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Sector-Based Algorithm for an Enhanced Handover and Load Balancing in 5G Heterogeneous Networks

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ABSTRACT

To improve load balancing in 5G heterogeneous networks (HetNets) by managing congestion and interference during handover operations, this paper introduces a unique sector-based approach. To maximize channel selection and enhance user experience, the algorithm incorporates Clear Channel Assessment (CCA) and Channel Annulling (CAA) approaches. almost sixteen hours of testing, there was a noticeable decrease in congestion, with average load factors in macro cells falling from 0.44 to 0.38, microcells from 0.28 to 0.22, and pico cells from 0.23 to 0.19, for an overall average drop of 15%. Furthermore, the approach successfully reduced interference, which resulted in higher Reference Signal Received Power (RSRP) metrics: Both the macro and micro cell RSRPs increased from -80 dBm to -71.5 dBm and -85 dBm toPico cell RSRP ranges from -86 dBm to -75.0 dBm, and -74.3 dBm. The suggested approach improves network performance by permitting smooth handovers, lessening congestion, and greatly enhancing signal quality.

Keywords: Clear Channel Assessment, Interference Management, Handover, Load Balancing, 5G HetNets

I. INTRODUCTION

In recent times, 5G holds the key towards becoming the primary platform for communication in the entire world, not only supporting normal talk and data exchange but also a specter of video performance, self-controlled automobiles, and an avalanche of connected devices, hence the desire to plume the network that is billowing gets unbearable. To satisfy this increasing need, it is essential to incorporate 5G heterogeneous networks which comprise macro, micro, and pico cells which are distributed in a given metropolitan area exceptionally well so that they ensure good coverage without loss of handover quality. A heterogeneous network (HetNet) is a network configuration that interconnects the services of multiple cells such as macro cell, micro cell, pico cell, femto cell, and radio relays within a cell coverage area for better resource distribution and management (Abonyi, 2019; Kulkarni and Sharma, 2019). Take for example; this when a user switches coverage areas for example; a mobile phone user can be active on various cells such that at times they need to clay within the sirens or streets connected with mobile communication for individual users moving about, this is within the domain of 5G HetNets. The movement in question in this case involves a user changing from one base station to another owing to HO. This movement of users between different coverage areas in a 5G HetNet is very vital as it calls for the proper interconnectivity of users without loss of coverage. Interference and congestion during handover are among the issues that result in compromised network performance leading reduction in call drop outcomes as well as reducing the incidents of call blocks a trend which is not pleasing to the end user (Kamel& Hassan, 2020).

Problem Statement

Smaller base stations (BS) are stacked on top of bigger, meticulously designed macro cells in a heterogeneous network. Stronger received signal strength (RSS) from the macro cells is the result of the macro base stations' higher power transmission than smaller cells. Users tend to associate with cells with stronger RSS and higher transmission power due to this power discrepancy; these characteristics, in addition to route loss, are important for user association. As a result, macro cells in heavily populated areas are vulnerable to carrier overload, which can cause congestion, call dropouts, network access failures (including call blocking), degradation of quality of service (QoS), delays in data transmission, and congestion. To increase QoS and user experience, this ongoing issue in 5G heterogeneous networks needs to be resolved.

In wireless networks, especially in densely populated areas, conventional load balancing strategies like traffic classification, traffic policing, traffic shaping, and queuing management are not proactive enough to handle traffic dynamics. During load balancing, a popular technique for dividing up extra traffic among nearby cells is the handover procedure. However, because wireless communication uses a shared frequency spectrum, other cells frequently interfere with this process. This is particularly true in 5G networks, where adjacent channels are employed to increase spectrum efficiency. Adjacent channel interference (ACI) may arise from this.

Channel selection strategy is one technique to reduce interference. The traditional techniques for allocating channels during handover aren't necessarily the best, though. Occasionally, busy channels are chosen for load redistribution, which causes congestion and subpar network performance as seen by important metrics like as signal quality, loss, throughput, latency, and call and changeover success rates. Adjacent channel interference arises when load balancing interacts with neighboring cells using adjacent frequency channels due to the redistributed traffic.

