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Cell Selection Approach towards Interference Coordination in 5G and Beyond Networks

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ABSTRACT

Advancements in fifth-generation (5G) and beyond networks have significantly increased the demand for high-speed multimedia applications. However, evolved NodeBs (eNodeBs), macros and supplementary low-power nodes (LPNs) coexisting can result in heightened interference within these networks. Due to elevated transmission power of macro cells, only a small number of users are offloaded to nearby Pico cells, leading to Pico cells being underutilized in ultra-dense networks (UDNs). To address this, range extension (RE) presents a practical approach to put LPN resources into better utilization and enhance cell edge performance. Cell range expansion (CRE) enables a bias to be applied by user equipment (UE) to the received signal strength from Pico cells, facilitating traffic to be transferred from macro cells to Pico cells. However, improper bias value settings that do not account for user distribution and network density can exacerbate interference. This paper presents an Intelligent Pico CRE solution that independently calculates the optimal bias value assigned to each mobile station. Simulation results show that this approach reduces outages when an optimal bias value of 12 dB is attained, and boosts the number of offloaded UEs in ultra-dense networks (UDN).

1. INTRODUCTION

The rapid advancement of internet of things (IoT), machine-to-machine (M2M), and internet of everything (IoE) is driving telecom enterprises and wireless communication providers to establish the architecture, specifications, and requirements for fifth generation (5G) and beyond networks (Alam *et al.*, 2024). The 5G network was conceptualized due to high demand on network capacity, mobility, high data rate, better end-to-end performance. One of the solutions to support this increasing data traffic is ultra-dense deployment of small cells. To meet these demands, multi-tier architectures are expected to be adopted in 5G and beyond networks. These architectures will integrate various network tiers with differing transmission powers, backhaul connections, and radio access technologies (RAT), creating heterogeneous networks that enhance coverage, capacity, and user experience RAT (Ning *et al.*, 2014). To increase capacity, users will need to be dynamically offloaded to less congested tiers, such as Pico and Femto cells, as well as remote radio heads (RRHs), even if this results in a lower signal-to-interference-plus-noise ratio (SINR) (Yuan and Liang, 2016).

The aim of deploying low-power nodes (LPNs) seeks to alleviate traffic on macro cells, improve coverage, and boost spectral efficiency through the spatial reuse of spectrum (Zhang *et al.*, 2022). Additionally, this approach reduces the separation between the transmitter and receiver, resulting in improved quality of the radio link. With increase in demand for data traffic rate growing exponentially, further enhancements are necessary to improve the spectral efficiency. Higher transmission power of macro cell leads to underutilization of small cells. This introduces a lot of challenges in the multi-tier network, one of which is inter-cell interference (ICI). In 5G and future networks, current techniques for management of interference will be inadequate to address effectively the issue of ICI. Cell range expansion (CRE) comes as a technique used to virtually extend the coverage area of Pico cells (Cao *et al.*, 2013). There are some studies on the SINR bias, but have not given any theoretical guidance on the best value. Hence, if the bias value is not appropriately selected, this could lead to overloading and low system performance, which defeats the purpose of deploying Pico cells.

Apparently, only a few users will be offloaded to the Pico cell if a small offset value is applied, due to the disparity in the reference signal received power (RSRP). The signal from the macro base station (BS) is stronger than that from the Pico BS, even with the added bias value. As a result, macro UEs performance will degrade due to the macro cell serving a higher number of UEs (Siddiqui *et al.*, 2022). Conversely, when the offset value is large, offloading of more UEs is experienced to the Pico cell, even when the distance is far from the Pico eNBs. Hence, the macro eNB introduces significant interference, which in turn increases the chances of outages and reducing throughput. Several studies have been conducted on range expansion. Tian *et al.* (2011) introduced a scheme with CRE that employs offset value adaptively, determined through a logarithmic approach, considering both throughput and the number of UEs. Additionally, Oh *et al.* (2012) suggested CRE strategies aimed at interference management. In these methods, the optimal offset value is established to ensure the desired system performance is attained. In the work of Lopez-Perez and Chu (2011), a novel cooperative Macro-Pico scheduling approach to mitigate inter-cell interference in the downlink of macrocell towards Pico ER UEs was proposed. However, with this proposed scheme, users in Pico regions may still suffer significant interference if proper and optimal bias value is not set.

