. One major area concerns the degradation in quality service especially for cell-edge users by the attenuation and the presence of interference. The key to unlocking the full potential of NOMA is to address the issue of disparity in service quality between cell-center and cell-edge users. The 3rd Generation Partnership Program (3GPP) introduces the first NOMA downlink standard as a multi-user superimposed transmission system in LTE Release-13. Further wireless researches steered the implementation of NOMA, especially in areas such as adaptive resource allocation, cooperative relaying, and interference mitigation to provide equitable and efficient service to all users in B5G environments.

Power-domain and code-domain NOMA provide enhanced spectral efficiency and extreme connectivity, but differ in complexity and performance [1, 2]. Device-to-device communication, multi input multi output (MIMO) communication, Cooperative Communication and heterogenous networks supports the power domain NOMA to overcome limitations of OMA in data intensive dense network [2]. In the article [3], NOMA system is leveraged to utilize cooperative communication by allowing user equipment (UE) with strong signals to act as relays for weaker ones, that maximized diversity gain and minimized outage probability. It also highlighted opportunities for optimal power allocation and integrating wireless power transfer. Architecture for downlink and uplink of NOMA Cooperative relays with key focus on improving energy efficiency through hybrid power allocation is introduced in article [4]. The instantaneous and statistical channel state information (CSI) are combined to reduce computational complexity and signalling overhead with minimal sum rate degradation. The letter [5] analyses exact end-to-end average error performance in closed-form of cooperative NOMA via simulations.

The design of Dual-hop cooperative relaying scheme [6] using NOMA enables two sources to communicate in parallel via a common relay. Significant gain in ergodic sum capacity and improvement in spectral efficiency are achieved empirically under perfect successive interference cancellation (SIC). The ergodic sum capacity of half duplex & full-duplex relaying cooperative NOMA is enhanced through closed-form optimization of dynamic power allocation using instantaneous CSI and fixed power allocation using statistical CSI [7].

Opportunistic based adaptive relay selection substantially improved ergodic sum rate [8] when compared to balanced fairness, and round robin based adaptive relay selection criteria. Instantaneous CSI based two stage relay selection scheme is employed with multiple relays and the outage behaviour of the system is improved in [9]. The cooperation zone is determined by choosing the best relays based on the optimal distance factor. System throughput increases as the number of relays in the cooperative zone increases [10]. The literature [11] presents a two-phase cooperative NOMA system that has group of dedicated-relay and near user to relay the information using AF and DF to far user. Adaptive relay selection is employed based on limited feedback and CSI to minimize system outage probability. Analytical results show full diversity order and that DF out performs AF. The authors in [12] developed threshold-based cooperation for NOMA system and derived outage probability. They improved the capacity and outage behaviour of the system in [13] using joint optimization of power allocation and threshold selection. A hybrid relaying NOMA system with maximal ratio combining (MRC) is deployed in [14]. Literature [15] enhances cooperative wireless networks by optimizing relay selection and power allocation using statistical CSI and the Lagrange multiplier method. The scheme improves power efficiency by 2.1 dB at an outage probability of 0.01. Secrecy rate enhancement, power allocation optimization, and fairness improvement in downlink CNOMA systems are implemented in [16]. Hybrid relay selection is investigated and spectral efficiency of CNOMA is enhanced by activating the relay with the highest SNR in [17]. In literature [18], the authors enhanced system throughput and user fairness by leveraging social-aware relay selection strategies. The hybrid relay switches between AF and DF protocols based on the instantaneous CSI of relay that improves diversity order and outage behaviour. In B5G systems, due to typical scattering and absence of line-of-sight paths, deep Rayleigh fading occurs which results in very low average SNR at the intra cell UE and cell edge UE. If the conventional cooperative NOMA is used in deep faded B5G scenario then the user fairness is affected and throughput is reduced. Hence, it is very essential to use a robust relay selection schemes and adaptive power allocation in Cooperative NOMA to satisfy the requirement of spectral efficiency for B5G network. In spite of various advancements of Cooperative NOMA studies from the above literatures, the scope for improving power allocation method, opportunistic relay selection and relaying protocol are identified making the cell-edge performance on par with the intra-cell UE. The core contribution of this research is to design a hybrid relaying CNOMA system with CAAF power allocation method and RFBP-ORS strategy suited for B5G to make its cell-edge performance on par with the intra-cell performance. The rest of this paper is as follows. In Section 2, the system model is proposed with CAAF power allocation and RFBP-ORS algorithms. Then, mathematical modeling of the considered system and its performance metrics are derived in Section 3. The simulation results are presented and discussed in Section 4. Finally, this paper is concluded in Section 5.

