ISSN: 2584-0495 Vol. 2, Issue 11, pp. 1349-1355

International Journal of Microsystems and IoT

ISSN: (Online) Journal homepage: https://www.ijmit.org

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Cite as: Thirunavukkarasu, G., Murugesan, G., & Devedharshini, P. D. (2024). An Efficient Channel Allocation in Crowded 5G Base Station. International Journal of Microsystems and IoT, 2(11), 13491355. https://doi.org/10.5281/zenodo.14964400

Published online: 29 November 2024

DOI: https://doi.org/10.5281/zenodo.14964400

International Journal of Microsystems and IoT
Vol.2, Issue 11, pp. 1349-1355; DOI: https://doi.org/10.5281/zenodo.14964400

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An Efficient Channel Allocation in Crowded 5G Base Station

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ABSTRACT

The deployment of 5G technology signifies a transformative moment for communication networks, offering unprecedented speed, capacity, and minimal latency. Urban centers, including bustling city hubs and crowded venues, pose unique challenges with diverse connectivity needs. 5G implementation faces technical hurdles in managing concentrated user bases and adapting to rapidly changing connectivity demands. Regulatory challenges also emerge, requiring collaboration with local authorities to navigate zoning regulations for secure and effective deployment. Overcoming technical obstacles involves deploying small cells, utilizing advanced beamforming and massive MIMO systems, and employing network slicing for customized connectivity. This work gives a solution for an efficient allocation of channels for the users within the coverage area of a base station. This base station is deployed with a 5G multicarrier air interface. A detailed calculation pertaining heterogeneous users and their allocated bandwidth is given in this paper.

KEYWORDS

Orthogonal Frequency Division Multiplexing (OFDM) 256 QAM, Channel Allocation, 5G New Radio (NR), massive MIMO, dynamic bandwidth allocation, and crowded base station.

1. INTRODUCTION

The fifth generation of mobile communication technology, commonly known as 5G [1], represents a revolutionary leap in wireless networking. Offering unprecedented speed, capacity, and connectivity, 5G surpasses its predecessors (2G, 3G, and 4G) and is poised to transform various industries. With applications spanning telecommunications, healthcare, manufacturing, transportation, and entertainment, 5G is a key enabler for developing smart cities and the broader digital transformation of society [10]. Promising significantly faster data rates compared to 4G, 5G can achieve download speeds of several gigabits per second (Gbps), facilitating high-quality streaming, ultra-fast downloads, and low-latency applications. Its networks boast lower latency, crucial for real-time applications such as virtual reality, augmented reality, autonomous vehicles, and remote surgery. The ability to support a higher number of devices simultaneously makes 5G suitable for densely populated areas and the Internet of Things (IoT), achieved through technologies like Massive Multiple Input, Multiple Output (MIMO) and beamforming [15]. 5G utilizes a broader spectrum of frequencies, including sub-6 GHz and millimeter-wave bands, each serving specific purposes. While millimeter-wave bands provide high capacity with limited coverage, sub-6 GHz bands offer better coverage and penetration.

The modulation and multiplexing technique Orthogonal Frequency Division Multiplexing (OFDM) [13] plays a pivotal role in 5G, enabling high data rates, efficient spectrum usage, and adaptability to varying channel conditions. OFDM variants in 5G, such as Universal Filtered ilter Bank Multi-Carrier (FBMC), Frequency Division Multiplexing (GFDM) [16] further enhances its capabilities. These advanced technologies contribute to the adaptability, coexistence with other wireless systems, and energy efficiency of 5G, making it a promising technology for next-generation wireless networks. Despite its advantages, OFDM, a key component of 5G, has some drawbacks, including high peak amplitudes, synchronization challenges, sensitivity to frequency and phase noise, and potential interference issues. These considerations highlight the need for careful management and optimization in the implementation of 5G networks.

