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Optimization of Interference Management and Power Control in (Noma) With (Hetnets) Through Sectoring Techniques

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Abstract. *The development of heterogeneous networks (HetNets), in the dynamic field of wireless communications still depends critically on the improvement of power control and interference management. An original sectoring technique to address the problems with Non-orthogonal Multiple Access (NOMA) systems such power allocation and interference management is presented in this study. It attempts to greatly lower inter-user and co-tier interference, increasing network efficiency and user fairness, by combining a strategic sectoring approach, round-robin channel allocation, and an inverse route loss power allocation framework. In the present work, the Bit Error Rate (BER) performance in a simulated two-tier NOMA-enabled HetNet is analysed using Monte Carlo simulation. The findings show that, especially at higher signal-to-noise ratios (SNR), sectoring considerably lowers BER by around 50% compared to the non-sectoring situation. The results of this work emphasize the need of sectoring in optimizing the efficiency of future wireless network infrastructures and have wide-ranging implications for the deployment of 5G networks and beyond. The findings back up the idea of combining sector-based designs to increase spectrum and energy efficiency, hence increasing the reliability and resilience of future communication systems.*

Keyword:*5G, Non-Orthogonal Multiple Access (NOMA), Heterogeneous Networks (HetNets), Sectoring, Bit Error Rate (BER), Energy Efficiency (EE), Spectrum Efficiency (SE)*

1. INTRODUCTION

The rapid advancement of smartphones has led to an increased demand for mobile broadband services that offer fast data rates and great quality of service (QoS), applications for mobile and linked devices, and other issues. Mobile networks must implement critical measures to handle the significant spike in wireless data traffic and the resulting spectrum gap[1]. Future generations of 5G mobile networks will meet User Equipment's (UE) requests, including a sizable number of mobile-linked gadgets in addition to 500-kilometer-per-hour bullet trains. Requirements for Fifth Generation 5G networks and their successors fundamentally differ from those of previous generations of mobile networks in that they must prioritize increased reliability and decreased latency. [2],[3],[4] To address these challenges, considerable interest has been directed towards the heterogeneous network (HetNet) framework, which operates on overlapping layers of small cells (SCs) in fifth-generation 5G and beyond cellular networks that are physically possible to coexist concurrently within the limitations of the macro cell (MC) level [5],[6]. Nonorthogonal multiple access (NOMA) technology is now being examined in heterogeneous networks to enhance the general sum rate compared to orthogonal multiple access (OMA). The NOMA approach improves spectrum efficiency (SE) and energy efficiency (EE); however, it also suffers from inter-user interference [7]. Though, including resource sharing among different tiers in HetNets with NOMA leads to co-tier and cross-tier interference [8].[9], [10], [11], [12]. Hence, the simultaneous management of all these sorts of interference is a pressing concern that must be considered to uphold the necessary performance level in HetNets with NOMA. In order to address inter-user interference, the user employs successive interference cancellation (SIC) to recover information from the superimposed signal [13] repeatedly. One way to mitigate cross- and co-tier interference in NOMA with HetNets is to regulate the power distribution to the adopted base stations (BSs), which guarantees that every BS broadcasts at the correct power level to preserve the QoS for its customers and prevent undue interference from users in other cells [14]. this study aims to add to the continuing efforts in optimizing next-generation wireless networks by examining the effectiveness of sectoring in a simulated NOMA HetNet environment. Several significant contributions to the field of wireless communications are presented in this work, especially in the enhancement of NOMA-enabled HetNets, which are compiled as follows:

- present a new sectoring approach that divides the network into several sectors with appropriate channel allocation, catered for various conditions, hence reducing interference.
- provide an inverse path loss power allocation technique to improve network coverage and energy EE by increasing signal strength for far-off users.
- Implementation of a round-robin channel allocation method guarantees fair access to network resources, hence improving SE and reducing the BER.