2 SYSTEM MODEL

Let us consider a B5G cell environment with gNB at the center of the cell, N user equipment $\left(\mathrm{UE}_R^n, 1 \le n \le N\right)$ in ICC and M user equipment $\left(\mathrm{UE}_D^m, 1 \le m \le M\right)$ in CEC assuming that $M \le N$. $N + M$ UE are randomly located inside their clusters as depticted in Fig. 1. In the proposed system, the gNB interfaces with a base band unit (BBU) to evaluate the channel state information from the received base band signals and dynamically allocates power to provide wireless interface for UEs at different clusters. B5G Core is the central part of the proposed network that is responsible for network management and routing of data through opportunistinc relaying plan.

Distance between gNB & UE_R^n is d_{BR_n}, gNB & UE_D^m is d_{BD_m} and UE_R^n & UE_D^m is $d_{R_n D_m}$. The UE in ICC serve as hybrid relays for the UE in CEC and achieve cooperation in two phases. During phase-1, gNB transmits superimposed NOMA signal to $N + M$ UE via N ICC downlinks $\left(\mathrm{gNB} \to \mathrm{UE}_R^n\right)$ and M CEC downlinks $\left(\mathrm{gNB} \to \mathrm{UE}_D^m\right)$. During phase-2, M opportunistic relaying UE transmit information to M destination UE with unique band and same power via M relay links $\mathrm{UE}_R^n \to \mathrm{UE}_D^m$ using the proposed opportunistic relaying plan as shown in Fig. 2. The system model has been designed to account for interference between ICC and CEC, ensuring efficient spectrum utilization. UE in ICC have ordered decoding successive interference canceller to avoid intra cell interference and relaying plan based interference canceller to avoid inter cell interference. The channel gain for link is represented by $h_{TR} = g_{TR} / L\left(d_{TR}\right)$ where $g_{TR} \sim \mathcal{CN}\left(0, \lambda_{TR}\right)$ refers to Rayliegh fading coefficient, $L(d_{TR})$ is pathloss due to distance d_{TR} and the terms $T \in (B, R_n)$ & $R \in (R_n, D_m)$. The statistical SINR of ICC downlink is $\gamma_{BR_{ij}}^s$ and that of relay link is $\gamma_{R_i D_j}^s$.

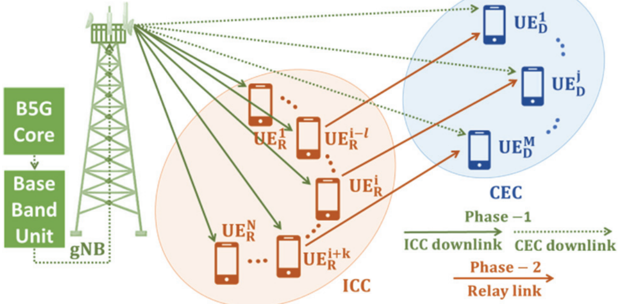

Figure 1 System architecture

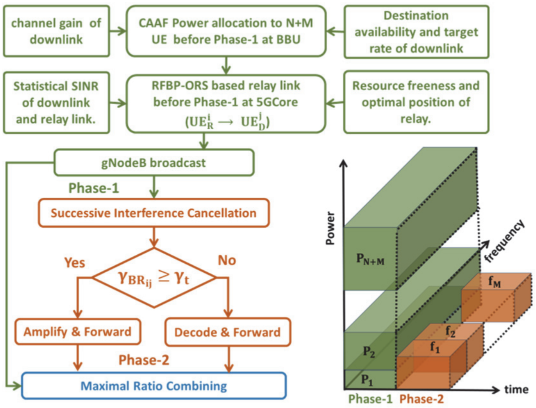

Figure 2 System flow diagram and resource allocation

2.1 CAAF Power Allocation

Base band unit (BBU) employs CAAF power allocation algorithm to dynamically plan resource allocation before the initiation of phase-1 transmission of gNB.