The New Radio (NR) technology in 5G, encompassing Massive MIMO, beamforming, and millimeter-wave spectrum, ensures unparalleled wireless performance. Operating in various frequency bands, 5G NR delivers ultra-high data rates, low latency, improved spectral efficiency, and the ability to connect a massive number of devices simultaneously. Network slicing, a key concept in 5G NR, enables the partitioning of the physical network infrastructure into multiple virtual networks, each tailored for specific use cases. Designed for real-time applications, 5G NR introduces enhanced security features, including encryption enhancements and authentication mechanisms. Technology is expected to evolve through software updates and network enhancements, paving the way for the introduction of new features and capabilities as technology advances [11]. In conclusion, 5G NR stands at the forefront of wireless communication, promising a connected, data-driven future with seamless integration across diverse services, devices, and industries.

In this paper, the second section gives a brief report on the relevant work useful for this project. The third section describes the congested base station scenario. The techniques involved in the calculation of user spectrum requirement and number of users in base station is detailed in section four. The proposed idea is simulated using MATLAB and the result is given in section five. The next section concludes the work.

2. LITERATURE SUMMARY

Performance Analysis of 5G Modulation Techniques is [6] evaluated, emphasizing spectral efficiency, error rates, and signal quality for efficient communication. Overview of Smart Applications in 5G has been done by [2] providing a comprehensive overview of 5G systems, focusing on architecture and capabilities for integration into smart technologies. In a paper, the concept of [1] waveform design is explored to enhance data transmission efficiency, spectral efficiency, reduce interference, and improve signal reliability in 5G. Another article investigates a wireless communication system incorporating index modulation, receive diversity, and reconfigurable intelligent surfaces (RIS) for improved reliability [4] and efficiency in 5G. A novel successive interference cancellation technique is [17] tailored for generalized frequency division multiplexing (GFDM) systems to enhance spectral efficiency and reduce interference in 5G networks Explores Deep learning's fusion with 5G systems is explored in [13] by focusing on channel estimation within OFDM networks for more accurate and efficient data transmission. Performance of NOMA systems in multipath fading channels [12] is evaluated particularly with Nakagami-m fading, for future wireless networks. A comprehensive view of multi-carrier waveforms and multiple access strategies is illustrated in [10], and it is crucial for understanding their complexities and opportunities in 5G networks.

Resource allocation management is significant in 5G systems due to heterogeneous users and network. A research article [9] proposes strategies for energy-efficient resource allocation in cooperative communications using GFDM, contributing to sustainable 5G networks. The latency performance of 5G-NR networks is investigated in [18], and gives detailed insights into their capabilities for supporting real-time, high-quality multimedia streaming. Another paper [20] analyses the performance of GFDM-assisted NOMA schemes, demonstrating lower BER and greater spectral efficiency in high-SNR regimes compared to conventional NOMA schemes. The channel in the airborne environment is distinct compared to conventional cellular systems. Performance of OTFS modulation for high Doppler airborne communication networks, is addressed in [3] and gives a solution as an efficient equalization of multiple Doppler shifts.

Analysis of the Performance of a 5G-R network is done in [11] in transmitting train control information in high-speed railway scenarios using HIL simulation and proposes an improved link decision algorithm. It is suitable for high-speed rail communication. NOMA is one of the modulation techniques used in 5G and considered [19] as a promising technology for improving spectral efficiency and supporting massive connectivity in 5G and beyond. In [15] the author analyzes the performance of discrete-time MIMO OFDM-based OTFS, a modulation scheme leveraging time, frequency, and space domains for high spectral efficiency and diversity. The authors of [5] analyses the performance of a hybrid radar and communication system, emphasizing the application of Orthogonal Frequency Division Multiplexing (OFDM) and Orthogonal Time Frequency Space (OTFS). The analysis investigates the impact of this integration on signal processing, spectral efficiency, and interference management. The results offer practical insights into the challenges and benefits of simultaneously employing radar and communication systems in complex environments.