To address the problem, Alam *et al.* (2024) developed a cell association based on load aware scheme to improve throughput and quality of service (QoS). The developed algorithm was assessed through simulations to outperform earlier cell association schemes in terms of load balancing and throughput. Although, the complexity of the developed algorithm requires more study and can be reduced by introducing adequate optimization techniques. Motivated by aforementioned challenges, a CRE technique is proposed in this paper to determine an optimal bias value for Pico users in order to reduce interference and outages. Section 2 of this paper outlines the RE system in 5G and beyond scenarios while Section 3 offers a detailed introduction to the proposed adaptive bias configuration technique. Section 4 discusses results of the simulation and their implications, whereas Section 5 provides the paper's conclusion.

2. METHODOLOGY

Range expansion has continued to be a topic of interest basically due to its continued benefits and role in establishing smart cities and IoT capabilities. The following sections highlight how the approach can be implemented in 5G and beyond networks.

2.1 Range Expansion Strategy in 5G and Beyond Networks

In 5G, the coverage area of low-power nodes, like Pico cells in the downlink is improved through range expansion, when a positive bias is introduced to their measured signal strengths during the process of cell association, in order to address the problem of load imbalance in the downlink (Jain *et al.*, 2020). These base stations are known as biased BSs. A greater range expansion bias (REB) leads to an increased number of macro cell user equipment (MUEs) being offloaded to Pico cells, however, it also raises co-channel interference for range-expanded Pico cell user equipment (PUE) in the downlink.

In traditional LTE systems, a UE needs to detect and monitor several cells to perform cell selection or reselection, ensuring it is "camped" on the most appropriate cell. Hence, the system information and paging (SIP) of the cell where a UE is located this way will be monitored. In addition, the UE must also keep track of the strength and quality of neighboring cells to assess whether cell reselection or handover is necessary. Hence, two types of cell selection methods are specified (Ning *et al.*, 2019). In the earlier Rel-8/9, the RSRP was the determining factor for the cell selection of a UE's power or quality, given by Bhuvaneswari *et al.* (2015) as shown in equation 1.

$$CellID_{serving} = \arg\max_{j}\{RSRP_j\} \tag{1}$$

However, when this approach is applied to ultra-dense networks (UDN), it can result in the underutilization of small cells due to their low transmission power and limited coverage. Moreover, overloading will be experienced by the macro cell in comparison to the small cells, resulting in only a finite number of users connecting to the latter. As a result, small cells resources will not be underutilized, while the available resources in the macro cell will continue to be highly competitive. To address this problem, a new scheme called cell selection that supports addition of bias value to the reference signal level (shown in Figure 1), to attract more UEs towards selecting Pico BS as their serving cell is given by Sasikumar *et al.* (2016) as shown in equation 2. Where b_j is the bias value applied to the Pico BS. In equation 2, the macro cell has zero bias while the small cells assume a non-negative value, resulting in a greater number of users transferring to the small cells.