The rest of these paper show the related work and carefully describe the system model details that form the basis of the suggested vectorization method in section 2. It describes in detail the components that make up the network architecture, how the sectorization algorithm was created, and how it integrates with the NOMA protocol. Following the methodological explanation, we provide a set of simulation results that verify the sectorization technique's ability to improve BER performance empirically illustrated in section 3. In the final section of the manuscript, the strategic implications of these findings for deploying advanced wireless networks are discussed, emphasizing how to maximize capacity and SE in diverse network settings on the verge of ubiquity.

2. RELATED WORK

The power allocation issue has been considered in HetNet systems to effectively handle the resulting co-tier interference in the multi-cell situation, as in [10] and[12].To address the power allocation (PA) issue, the authors of [10] Present a user scheduling methodology in conjunction with a distributed power control system. However, as stated in the method presented in [10], this analysis exclusively focuses on HetNets that consist of a solitary MC and a single SC. However, it does not take into consideration co-tier interference. The researchers in [15] suggests decoding demand of NOMA users. Conversely, the authors of [16] suggest implementing a distributed power allocation scheme with coordinated multipoint (CoMP) to control interference in NOMA HetNets. A user clustering strategy utilizing a dual Lagrangian scheme for power distribution in NOMA-enabled HetNets is proposed by the authors in reference [17]. In [18], the authors propose an approach for mixed-integer programming for the simultaneous distribution of power and association of users in NOMA HetNets. Furthermore, certain studies have focused on employing game theory principles to enhance the sum rate of NOMA-HetNets systems through the optimization of power allocation to the base stations (BSs), as demonstrated in references [12], [19] and[20]. The authors of [19], [20] propose a non-cooperative game, while [12] suggests the Stackelberg game. However, both studies [12]and [19] exclusively focus on a single tiny cell, neglecting the consideration of co-tier interference. In addition, the SBS is subject to unjust treatment compared to the MBS in terms of the sum rate, principally due to the Stackelberg game's leader-follower structure. Hence, can conclude from the preceding literature that cross-tier and co-tier interference contributes to the power control issue. Furthermore, the algorithms described above remain highly complex. Therefore, the proposed system attempts to address these issues.