To address these challenges, this study suggests an algorithm that determines the optimal traffic distribution path that is free of interference and congestion for enhanced load balancing.

II. RELATED WORK

2.1 Congestion and Interference in 5G Networks

Congestion in 5G networks is often caused by the unpredictable nature of user traffic, device density, and real-time application demands. Similarly, interference between adjacent cells—especially in HetNets where macro, micro, and pico cells coexist—can degrade the network's overall performance. The introduction of 5G technologies has led to an evolution of mobile communication services that is however prolific with issues of congestion, interference, and the maintenance of the right Quality of Services (QOS). This section addresses the existing literature addressing this aspect of interference management, load balancing, and handover optimization in 5G HetNets, which will aid in proposing the Sector-Based Algorithm.

2.2 Handover Challenges in 5G HetNets

Handover (HO) refers to the single most characteristic in mobile networks globally with users moving from one cell management area to another with few, if any dropped calls. But in the case of 5G HetNets where macro, micro, and pico cells often overlap, conducting handover is more complicated than in past generations because of the high deployment as well as many variations in coverage area (Andrews et al., 2014). The bulk of the issues normally come about because of patient disturbance and other forms of interference, especially when one has to carry out a shift with a system. Ordinary methods of handover management mostly use RSRP or RSRQ to help in determining and forming transition communication with a new RAN. So even those who try to form a transition in the middle of the traffic may not account for the congested traffic and interference, leading to inefficient transitions (Kibria et al, 2018).

In a quest to solve these problems, a few ways of handover optimization have been proposed by researchers For instance, Kamel and Hassan (2020) suggested an approach that employs both signal strength and load-balancing techniques to optimize cell selection during handovers. However, the authors remain silent on the issue of considering interference. Dobre and Gaudio (2019) underlined the fact that the available static handover methods do not succeed in a situation where users and the traffic are dynamic, going on to argue for the use of more intelligent algorithms.

2.3 Interference Management in 5G HetNets

Interference is an issue that is not new to a cellular network, rather, it gets worse in the case of HetNets constructed with small (micro,pico) and macro cells in close proximity. Which region suffers the most severe inter-cell interference, especially in urban clutter, and how does it affect network performance (Soret et al, 2019)? EICIC and CoMP are examples of system level approaches and interference coordination approaches that have been proposed in HetNets. These approaches aim at reducing the level of interference through improving interactions among base stations, but such approaches may come at the expense of inducing large signaling traffic and delay which is not helpful in environments which are populated.

Recently, interest has been drawn to more efficient machine learning approaches that are able to model interference and self-optimize resource distribution Zhiyong et al. The reinforcement learning method proposed by (2021) for dynamic resource allocation managed to significantly reduce interference and carry out the load distribution efficiently. Nonetheless, the downside to those methods is that these are data-hungry and difficult to implement for realtime applications.

2.5. Innovations in Handover Optimization

Recent advancements in handover optimization leverage both interference management and load-balancing techniques. Liang et al. (2019) emphasized the need for dynamic handover mechanisms that account for both **RSRP** and **RSRQ** alongside real-time network conditions such as congestion and interference levels. Such mechanisms are particularly valuable in **HetNet environments**, where small cells can become overloaded quickly due to user mobility.

Additionally, studies like that of Jaber et al. (2020) have explored **traffic-aware handover mechanisms** that monitor network conditions in real time, ensuring that the best cell is selected during handovers. However, these studies often fall short of effectively combining traffic and interference management.

The research identifies several difficulties with 5G HetNet load balancing, interference, and handover management. There are several ways to deal with these issues, but most of them concentrate on only one, like interference or traffic, without taking both into account asa whole. To close this gap, the Sector-Based Algorithm presented in this study combines traffic detection techniques using artificial neural networks with Clear Channel Assessment and Channel Annulling. This ensures optimal handover decisions that take interference and traffic load into account, ultimately enhancing the overall Quality of Service (QoS) in 5G HetNets.