Another paper based on resource allocation [7] focuses on energy-efficient resource allocation in GFDM cooperative communications, specifically for simultaneous wireless information and power transfer. The study explores strategies for optimizing resource utilization in the context of cooperative communication systems. Key aspects include enhancing energy efficiency, managing resources for both information and power transfer, and addressing challenges in GFDM-based networks. The research in [8] explores the potential of this new waveform in addressing challenges and advancing wireless communication technologies. Key aspects include waveform design, signal processing advancements, and the applicability of Filtered OFDM in emerging wireless systems. Another technical paper [14] examines the potentials and challenges associated with NOMA technology. It provides a comprehensive overview of power-domain NOMA, emphasizing its relevance and implications in the context of 5G networks. The paper discusses the advantages, potential applications, and addresses challenges in implementing NOMA. The authors of [16] illustrated the integration of IRS technology to enhance the performance of Generalized Frequency Division Multiplexing (GFDM) communication systems. The study likely investigates the benefits and challenges associated with incorporating intelligent reflecting surfaces in GFDM networks. This paper contributes to the understanding of how IRS can optimize communication systems, offering insights into the synergies between IRS and GFDM.

3. CONGESTED NETWORK SCENARIO

3.1 Characteristics of 5G Base Station

In congested areas, 5G networks strategically employ small cells and millimeter-wave frequencies to enhance connectivity, with small cells addressing urban traffic congestion and millimeter-wave bands delivering high data speeds in densely populated locations. The utilization of diverse frequencies, including millimeter-wave bands and sub-6 GHz, in 5G networks offers tailored solutions for high-speed data requirements, albeit with the need for additional base stations due to the limited coverage of millimeter-wave frequencies. Integral to 5G base stations, Massive MIMO technology dynamically enhances network capacity by utilizing numerous antennas and directing beams to specific devices, optimizing connectivity in areas with evolving user demands. Beamforming technology is extensively used in 5G base stations to precisely direct signals, improving signal quality and capacity in crowded locations. The introduction of network slicing allows operators to create virtual networks with varied features, customizing support for diverse applications in congested locations. Some 5G [22-24] base stations in crowded areas incorporate edge computing, enabling low-latency data processing at the network's edge for faster information access.

Densification strategies involve deploying base stations and small cells closer together to reduce congestion and provide ample access points for the growing number of connected devices. High-capacity, low-latency backhaul and fronthaul links are crucial for 5G base stations to connect to the core network, ensuring efficient data transmission. Dynamic resource allocation algorithms in 5G base stations enable the real-time assignment of bandwidth and resources, maximizing capacity utilization. Automated network management and optimization processes, leveraging machine learning and AI, anticipate congestion and optimize resources in crowded locations. The adoption of advanced waveforms and modulation schemes, such as quadrature amplitude modulation (QAM), is a key component of 5G standards, optimizing data transmission. Advanced coding techniques ensure reliable communication in challenging environments. Dynamic spectrum access, or spectrum sharing, efficiently utilizes the radio spectrum in 5G, exploring available frequencies for optimal performance. While sub-6 GHz frequencies are initially used, the exploration of millimeter-wave frequencies is considered to enhance capacity and data rates in densely populated areas, showcasing the adaptive and innovative nature of 5G networks.

3.2 5G Scenario

In the 5G context, a congested network occurs when the communication infrastructure of a 5G cellular network is overwhelmed by a substantial volume of data traffic, leading to performance issues and service disruptions. This congestion stems from an excessive demand for network resources, including bandwidth, signaling capacity, and computing power, surpassing the network's effective handling capacity. Factors contributing to congestion include high user density, intensive data applications such as virtual reality and video streaming, the proliferation of Internet of Things (IoT) devices generating bursts of data traffic, network architecture limitations, slower data speeds, increased latency affecting real-time applications, dropped calls, and challenges in implementing 5G New Radio (5G NR) in congested areas. To mitigate these issues, operators employ strategies like enhanced capacity through 5G NR, small cells deployment, dynamic spectrum sharing (DSS), and network slicing. Quality of Service (QoS) techniques, load balancing, and spectrum aggregation further contribute to reducing congestion and ensuring a high-quality user experience. Rigorous network planning, infrastructure investment, and ongoing optimization are deemed essential for the successful implementation of 5G NR in crowded regions. Additionally, technologies like millimeter-wave spectrum utilization and subcarriers play crucial roles in enhancing signal quality and optimizing data transmission. Overall, as 5G becomes integral to daily life and data-intensive applications proliferate, continuous assessment and improvement of networks are imperative for meeting user expectations and demands.

