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Efficient Radio Resource Management for Future 6G Mobile Networks: A Cell-less Approach

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***Abstract*—Existing mobile communication systems are unable to support ultra high system capacity and high reliability for the edge users of future 6G systems, which are envisioned to guarantee the desired quality of experience. Recently, cell-less radio access networks (RAN) are exploited to boost the system capacity. Therefore, in this letter we propose a cell-less networking approach with an efficient radio resource optimization mechanism to improve the system capacity of the future 6G networks. The simulation results illustrate that the proposed cell-less NG-RAN design provides significant system capacity improvement over the legacy cellular solutions.**

***Index Terms*—Next-generation radio access network, Cell-less networking approach, System capacity, Legacy cellular network, Radio resource management.**

I. Introduction

FUTURE networks are heading towards an increasingly digitized world, where many services will be based on unlimited connectivity [1]. With an incredible surge of mobile traffic massive requirements of capacity and stringent quality of services (QoS) are needed [2], [3]. 6G networks are envisioned to satisfy demanding services. The transition from the 5G requires efficient approaches in the network design that are able to achieve the required key performance indicators (KPIs) [4]. These could be managed by a number of technological features e.g., wider bandwidth, new radio interfaces, antenna configuration, and different levels of network densification. The concept of cell-less refers to the network where users can dynamically communicate with one or any required number of access points (APs) if necessary. It has been proposed to overcome the major limitations of cellular networks, e.g., network convergence, load balancing, frequent handover, and interference through the horizontal convergence in celled architectures of APs [5]–[7].

In a conventional cellular network architecture, the radio unit (RU) from a specific service provider is allocating resources by assuming only the local knowledge of the radio environment and underpinning its users. The internal competition for the resources (i.e., between the RUs from the same operator) causes the RUs to assign resources in a non-optimal way. This "competition" is the consequence of the cellular network architecture which needs to be shifted towards the cell-less architecture for the next generation radio access networks (NG-RAN) of 6G networks. The cell-less concept can help the network to meet the requirements of 6G use-cases in several ways, including enhanced capacity, efficient resource allocation, improved security, etc. These are essential for 6G use cases requiring high data rates and those where a large number of devices are connected simultaneously, like smart cities and industrial automation. The concept of "small-cells" that have been largely discussed for 4G/5G networks [8], [9] is now evolving towards networks with many small RUs. For the cellular network architecture, OFDMA-based mobile wireless networks have generally studied the user association, physical resource block allocation, power allocation, sub-carrier assignment problems either separately or jointly, to maximize the data rate, throughput, sum rate, spectral efficiency, and achievable data load of the networks [10]–[13]. These reference schemes considered resource allocation strategies for the cellular network architecture without exchanging any information amongst the users and the RUs of the networks.

However, the inter-cell interference (ICI) effect on the cellular network design can significantly degrade the capacity of the networks if the interference of the underlying RAN is not efficiently managed by the scheduler at the RUs. In the cell-less architecture, the ICI effect of the RAN can be eliminated through either cooperative scheduling and efficient resource allocation or joint transmission techniques. By managing the interference, the system capacity of the networks could be significantly improved. Several research works have already proved that the cell-less solution may improve the system capacity of the networks by simultaneously serving users by a number of RUs. The work in [14] focuses on maximizing the weighted sum rate through efficient resource allocation in multi user cell-less multiple input multiple output (MIMO). Recently, resource management has made a significant contribution in performance of cell-less networks. However, the deployment of any practical cell-less scheme needs to consider the finite capacity of individual RUs. On the other hand, a user-centric approach can outperform a general cell-free network where users are served by all RUs [15].