In this research article, B5G downlink quality is assessed by the BBU through CSI measurements. UEs in ICC exhibit higher SINR, while UEs in CEC have lower SINR due to poor channel conditions. Hence, the proposed algorithm gives priority to the UE in CEC during power allocation. The power allocation to the UE in CEC depends on data availability factor from gNB, target data rate at the cell-edge UE and channel gain. The remaining power is allotted to UE in ICC based on relay resource free factor and statistical CSI. Data availability factor of each UE in CEC (DA_m, for $1 \le m \le M$) is given by

$$DA_m = \begin{cases} 1, \text{ if gNB transmits } x_{D_m} \\ 0, \text{ if gNB does not transmit } x_{D_m} \end{cases} \tag{1}$$

Assume that gNB transmits data to L UE in ICC, where $L \le N$. Resource free factor of each UE in ICC (RF_n, for $1 \le n \le N$) is represented as follows

$$RF_n = \begin{cases} 1, \text{ if gNB does not transmit } x_{R_n} \\ 0, \text{ if gNB transmits } x_{R_n} \end{cases} \tag{2}$$

Resource freeness ensures that the UE in ICC have no active data to receive directly from the gNB but are available to relay the information to UE in CEC. The number of UE in ICC whose resources are not free (L) is given as

$$L = N - \sum_{n=1}^{N} RF_n \tag{3}$$

```
Algorithm 1: CAAF Power Allocation Method
1) Initialize parameters: gNB transmission power ($P_B$), downlink bandwidth ($B$), downlink target rate ($R_t$),
   downlink target SINR $\gamma_t = 2^{(R_t/B)} - 1$,
2) Compute power split factor for each downlink in CEC
       $a_{D_m} = \frac{DA_m P_B |h_{BD_m}|^2}{\gamma_t \sigma_m^2}$, for $1 \le m \le M$
   Total power split factor for N downlinks in ICC
       $a_R = 1 - a_D = 1 - \sum_{m=1}^{M} a_{D_m}$, $a_D > a_R$
3) Set power split factors for each downlink in ICC
       $a_{R_n} = \frac{(1 - RF_n) a_R |h_{BR_n}|^2}{\sum_{i=1}^{N} (1 - RF_i) |h_{BR_i}|^2}$, for $1 \le n \le N$
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2.2 RFBP-ORS Algorithm

B5G Core employs RFBP-ORS algorithm to dynamically choose the best M number of UEs among N number of UEs in ICC as communication relays in the B5G system to forward the information M number of UEs in CEC. The proposed RFBP-ORS algorithm dynamically identifies the best M number of optimal subset of

$$(i, j) \subseteq \{(1, 1), ..., (1, M), (2, 1), ..., (2, M), ..., (N, 1), ..., (N, M)\}$$

for any UE_R^i in ICC to relay information to any UE_D^j in CEC. The algorithm considers three facts such as (i) resource freeness, i.e., UE_R^i that do not have their own data from gNB but possess information to be relayed to UE_D^j, (ii) UE_R^i optimally positioned in linear/triangular geometry that minimizes likelihood of outages and (iii) the statistical SINR of the ICC downlink and relay link.

```
Algorithm 2: RFBP-ORS Strategy
1) Initialize parameters: Relaying power ($P_R$), and relay resource availability of $\mathrm{UE}_R^i$
2) Compute ORS factor
       $O_{ij} = \alpha_r RF_i + \alpha_d \left( \frac{d_{BD_j}}{d_{BR_i} + d_{R_i D_j}} \right) + \alpha_c \left( \frac{\gamma_{BR_{ij}}^s \gamma_{R_i D_j}^s}{\gamma_t^2} \right)$
   Where $\alpha_r$, $\alpha_d$ and $\alpha_c$ are coefficients of resource availability, distance and CSI. ($\alpha_r + \alpha_d + \alpha_c = 1$)
3) Identify Opportunistic relay links $\mathrm{UE}_R^i \to \mathrm{UE}_D^j$
       $\{\mathrm{UE}_\mathrm{R}^\mathrm{i}, \mathrm{UE}_\mathrm{D}^\mathrm{j}\} = arg \max_{\mathrm{i, j}} (\mathrm{O_{ij}})$
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The algorithm computes a relay selection metric that integrates these factors and determines opportunistic relaying plan $\mathrm{UE}_R^i \to \mathrm{UE}_D^j$. The best M number of UEs in ICC with the highest selection metric is chosen as relays, ensuring efficient utilization of network resources in ICC and enhanced performance for the CEC.