4. METHOLOGY

Initially, the count for various users for ideal, calling, audio streaming, video streaming, and gaming are fixed with a constant value. It is assumed that it will be constant for some time duration. The center and radius of the base station (BS) coverage area are defined. Points are generated along the circumference of the circle to represent the coverage area. A figure is created with a white background. The base station's location is plotted. For each type of user, random user locations are generated. The script calculates the distance of each user from the base station, counts the number of users within the coverage area (based on a distance threshold of 100 units), and prints the counts for each user type. The user locations are plotted using different markers. Access points are plotted as green circles. Data rates for different user types are defined (Rcall, Ras, Rvs, Rg, Rm) in kilo-bits per second. The overall data rate (R) is calculated by summing the product of the data rate and the number of users for each type. The total required spectrum (Nyquist bandwidth) is calculated as half of the overall data rate (B). A table is created to display user types, the number of users for each type, individual data rates, and the total data rate for each type. The script calculates the total data rate for all user types (Total Data Rate) and the Nyquist bandwidth required for the network. Total Data Rate is the sum of the product of data required for each type of user and the number of users in each user type within the coverage area

$$R = \sum R_a N_a \tag{1}$$

$a : represents\ the\ index\ of\ different\ types\ of\ users,$

Total data rate is calculated using the following expression

$$R = R_{cell}N_{call} + R_{as}N_{as} + R_{vs}N_{vs} + R_gN_g + R_mN_m \tag{2}$$

Where,

$R : Total\ data\ rate\ required\ in\ bits\ per\ seconds$
$R_{call} : Data\ rate\ required\ for\ cell\ users$
$N_{call} : number\ of\ call\ users\ within\ a\ coverage\ area$
$R_{as} : data\ rate\ required\ for\ audio\ stream\ users$
$N_{as} :$
$Number\ of\ audio\ stream\ users\ within\ the\ coverage\ area$
$R_{vs} :\ Data\ rate\ required\ for\ video\ stream\ users$
$N_{vs} :$
$Number\ of\ video\ stream\ users\ within\ the\ coverage\ area$

R_g : $Data\ rate\ required\ for\ game\ users$
N_g : $Number\ of\ game\ users\ within\ the\ coverage\ area$
R_m : $Data\ rate\ required\ for\ message\ users$
N_m : $No. of\ message\ users\ within\ the\ coverage\ area$

The baseband bandwidth required is decided by the Nyquist bandwidth for distortion less transmission. It is related with the total data rate as

$$B = \frac{Total\ Data\ Rate\ R}{2} \qquad (3)$$

Allocated bandwidth is calculated by

$$B_A = \frac{B_T}{B_{TRB}} \times B_{RB} \qquad (4)$$

Where
B_T : $Total\ bandwidth$
B_{TRB} : $Total\ required\ bandwidth$
B_{RB} : $Required\ bandwidth$

Bandwidth required per user is

$$B_{pU} = \frac{B_{ApU}}{N_{Ut}} \qquad (5)$$

Where
B_{ApU} ; $bandwidth\ allocated\ for\ particular\ type\ of\ users$
N_{Ut} : $number\ of\ users\ of\ particular\ type$