In summary, the main limitations of so-far reviewed works are as follows: most of them do not specifically address the impact of efficient resource allocation itself in the baseline cell-less network compared to the legacy cellular network. In addition, the effect of user density and environment in cell-less networks is ignored. Hence, most of them are not ensuring the applicability of the proposed schemes in different

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scales of network size. In this work we propose a cell-less networking approach along with a radio resource management (RRM) algorithm that can significantly improve the system capacity performance over legacy schedulers. The resource allocation for an UE is performed based on the consideration of available resources from all other neighboring RUs. The main contribution of the letter can be listed as follows:

- We propose a cell-less RAN design and an efficient RRM algorithm for future 6G networks to improve the system capacity performance.
- We validate the approach of cell-less RAN by considering the mitigation of the network level interference introduced through the utilization of the same resources of the underlying RUs.
- We highlight potential benefits of the proposed approach and its RRM strategies over the legacy cellular RAN approach where the scheduling algorithm considers the strongest link for the RU-UE association.
- We also analyze the effect of user density of our proposed algorithm and compare the performance with legacy systems in terms of system capacity performance enhancement for a different scale of network setup in several deployment environments.

II. System Model and Problem Statement

We consider a system model that consists of set of RUs defined as, $\mathcal{M} = \{1, \ldots, M\}$ and a set of UEs $\mathcal{K} = \{1, \ldots, K\}$, respectively, where M and K are the total number of RUs and single-antenna UEs in the network, accordingly. The Open RAN architecture - having disaggregated RU, centralized unit (CU), distributed unit (DU) - is considered. The central RAN intelligent controller (RIC) is supporting the coordination of RAN (through our proposed RRM application) and the network information exchanging and storage.We assume an orthogonal frequency division multiple access (OFDMA) based cell-less networking approach where all the RUs will utilize the full amount of resources, i.e., the bandwidth available for the network. $\mathcal{N} = \{1, \ldots, N\}$ is the set of RBs, where the assigned RB n to k-th UE is denoted by indicator $b_{k,n}$ and will be equal to $b_{k,n} = 1$ if being allocated, otherwise $b_{k,n} = 0$. $\boldsymbol{X_b}$ includes binary indicators of any $b_{k,n}$, for $\forall k \in \mathcal{K}$, $\forall n \in \mathcal{N}$. In the considered cell-less network model, each resource block (RB) is 180 KHz wide in frequency and one time slot long for 0.5 millisecond (msec). Moreover, each time slot will be carrying 7 OFDM symbols and at the frequency domain it will utilize 12 sub-carriers with 15 KHz subcarrier spacing.

The resources are allocated in a cell-less way which will be further explained in the next section. Let us assume $\gamma^{D}_{m,k,n}$ is the signal to interference plus noise ratio (SINR) of user k associated to RU m on RB n, which is defined as

$$\gamma^{D}_{m,k,n} = \frac{y_{k,m} P_{m,n} |h_{m,k,n}|^2}{\sum_{j \neq m, j \in \mathcal{M}} P_{j,n} \, |h_{j,k,n}|^2 + \sigma^2} \tag{1}$$

where $y_{k,m} = 1$ indicates user k associated with RU m, otherwise $y_{k,m} = 0$. $\boldsymbol{X_y}$ includes binary indicators of any $y_{k,m}$, for $\forall k \in \mathcal{K}$, $\forall m \in \mathcal{M}$. $h_{m,k,n}$ is the channel gain from RU m to user k on RB n including the path loss and shadowing effects, $P_{m,n}$ is the transmission power of RU m on RB n, and σ^2 is the additive white Gaussian noise power at each receiver.

The cell-less-enabled RAN controller operates the RRM application to manage and enhance RAN performance. The proposed cell-less networking approach would dynamically adapt to the network condition by targeting the system capacity optimization as an objective function. The achievable throughput obtained through Shannon formula [1] for a particular RU m in downlink transmission for user k over RB n is

$$R^{D}_{m,k,n} = \log_2 \left(1 + \frac{y_{k,m} P_{m,n} |h_{m,k,n}|^2}{\sum_{j \neq m, j \in \mathcal{M}} P_{j,n} \, |h_{j,k,n}|^2 + \sigma^2} \right). \tag{2}$$

The system capacity can be calculated as the aggregation of all active RUs throughput. Then we propose the following as