3. SYSTEM MODULE

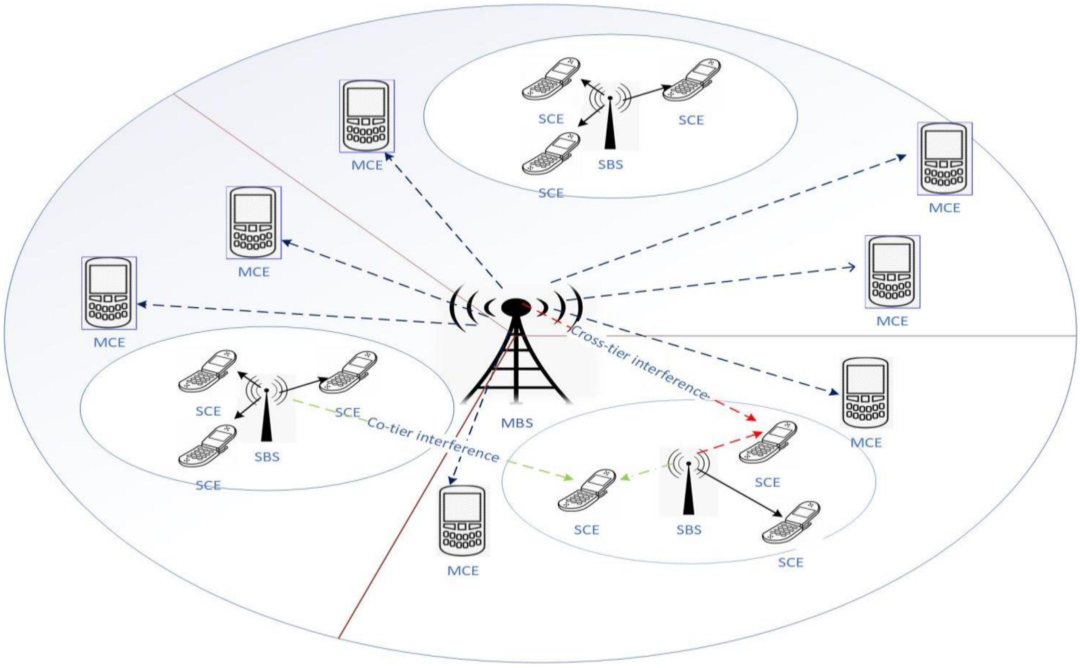

Figure 1. NOMA-enabled HetNets with sectoring

We consider, as shown in Figure 1, the downlink of a tow-tire Nonorthogonal Multiple Access NOMA-enabled Heterogeneous Network (HetNet) composed of a Macro Base Station (MBS) with N_{MU} macro-cell equipment (MCE) and multiple Small Cell Base Stations (SBS_s) with N_{SU} small-cell equipment (SCE), the setup involves implementing Number of small cell (N_{sc}) and SC_s which denote to The set of SCs tiers of a single-antenna small base station (SBS) is positioned within the identical coverage area as a sectored-antenna macro base station (MBS) with a single MC layer. The network utilizes a sectoring strategy to spatially separate users, thereby reducing co-tier and cross-tier interference. This strategy is executed by dividing the coverage areas of the MBS into sectors and applying two-tier NOMA in each sector. Let *SM* denote the number of sectors within the MBS. The user distribution within these sectors is modelled as a random variable over the defined area. This model explores the impact of sectoring on network performance, mainly focusing on the BER across varying Signal-to-Noise Ratio (SNR) levels {0 to 30 dB}.

3.1. Signal Modelling

To implement SIC for NOMA signal detection, The signals with poor channel conditions are expected to be decoded previously and subsequently removed from the observed overlaid signals. [12]. The channel state of a user is inversely proportional to the power assigned to that user within the SCs., to ensure fairness. Additionally, it is assumed that every base station (BS) shares the users' channel state information (CSI)

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with a central control unit CCU through a high-speed backhaul link. The CCU then allocates power and resource blocks (RBs) to the BSs; users are already registered with specific macro cell (MCs) or SCs.

As in equation (1) and (2) Suppose the transmitted overlaid NOMA signal from the MBS and the SBS$_i$ are $x^{[M]} = \sum_{n=1}^{N_{MU}} x_n^{[M]}$ and $x_i^{[S]} = \sum_{n=1}^{N_{SU}} x_{i,n}^{[S]}$ respectively, where the transmitted signal to (MU$_n$) and SU$_{i,n}$, $x_n^{[M]} = \alpha_n^{[M]} p^{[M]} s_n^{[M]}$ and $x_{i,n}^{[S]} = \alpha_{i,n}^{[S]} p_i^{[S]} s_{i,n}^{[S]}$ respectively. Where $p^{[M]}$ and $p_i^{[S]}$ are allocated to (MU$_n$) and SU$_{i,n}$, respectively, where it is A portion of $\alpha_n^{[M]}$ and $\alpha_{i,n}^{[S]}$ from the (MBS's) power Moreover, (SBS's) power and the message signals to (MU$_n$) and SU$_{i,n}$, are $s_n^{[M]}$ and $s_{i,n}^{[S]}$, respectively, Given that i belongs to the set of SC ($i \in \mathcal{SC}$) and n belongs to the set of SU ($n \in \mathcal{SU}$), the received signal SU$_{i,n}$, $y_{i,n}^{[S]}$, can be expressed as [21].

$$y_{i,n}^{[S]} = \underbrace{h_{i,n}^{[S]} x_{i,n}^{[S]}}_{\text{Desired signal}} + \underbrace{h_{i,n}^{[S]} \sum_{l=1, l\neq n}^{N_{SU}} x_{i,l}^{[S]}}_{\text{Inter-user interference}} + \underbrace{\sum_{j=1, j\neq i}^{N_{SC}} f_{j,i,n}^{[S]} x_j^{[S]}}_{\text{Co-tier interference}} + \underbrace{g_{i,n}^{[S]} \sum_{k=1}^{N_{MU}} x_k^{[M]}}_{\text{Cross-tier interference}} + \underbrace{z_{i,n}^{[S]}}_{\text{Noise}}, \quad (1)$$