Data rate per user is related with the bandwidth per user is given with the use of Nyquist bandwidth

$$R_{pU} = \frac{B_{pU}}{2} \qquad (6)$$

In 5G communication systems, the number of bits per symbol depends on the modulation scheme used. It can range from BPSK (1 bit per symbol) up to 256-QAM (8 bits per symbol). So for a 5G communication system for one subcarrier spacing has 1 radio frame. A radio frame contains 20 slots for a 30 kHz subcarrier. Each subframe has only one slot in it.
The number of OFDM (Orthogonal Frequency Division Multiplexing) symbols within a slot is 14. One symbol has 8 bits in it. Therefore, the number of bits per slot is calculated as

$$8 \times 14 = 112\ bits/slot$$

One sub-frame has 2 slots. Therefore, number of bits contained in a sub-frame is calculated by

$$2 \times 112 = 224\ bits\ per\ sub - frame$$

A radio frame contains 10 subframes. Then there are 10×224=2240 bits / radio frame available in 5G communication system. One radio frame duration is one milli-second. That is 2240 bits are transmitted in 1 ms.

The bit rate is found to be

$$\frac{2240}{10^{-3}} = 2240\ kbps$$

The symbol rate, also known as the baud rate, is a fundamental parameter in digital communication systems. It refers to the number of symbols (or signal changes) transmitted per second in a digital communication system

$$Symbol\ rate\ (R_s) = \frac{Bit\ Rate}{Number\ of\ bits\ per\ symbol} \qquad (7)$$

Bit rate is calculated to be 2240 kbps and number of bits per second is 8 bps. The symbol rate is calculated as

$$R_s = \frac{2240\ kSps}{8}$$

The symbol rate for one subcarrier spacing in 280 kilo symbols per second, i.e.,

$$R_S = 280\ kSps$$

$$number\ of\ users\ per\ subcarrier = \frac{symbol\ rate}{data\ rate\ of\ each\ user} \qquad (8)$$

The above formulas are used to calculate the number of users of specific type in a base station and the total bandwidth requirement. If the total required bandwidth exceeds the available bandwidth in a base station, time division multiplexing is implemented on demand of the users. TDM allows multiple users to share the same channel by taking turns to transmit in a time-sequential manner.

Time slots in a networking context refer to specific intervals of time allocated for communication purposes within a system. In the process of network management and resource allocation, it is crucial to define the number of time slots to be assigned for different user types. This allocation can be equal across user types or adjusted based on their respective data rate requirements. The total number of time slots needed for all user types combined must align with the available time slots within the system. To facilitate efficient organization and representation of user data, data structures like arrays or structures can be employed, capturing information such as user type and the allocated time slots. The final step involves the allocation of these time slots to each user type, ensuring adherence to their specific requirements and preventing the exceeding of the total available time slots in the system. This meticulous approach to time slot management is integral to optimizing network performance and meeting diverse user needs.

5. RESULTS OBTAINED AND ANALYSIS

Schematic results are obtained from (Figure 1) the MATLAB code implied to calculate the number of different types of users. The diagram represents the number of different types of users for a 10-kilometer radius. It is not so accurate that each user consumes the same amount of data. Some users may keep their devices idle while some of them use higher data rates for gaming. Also, the types of users within the coverage area for 10 users of each type is shown in this figure 1.

There are different types of data users across the given area. The list of different types of data users are listed below:

1) Idle users
2) Users consuming data for Call

3) Users consuming data for Audio stream
4) Users consuming data for a Video stream
5) Users consuming data for Games
6) Users consuming data for messages