3 MATHEMATICAL MODELLING

After CAAF power allocation at BBU and RFBP-ORS at B5G core, the BBU generates the payload for M number of relaying UE by combining the data and opportunistic relaying plan $\mathrm{UE}_R^i \to \mathrm{UE}_D^j$, the payload for N-M number of UE in CEC and the payload M number of UE in ICC. As the B5G involves NOMA cooperation, the communication process is achieved in two phases. gNB broadcasts the payload to $N + M$ UE in the B5G cell during phase-1 through superimposed NOMA waveform, which is given by

$$x_B = \sum_{n=1}^{N} \sqrt{a_{R_n} P_B} x_{R_n} + \sum_{m=1}^{M} \sqrt{a_{D_m} P_B} x_{D_m} \tag{4}$$

The signals received by UE_R^i and UE_D^j from gNB during phase-1 are given by

$$y_{BR_i} = x_B h_{BR_i} + w_{R_i} \tag{5}$$

$$y_{BD_j} = \left(\sum_{m=1}^{M} \sqrt{a_{D_m} P_B} x_{D_m} \right) h_{BD_j} + w_{D_j} \tag{6}$$

where $w_{R_i} \sim \mathcal{CN}\left(0, \sigma_i^2\right)$ and $w_{D_j} \sim \mathcal{CN}\left(0, \sigma_j^2\right)$ denote additive white noise (AWGN) present in UE_R^i and UE_D^j with zero mean and variance σ^2. $E\left[\left|x_{R_n}\right|^2\right] = 1$ for $1 \le n \le N$ and $E\left[\left|x_{D_m}\right|^2\right] = 1$ for $1 \le m \le M$.

3.1 Hybrid Relaying (HR) Strategy

During phase-2 UE_R^i implements ordered decoding & relaying plan based SIC and forwards information to UE_D^j using constant power P_R and unique band. In this phase gNB does not transmit any information. HR strategy uses AF scheme if $\gamma_{BR_{ij}} \ge \gamma_t$ or else uses DF scheme [10]. The signal transmitted by UE_R^i to UE_D^j is given as

$$x_{R_i D_j} = \begin{cases} \beta_i \left(\sqrt{a_{D_j} P_B} x_{D_j} h_{BR_i} + w_{R_i} \right), & \text{If AF} \\ \sqrt{P_R} x_{D_j}, & \text{If DF} \end{cases} \tag{7}$$

where amplification factor

$$\beta_i = \sqrt{\frac{P_R}{P_B \left| h_{BR_i} \right|^2 + \sigma_i^2}} \tag{8}$$

UE_D^j receives the following signal during phase-2 from UE_R^i

$$y_{D_{ij}} = x_{R_i D_j} h_{R_i D_j} + w_{D_j} \tag{9}$$

3.2 Achievable Data Rate & Energy Efficiency

The achievable data rate measures the utilization of the B5G spectrum with the proposed opportunistic hybrid relaying CNOMA. The achievable data rate for any UE is directly influenced by the instantaneous SINR of the direct downlink, which depends on CAAF power allocation, channel gains, and noise variance in the direct downlinks and opportunistic relay links. Instantaneous SINR of the downlink at UE_R^i if $R_i = 0$ is given by

$$\gamma_{BR_i} = \frac{\left(a_{R_i} + a_{D_j} \right) P_B \left| h_{BR_i} \right|^2}{\left(1 - a_{R_i} - a_{D_j} \right) P_B \left| h_{BR_i} \right|^2 + \sigma_i^2} \tag{10}$$

Instantaneous SINR of the ICC downlink at UE_R^i to decode the information of UE_D^j and its achievable data rate are expressed in Eq. (11) & Eq. (12).

$$\gamma_{BR_{ij}} = \frac{a_{D_j} P_B \left| h_{BR_i} \right|^2}{\left(1 - a_{D_j} \right) P_B \left| h_{BR_i} \right|^2 + \sigma_i^2} \tag{11}$$

$$R_{BR_{ij}} = \log_2 \left[\frac{P_B \left| h_{BR_i} \right|^2 + \sigma_i^2}{\left(1 - a_{D_j} \right) P_B \left| h_{BR_i} \right|^2 + \sigma_i^2} \right] \tag{12}$$

