QoS-Aware Cell Association in 5G Heterogeneous Networks with Massive MIMO

Open Call

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Abstract

5G cellular networks aim to improve the connection speed that assures ultra-low latency (e.g., to support real-time video streaming service) through heterogeneous environments. Heterogeneous networks (HetNets) composed of different types of cells (e.g., macrocells and small-cells) are the major direction of 5G network design. In this article, we first introduce the key features and highlight resource management issues in 5G HetNets. We then focus on the cell association problem of multiple classes of users in the HetNets. The users in different classes have different data rate requirement and will choose to associate with the cell (e.g., a macrocell or small-cells) that yields the highest data rate. Therefore, the cells also have to allocate resource in terms of antennas to different classes of users to maximize their total revenue. We introduce the cell association and antenna allocation algorithms based on the evolutionary game theory. The algorithms can achieve equilibrium solutions, ensuring that the users and the cells cannot gain higher data rate and total revenue, respectively, by changing their cell association and antenna allocation.

I. INTRODUCTION

While 4G cellular networks are being deployed in large areas of the world, the industry has clearly seen unprecedented challenges to meet users' and telecommunication operators' growing expectations in

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the near future. Firstly, the network capacity has to be increased massively to support bandwidth-intensive traffic (e.g., video and multimedia). Emerging transmission technologies including massive MIMO become a pertinent candidate for meeting such a demand. Secondly, the network must have greater flexibility to accommodate various types of heterogeneous devices (user equipments 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. Thirdly, the network must incorporate computing resource to provide value-added services for business. Therefore, academia and industry have recently proposed the concept of 5G cellular networks. They are all moving toward heterogeneous networks (HetNets) due to its capability to support high speed connections, flexbility of resource management, and integration of distinct access technologies including massive MIMO.

In this article, we first present key directions of technological development toward 5G cellular networks, where HetNets is among the top priority. Then, we highlight the importance of resource management which has to be evolved to meet the new features of 5G HetNets. We focus on cell association which is an integral part of resource management in 5G HetNets. We first introduce the background and review some literature. Then we outline the key requirements of cell association. Subsequently, we propose the cell association algorithm for users with different data requirements. The objective is to maximize the data rate and meet the requirement. We observe that the cell association of the users depends on available resource provided by the cells. Therefore, we introduce the algorithm to allocate antennas to different classes of users. The objective is to maximize the total revenue of the cell. Both algorithms are based on an evolutionary game implementation. The algorithms have attractive properties of supporting bounded rationality of the users and the cell, distributed implementation, and requiring minimal information exchange.

The remainder of this article is organized as follows. Section II introduces key features of 5G cellular networks and importance of HetNets. Section III discusses about the cell association problem for HetNets. Section IV presents the cell association and antenna allocation algorithms. Finally, Section V concludes the article.

II. 5G CELLULAR NETWORKS

The goals of 5G network design are to achieve not only large network capacity but also ultra low latency, and heterogeneous device support. This is due to the new emerging applications of 5G networks including video streaming, sensor networks, and data-intensive applications in addition to Internet access. To meet these goals, therefore, 5G networks will encompass a few new features [1].

