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Diverse Cell Association Schemes for Fifth-Generation Wireless Networks

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Abstract*: One of the underlying challenges in infrastructure-based multi-cell wireless networks is ensuring the proper association of a particular mobile User Equipment (UE) to the appropriate base stations (BSs). In the network terminology, this is usually referred to as cell association, user association, cell selection, or BS assignment. For now, the term cell association will be used for further discussion within this paper. In a wireless network with dense deployment of the base stations (BSs), the number of potential BSs with which a UE can be associated increases significantly with the increasing network complexity. The network densification demands the need for designing optimal or distributed cell association schemes. This is because, in case of improper association of UEs with BSs, it may result in increased interference, reduced throughput, inefficient energy consumption, load imbalance and higher latency in both uplink and/or downlink. 5G cellular networks aim to improve the connection speed and provide ultra-low latency through heterogeneous environments. While maintaining these parameters, the Quality of Service (QoS) needs to be maintained along with a sustained data rate. In such a case, the design of efficient cell association scheme for smooth flow of the traffic in the network is a real challenge which needs to be tackled. The aim of this paper is to study cell association techniques for 5G and beyond wireless networks, analyze the benefits of the methods and propose evolved and better solutions for cell association schemes.

***Keywords* : Base Station (BS), Cell association, 5G networks, load balancing, user equipment(UE)**

I. INTRODUCTION

With the exponential increase of fourth generation (4G) cellular networks being deployed in large areas of the world, the industry has clearly seen unprecedented challenges in meeting users' and telecommunication operators' growing expectations in the near future. First, the network capacity has to be increased massively to support bandwidth-intensive traffic (e.g., video and multimedia). Emerging transmission technologies, including massive multiple-input multiple-output (MIMO), have become essential to meet the growing demands of the network utilities.

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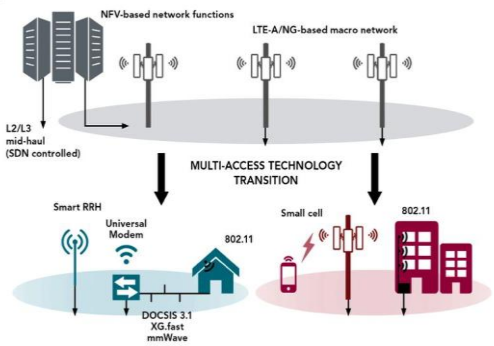
Second, the network must have greater flexibility to accommodate various types of heterogeneous devices (user equipment and sensors), applications, and services, while quality of service (QoS) becomes more and more stringent to support real-time video streaming service, which will be more than half portion of future mobile phone services. Third, the network must incorporate computing resources to provide value- added services for business. Therefore, academia and industry have recently proposed the concept of the fifth generation (5G)

cellular networks. They are all moving toward Heterogeneous Networks (HetNets) due to their capability to support flexibility of resource management, high-speed connections, and integration of distinct access technologies including massive MIMO.[1][2] Apart from this, massive machine-type communication (mMTC) is expected to play a pivotal role in emerging 5G networks. Considering the dense deployment of small cells and the existence of heterogeneous cells, an MTC device can discover multiple cells for association.[3]Upcoming 5G mobile and wireless networks provide significant advancements in three broad categories, namely enhanced mobile broadband (eMBB), massive machine-type communications (mMTC), and ultra-reliable and low latency communications (URLLC). Due to a massive number of devices, high-density deployment, small-sized packet transmissions, and a large uplink-to-downlink traffic volume ratio, providing cell association for mMTC services appears as a challenging task in 5G. For instance, one of the essential requirements for mMTC applications is high availability and reliability to ensure low latency, accurate, and flawless operations. To provide mMTC services, multiple technical challenges need to be addressed. Those challenges include quality of service (QoS) provisioning, radio access network (RAN) congestion control for dynamic and sporadic MTC traffic. On the other hand, dealing with huge signaling overhead generated by a massive number of autonomous connections is another tedious and resource-demanding task. Fig 1 refers to a complete end to end 5G architecture which relates all the required areas and connections of a proposed



5G network.