Where the channel factors between (SBS$_i$) and (SU$_{i,n}$) are $h_{i,n}^{[S]}$, $\square_{fj,i,n}^{[S]}$, and $g_{i,n}^{[S]}$, which are the co-channel factors that between (SBS$_j$) and (SU$_{i,n}$), and the cross-channel factors that between (MBS) and SU$_{i,n}$, respectively, while the additive white Gaussian noise AWGN at SU$_{i,n}$ with variance σ^2 is $z_{i,n}^{[S]}$, the received signal at the MU$_{i,n}$, $y_n^{[M]}$, by assuming ($n \in \mathcal{MU}$), Similarly can be expressed as [21]:

$$y_n^{[M]} = \underbrace{h_n^{[M]} x_n^{[M]}}_{\text{Desired signal}} + \underbrace{h_n^{[M]} \sum_{l=1, l\neq n}^{N_{MU}} x_l^{[M]}}_{\text{Inter-user interference}} + \underbrace{\sum_{i=1}^{NSC} g_{i,n}^{[M]} x_i^{[S]}}_{\text{Cross-tier interference}} + \underbrace{z_n^{[M]}}_{\text{Noise}}, \quad (2)$$

The channel factors between (MBS) and its (MU$_n$) and the cross-channel factors between (SBS$_i$) and (MU$_n$) are $h_n^{[M]}$ and $g_{i,n}^{[M]}$, respectively. The AWGN at (MU$_n$) is $z_n^{[M]}$.

Equations (1) and (2) show that there are three different types of interference because the MC and SCs utilize the same resources. Inter-user interference arises between users inside the same cell due to the non-orthogonal multiplexing technique known as NOMA. Secondary users (SUs) encounter interference from other co-tier small base stations (SBSs). In contrast, both SUs and multiple users (MUs) are impacted by interference from macro base stations (MBS) and SBSs.

3.2. Power Allocation

In this paper, we consider path loss as a channel condition for each user, so let us suppose a group of N users by which each user experiences a path loss represented by *Li*. The approach employed is to provide transmission power to the users in inverse proportion to their path loss while also normalizing it according to a total power constraint; the following technique is assumed:

- *Path Loss Calculation*

First; we compute the path loss corresponding to distance by estimate the Friis free space path loss (FSPL)

Equation as in [22] .

$$\text{FSPL}\,(f,d)[\text{dB}] = 20\log_{10}\left(\frac{4\pi df}{3\times 10^8}\right) \quad (3)$$

Where d is the distance between the BS_s and users, f is the frequency and (3×10^8) it's the speed light in the vacuum

- *Inverse Path Loss Calculation*

First, for each user *i*, calculate the inverse of the path loss, denoted by *Ii*:

$$I_i = \frac{1}{L_i} \quad (4)$$

- *Normalization of Power Allocation Coefficients*

To estimate the power allocation coefficient for each user, denoted as *Pi*, the inverse path loss values are normalized to guarantee that the sum of all assigned power coefficients is equal to 1. The equation that defines this normalization method is as follows:

$$P_i = \frac{I_i}{\sum_{j=1}^{N} I_j} \quad (5)$$

For every N user, $\sum_{j=1}^{N} I_j$ is the inverse losses path summing that guarantees the scaling factor normalization of the total power distribution to unity. It is suggested to use a balanced power distribution technique that gives customers with greater degrees of route loss more power in order to lower their failure rates. This kind of approach is necessary to develop equitable and effective power management strategies in wireless communication networks to raise overall system performance while adhering to power constraints.

3.3. Channel Assignment

An optimal way to allocate a finite number of communication channels among users has been offered via a system model. Other goals of the strategy include lowering interference and guaranteeing equitable access in many industries.

Phase 1: round-robin algorithm

Within the system model, one of the most often employed methods is the Round Robin (RR) scheduling system as the simplicity scenario and lack of characterizing of the UE's channel status call for it. Under a BS, every UE is handled similarly in line with standards [23]. That specifically developed to partitions a limited number of user communication channels (Nc) into a predefined number of sectors. The channel assignment procedure is shown in figure 2, frequently and sequentially.