- *New access technologies:* To achieve higher throughput, which is the ultimate goal of next generation network, a couple of candidate access technologies are being considered including millimeter wave (mmWave) and massive MIMO [2]. Due to large bandwidth of upband (i.e., higher frequency band around 30-50GHz), mmWave can provide much better performance. It can be adopted for short-range services (e.g., IEEE 802.11ad) and small-cells. Alternatively, massive MIMO can improve network performance with a great number of antennas to multiplex traffic. Recently, the idea of applying mmWave with massive MIMO has been introduced. In other words, massive MIMO will be made feasible in upband where only the line-of-sight transmission will be preferred due to the large propagation loss, as well as the space limitation of large array size at base station. For this reason, the massive MIMO will be highly likely to be implemented with the small-cell coverage. The benefit is not only higher throughput, but also ultra low latency and high energy efficiency since the transmission range will become shorter. Moreover, it is also attractive for a backhaul connection which prefers wireless links over a wired link (e.g., fiber optic) due to lower cost.
- *Densely deployed small-cell:* The concept of “super” small-cell network is introduced for densely deployed small-cells. This concept is composed of the reliable placement of a control plan (C-plane), e.g., soft cell and phantom cell, by the macrocell while keeping the massive deployment of small-cells for higher energy efficiency in a user plane (U-plane) separately [4]. Moreover, the “super” small-cell network can adopt an amorphous or virtual cell approach (e.g., soft cell) to substitute the classical concept of hexagonal cell (for ease of spectrum reuse and interference control), and employ hierarchical placement to achieve frequency separation (e.g., phantom cell).
- *Flexible spectrum management:* To meet dynamic traffic demand from users with different applications and requirements, spectrum management can be made more flexible (e.g., channels can be allocated adaptively to load conditions). Under the cognitive radio concept, network entities (e.g., base stations and user devices) are able to observe, learn, adapt, and optimize their spectrum usage to improve resource utilization and transmission efficiency. Cognitive radio concept can be adopted to support flexible and intelligent spectrum management [3].
- *Device-centric architecture and device-to-device (D2D) communications:* Wireless network design is shifting from a base station centric paradigm to user/device centric architecture. Users will participate in network operations by adapting their transmission to meet individual objective. D2D communications is one of such approaches which allows multiple devices to form a cluster and communicate directly without or with minimal control from the network. With the cluster of communicating devices,

latency will be lower, spectrum for a macrocell or small-cell can be reused, and energy efficiency will be higher. In addition, D2D communications can easily support multicast transmission.

- *Mobile cloud:* 5G networks will be moving from wireless data transfer to mobile services. As a result, radio resource access must be integrated with data processing to support mobile applications. Cloud computing can be adopted to provide facilities for efficient data access and processing. Furthermore, radio access networks can take advantage of cloud computing technology to provide flexible communication, i.e., cloud-RAN.

Based on the above features and requirements, 5G networks will be designed based on the concept of heterogeneous networks (HetNets). 5G HetNets 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.

Callout: Figure 1 Resource management.

Resource management will play a vital role in 5G HetNets not only to achieve optimal performance but also to ensure fairness and to meet user demand and application requirement. Figure 1 shows a diagram of a typical resource management framework with various considerations, including QoS requirement, radio resource limitation, energy consumption, cost/profit, etc. We can divide resource management into two parts, i.e., before and after connection establishment. The first part, i.e., cell association, accounts for making a decision on which cell of the HetNets should provide service to the user. The second part, e.g., antenna allocation, power control, channel allocation, cooperative transmission, mobility management, etc, is performed after the user connection is established.

Next we will focus on the cell association for HetNets. Although some works have investigated this problem, there are some related issues that are open for innovations.

III. CELL ASSOCIATION FOR HETEROGENEOUS NETWORKS

A. *Access Modes*

Three different access modes of a small-cell in HetNets are [5]:

- In the open access mode, users are treated equally and can be unconditionally allowed to access the small-cell, depending on availability of resource.
- In the closed access mode, the small-cell will differentiate users (i.e., small-cell subscribers) in a closed subscriber group (CSG) and yield higher access priority to the subscribers.

- In the hybrid access mode, the small-cell reserves part of its resource for the subscribers, while also allowing non-subscribers to access.

The access mode is related to the standard. For example, [5] describes a small-cell search function under the 3GPP specification and explains the roles of a home NodeB (HNB) and core network as well as their signaling when a new user initiates a connection (i.e., a registration process). However, to initiate and serve a new connection from a user, performance has to be evaluated. Specifically, if the new user is accepted, the network must ensure that all ongoing users and the new user will have an acceptable performance level. In the literature, this problem can be referred to as cell or base station association/selection. Two approaches exist, i.e., network-driven and user-driven.

- In the 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 the cell (e.g., a macrocell or small-cell) that the user will be associated with. The benefit of the network-driven cell association is at the full network control by an operator, which aims to achieve a particular objective (e.g., maximum network capacity or highest profit).
- In the user-driven cell association, the user makes a decision on which base station or access point to connect to. The user will observe and estimate the performance (e.g., SINR) of nearby cells and make the decision accordingly. In contrast to the network-driven cell association, the benefit of the user-driven cell association is at the independence of users in making their decision and the ease of taking users' preference into account (e.g., maximal user's satisfaction).

Additionally, a hybrid approach is also possible. First, the users select cell or base station of their preference. Then, the networks make decision to accept the users or not. Figure 2 shows the three approaches.