Fig 1 An envisioned 5G End-to-End Network [4]

The structure of this paper is such that it first explores the key concepts and areas in 5G networks. The following sections explore various new cell association schemes proposed under different areas of cellular 5G networks, their possible advantages and limitations.

II. 5G CELLULAR NETWORKS

A. 5G Network and Radio Architecture

The primary goal of mobile networks over generations has simply been to offer fast, reliable mobile data services to network users. 5G has broadened this scope to offer a wider range of wireless services delivered to the end user across multi-layer networks and multiple access platforms. 5G is a coherent, dynamic and flexible framework of multiple advanced technologies supporting a large pool of applications. 5G adopts a more intelligent architecture, with Radio Access Networks (RANs) no longer limited by base station proximity or complex infrastructure. 5G creates new network functionalities, using distributed, flexible and virtual RAN with new interfaces to create additional data access points.

Multiple frequency ranges are now being solely assigned to 5G new radio (NR). This portion of the radio spectrum with frequencies between 30 GHz and 300 GHz is known as the millimeter wave, as the wavelengths range from 1-10 mm. Frequencies between 24 GHz and 100 GHz are now being allocated to the 5G services in multiple regions worldwide. In addition to the millimeter wave, underutilized UHF frequencies between 300 MHz and 3 GHz are also being reassigned for 5G. The diversity of frequencies employed can be customized to the unique applications considering the higher frequencies are characterized by higher bandwidth leading to shorter range. The millimeter wave frequencies are perfect for densely populated areas, but inefficient for long distance communication. Within these low and higher frequency bands dedicated to 5G, each carrier has begun to carve out their own discrete individual portions of the 5G spectrum. Fig 2 illustrates the core 5G RAN separated into the user and control function planes.

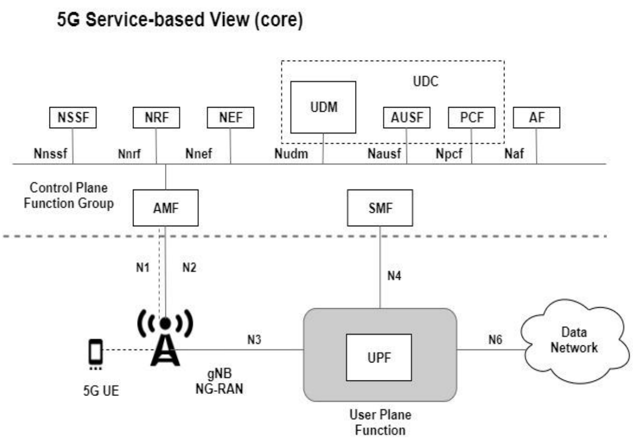


Fig 2 5G Core Architecture

B. Multi-Access Edge Computing (MEC)

Multi-Access Edge Computing (MEC) is an important feature in the 5G architecture. MEC is an evolution in cloud computing that brings the applications from centralized data centers to the network edge, and therefore nearer to the end users and their devices. This creates a shorter path for delivery of content between the host and user by reducing the long network path and round trip time that initially separated them.

This technology is not exclusive to 5G but is definitely key to its efficiency. Characteristics of the MEC architecture include high bandwidth, low latency and real time access to RAN information that differentiate 5G architecture from its predecessors. This convergence of the RAN and core networks will require operators to leverage new approaches to network services, testing and validation. Apart from the latency and bandwidth advantages provided by the MEC architecture, the distribution of computing power will better enable a higher volume of connected devices inherent to 5G deployment and the facilitate the growth of the Internet of Things (IoT) services.