$$CellID_{serving} = \arg\max_{j}\{RSRP_j + b_j\} \tag{2}$$

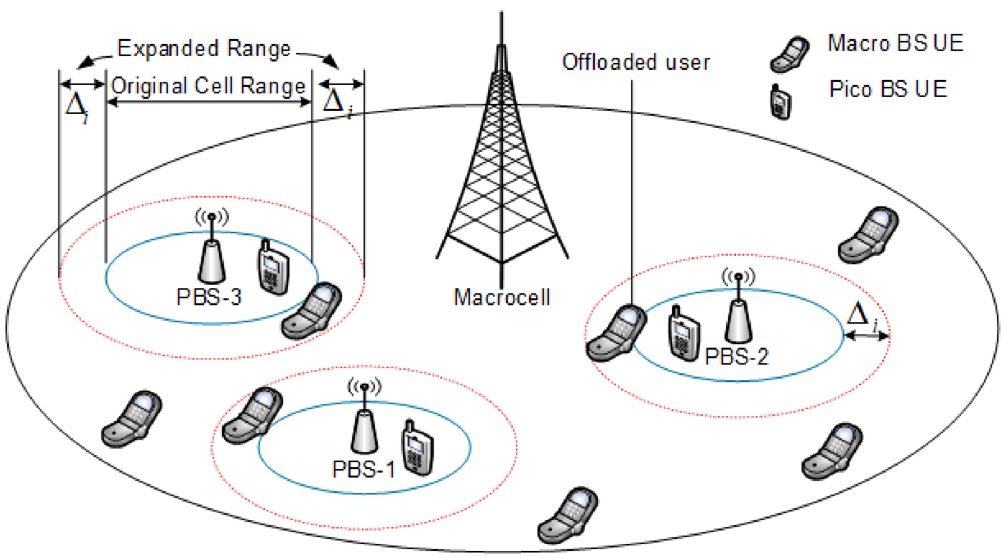

Figure 1: Cell selection with range expansion in UDN

Nevertheless, the bias value must be selected carefully to take advantage of the efficiency of range expansion, as an excessively high value of b_j will significantly increase the interference for users within the expanded range of Pico cells. Additionally, a low value of b_j will not have any impact on the global performance, such as load balancing or fairness, hence the purpose of deployment is defeated. Hence, the following setting determines the selection of BS having the highest downlink SINR in addition to a positive value of CRE (equation 3).

$$CRE_j = \begin{cases} CRE & ; \ if \quad j \quad is \quad a \quad Picocell \\ 0 & ; \ if \quad j \quad is \quad a \quad Macrocell \end{cases} \tag{3}$$

Interestingly, the bias value for the RE strategy significantly impacts UDN system performance by modifying the coverage of Pico cells. As shown in Figure 2, a larger bias value results in an expanded coverage area for Pico cells. However, the bias value cannot be infinite, as this would create "empty" macro cells since all users might connect to the Pico cells, as indicated in equation 2. Consequently, there must be an optimal bias value for specific scenarios. Unfortunately, the value of the bias is fixed typically in a given situation (Moon e*t al.*, 2014), it does not adjust to changes in user distribution. This may lead to an uneven traffic load between macro and Pico cells, leading to scheduling outages and suboptimal performance at the cell edge due to increased interference.

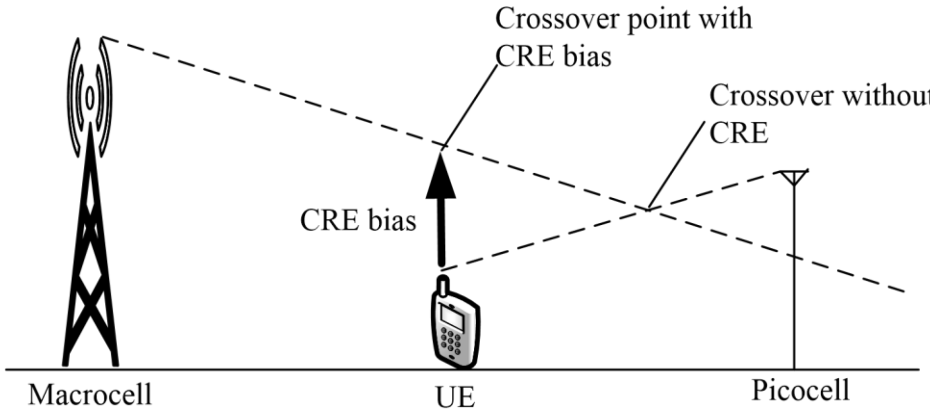

Figure 2: CRE bias for Pico cell expansion

2.2 Problem Formulation

This paper focused on the downlink of an orthogonal frequency division multiple access (OFDMA) network. The topology of the network consists of a macro BS and a set of Pico BSs which are distributed within a single cell. Moreover, both macro and Pico base stations function in open access mode, allowing all user equipment (UEs) to connect to them. Additionally, the area utilized is well-defined for our simulation. All UEs are deployed within the coverage of both macro and Pico BSs, which communicate using the X2 interface.

Let $\mathcal{U}$ denote the set of users, and let $\mathcal{M}$and $\mathcal{P}$ denote, respectively, the set of macro and Pico BSs, so that the set of BSs $\mathcal{B} = \mathcal{M} \cup \mathcal{P}$. In UDN, coordination among different BSs is usually difficult. This method results in considerable computational complexity in the formulated optimization problem; therefore, a distributed solution with low-complexity is desirable for functions with or without central coordination, while computation is minimal. In our proposed user association algorithm, we compute the bias value based on equations 1 - 3, where b could assume a variable value within a specific range, usually 0~25 dB.

2.3 User Association Algorithm

i) Each user $i \in \mathcal{U}$ measures the RSRP is based on received pilot signals from all available BSs, and it also incorporates the biasing factors communicated by each Pico BS. $j \in \mathcal{P}$, starting with the initial state where $b_j = 0$.

ii) Each user $i \in \mathcal{U}$ connects to BS $j*$, satisfying the following formula: $j^* = \arg\max \{RSRP_{ij} + b_j\}$. If there are multiple optimal associations available simultaneously, user i can select any of them, as illustrated in the flowchart outlining the steps for choosing a BS with or without CRE, in Figure 3.