Callout: Figure 2 Network-driven cell association and user-driven cell/base station selection.

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, the SINR based association does not take the network load into account. The scheduling and 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 less users, depending on the current or future load. In the following, we will discuss about different approaches of cell association.

1) Types of Cell Association Implementation: To implement the network-driven or the user-driven cell association, three approaches can be adopted, i.e., centralized, decentralized, and distributed.

- For the centralized approach, a central entity (e.g., a macrocell base station or a network gateway) makes a global cell association decision for all cells and users. This approach requires heavy information exchange and gathering. However, it can achieve an optimal network performance due to complete information of the networks and users.
- For the decentralized approach, the network is divided into smaller parts (e.g., each subnetwork is composed of a few small-cells). In each part, there will be a controller to make a cell association decision for its members. The decentralized approach aims to achieve a network-wide objective, but with less information exchange and self-interest objective.
- For the distributed approach, each network entity (e.g., a small-cell access point) can make its own decision independently with minimal information exchange. The distributed approach may aim to maximize individual performance, which could be different from that of an entire network (e.g., a small-cell aims to maximize its own profit).

The network-driven cell association can adopt three above approaches, depending on system setting and network configuration. For example, if all cells are operated by one operator with a single objective, the centralized and decentralized approaches can be adopted. By contrast, if small-cells belong to individual owners with different objectives, the distributed approach can be adopted. For user-driven cell association, typically the distributed approach is used due to limited information exchange.

For centralized, decentralized and distributed network-driven and user-driven cell association, a decision maker has to evaluate the performance of the network and individual user. Therefore, almost all the existing cell selection/association schemes are designed jointly with the power control and channel allocation which are the integral parts of OFDMA- and CMDA-based cellular networks.

2) Network-Driven Cell Association: [9] introduces a simple cell association policy for an OFDMA-based small-cell with the hybrid access mode. The small-cell makes a decision to accept a new user based on a threshold. In particular, the cell association policy determines the maximum number of non-subscribers (i.e., the threshold) to be served by the small-cell. [9] discusses different possible ways of determining this threshold (e.g., static or dynamic). Some simulation results show that when the threshold increases, the throughput of the subscribers increases, while that of the non-subscriber decreases, and the number of non-subscribers in outage increases. However, a method to optimize the threshold is not discussed.

A few works consider the power adaptation and cell association jointly, e.g., [6] for OFDMA-based small-cell networks. 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. [10] introduces a simple 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. [10] is able to derive the success probability for closed and open access modes of the small-cell. Along the same line, [11] introduces a joint cell association and channel allocation. The cell association is performed to maximize the sum of utility of average rates of all users across cells.

3) User-Driven Cell/Base Station Association: [7] 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 macrocell based on the current load condition. Firstly, 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 the nearby base stations.

[13] introduces a coalition formation game for cell association. In this scheme, the small-cells and macrocell use a self-control strategy which let the users decide on the cell to join independently, i.e., based on their individual performance. If congestion happens or performance degradation is observed, the users will switch their cell automatically. Using a Markov chain analysis, the stable cell association of users can be obtained.

4) Network- and User-Driven Cell Association: Both network (i.e., small-cells) and user can jointly decide their access. [8] considers hybrid access mode and addresses the mutual selection cell association. Specifically, the cell association is considered as a matching problem between small-cells and users to meet their preference and satisfaction. The small-cells divide users into different groups based on their preference (e.g., users with good and bad channel quality). Similarly, each user has a list of preferred small-cells (e.g., small-cells with high and low transmission rates). Based on these lists of small-cells and users, [8] introduces matching algorithms to assign the small-cell to the user and vice versa. The stability of the algorithm is analyzed.

[12] considers a similar problem, but bases the user selection on a resource request and auction process. In [12], users bid for radio resource by sending requests to a target base station (e.g., an available macrocell

or small-cell). The base stations of the macrocell and small-cells collect all bids and determine the resource allocation for all bidding users. The auction process is proved to achieve both efficiency and fairness.