Instantaneous SINR of the downlink at UE_D^j of CEC during phase-1 and the instantaneous SINR of the opportunistic hybrid relay link $\mathrm{UE}_R^i \rightarrow \mathrm{UE}_D^j$ during phase-2 are represented in Eq. (13) & Eq. (14)

$$\gamma_{BD_j} = \frac{a_{D_j} P_B \left| h_{BD_j} \right|^2}{\left(a_D - a_{D_j} \right) P_B \left| h_{BD_j} \right|^2 + \sigma_j^2} \tag{13}$$

$$\gamma_{R_i D_j} = \begin{cases} \dfrac{a_{D_j} P_B P_R \left| h_{BR_i} \right|^2 \left| h_{R_i D_j} \right|^2}{P_R \left| h_{R_i D_j} \right|^2 \sigma_i^2 + P_B \left| h_{BR_i} \right|^2 \sigma_j^2 + \sigma_i^2 \sigma_j^2}, & \text{If AF} \\ \dfrac{P_R \left| h_{R_i D_j} \right|^2}{\sigma_j^2}, & \text{If DF} \end{cases} \tag{14}$$

The UE_D^j employs MRC [10]. The instantaneous SINR and the achievable data rate are given by

$$\gamma_{D_j} = \gamma_{BD_j} + \gamma_{R_i D_j} \tag{15}$$

$$R_{D_j} = \log_2 \left(1 + \gamma_{D_j} \right) \tag{16}$$

The energy efficiency of the proposed opportunistic hybrid relaying CNOMA, i.e., the maximum achievable data rate with the least possible energy is given by

$$\eta_{EE}^{ij} = \frac{R_{D_j}}{\left(a_{R_i} + a_{D_j} \right) P_B + P_R} \tag{17}$$

The statistical SINR is updated to B5G core after every t^{th} time slot based on exponential moving average method to optimize opportunistic relay selection for the next phases.

$$\gamma_{TR}^s (t) = \varepsilon \left[\gamma_{TR} (t) \right] + (1 - \varepsilon) \left[\gamma_{TR}^s (t-1) \right] \tag{18}$$

where ε is the smoothing factor and $TR \in (BR_{ij}, R_i D_j)$. The B5G system with proposed opportunistic hybrid relaying CNOMA uses both direct downlinks and opportunistic relay links, employing MRC at the destination user to maximize the combined SINR, to enhance the achievable data rate and overall spectrum utilization. The periodic update of statistical SINR ensures optimal relay selection, maintaining high performance across varying network conditions.

3.3 Outage Behaviour

Outage probability quantifies reliability of the proposed algorithms in hybrid relaying CNOMA for B5G system by indicating the likelihood that the instantaneous SINR falls below the SINR required to achieve target data rate. The outage probability of UE_R^i from gNB to decode the information of UE_D^j even if the resource is free for relaying only during phase-1 is given by

$$p\left(O_{R_{ij}}\right)=1-p\left[\gamma_{BR_{ij}}\geq\gamma_t\right] \tag{19}$$

$$p\left(O_{R_{ij}}\right)=1-\exp\left\{\frac{\lambda_{BR_i}\gamma_t\sigma_i^2}{P_B\left[\gamma_t-a_{D_j}\left(1+\gamma_t\right)\right]}\right\} \tag{20}$$

Due to the MRC at UE_D^j, outage probability reflects the combined effectiveness of both the direct transmission at phase-1 and the opportunistic hybrid relayed transmission at phase-2. Hybrid relayed transmission dynamically switches between AF and DF protocols depending on the instantaneous CSI of Rayleigh fading environment in the relay link. Outage probability of the UE_D^j at the end of phase-2 is given by

$$P\left(O_{D_j}\right)=1-p\left[\gamma_{D_j}\geq\gamma_t\right] \tag{21}$$

$$P\left(O_{D_j}\right)=1-\exp\left(\frac{\lambda_{BD_j}\gamma_t\sigma_j^2}{P_B\left[a_D\gamma_t-a_{D_j}\left(1+\gamma_t\right)\right]}-\chi_{ij}\right) \tag{22}$$

where

$$\chi_{ij}=\begin{cases}\dfrac{\lambda_{BR_i}\lambda_{R_iD_j}\gamma_t\sigma_i^2\sigma_j^2}{a_{D_j}P_BP_R}, & \text{if AF}\\[2ex] \dfrac{\lambda_{R_iD_j}\gamma_t\sigma_j^2}{P_R}, & \text{if DF}\end{cases} \tag{23}$$

4 SIMULATION RESULTS

The simulation for the proposed hybrid relaying CNOMA system in a B5G network is accomplished using the MATLAB R2023a environment running on computer system with Intel i5 processor, 16 GB RAM, and Windows 11 operating system. The proposed B5G network environment is simulated using a realistic network topology with a central gNB and randomly distributed ICC and CEC UE with the simulation parameters as given in Tab. 1.