C. Network Function Virtualization (NVF)

Network function virtualization (NFV) decouples software from hardware by replacing several network functions such as routers, load balancers and firewalls with virtualized cloud instances running as software. This removes the necessity to invest in expensive hardware elements and can also significantly accelerate network installation, thereby providing faster revenue generating services to the customer. NFV sanctions the 5G infrastructure by virtualizing appliances within the 5G network. This includes the network slicing technology that enables multiple virtual networks to run simultaneously. NFV can address other 5G challenges through virtualized computing, network and storage resources that are customized based on the applications and customer segments.

The concept of NFV extends to the radio access network (RAN) through, for example, network dis-aggregation brought out by alliances such as O-RAN. This promotes flexibility and creates new opportunities for competition, provides open interfaces and open source development, ultimately to ease the deployment of new features and technology on a scalable and industrial level.

D. Network Slicing

One of the major factors, which enable the full potential of 5G architecture to be realized, is network slicing. This technology adds an extra vertical to the NFV domain by provisioning multiple logical networks to simultaneously run on top of a shared physical network infrastructure. This becomes a key factor in 5G architecture which works by deploying end-to-end virtual networks that include both networking and storage functions. Operators can effectively manage diverse 5G use cases with differing latency, throughput and availability demands by partitioning and real-time sharing network resources to multiple users or tenants.

Network slicing becomes extremely important for applications like the IoT where there a large number of users with low individual bandwidth requirements.

Each 5G vertical will have its own requirements, so network slicing translates to an essential design consideration for 5G network architecture.

With this level of customization now possible, costs, resource management and flexibility of network configurations can all be improved and optimized. Apart from this, network slicing enables expedited trials for potential new 5G services and quicker time-to-market deployment.

III. CELL ASSOCIATION PRINCIPLES

5G networks will be designed based on the concept of HetNets which will be composed of different types of cells. Interaction between a macrocell and multiple small cells is important to facilitate resource and user connection management. Resource management will play a vital role in 5G HetNets not only to achieve optimal performance, but also to ensure fairness and meet user demands and application requirements. The primary process is cell association, which consists of making a decision on which cell of a HetNet should provide service to the user. Apart from that the events include antenna allocation, power control, channel allocation, cooperative transmission and mobility management which is performed after the user connection has been established. [5]

A. Network-Driven Cell Association

In network-driven cell association, a network- side entity (e.g., a base station, access point, or gateway) makes a decision on whether the new user can be served or not. The decision may also advise on with which cell (e.g., a macrocell or a small cell) the user will be associated. The benefit of network-driven cell association lies in the full network control of an operator, which aims to achieve a particular objective (e.g., maximum network capacity or highest profit).

A few OFDMA-based small cell networks consider power adaptation and cell association jointly. The power adaptation algorithm is designed based on game theory, and the Nash equilibrium of the transmit powers is obtained iteratively. The cell association algorithm is then devised based on a semi-Markov decision process in which the optimal cell association policy is obtained analytically. Some works consider radio resource optimization between closed and open access modes. Others consider a small cell access policy, where a user is assigned based on the distance to the base station and access point. Then the channel allocation is performed, and the throughput is optimized.

B. User-Driven Cell Association

In user-driven cell association, the user makes a decision on to which base station or access point to connect. The user will observe and estimate the performance (e.g., signal-to-interference-plus noise ratio, SINR) of nearby cells and makes the decision accordingly. In contrast to network-driven cell association, the benefit of user-driven cell association is in the independence of users to make their decision and the ease of taking users' preferences into account (e.g., maximal user satisfaction).

Some methods considers a transmit power update function to achieve optimal network performance. Then the load-aware base station association algorithm is introduced to let users be served by small cells or a macrocell based on current load condition. First, a base station estimates average channel power gain from each user. Using this information, the base station then estimates the corresponding SINR given the power update function. The user decides to associate with the base station based on the largest SINR reported from all nearby base stations.