B. Cell Association for 5G HetNets

Network heterogeneity and new access technologies will be driving factors of designing cell association schemes and algorithms for 5G HetNets. With several types of radio access networks and technologies (e.g., massive MIMO and mmWave), and value-added services (e.g., mobile cloud), the cell association must be developed to meet users' requirement. Additionally, due to heterogeneity in various dimensions, to achieve efficient operation, distributed algorithms would be required. As 5G HetNets will inherently be composed of a number of cells, the only viable and scalable solution is using distributed algorithms for cell association. Users should be able to make a cell association decision with facilitation from the networks, achieving scalable solutions.

In the next section, we propose the cell association algorithm for the HetNet with massive MIMO. The algorithm is fully distributed requiring minimum information exchange in the network.

IV. QoS-Aware Cell Association and Antenna Allocation

In this section, we study the cell association problem in the heterogeneous network (HetNet) with massive MIMO. The main purpose is to examine how the massive MIMO technology affects the cell association decision of users. In massive MIMO, a base station will be equipped with a large number of antennas [14]. By allowing the channels to be estimated based on orthogonal pilot signals sent from the user equipments, massive MIMO can achieve better performance without increasing training overhead significantly when the number of antennas increases. [14] defines the massive MIMO as an operating condition that multiuser interference and noise are small compared to pilot contamination and studies the performance of matched filter (MF) and minimum-mean-square-error (MMSE) detection under a general channel model. In the following, we present the system model of the HetNet with massive MIMO. Then we describe the cell association algorithm for HetNet users, and antenna allocation algorithm for the HetNet cells. Finally, we present the performance evaluation.

A. System Model

We consider the HetNets composed of a macrocell and multiple small-cells (e.g., microcells, picocells, and femtocells). The small-cells are overlaid in the macrocell. The massive MIMO is employed at the macrocell base station and small-cell access points. If the users are outside the coverage of any small-cell, they have only one choice to associate with the macrocell base station. By contrast, if the users are inside the coverage of any small-cell, they can choose either to connect to the small-cell or macrocell. The HetNets supports C classes of users. Each class c has a data rate requirement denoted by R_c. If the rate requirement cannot be met by either the macrocell or small-cell, the user will disassociate from the network. A class-c user pays a price ϕ_c (i.e., a revenue per class-c user) to the cell that the user is associated with. 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 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 disassociate from the network, creating revenue loss to the cells.

In the following, we will propose the algorithms for cell association for HetNet users and antenna allocation for a macrocell and small-cells. The proposed algorithms have the following features.

- *Achieving individual objective of users, macrocell and small cells:* These entities have their own objective. The users want to perform cell association to maximize their data rate. By contrast, the macrocell and small-cells want to perform antenna allocation to maximize their total revenue earned from the associated users.
- *Distributed algorithm:* The users should make their decision on cell association without a centralized controller. Likewise, the macrocell and small-cells should allocate their antennas independently.
- *Minimum information exchange:* The users, macrocell, and small-cells should rely on the minimal information exchange to minimize the overheads of cell association and antenna allocation.

B. QoS-Aware Cell Association and Antenna Allocation

We then propose the cell association and antenna allocation algorithms to achieve aforementioned features.

1) Cell Association: Since the users are interested in their own data rate, we can consider the cell association as a game. Evolutionary game is particularly suitable for the cell association since the number of users can be large and sometimes the users can make some irrational decision due to the lack of complete information in a distributed environment. Under the evolutionary game framework, we define the cell association problem as follows:

- *The players* are HetNet users.
- *The population* is a set of users in the same class.
- *The strategy* is to choose one of the available cells to associate with or disassociate from the network if the data rate is lower than the requirement.
- *The payoff* is data rate.
- *The solution* is an evolutionary equilibrium. The evolutionary equilibrium ensures that the population will not change their strategy as the players have received the highest payoff given the strategies of other players.

Algorithm 1 shows the cell association algorithm of each user. The algorithm is based on a learning implementation of an evolutionary game [15].

Algorithm 1 Cell association algorithm.

```
A user chooses an available cell randomly.
loop
    The user observes data rates broadcast by all available cells.
    The user estimates the average data rate.
    if $rand() < \gamma$ then
        if The current data rate of the user is lower than the requirement then
            The user disassociates from the network.
        else
            if The current data rate of the user is lower than the average data rate then
                The user switches to choose another different cell.
            end if
        end if
    end if
end loop
```

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 the probability γ, 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 different cell.