Optimization problem:

$$\underset{\boldsymbol{X_b}, \boldsymbol{X_y}}{\arg\max} \; \Big(\sum_{m \in \mathcal{M}} \sum_{k \in \mathcal{K}} \sum_{n \in \mathcal{N}} b_{k,n} R^{D}_{m,k,n} \Big) \tag{3}$$

Subject to:

$$\textbf{C1}: y_{k,m} \in \{0,1\}, \quad \forall k \in \mathcal{K}, \quad m \in \mathcal{M} \tag{4}$$

$$\textbf{C2}: b_{k,n} \in \{0,1\}, \quad \forall k \in \mathcal{K}, \quad n \in \mathcal{N} \tag{5}$$

$$\textbf{C3}: R^{D}_{m,k} \geq R^{D,\min}_{m,k}, \quad \forall k \in \mathcal{K}, \quad m \in \mathcal{M}. \tag{6}$$

The constraints C1, C2, and C3 indicate the user k will associate with a particular RU m, allocate with RB n, and guarantee minimum rate requirements of the users, respectively.

III. Proposed RRM Scheme with Cell-less RAN

We consider the system capacity optimization problem (OP) as shown in eq. (3) within the proposed cell-less architecture. To improve the overall system capacity performance, we need to manage and reuse the entire network resources while satisfying the minimum quality-of-service (QoS) of the users. Therefore, the proposed cell-less RRM application will be avoiding the user service dropping along with enhancing the system level KPI. The proposed cell-less approach of networking has an opportunity to access the entire available resources by users. Moreover, the cell-less RRM application mitigates the available interference in a cooperative manner (i.e., considering a set of RU's conditions and constraints) to maximize the system capacity of the networks.

In this letter, a network-wide view point of optimizing the system capacity is realized and we consider the inter RUs interference due to reuse of the resources within different RUs in the proposed design. Therefore, we divide the solutions for the inter RU interference management into two categories. In the first category, the solution is transmission cooperation by the interfering RUs while considering joint transmission as used for cell-free massive MIMO networks in [16] to

[1] Any other mapping between SINR and throughput can be used as well. We take this for simplicity.

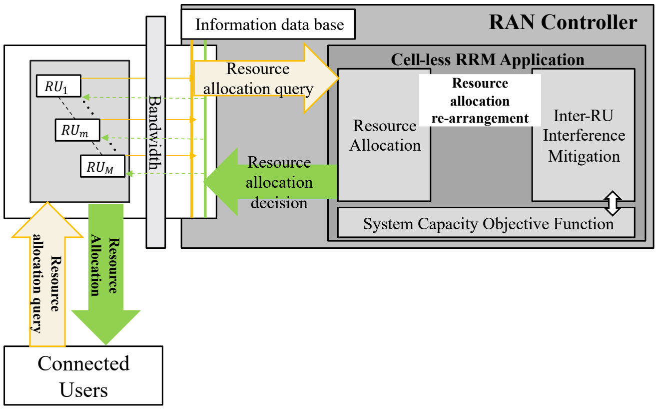


Fig. 1: System model with RRM application within cell-less RAN architecture.

maximize per user spectral efficiency. In the second category, the solution instead mainly focuses on managing the resources efficiently. As it is presented in Fig. 1, the system capacity improvement application would behave based on the resource allocation opportunities.