III. METHODOLOGY

3.1 Sector-Based Traffic ControlAlgorithm

Sector-based traffic control was proposed in this study to address spectrum congestion and interference difficulties during load balancing in 5G HetNet and to redistribute and balance the load inside the cells. By using sophisticated handover techniques, this sector-based traffic control model transfers users from congested to less congested sectors. To make well-informed handover decisions, it takes into account variables like signal strength and interference levels. Combining certain methods and algorithms, a 5G HetNet's sector-based traffic control model will efficiently distribute the load across its sectors, guaranteeing maximum resource efficiency, reducing congestion, and offering a superior user experience.

The method started by the Sector-based Traffic Control system has been triggered by the traffic detection system, to make load-balancing decisions. The traffic detection model (TDM) uses ANN to detect an overload of a cell. Due to increased meddling, overcrowding in one sector might result in poor performance in that sector and nearby ones. Different frequency bands can be used to shift traffic to unused areas through the use of frequency division multiplexing in load balancing. By doing this, interference is lessened and users throughout the network can continue to receive appropriate signal quality and throughput.

Following the detection of an overload, the Sector Based Traffic Control system assigned a band to each HetNetcell using the Frequency Division Multiplexing (FDM) technique (Vaeed et al., 2023).

The 5G frequency band of MTN is 3500MHz –3600MHz giving the total bandwidth of 100MHz. In this work, the coverage area of the network was divided into four sectors. The STC leveraged FDM to divide the available spectrum into multiple frequencies. The four sectors have a frequency band of 25MHz each.Subsequently, the Orthogonal Frequency Division Multiplexing (OFDM) technique (Naveed et al., 2023)was used to divide each newly discovered frequency band into a sub carrier channel to distribute resources. The subcarrier spacing used was 15KHz and the 25MHz allocated to each sector was divided into subcarriers using the 15KHz subcarrier spacing. When it comes to efficient spectrum usage and resilience against multipath fading, OFDM is especially useful in high-speed data transmission scenarios (Junejo et al., 2022). OFDM is the primary modulation and multiplexing technology in 5G communication systems. It is especially successful in high-speed data transmission scenarios, offering robustness against multipath fading and efficient spectrum usage (Junejo et al., 2022).

3.2 Clear Channel Assessment and Carrier Anulling Algorithm

To further address the issues of interference in the cell, the signal-to-noise ratio for the channel in Equation 1 and the signal-to-noise and interference ratio in Equation 2 were used to

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determine the fitness of the channel for carrier allocation.These were done using a clear channel algorithm and carrier annulling algorithm. The channels were used to check the interference level for each of the subcarriers. The SNR is a metric that contrasts the strength of an intended signal with the strength of ambient noise, or undesired signal. The definition of it is the signal-to-noise power ratio. More signal than noise is indicated by a ratio greater than 1:1.

$$SNR = \frac{P_{signal}}{P_{noise}} \dots\dots\dots\dots\dots (1)$$

Signal-To-Interference plus Noise Ratio (SINR)

This statistic aids in handover decisions by optimizing the transmit power level for a target quality of service. A more effective system and a greater user-perceived quality of service are provided by accurate SINR estimation. The ratio of signal power to the sum of noise and interference power is known as SINR.

$$SINR = \frac{P_{signal}}{P_{noise} + P_{interference}} \dots\dots\dots\dots\dots (2)$$

To find the channel's potential for interference, these equations 1 and 2 were used by the CAA. Next, the Clear Channel Assessment (CCA) model in Figure 1 (Paul, 2020; Patel and Kumar, 2017) belowwas used to prevent collision with a busy channel. The selected Carrier Annulling Algorithm (CAA) (Najlah and Sameer, 2020) was then implemented to avoid the channel during carrier allocation for handover. To keep an eye on busy channels and postpone their assignment until they were available, the CCA implemented a time control function. The process has a 10ms time delay specified. < 15dB is the threshold that has been chosen for interference detection (Meraki, 2023). The flow chart of the CCA and CAA is shown in Fig. 1and 2 below respectively.