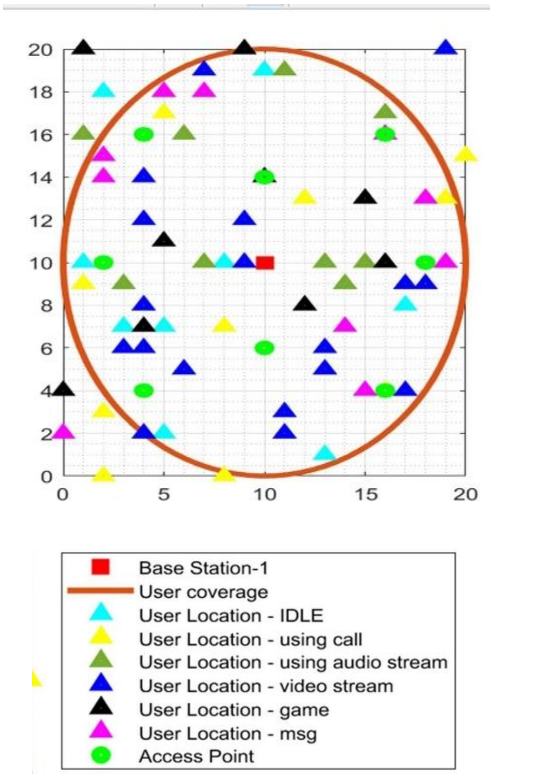

Fig. 1 Types of users within the coverage area.

```
datarate =

  6×4 table

        Usertype         NofUser    IndividualDR    TotalDR
    ________________    _______    ____________    _______

    "idle user"             9               0           0
    "call user"             6              64         384
    "audiosteaming"         9            1411       12699
    "videostreaming"       18            1560       28080
    "game user"             7            6000       42000
    "msg user"              9               1           9


totalDataRate =

       83172


NyquistBandwidth =

       41586
```

Fig. 2 Data rate Table for regular average users

The straight line represents the boundary of a 10-kilometer radius. A square point representing the Base station is kept at the center of the area and a circle point represents the access points.

Figure 2 represents the number of users for each type and their individual and total data rate. A random number of users is generated for each given type of user with a maximum of 10 users of each type. The sum of the total data rate from each user is used to calculate the Total Data Rate for the given users from the area of the given radius.

```
idle user: Allocated Bandwidth = 0.00 Mbps
call user: Allocated Bandwidth = 0.42 Mbps
audio streaming: Allocated Bandwidth = 12.86 Mbps
video streaming: Allocated Bandwidth = 14.22 Mbps
game user: Allocated Bandwidth = 62.50 Mbps
message user: Allocated Bandwidth = 0.01 Mbps
```

Fig. 3 Allocated Bandwidth of each type of bandwidth

The bandwidth allocated (Figure 3) for the total number of each type of user within the coverage area calculated by equation (4). This allocated bandwidth is used to calculate bandwidth per user.

```
Bandwidth per idle user = 0.000000 kbps
Bandwidth per call user = 8.332731 kbps
Bandwidth per audio user = 183.710669 kbps
Bandwidth per video user = 203.110307 kbps
Bandwidth per game user = 781.193490 kbps
Bandwidth per msg user = 0.130199 kbps
```

Fig. 4 Bandwidth per user

The bandwidth required for a user of each user type (Figure 4) within the region which is calculated by the equation (5). This bandwidth per user is used to calculate the data rate per user

```
Datarate per idle user = 0.000000 kbps
Datarate per call user = 16.665461 kbps
Datarate per audio user = 367.421338 kbps
Datarate per video user = 406.220615 kbps
Datarate per game user = 1562.386980 kbps
Datarate per msg user = 0.260398 kbps
```

Fig. 5 Data Rate per user

The data rate required for a user (Figure 5) of each user type within the region which is calculated by equation (6). This is the required data rate which is required by an individual. The online gaming users will be allocated with nearly 1.5 Mbps of data rate per user. However, it can be ensured that there may be very less number of online gaming users are there in the peak hours. The video users are allocated with the second highest data rate as it is needed. The least data rate per user is for the calling users since only voice communication is carried out in this category.