In some others, a coalition formation game for cell association. In this scheme, the small cells and macrocell use a self-control strategy that lets users decide on the cell to join independently, that is, based on their individual performance. If congestion occurs or performance degradation is observed, the users switch their cell automatically. Using a Markov chain analysis, the stable cell association of users can be obtained.

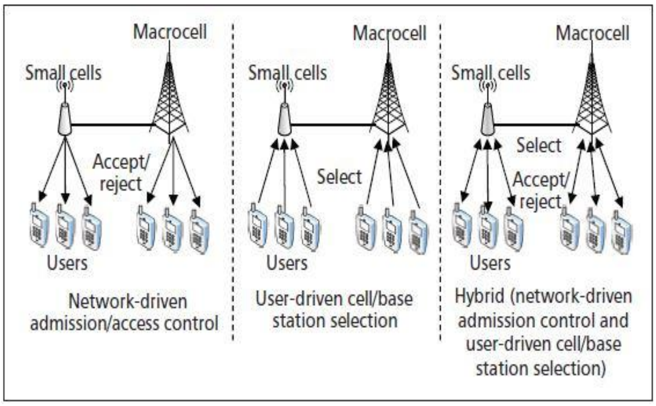


Fig 3 Network-driven cell association and user-driven cell/base station selection

C. Hybrid Cell Association

A hybrid approach is also possible. First, users select the cell or base station of their preference. Then the networks make the decision whether to accept the users or not. Traditionally, cell association is performed based on SINR (i.e., SINR-based association). A user will be associated with the cell that has the highest SINR, implying that the transmission quality (e.g., data rate) will be the best. However, SINR based association does not take the network load into account. The scheduling and medium access control (MAC) will affect the user's perceived performance, and hence cell association can be based on throughput and delay. Finally, the cell association can be based on cell range expansion, which allows the cell to scale its service (e.g., coverage) to serve more or fewer users, depending on the current or future load.[6] A comparison between all three approaches of user-driven, network-driven and a hybrid approach for cell association is illustrated in Fig 3.

IV. PROPOSED CELL ASSOCIATION FOR 5G NETWORKS

The necessity for efficient and optimal use of network resources is continuously increasing with the growth of traffic demand. However, current mobile systems have been designed and deployed so far with the sole aim of enhancing radio coverage and capacity. Unfortunately, this approach is no longer sustainable as 5G communication systems will have to cope with larger amounts of traffic, heterogeneous in terms of connections and latency among other Quality of- Service (QoS) requirements.

Thus several new schemes for cell association have been proposed for 5G networks, each which uses particular parameters for quality estimation and performance analysis.

A. QoS-Aware Cell Association and Antenna Allocation

A particular research considers a HetNet composed of a macrocell and multiple small cells (e.g., microcells, picocells, and femtocells). The small cells are overlaid in the macrocell. Massive MIMO is employed at the macrocell base station and small cell access points. If users are outside the coverage of any small cell, they have only one choice: to associate with the macrocell base station. In contrast, if the users are inside the coverage of any small cell, they can choose to connect to either the small cell or the macrocell. The HetNet supports C classes of users. Each class c has a data rate requirement denoted by Rc. If the rate requirement cannot be met by either the macrocell or a small cell, the user will dissociate from the network. A class C user pays a price fc (i.e., revenue per class C user) to the cell with which the user is associated. A cell can allocate a certain number of antennas to support data transmission of class C users.

The users in each class face the decision making problem of cell association (i.e., to choose either a macrocell or any small cell to communicate with). The objective of the users is to maximize their data rates, which must be higher than or equal to the requirement of each class. The macrocell and small cells face the scheduling problem in terms of antenna allocation. In particular, they have to allocate available antennas to the different classes of users such that their total revenue is maximized. The cells have to take the data rate requirement of every class of users into account. If the requirement cannot be met, the users will dissociate from the network, incurring revenue loss to the cells. The proposed algorithms have the following features.

a) Achieving the Individual Objective of Users Macrocell, and Small Cells: These entities have their own objectives. Users want to perform cell association to maximize their data rate. In contrast, the macrocell and small cells want to perform antenna allocation to maximize their total revenue earned from the associated users.

b) Distributed Algorithm: The users should, make their decisions regarding cell association, without using a centralized controller. Likewise, the macrocell and small cells should allocate their antennas independently.

c) Minimum Information Exchange: The users, macrocell, and small cells should rely on minimal information exchange to minimize the overheads of cell association and antenna allocation.