The algorithm requires only the cells to broadcast data rates periodically. This will incur only small overhead in the network.

2) Antenna Allocation: The cells in the HetNets (e.g., a macrocell and small-cells) do not have complete information about cell association (i.e., the users gradually observe and change their decisions) and about antenna allocation performed by other cells. Therefore, the cells have to periodically observe and adapt their allocation. Again, we adopt an evolutionary game for the antenna association as follows:

- *The players* are HetNet cells.
- *The population* is a set of antennas of each cell.
- *The strategy* is the allocation of antennas to different classes of users. Let $A_{i,c}$ denote the number of antennas of cell i allocated to class-c users, and $\mathbf{A}_i = (A_{i,1}, \dots, A_{i,c}, \dots, A_{i,C})$ denotes an allocation, where $\sum_{c=1}^{C} A_{i,c} = A_i$, while A_i is the total number of antennas of cell i and C is the total number of classes.
- *The payoff* is the total revenue of the cell, which is the number of associated users in all classes multiplied by the prices paid by them.
- *The solution* is an evolutionary equilibrium.

Algorithm 2 shows the major steps of antenna allocation algorithm. Again, the algorithm is based on a learning implementation of an evolutionary game [15].

Firstly, 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 different allocation if it yields higher estimated and recorded total revenue.

The cell association for users and antenna allocation for cells are interrelated. Firstly, the cells perform antenna allocation. Secondly, the users observe the data rate given the allocation, and they perform cell association accordingly. Again, the cells observe the cell association by users in all classes and adjust the antenna allocation. In summary, the antenna allocation is performed in the longer time scale than that of the cell association.

3) Numerical Results: We consider a HetNet with a macrocell and two small-cells with a massive MIMO scheme as in [14]. We adopt the match filter user detection. However, the HetNet can also adopt more sophisticated minimum-mean-square-error (MMSE) detection. Similar to [14], we use the following parameters: the intercell interference factor is $\alpha = 0.1$ and transmit SNR is $\rho = 0$dB. The number of

Algorithm 2 Antenna allocation algorithm.

```
A cell allocates antennas to different classes randomly, where the vector of allocation is denoted by $\mathbf{A}_i$.
loop
  while There is change in the cell association decision of users do
    The cell does nothing.
  end while
  The cell observes cell association by users in each class.
  The cell calculates the data rate of the associated users and broadcasts it.
  The cell calculates the total revenue from $V = \sum_{c=1}^{C} \phi_c N_{i,c}$, where $N_{i,c}$ is the number of class-$c$ users choosing cell $i$ and $\phi_c$ is the revenue per class-$c$ user.
  The cell then updates the total revenue for the current allocation, i.e., $\overline{V}(\mathbf{A}_i)$.
  if The current allocation $\mathbf{A}_i$ yields lower total revenue than that of other allocation $\tilde{\mathbf{A}}_i$, i.e., $V(\mathbf{A}_i) < \overline{V}(\tilde{\mathbf{A}}_i)$ then
    The cell switches to the allocation $\tilde{\mathbf{A}}_i$
  end if
end loop
```

antennas of the macrocell is 100. The first and second small-cells have 10 and 12 antennas, respectively. All the small-cells are non-overlapping. There are two classes of users, denoted as class-1 and class-2. The rate requirements of class-1 and class-2 users are 1.0 and 0.7 b/s/Hz, respectively. In both small-cells, there are 10 users in each class. For the users in the macrocell, there are 20 class-1 users and 30 class-2 users having the access to the macrocell only (i.e., they are not in the coverage of any small-cell).

Callout: Figure 3 Data rate of users and total revenue of macrocell.

Figure 3 first shows the data rate for class-1 users choosing the macrocell or small-cell 1. We set the number of antennas allocated for class-1 users for the macrocell and small-cell 1 to be 50 and 5, respectively. Clearly, when more number of class-1 users choose the macrocell, the corresponding data rate decreases, while the data rate of the class-1 users choosing the small-cell increases. There is a turning point that the data rate obtained from choosing the small-cell is higher than that of choosing the macrocell. In this case, the class-1 users will be distributed between the macrocell and small-cell 1 such that their data rate is identical. Note that if the data rate is lower than the requirement (i.e., 1 b/s/Hz for a class-1 user), then the users will leave the service by choosing none of the macrocell or small-cell. The proposed algorithm aims to achieve the cell association to reach the point where the data rates of choosing different cells are balanced.