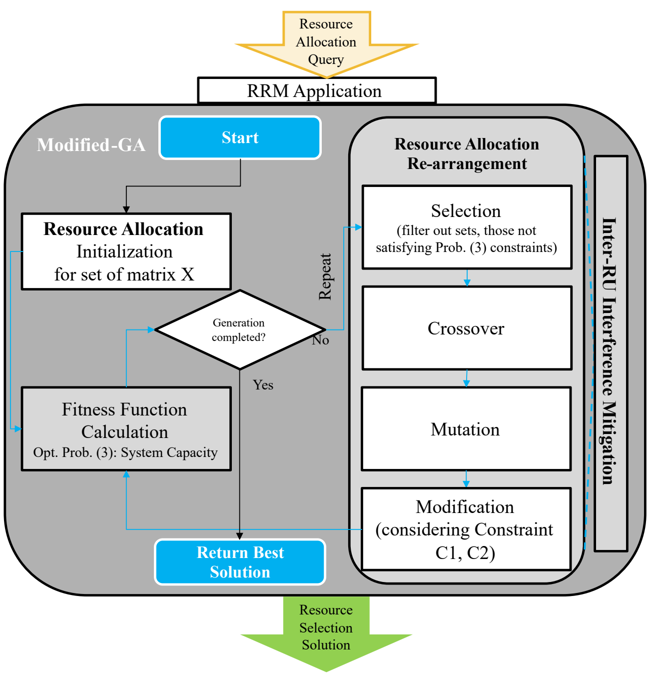


Fig. 2: Flowchart of the modified genetic algorithm (MGA) for cell-less RRM application.

In the proposed scheme, the connected users will periodically send their channel information feedback. The corresponding RUs that receive the feedback from the users would send a query to the cell-less RAN controller carrying the available information of the channel condition, e.g., the reference signal received power (RSRP) of the serving users. Considering the channel conditions of the underlying RAN along with the inter RU interference, i.e., the co-channel interference (CCI), the cell-less RRM application will target the system capacity KPI. To enhance the system capacity, the cell-less RRM application would rearrange the resource allocation through mitigating the CCI.

The OP in eq. (3) is comprised of RB allocation and user association which is a non-convex problem. Due to the non-convex behavior, it is difficult to solve it by traditional convex optimization algorithm unless the problem is transformed into a convex problem. As is known, the genetic algorithm (GA) is a technique that can obtain near-optimal solutions in a relatively low computation complexity (in the worst case it is of $O(|\mathcal{K}|\,|\mathcal{N}|\,N_g N_X)$, where N_g and N_X indicate number of generations in GA and number of individuals (i.e., set of matrix X) per generation, respectively.), while it does not require the OP to be convex [17]. Hence, we consider the modified genetic algorithm (MGA) to solve the OP in (3). In the MGA, the cost function of the OP will be used as the fitness function to evaluate the solution of allocated resources. Therefore, the Matrix X of the proposed MGA can be defined as

$$\boldsymbol{X} = \{\boldsymbol{X_y} \quad , \quad \boldsymbol{X_b}\}, \tag{7}$$

where $\boldsymbol{X_y}$ and $\boldsymbol{X_b}$ are as follows

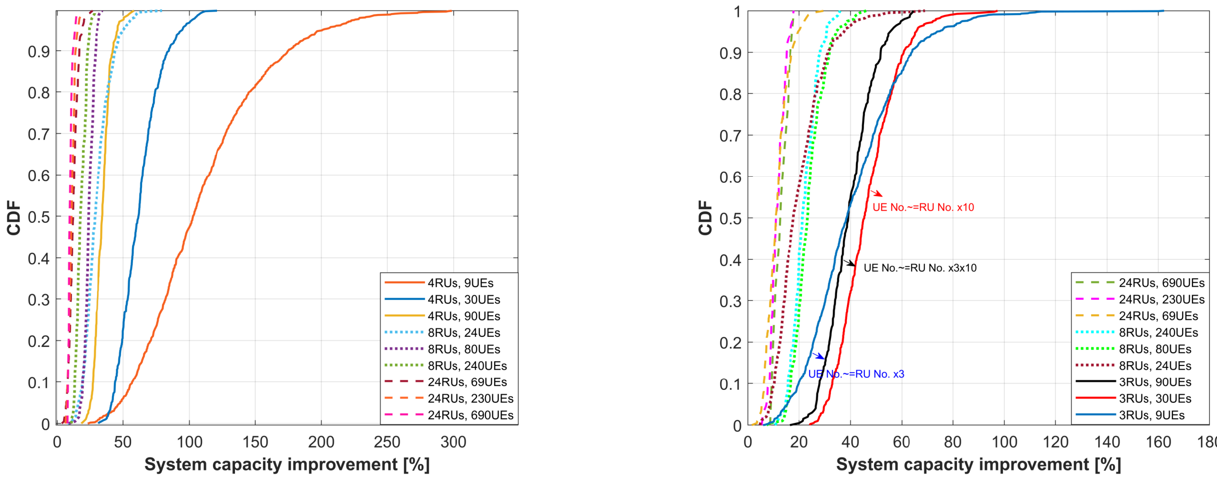
$$\boldsymbol{X_y} = \begin{Bmatrix} y_{1,1} & y_{1,2} & \cdots & y_{1,M} \\ y_{2,1} & y_{2,2} & \cdots & y_{2,M} \\ \cdots & & & \\ y_{K,1} & y_{K,2} & \cdots & y_{K,M} \end{Bmatrix}, \tag{8}$$