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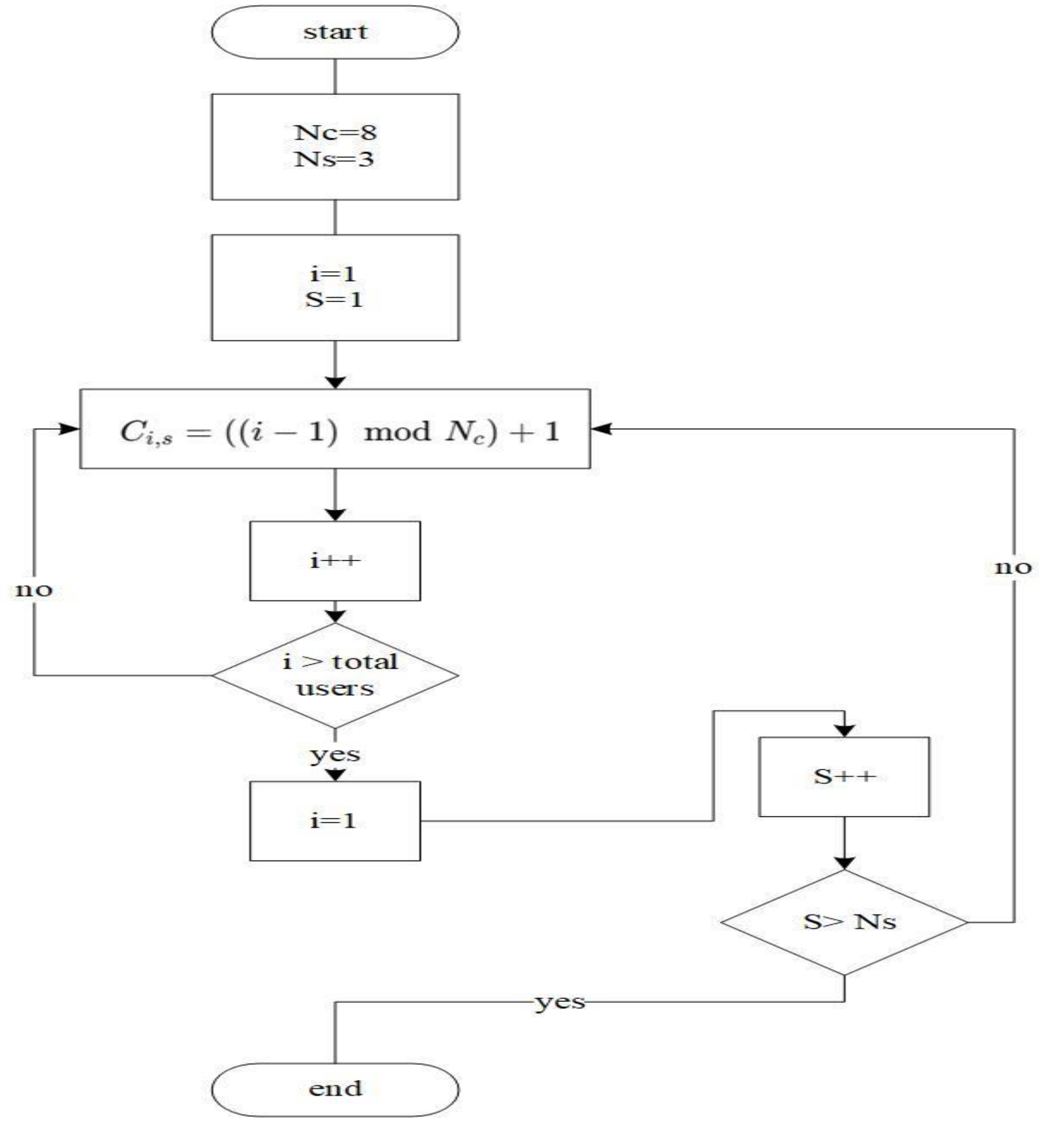

Figure 2. Block diagram of Round-robin channel assignment algorithm.