For cell association, initially a user chooses an available cell (e.g., a macrocell or small cell) randomly. Then the user observes the data rates broadcast by all available cells and estimates the average data rate. The user randomly makes a cell association decision with probability g, where rand() is a random number generator. If the current data rate of the user is lower than the estimated average data rate, the user switches to choose another cell.

The algorithm requires only the cells to broadcast data rates periodically. This will incur only small overhead in the network. For antenna allocation, first the cell waits until the cell association of users becomes stable. Then the cell observes the cell association decision of users and uses this to calculate the total revenue.

The cell will switch to a different allocation if it yields higher estimated and recorded total revenue. The cell association for users and antenna allocation for cells are interrelated. First, the cells perform antenna allocation. Second, the users observe the data rate given the allocation, and perform cell association accordingly. Again, the cells observe the cell association by users in all classes and adjust the antenna allocation. In summary, antenna allocation is performed on a longer timescale than that of cell association. [7][8]

B. MEC-Aware Cell Association

Focusing on a Heterogeneous Network (HetNet), a particular research proposes a comparison between the conventional radio-only cell association and MEC-aware cell association rules, taking the condition of task offloading in the Uplink (UL) as an example. Numerical evaluations indicate that the proposed cell association rule provides almost 60% latency reduction, as compared to its standard, radio-exclusive counterpart. [9]

a) Focusing on a MEC-enabled HetNet, a novel concept is introduced, UE-cell association metric, which evaluates the proximity of MEC resources to an appropriate UE.

b) To showcase the benefits of the proposed association rule, an Extended-Packet Delay Budget (E-PDB) metric is introduced, which is a single link latency consisting of the radio transmission time of an input packet between the connected eNB in the UL and the UE, along with the execution time of a given task at the MEC host. **c)** A numerical evaluation is carried out to compare the proposed association rule to the traditional RSRP approach rule, in terms of E-PDB performance for various inter-tier resource disparities, as well as for different network deployment densities. Radio-based achievable gains, with reference to Uplink (UL) rates, system throughput and load balancing have been shown effectively however, the UL cell association is obtained based on an eNB proximity criterion, hence, leading to the minimum path-loss experienced by the UE. A new MEC-aware cell association rule is proposed that aims ensuring connectivity to the closest eNB, along with minimizing the execution time at the MEC host. This is motivated through questioning the feasibility of the conventional, maximum Downlink Reference Signal Received Power (DL-RSRP)-based association rule, when it comes to the task of reducing latency experienced by a UE in a HetNet.The maximum DL-RSRP association rule indicates a node for connectivity which is different from the one obtained by applying the proposed computational proximity-based association rule. This occurs because huge cross-tier radio/ MEC disparities lead towards quite diverse radio/ MEC coverage areas. Such an observation creates a way towards a different insight on the network planning and architecture, taking into account the all the available computational resources along with the radio transmission capabilities, as both of them directly affect the E-PDB experienced by a particular UE, when the latter wishes to offload an extensive processing task to a MEC host.[10][11]

C. Machine Learning based mMTC Device Cell Association

Under traditional cell association mechanisms, MTC devices are typically associated with an eNodeB with highest signal strength. However, the selected eNodeB may not be able to handle mMTC requests due to network congestion and overload. Therefore, reliable cell association would provide a smarter solution to facilitate mMTC connections. To enable such a solution, a hidden Markov model (HMM) based machine learning (ML) technique is proposed in this paper to perform optimal cell association. As such, we consider MTC devices with network-assisted decision-making capabilities for selecting the most appropriate eNodeB for data transmission. The proposed HMM based ML technique focuses mainly on the reliability and availability of network resources.