Figure 3 also shows the total revenue of the macrocell when the number of antennas allocated to class-1 users is varied. This total revenue is under different number of antennas allocated to class-1 users by small-cells 1 and 2, i.e., denoted by $A_{1,1}$ and $A_{2,1}$, respectively. Clearly, there is an optimal point of the total revenue for the macrocell. The proposed algorithm aims to achieve such a point.

Callout: Figure 4 Adaptation of cell association strategy of class-1 users in small-cell 1 under different rate requirement.

Figure 4 shows the cell association strategy of class-1 users in small-cell 1 when the rate requirement of class-1 users is varied. We observe that when the rate requirement increases, some users will choose none of the macrocell or small-cell, since they cannot provide the data rate higher than the requirement. This figure also shows that the data rate of the users in both classes can be always maintained above the requirement. Note that we can expect similar results for class-1 users in small-cell 2 and also class-2 users. We omit such results for brevity of the article.

Callout: Figure 5 Rate under different revenue per class-1 user.

Figure 5 shows the data rate of class-1 and class-2 users under different revenue per user. Clearly, when the revenue per class-1 user increases, the small-cells will allocate more antennas to the class-1 users, resulting in higher data rate. However, when the data rate requirement of class-2 is reached (i.e., 0.7 b/s/Hz), the small-cells will no longer increase the number of antennas allocated to class-1 users to meet the requirement of the class-2 users.

Callout: Figure 6 Total revenue under different number of antennas at the macrocell.

Figure 6 shows the total revenue and the number of antennas allocated to class-1 users when the number of antennas at the macrocell is varied. When the number of antennas at the macrocell increases, the macrocell can allocate more antennas to class-1 users. Although the number of antennas allocated to class-1 users of the small-cells is not significantly affected by this action of the macrocell, the total revenue decreases. This is due to the fact that the users will prefer to choose the macrocell as it yields higher data rate. Consequently, the total revenue of the macrocell increases, while those of the small-cells decrease. Note that similar results are expected for class-2 users, which we omit for brevity of the article.

Additionally, when the number of users in any class increases, the macrocell and small-cells will increase the number of antennas allocated to that class of users. However, they will have to ensure that the minimum data rate requirement of other classes of users will not be violated. From the above results, the proposed cell association and antenna allocation algorithm can support QoS to users in 5G HetNets with massive MIMO.

V. CONCLUSION

We have presented the key features of 5G heterogeneous networks (HetNets) and discussed about their resource management issues. We have emphasized on the cell association problem where we have reviewed existing approaches and research directions. We have then developed a QoS-aware cell association algorithm for users divided into different classes with their data rate requirements and an antenna allocation algorithm for cells (e.g., a macrocell and small-cells). The cells perform the antenna allocation algorithm such that their total revenue is maximized.

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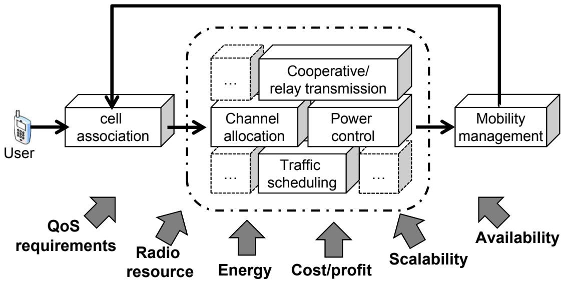

Fig. 1. Resource management.

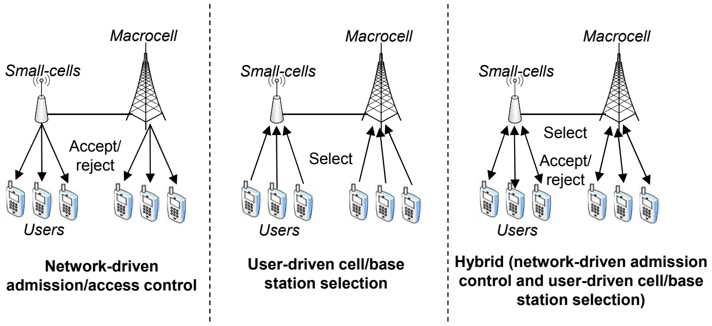

Fig. 2. Network-driven cell association and user-driven cell/base station selection.