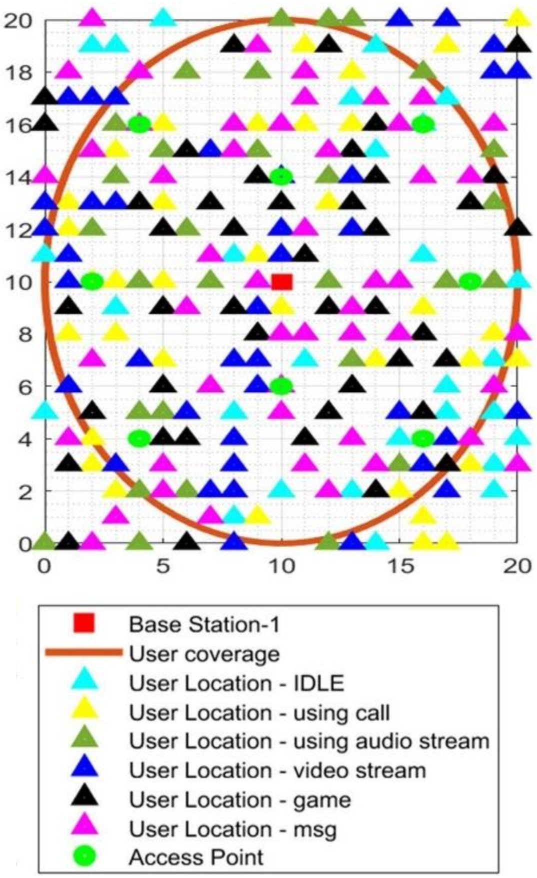

Fig. 6 Types of users within the coverage area at crowded times

During the peak hour, the number of users in a base station is abruptly high compared to the normal hours. At this time the network speed will get reduced and the users will face network issue.

datarate =

6×4 table

Usertype	NofUser	IndividualDR	TotalDR
"idle user"	32	0	0
"call user"	37	64	2368
"audiosteaming"	37	1411	52207
"videostreaming"	34	1560	53040
"game user"	42	6000	2.52e+05
"msg user"	39	1	39

totalDataRate =

359654

NyquistBandwidth =

179827

Fig. 7 Data rate Table for the excess number of users

Total data rate and individual data rate (Figure 7) for each type of user in the peek time. The total data rate abruptly increased when the number of users increases. Therefore, the number of users is directly proportional to the data rate if the number of users increases the data rate will also get increase

totalDataRate =

359654

NyquistBandwidth =

179827

Insufficient bandwidth for allocation.

Fig. 8 Result of the excessive number of users

There may be the situation that the user demand is exceeding the available bandwidth (Figure. 8) in a given base station. Here are some possible actions that can be taken when bandwidth is not enough to meet the requirements of all user types.

In network management, the allocation of bandwidth is a critical aspect, and various strategies can be employed to address insufficient bandwidth conditions and optimize service delivery. Prioritizing certain user types based on importance or service agreements ensures critical services, such as "emergency calls" or "critical data," receive bandwidth precedence. Load shedding allows for selective dropping or delaying of less critical traffic during extreme congestion, adhering to predefined policies. Queuing data for users who cannot be immediately served due to bandwidth constraints, along with throttling by proportionally reducing data rates, provides a balanced approach to managing limited bandwidth resources. Dynamic bandwidth allocation, responsive to real-time network conditions, allows for on-demand adjustments. Additionally, user notification strategies involve informing users about network congestion, enabling them to decide whether to continue their activities or reduce bandwidth consumption. The optimal strategy depends on network goals, service agreements, and service criticality, aiming to minimize the impact on user experience while ensuring equitable and efficient bandwidth utilization.

6. CONCLUSION

The deployment of 5G air interfaces in crowded areas is essential to meet the growing demands of data-hungry applications and the increasing number of connected devices. While it presents unique challenges, such as spectrum management and infrastructure requirements, 5G technology offers the promise of transforming the way we experience wireless communication in urban and crowded environments. As 5G technology continues to evolve and deployment progresses, it is poised to revolutionize connectivity, opening doors to innovative applications and services that were once considered impractical in crowded areas. This paper serves as a foundation for understanding the critical factors and technologies involved in deploying 5G in crowded areas, facilitating the development of efficient, high-performance networks in these challenging environments. This is achieved by allocating the required bandwidth for different types of users by giving a different number of subcarriers by carrier aggregation.

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