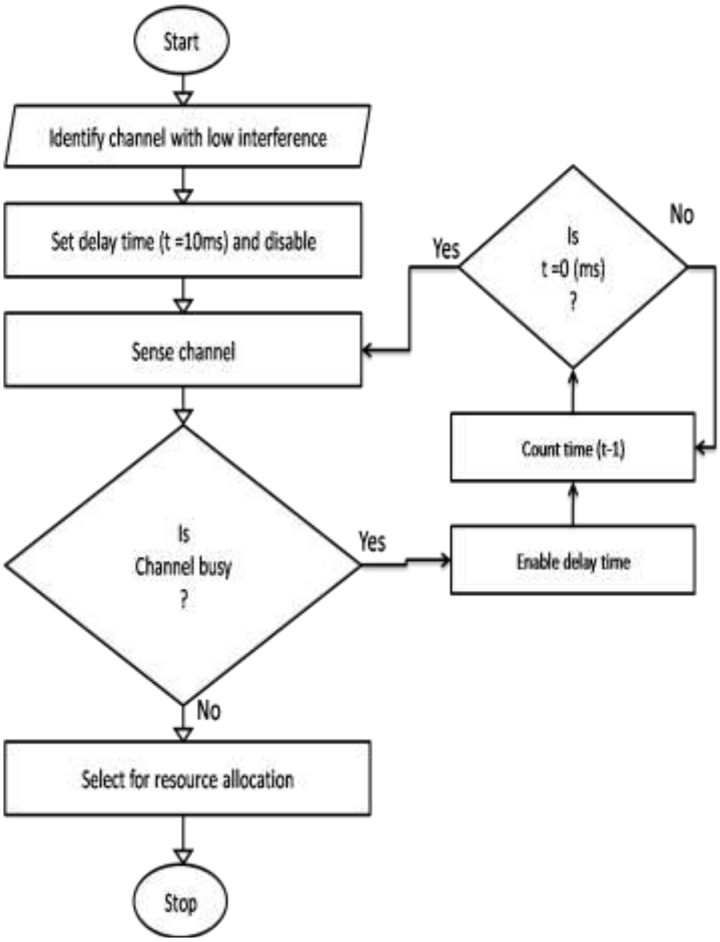

Fig. 1. The CCA flow chat

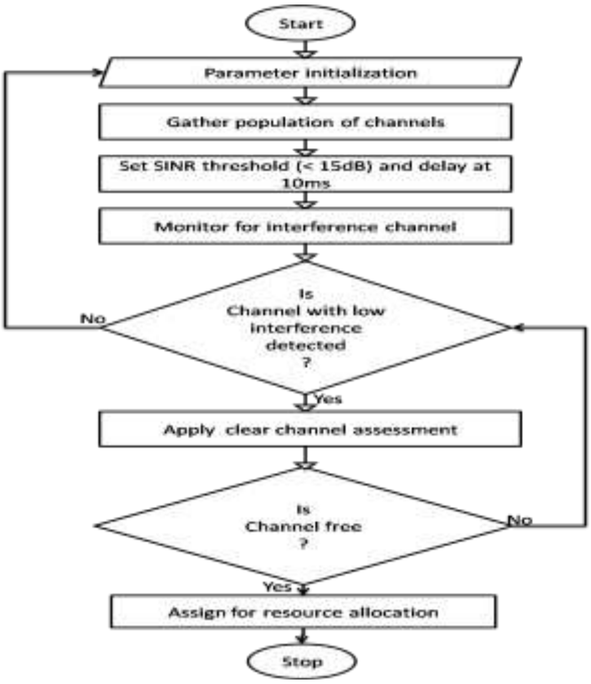

Figure 2: Flow chart of the CAA

Figure 2 presents the flow chart of the CAA for the optimization of the load-balancing process. The Algorithm examines the received signals in both the over-utilized cell and its neighboring cells. First, the population of channels was detected, then the interference level for each channel was detected and those with low interference potential were identified for resource allocation. Before the resources were allocated, the CAA was applied to sense busy channels, to address congestion. Channels that are free and with low interference are selected and then mapped for resource allocation during the load distribution process. The proposed CAA was used to optimize thesector-based traffic control system as depicted in the STC model of Figure 3;