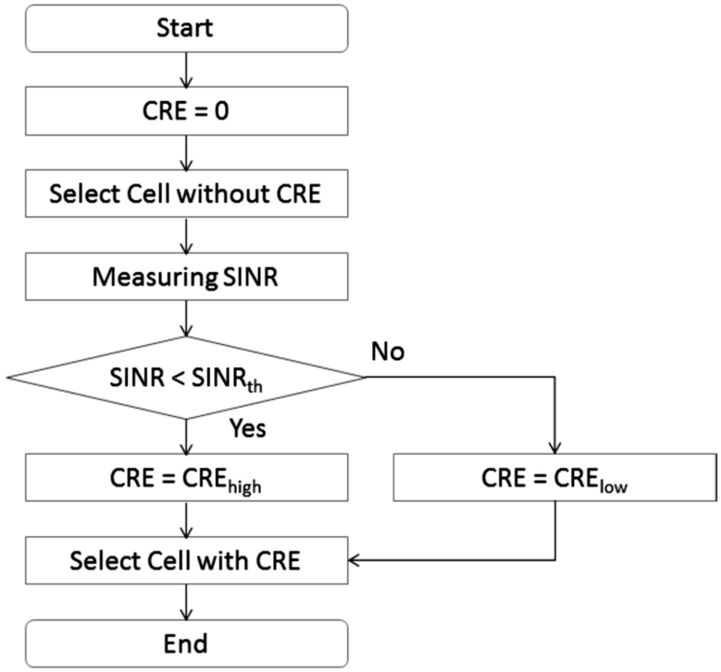

Figure 3: Flowchart of user association technique

3. RESULTS AND DISCUSSION

The simulation setup comprises a 1-cell topology with a single macro BS having 4 Pico BSs. In this paper, it was assumed, for simplicity, that the Pico BSs and 20 users are independently distributed uniformly throughout area of the macro cell. Each base station operates with a bandwidth of 20 MHz, and 1 Mbps is set as the rate requirement for each user, in line with 3GPP specifications (3GPP Release 13, 2012). Additionally, the power level of noise is assumed to be -174 dBm/Hz, while the path loss for macro and Pico base stations is calculated using the formulas L(d) = 128.1 + 37.6 log(d) and L(d) = 130.7 + 36.7 log(d), respectively, where d represents the distance between a user and its associated base station in kilometers.

Figure 4 represents the percentage of UEs connected to both macro and Pico BSs. It is shown that users are categorized according to their mode of connection to Pico cells. In this case, the bias values (in steps of 6 dB) range from 0 dB, when majority of users are connected to macro cell to 18 dB when more users are pushed to Pico cells. There is an optimal bias value of 12 dB, as illustrated in Figure 4, which significantly minimizes UEs outage number, thereby promoting load balancing and improved spatial reuse. Additionally, it is evident that a higher bias value results in an increased number of UEs connecting to the Pico BS. This is because the UEs number in the expanded region increases with increase in the bias value.

However, an excessively high value of bias can overload the Pico BSs by directing more users to access their limited resources. This was evident in our simulation when the bias value reached 18 dB. At this stage, the throughput of range-expanded UEs decreased because users positioned far from the Pico base stations were connected to them while facing substantial interference from the macro base station. Thus, it is evident that by not carefully selecting the offset value, enhancing throughput for either macro or Pico UEs may negatively impact the other.

Moreover, Figure 4 illustrates that the outage probability increases with the bias value. This occurs because, as the bias value rises, as seen at 18 dB (21.67% / 78.33%), all UEs located farther from the Pico BSs are offloaded to Pico cells, where they encounter lower SINR. However, with an optimal bias value of 12 dB, the network comes close to achieving optimal cell selection. The results indicate that bias-based cell association significantly improves resource utilization and effectively balances the load traffic, resulting in greater overall rate gains for the majority of users. Compared to previous works (Sun *et al.*, 2014; Lopez-Perez and Chu, 2011), it was observed that a 35-40% rate of UEs selected the Pico BS as their serving cell.