Several traditional approaches do not consider cell association for MTC scenarios in 5G networks. This particular research proposes an HMM based machine learning (ML) algorithm with two cell association schemes to let MTC devices select an appropriate cell among the available cell set. The proposed ML algorithm runs on MTC devices and enables the devices to select the eNB intelligently, hence aiming at mitigating signaling overhead in random access and thus achieving better performance. Two schemes for HMM learning are studied, Scheme 1 is a reliability function based model is used to select the most reliable cell for association and Scheme 2, which uses the HMM predicted next probable state to determine the cell for association.[12][13]

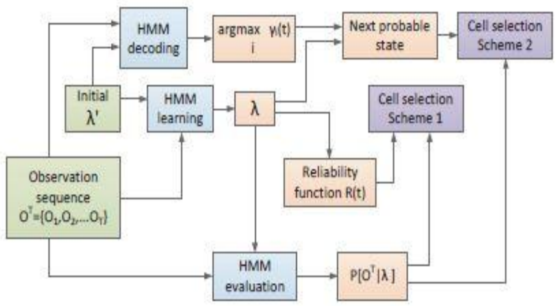


Fig 4 HMM based cell association

Fig 4 illustrates the proposed HMM based cell association and maps the schemes 1 and 2 to the results. According to the analyses made, the more are the MTC requests in the unit time, the higher the possibility that an MTC request is blocked due to a fixed amount of resources (channels). Simulations are results have shown that both the proposed schemes outperform the random cell selection scheme. In the random scheme, MTC devices arbitrarily select one of the available eNBs for communication regardless of the observation sequence. In Scheme 1, however, MTC devices search for the most reliable cell based on the reliability function estimated after the HMM learning process. On the other hand, MTC devices which adopt Scheme 2 search for the most available cell based on the next probable state estimated after HMM learning. Therefore, both schemes lead to higher availability compared to the random cell selection.

In cell association, Scheme 1 checks the availability of channels for the next set of time slots. Instead of this reliability check, Scheme 2 evaluates only the next probable state to decide the appropriate cell. Therefore, the available time of idle channels is relatively higher in Scheme 1. Consequently, the probability of blocking an MTC device by the selected cell can be reduced in Scheme 1 compared to Scheme 2. [14]

V. RESULTS AND DISCUSSION

Considering the simulations, data and analyses made in the schemes for review, we would like to propose comparative results and inferences for this paper. By using several parameters as a basis for study, the results are as follows as shown in Table 1.

Table 1: Parameters for Algorithm Comparison

Cell Association(CA) Method	Base Parameters Considered
QoS Aware Cell Association	Data rate, proportion of users, revenue of macrocell, number of eNodeBs
MEC Aware Cell Association	Bandwidth, Reference Signal Received Power (RSRP), Packet Delay, number of eNODEbs
Machine Learning based mMTC Cell Association	Reference Signal Received Power (RSRP), number of eNODEbs, channel availability, request rate

As we can infer, the parameters common to the algorithms are the RSRP and the number of eNodeBs, both of which play an important role in determining the efficiency of the cell association schemes. Apart from this, based on the computational complexity of the algorithms, all the algorithms are relatively low in time complexity with comparable efficiencies. All the algorithms run in a base time complexity of O (N) with several conditional instances which need to be satisfied during the entire analysis. The QoS Aware Cell Association considers a HetNet with a macrocell and two small cells with a massive MIMO scheme, using data rate, number of devices and a small transmit Signal to Noise Ratio (SNR) for its study. The MEC Aware Cell Association investigates a two-tier HetNet, studying the packet delay budget, number of devices and RSRP in order to determine the efficiency of the algorithm. Finally, the machine learning based mMTC model proposes a 2 cell HetNet and varies the RSRP, channel availability, request rate and number of devices to produce the lowest latency in the outcome. A comprehensive research undertaken in all the cases shows that numerical evaluations have successfully demonstrated that the given cell association schemes ae practical and can be deployed on real-time network scenarios. Table 2 shows the analysis and inferences drawn from the algorithms which have been studied and simulated.