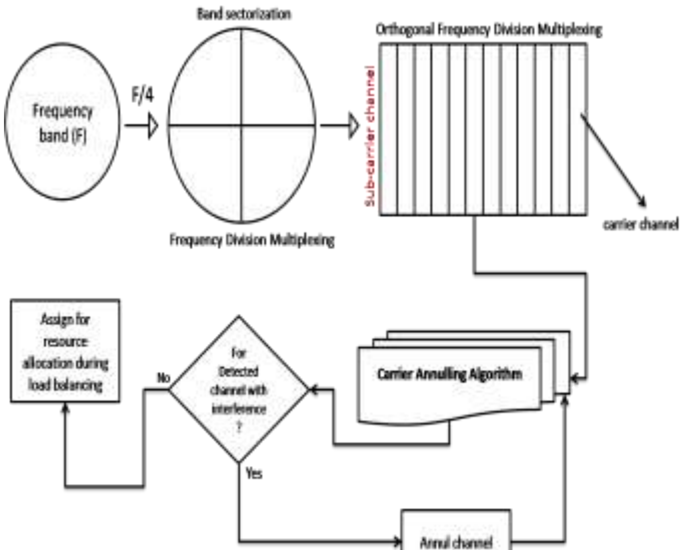

Figure 3: The Sector-based traffic control Model

Using the FDM approach, the frequency allotment to each cell was sectored as shown in Figure 3. Using OFDM for resource allocation, each segmented sector was further split into sub-carrier channels. The STC finds a channel for the distribution of the load from the overloaded sector

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by utilizing its structures (FDM and OFDM). The suggested CAA was used to monitor the channel condition considering SINR and then identify the fit channels for resource allocation, while the unfit channel with interference and low signal-to-noise ratio are annulled. This prevents interference and congestion during the data transmission process.

Sector-Based Traffic Control Algorithm

1. Start
2. Parameter initialization
3. Identify network parameters% frequency SINR, SNR
4. Sectorized cell into four segments % Using FDM
5. Create a sub-carrier channel for each segment% Using OFDM
6. Apply the proposed CAA algorithm % to detect fit channels
7. Assign a channel for resource allocation
8. Return to step 6
9. End

Once a suitable target sector and channel for the distribution was identified, the handover process was initiated for the user equipment (UE) connected to the overloaded sector to be handed over to the less congested one.

3.3 Handover process in load balancing

To balance the load from the congested cell, handover (HO) was employed. To guarantee that users have a seamless transition when offloading from a crowded cell to one that is less crowded, the handover procedure is essential. The user equipment (UE) connected to the overloaded sector undergoes a handover process once a suitable destination sector and channel are located. Initialization, connecting to the intended cell, and data transfer to the intended cell are the three processes in the process (Onuigbo and Ogili, 2023). The parameters for the handover request procedure are set in motion as part of the process initialization. Following the HetNet's cell population, the network condition of the cells was observed while taking into account Carrier Signal Information (CSI) such as Reference Signal Received Quality (RSRQ) and RSRP. This was done using a rule-based approach, as described by Oniigbo and Ogili (2023), to identify the targeted cell as the most suitable cell for handover. After that, connections are made with the main cell and the HO request is forwarded to the cell. The load was then transferred from the main cell or the overloaded sector to the targeted cell using the sector-based traffic control algorithm. The suggested CAA was used in this procedure to identify channel which are free from adjacent channel interference and congestion. The Figure 4 presented the flow chart of the HO process.