Table 1 Simulation parameters and values

Parameter	Value
Cell Layout	1000 × 1000 m
gNB Position	(500 m, 500 m)
Number of ICC UEs (N)	55
Number of CEC UEs (M)	40
Bandwidth (B)	500 MHz
Target data rate (R_t)	5 Gbps
gNB transmit Power (P_B)	40 dBm
Relaying Power (P_R)	20 dBm
Path Loss Exponent	3.5 (Urban)
Noise Power $\left(\sigma_i^2\right)$	10^{-9} W
α_r, α_d and α_c	{0.5, 0.3, 0.2}
smoothing factor (ε)	0.1
Relay Protocols	Hybrid AF/DF
SINR	0-30 dB

In this section, the conventional CNOMA, Opprotunistic Relay Selection based NOMA (ORS NOMA) in [6] and the proposed RFBP-ORS CNOMA with hybrid relaying capabilities are validated with simulation. The B5G network topology is designed in a geographical region of 1000 × 1000 m with gNB at centre (500 m, 500 m) that represents a standard urban macro-cell scenario commonly used in 5G and B5G simulations. The experiments incorporate real-world network congestion scenarios and assess large-scale deployments to validate the scalability of the system. The choise of N = 55 and M = 40 ensures sufficient density to simulate user cooperation and interference in a dense network scenario and allows critical testing efficiency of the proposed algorithm in realistic scenario. 55 UE are deployed randomly in ICC located in radius of $50\text{ m}\leq d_{BR_n}\leq 300\text{ m}$ from gNB and 40 UE are deployed randomly in CEC located in radius of $300\text{ m}\leq d_{BD_m}\leq 500\text{ m}$ from gNB as shown in Fig. 3. In this random deployment of UE nodes, UE_D^6 is the farthest UE in CEC located at 486.89 m from gNB and result analyses are done at this cell edge UE. The real time traffic and network fluctuations are incorporated in this research work by setting $\{RF_1, ..., RF_{55}\}$ and $\{DA_1, ..., DA_{40}\}$ based on poisson distribution for every iteration with constraint of the cell edge user has DA_6 = 1. We consider the simulation parameters B = 500 MHz suitable for FR_2, P_B = 40 dBm, R_t = 5 Gbps, 16-QAM modulation and P_R = 20 dBm. CAAF power allocation is empirically done at BBU which provides a_D = 0.742 and a_R = 0.258 in the presence of Rayleigh fading channel. The power allocation factor to UE_D^6 is $a_{D_6}=0.026$.

RFBP-ORS algorithm is evaluated in various configurations (case 1 to case 7) at B5G core by considering different values for α_r, α_d and α_c based on dominancy on resource freeness, optimal location and attainment of target SINR to select the best opportunistic relay as shown in Tab. 2. Testing various configurations allows exploration of trade-offs between resource freeness, positioning, and SINR, providing insights into optimal system design. Experimentation outcomes such as RFBP-ORS based opportunistically identified relays for each configuration to relay the information to UE_D^6 and CAAF power allocation to those relaying UE are also tabulated in Tab. 2.

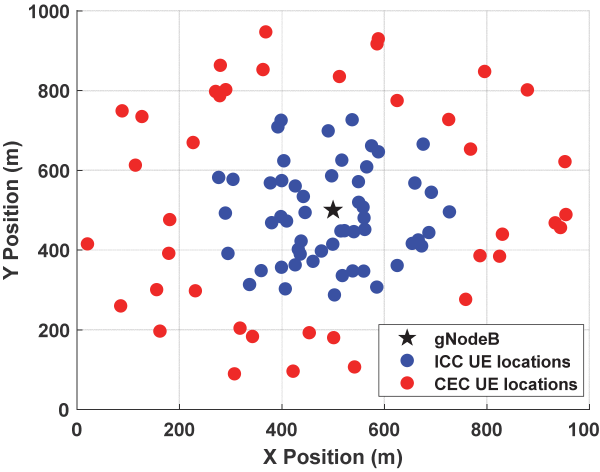

Figure 3 B5G network topology with UE in random locations

Table 2 RFBP-ORS coefficients with otpimally selected relays with CAAF power allocation