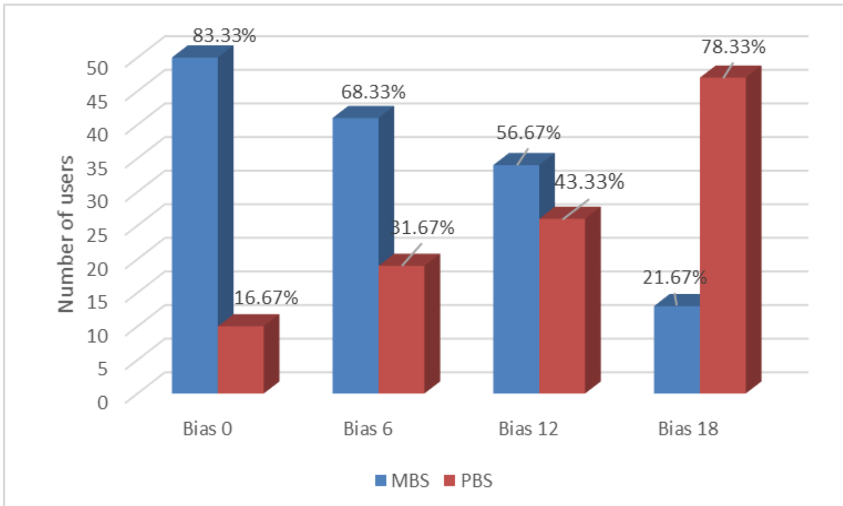

Figure 4: Cell association connection statistics

Figure 5 illustrates the BS power plotted against the signal energy per bit divided by the noise spectral density (Eb/No). Expectedly, the macro BS total transmission power increases when the Eb/No increases. This results in unnecessary battery drain as the macro BS attempts to satisfy users with good and bad radio conditions. Figure 6 shows the plot of the total power expended by the BSs and the number of UEs. Initially when the majority of UE are connected to the macro BS, the macro BS utilizes high power in other to satisfy both cell edge and cell centre users. However, as some users are offloaded to the pico BSs, there is a considerable reduction in the amount of power usage by the macro BS. This approach, therefore, helps to conserve battery life thereby resulting in green energy transmission.

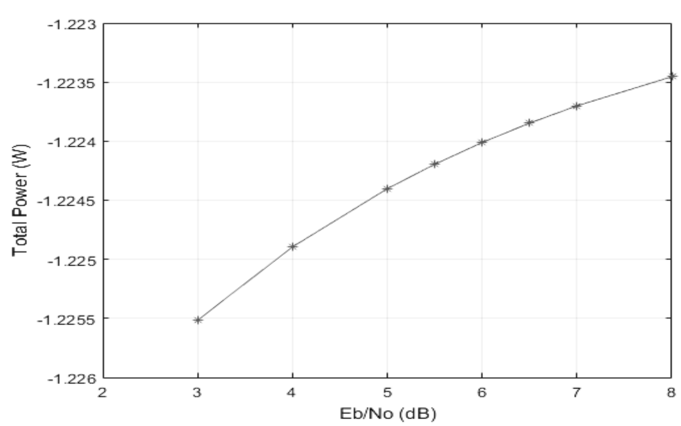

Figure 5: BS power vs E_b/N_o

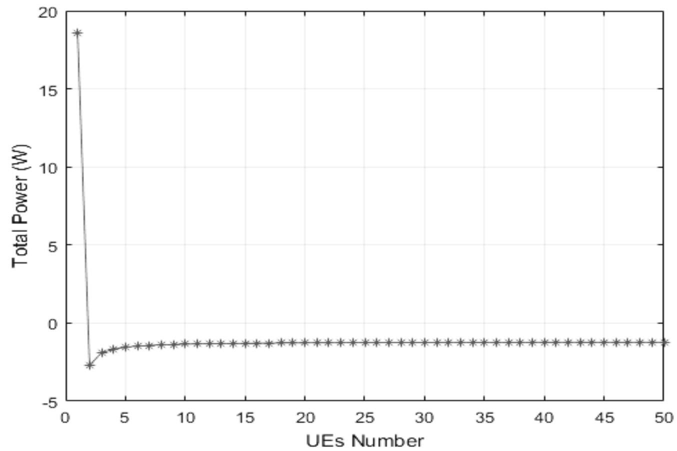

Figure 6: BS power vs No. of UEs

4. CONCLUSION

In this paper, range expansion technique was examined to minimize outages and enhance the number of offloaded UEs in ultra-dense networks. In a macro-pico scenario, the range expansion strategy was used to maximize the utilization of low-power node resources and enhance performance at the cell edges. Simulation results showed that Pico cells with extended coverage, facilitated by the proposed cell association algorithm, can reduce user equipment outages and substantially enhance spatial reuse in ultra-dense network environments, as expected in 5G and beyond networks.

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