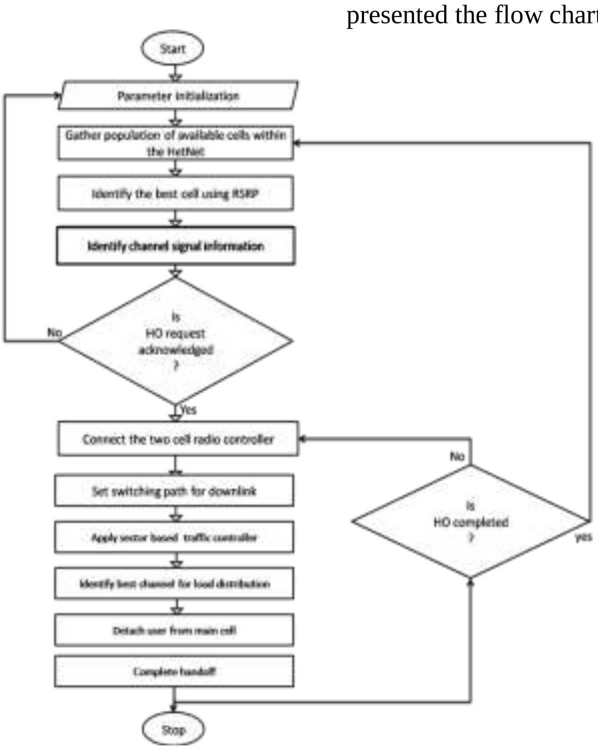

Fig. 4. Flow chart of the HO process

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IV. RESULTS AND DISCUSSION

4.1 Channel selection

The TDM was used as an input to start the load distribution process in the sector-based traffic control system. The STC for intelligent load balancing was triggered when the TDM detected overload. As seen in Figure 3, the STC employed FDM to section the cell's band into segments. Each sector was then further divided into subcarrier channels using OFDM.

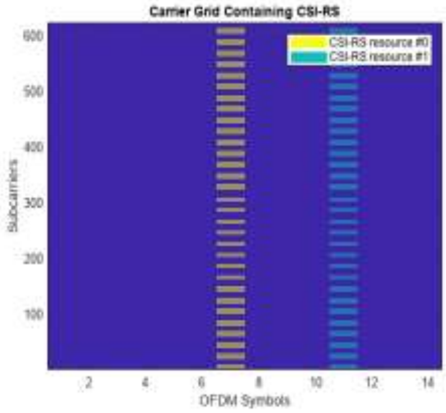

Figure 4. A carrier grid containing Channel State Information - Reference Signals

The results of the available channels that the CCA selected are displayed in Figure 4. The channels that were selected from the total number of channels and assigned based on their Signal-to-Noise Ratio (SNR) and Signal-to-Interference-plus-Noise Ratio (SINR) values—which were obtained using equations 1 and 2—are highlighted by the presence of CSI-RS resources in the grid. The interference level was monitored using the SNR in equation 3.9 and the SINR in equation 2, and the channels with the least amount of interference were selected for the distribution of traffic or load. The Carrier Annulling Algorithm (CAA) and Clear Channel Assessment (CCA) criteria for minimal interference and user non-engagement have been satisfied by the selected channels (yellow and cyan). The channels selected above are free from interference or congestion and therefore suitable for the handover procedure, successfully reducing congestion by avoiding crowded paths. All busy channels and those prone to interference were canceled by the CAA due to high interference, while the fit channels with low interference and carrier-free are selected as the HO route.

4.2 Performance of the Handover process for load distribution

An extensive assessment of the network performance for the available cells was the first step in the HO process. This evaluation takes into account CSI characteristics, namely RSRP and RSRQ, as shown in Figures 4.15 and 4.16, respectively. The assessment of RSRP and RSRQ as essential phases in the handover (HO) process was plainly shown in the Figures. The network can decide which neighboring cells are best for handover by using the useful information provided by these CSI metrics on signal quality. In addition to ensuring peak network performance, this lowers the possibility of interference and congestion.