For each user, the following equation assigns me a channel $C_{i,s}$; the system sequentially assigns channels, ensuring a balanced distribution:

$$C_{i,s} = ((i-1)\mathrm{mod}N_c) + 1 \qquad (6)$$

Whereas N_c refers the available channels total number, and i refers to the index of user.

Phase 2: sectored-based channel reallocation

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For sector-specific allocation, to prevent overlap and interference, the starting channel S_s for sector s is determined by:

$$S_s = \left((s-1)\text{mod}\frac{N_c}{N_s}\right) + 1 \quad (7)$$

With N_s representing the total number of sectors. Each user within a sector s is then assigned a channel based on:

$$C_{i,s} = (S_s + (i-1)\text{mod}N_c) + 1 \quad (8)$$

This methodology optimizes channel utilization and minimizes interference, significantly enhancing network performance.

Phase 3: interference management

Furthermore, the model integrates a straightforward interference control method by adjusting the channel assignment inside each sector and the sector-based reallocation. Consistent with the preceding procedure, the channel assignments among the sector's users are alternated, commencing anew from a computed start_channel. The redundancy in alternating channel assignments is implemented to verify and reduce interference between different sectors and within the same sector, improving the overall communication quality within the network.
In order to facilitate effective interference management within each sector and at a network-wide level, the channel assignment can be modified in the following manner:

$$C_{i,s} = \left((\text{ start\_channel }_s + i - 2)\text{mod}N_c\right) + 1 \quad (9)$$

Where the start_channel $_s$ The starting channel for sector S is calculated based on the sector index to avoid interference with adjacent sectors.

4. SIMULATION RESULT

The simulation in this study measured the performance improvements in a wireless communication network from sectoring, targeted power allocation, and channel assignment methods using 105 Monte Carlo iterations. Twenty users were evenly distributed throughout a 2000 m by 2000 m area to investigate the BER as a function of SNR, which ranged from 0 to 30 dB.
The design of the network became evident with the inclusion of sectoring Ns = 3. To increase coverage and simplify communication within their borders, the sectors were outfitted with MBS. As the results, as illustrated in Figure 3, demonstrate, the BER within the segmented network was much decreased. It is clear from the fact that the decline remained constant for all SNR levels how well sectoring reduces interference and improves signal clarity.

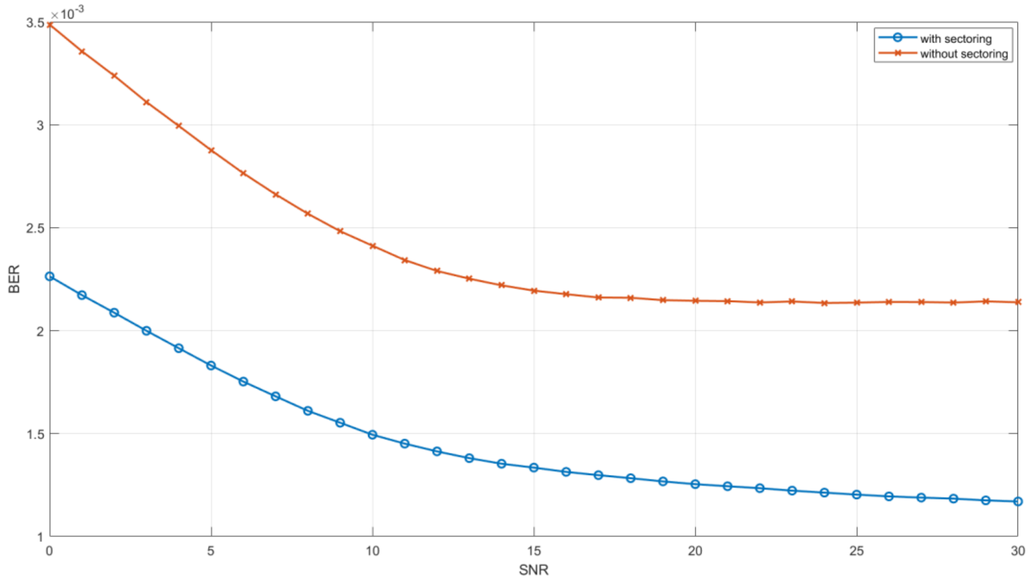

Figure 3.
Comparative Analysis of BER Performance with and without Sectoring at Various SNR Levels.