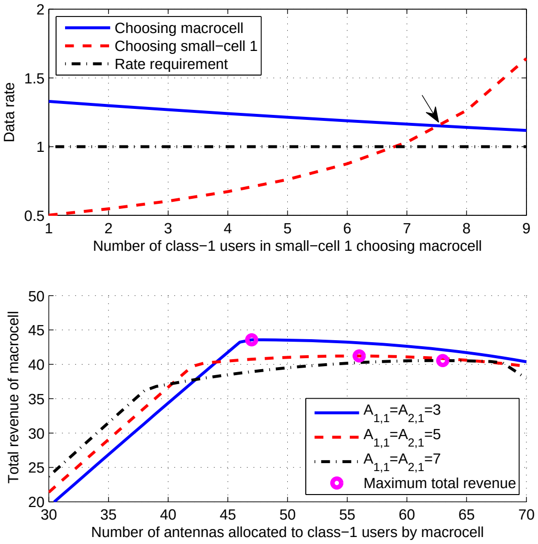

Fig. 3. Data rate of users and total revenue of macrocell.

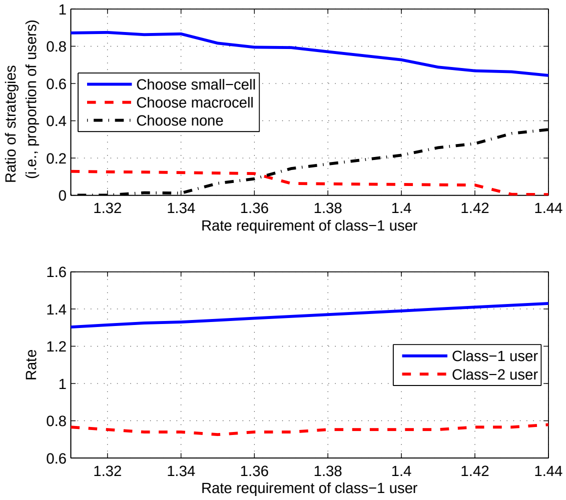

Fig. 4. Adaptation of cell association strategy of class-1 users in small-cell 1 under different rate requirement.

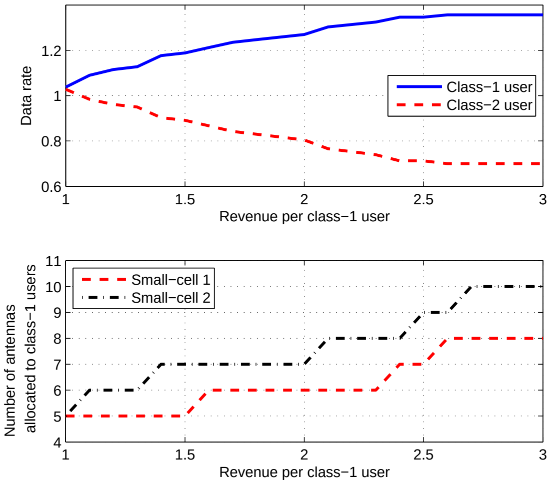

Fig. 5. Rate under different revenue per class-1 user.

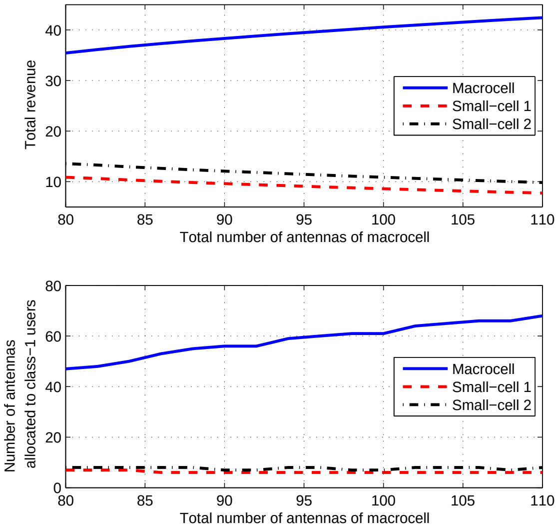

Fig. 6. Total revenue under different number of antennas at the macrocell.