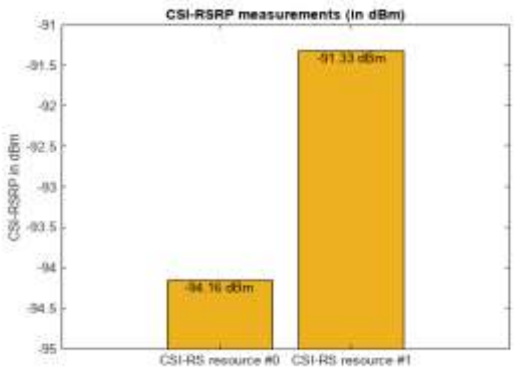

Figure 5. RSRP assessment for HO

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The RSRP result, which provides a picture of the received power levels from nearby cells, was shown in Figure 6. The RSRP is -94.16dBm for the first available cell in the HetNet with serial number #0, and -91.33dBm for the second available cell in the HetNet with label #1. This indicates that cell 2, which was chosen for the load distribution using the chosen channel from the sector-based control model to prevent interference and congestion, is optimal for the HO process. The RSRQ was taken into consideration as a criterion for the cell selection in the subsequent outcome, as shown in Figure 6.

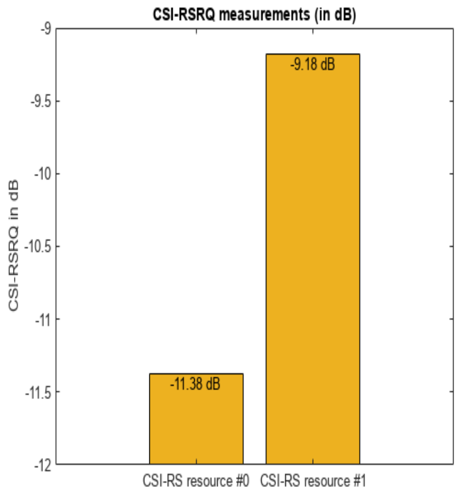

Figure 6. RSRQ assessment for HO process

V. OVERALL ALGORITHM PERFORMANCE

Congestion and interference control significantly improved when CCA and channel annulling were combined. The modified handover procedure resulted in a more effective load distribution throughout the network, decreased latency, and increased handover success rates.

5.1 Reduced Congestion

The sector-based algorithm showed notable advancements in the control of traffic.

The macro cell load factor was 0.44 (without an algorithm) - 0.38 (with an algorithm).

Algorithm-Based Micro Cell Load Factor: 0.28 -> 0.22 (With Algorithm)

The load factor of a pico cell was 0.23 (without an algorithm) - 0.19 (with an algorithm).

With an average 15% drop in the load factor, the algorithm decreased congestion in all cell types.

5.2 Mitigation of Interference

The use of both Channel Annulling and CCA significantly decreased interference. There were noticeable gains in the RSRP and RSRQ metrics:

Macro Cell RSRP: -80 dBm (Independent) → -71.5 dBm (Independent)

Algorithm-Based Micro Cell RSRP: -85 dBm -> -74.3dBm

The RSRP of a Pico Cell was -86 dBm (without an algorithm) → -75.0 dBm (with one)

Overall, the technique increased RSRP values by about 10 dBm.

VI. CONCLUSION

This study's sector-based approach shows a significant improvement in 5G heterogeneous networks (HetNets) load balancing management. The method efficiently tackles the crucial issues of congestion and interference during handover processes by incorporating the Clear Channel Assessment (CCA) and Channel Annulling (CAA) techniques. The testing results show that all cell types have significantly lower load factors, with an average decrease of 15%, indicating better resource allocation and user experience.

Moreover, the improvements in Reference Signal Received Power (RSRP) metrics demonstrate how well the algorithm reduces interference, which is essential for preserving good service in crowded locations. The observed enhancements, which include up to 10 dBm increase in RSRP values, highlight the algorithm's capacity to deliver strong signal strength and enable smooth user transitions between cells.

In conclusion, this study offers insightful information about how to best manage traffic in 5G HetNets. Subsequent research endeavors will center on optimizing the algorithm for wider use cases, examining its efficacy in diverse real-world scenarios, and researching its amalgamation with nascent technologies to amplify network productivity and user contentment.Future work is to conduct field trials to evaluate the performance of the sector-based algorithm in diverse urban and rural settings, assessing its effectiveness in live network conditions.

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