Case	Coefficients			RFBP-ORS relay	CAAF Power Allocation
	α_r	α_d	α_c		
1	0.5	0.3	0.2	UE_R^{18}	0.0024
2	0.5	0.2	0.3	UE_R^{26}	0.0031
3	0.3	0.5	0.2	UE_R^{9}	0.0028
4	0.2	0.5	0.3	UE_R^{15}	0.0032
5	0.3	0.2	0.5	UE_R^{32}	0.0034
6	0.2	0.3	0.5	UE_R^{3}	0.0039
7	0.34	0.33	0.33	UE_R^{51}	0.0027

Fig. 4 illustrates achievable data rate (in bps/Hz) as a function of SINR (in dB) for conventional CNOMA, ORS CNOMA and the proposed RFBP-ORS CNOMA for different cases mentioned in Tab. 2. Case 1 shows the highest achievable data rate consistently across all SINR values, at reaching up to 11.52 bps/Hz at SINR of 30 dB. Case 2 follows closely behind Case 1, showing a high data rate, particularly at higher SINR values. It achieves around 10.13 bps/Hz at 30 dB SINR. This configuration shows superior performance over all other cases in the proposed RFBP-ORS CNOMA. Similarly, achievable data rate of the proposed RFBP-ORS CNOMA in all cases outperforms the same of conventional and ORS CNOMA enormously. Within the proposed RFBP-ORS CNOMA scheme, Cases 1 and 2 show dominant performance over other configurations as relay resource freeness being the dominant criterion in selecting the RFBP opportunistic hybrid relay. This ensures efficient spectral utilization and contribution of whole power allotment for relaying process. In all cases the energy efficiency is in the order of 1 Gb/J from 12.5 dB of SINR. The proposed CAAF power allocation scheme introduces a dynamic, data-centric, and channel-state-driven approach that is distinct from conventional NOMA-based and cooperative power allocation strategies. CAAF allocates more transmission power proactively to cell-edge UEs exhibiting lower SINR and higher data demands, ensuring their target data rate is met despite poor channel conditions. Power to ICC UEs is not blindly distributed; it is adaptively shared only among UEs whose resource state (relay availability) allows participation in cooperation, thus preventing wastage of resources on inactive or congested links.

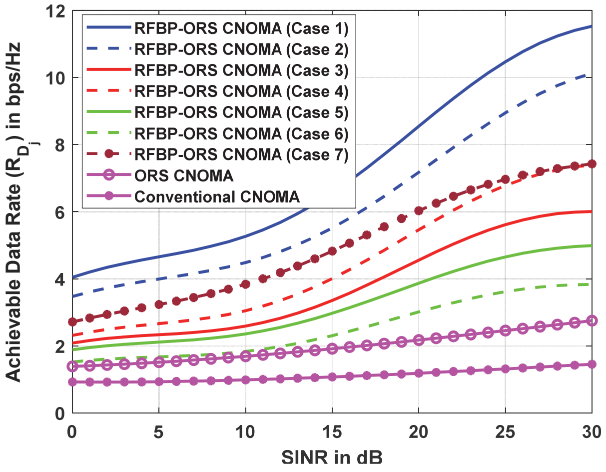

Figure 4 Comparison of achievable data rate at UE_D^6 for L = 25

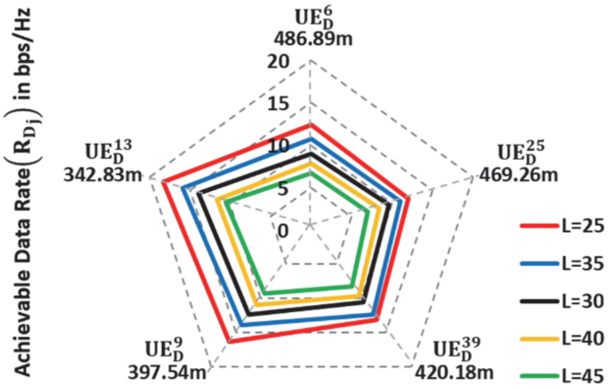

Figure 5 Comparison of achievable data rate at different UE in CEC with fixed SINR of 15 dB