Table 2: Analysis of Algorithms

Cell Association(CA) Method	Main Analysis Factors
QoS Aware Cell Association	Transmit SNR is close to 0 dB, the data rate is in the range 0.7-1 b/s/Hz, output data rate is the main metric
MEC Aware Cell Association	Latency is measured in using Packet Delay Budget, downlink RSRP is measured for comparison to MEC, Monte-Carlo simulations used for analysis
Machine Learning based mMTC Cell Association	Channel availability is measured, RSRP is used as a base value, reliability analysis is used on the machine learning model

The results obtained in all the three algorithms are promising. Computationally, all the algorithms are low in time complexity as the structure is defined using lesser iterations and more conditions. In the QoS Aware Cell Association scheme, simulations have shown that allocation of antennas or eNodeBs is made significantly more efficient using the antenna allocation algorithm. Users can obtain higher data rates due to the newer allocation scheme which dynamically checks for the number of devices in the cell, maps it to revenue earned and assigns the best possible cell to the UE, thereby reducing the latency while maintaining the data rate. The MEC Aware Cell Association Scheme shows that ordinary measurement of RSRP does not give the best possible cell for association always. With simulations, it has been shown that there is nearly a 60% reduction in the MEC based cell association as compared to the raw DownLink (DL) RSRP selection scheme. By varying the ratio of the radio to MEC disparities, the analysis has shown that there is consistent numerical advantage of the MEC based association as compared to the base RSRP association. Finally in the machine learning based mMTC Cell Association scheme, a reliability function is used for analysis of the channel availability. Simulations have been carried out using the HMM learning algorithm, on top of a beta and Poisson distribution and the results have shown increased channel availability using the scheme as compared to a random selection of the eNodeB or using an RSRP based selection scheme directly. Simulation results demonstrate that our schemes improve the network performance in terms of channel availability since it takes both availability and reliability of channels into account. In closing, all the algorithms, simulations have shown promising results and further studies and analysis on these schemes will ensure their implementation in the practical world.

VI. CONCLUSION

In this survey, we have attempted to study the newest proposed cell association methods to be used in 5G communication networks. We began with an overview of the 5G architecture, its features and the challenges it poses for cell association over previous generation networks. Following that, an in depth analysis of cell association principles have been studied as have existed over the many generations of wireless communications. Towards the end, several recent proposals for cell association in 5G communication have been studied in detail so as to further research in the area.[15][16]

5G communication networks pose several challenges in maintaining the QoS and throughput, while keeping up ultra-low latency, low interference, and improved fault tolerance, distributed flow of traffic and high data rates. In such a scenario, optimum cell association techniques need to be adopted for the smooth flow of traffic in the network. Cell association is a dynamic problem in 5G and beyond communication networks. As the number of devices connected on the network increases, the necessity for developing faster and more robust algorithms for cell association will be a continuous challenge. Whether a predictive model for cell association is adopted or a statistically inferred and calculated one, the key challenges of ultra-low latency and high QoS and data rates need to be maintained. 5G aims to bridge the gap between network speeds and availability of devices for communication. Virtualization and cloud native techniques have shown the effectiveness of the radio architecture proposed under the 5G sphere. Cell association remains a challenge as the networks grow in size and functionality. Several advancements have been made in the area after analyses and mathematical modelling of the networks. Further research still needs to be carried out in the sphere in order to develop better, faster and more economical solutions.

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