The careful use of a round-robin algorithm for channel allocation ensured an efficient and fair distribution of the eight available channels ($N_{c=8}$) among the user population. As demonstrated in Figure 4, this specific technique was essential in reducing the possibility of channel overlap and interference, which is an essential component in network optimization, particularly in a sectorized environment.

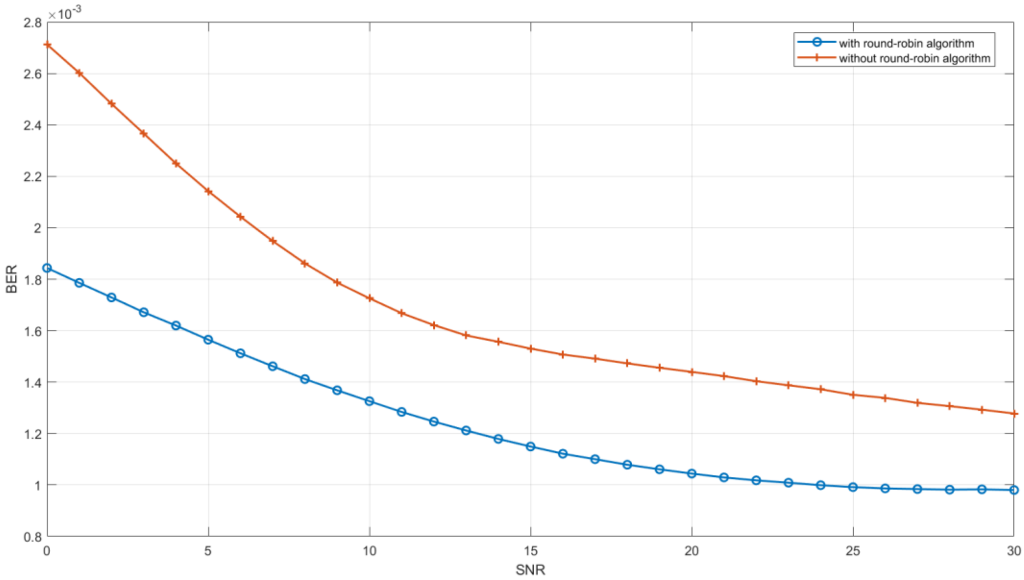

Figure 4. BER Performance Enhancement Using Round-Robin Channel Allocation

Moreover, a critical component of the NOMA approach was the power distribution, which was continuously modified in reaction to the path loss (PL) that the customers encountered. Scaling the power to the route loss inversely enhanced the power the user received at longer distances or with higher attenuation. This strategic allocation was implemented by efficiently handling the variations in route loss that users encountered, therefore preserving a balanced communication capacity across the network.

The results of the simulations definitely demonstrated the benefits of sectoring with the MBS. When sectoring was coupled with astute channel assignment and power allocation techniques, BER was decreased while network performance was increased. As the curve in the picture above shows, sectoring may considerably reduce the BER, particularly at higher SNR levels. This implies better network and optimized use of the spectrum resources. The simulation demonstrates that consistent channel and power allocation methods are not enough to improve the quality of service in wireless networks; sectoring is necessary. These findings confirm the need of sectoring in the design of modern network architectures.

5. CONCLUSION

In order to reduce interference and improve network performance, this paper investigated a sectoring method in NOMA-based HetNets. BER at different SNR levels is shown to be much improved by combining sectoring with round-robin channel allocation and inverse route loss power regulation in the simulation results. These results indicate that the 5G of networks needs these strategies to be developed. Improving wireless communication systems will be the main goal of future study to satisfy the growing needs for wide coverage and high efficiency

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