Fig. 5 shows the radar chart of achievable data rate performance at five different UE $\left\{\mathrm{UE}_D^6, \mathrm{UE}_D^{25}, \mathrm{UE}_D^{39}, \mathrm{UE}_D^9 \text{ and } \mathrm{UE}_D^{13}\right\}$ in CEC located at different distances {486.89 m, 469.26 m, 420.18 m, 397.54 m, 342.83 m} from the gNB at constant SINR of 15 dB for different values of L {25, 30, 35, 40, 45} and case 1 configuration. From this figure it is understood that the number of UE in ICC (L) and the distance between the gNB and UE in CEC are the key determinant factors of achievable data rate performance. The empirical analysis shows that as L decreases, more UE in ICC are available for better cooperation which enhances data rate. This inverse relationship between L and data rate highlights the importance of RFBP-ORS strategy in leveraging the choice of opportunistic UE in ICC to improve the performance for UE in CEC. As the distance between gNB and UE in CEC decreases, the data rate increases due to minimal path loss. This pattern is consistent across all L, indicating that proximity to the gNB is a critical factor in determining the quality of the received signal and thus the achievable data rate. From this result it is revealed that the moving UE in ICC away from gNB has consistent throughput as the receiving SINR is reduced.

Fig. 6 shows the outage probability versus SINR for conventional CNOMA, ORS CNOMA and different configurations of the proposed RFBP-ORS CNOMA (Case 1-7). Across all SINR values, all configurations of the proposed RFBP-ORS CNOMA schemes consistently exhibit the lowest outage probabilities when compared to conventional and ORS CNOMA. Case 4 configuration achieves the most significant reduction in outage probability when compared to all the configurations proposed. Case 4 configuration achieves outage probability of 0.01 at SINR of 20 dB whereas conventional CNOMA achieves at SINR of 29 dB. From this result, it is revealed that UE in ICC moving from good SINR to bad SINR can hold better QoS with maximum coverage. It is also understood that the best outage behavior is obtained when distance and statistical SINR metrics dominate relay resource freeness. This result ensures good coverage under the Rayliegh fading with path loss scenario when optimal position of the relay is dominant. The proposed CAAF power allocation and RFBP-ORS strategies dynamically adjust resource allocation based on real-time channel variations, ensuring consistent performance even in highly fluctuating network environments. Extensive Monte Carlo simulations demonstrate that the opportunistic relay selection enhances system robustness by dynamically adapting to varying link qualities, ensuring optimal relay assignment for seamless data transmission.

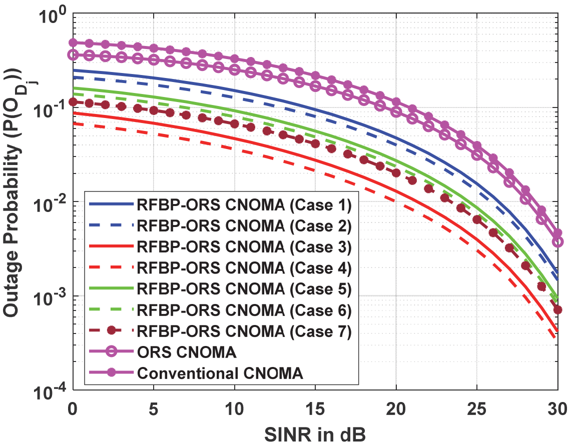

Figure 6 Comparison of outage probability of UE_D^6 for $L = 25$

5 CONCLUSION

The proposed hybrid relaying cooperative NOMA system, incorporating the novel CAAF power allocation and RFBP-ORS techniques, represents a significant advancement in improving the performance of B5G wireless networks. This study also provides insights into the system's performance under dynamic channel conditions and real-time network fluctuations. By addressing the persistent challenges faced by cell-edge users, this approach demonstrates remarkable improvements in data rates and a substantial reduction in outage probabilities compared to traditional CNOMA and ORS-based CNOMA systems. Outcomes of the simulation confirm that the RFBP-ORS is beneficial in terms of spectral efficiency when used with resource free dominant configurations (cases 1 and 2) and coverage when used with optimum position dominant configurations (cases 3 and 4). Improved data rates at the cell edge enhances overall user experience, reduces latency and increases the reliability of data transmissions. Well reduced outage probability ensures a more consistent QoS for cell-edge users without interruptions. This research provides a robust foundation for the system level implementation of B5G with opportunistic hybrid relaying CNOMA with focus on future advancements in balancing complexity in B5G Core and BBU.

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