$$\boldsymbol{X_b} = \begin{Bmatrix} b_{1,1} & b_{1,2} & \cdots & b_{1,N} \\ b_{2,1} & b_{2,2} & \cdots & b_{2,N} \\ \cdots & & & \\ b_{K,1} & b_{K,2} & \cdots & b_{K,N} \end{Bmatrix}. \tag{9}$$

A particular matrix X represents a solution for the cell-less RRM application, where a larger corresponding fitness function reflects a better solution. A set of solutions will be initialized through the UE-RU association based on the strongest links (with the maximum RSRP) and Round Robin process for UE-RB allocation. Depending on their fitness functions, some of the solutions will be going through a four-step MGA process (i.e, selection, crossover, mutation and modification) to create a next evolved generation of solutions [18]. The generations will be evolved through re-arrangement of allocated resources (represented by $b_{k,n}$ and $y_{k,m}$ indicators) to reach the optimized solution for matrix X. The example flowchart of the implemented MGA is presented in Fig. 2. Through the interference awareness of the entire cell-less network, the resource allocation would be dynamically rearranged. This allocation process would improve the system capacity and evolve the entire network allocation efficiency, with a full central information awareness rather than facing performance degradation due to allocation competition. The entire competition between users on the allocated bandwidth would be taken as an opportunity by the proposed cell-less RRM application to optimize the system capacity. The more competition, the more space for efficient resource allocation, and so the more gain for system capacity.

IV. Simulation Results and Performance Analysis

Without loss of generality, in our illustrative example, different scales of the network setups are deployed in dense urban Micro and indoor environments. The dense urban Micro environment is configured with a hexagonal topology with 200 m inter-RU distance, 33 dBm maximum transmit power and



(a) Indoor environment

(b) Outdoor environment

Fig. 3: CDF of system capacity improvement.

15 m height for each RU. The indoor environment is formed with a rectangular topology with 20 m inter-RU distance, with 24 dBm maximum transmit power and 3 m height for each RU. Moreover, different numbers of RUs are configured in simulations. A 20 MHz channel bandwidth including 100 RBs is considered. The rest of the parameters which are used in this work including channel models are configured aligned with ITU-R recommendation [19].

A. *Analysis of System Capacity Performance*

In order to analyze the network performance for different user densities, we consider different number of user configurations, guaranteeing 1 Mbps for each user as the minimum required throughput. The cumulative distribution function (CDF) of the system capacity improvement (i.e., $((R_{\text{cell-less}} - R_{-}\text{legacy})/R_{\text{legacy}}) \times 100$, where R_{x} is the system capacity of network x (x = $\{$cell-less, legacy$\}$) that can be obtained from eq. (2).) due to the proposed cell-less RAN design over legacy cellular RAN for indoor and outdoor environments is illustrated in Fig. 3a and Fig. 3b. The results indicate that the cell-less networking approach with our proposed RRM algorithm shows higher system capacity performance over legacy cellular networks for different network setups in several simulated environments from [19]. This is because during the resource allocation phase, the proposed approach considers the status of all available resources of the underlying RAN. In contrast, the legacy cellular RAN allocates resources competitively in a Round Robin manner (in line with the random RB mutation in MGA) from the RUs providing the highest RSRP. Due to such competitive allocation the users are receiving more interference from the neighboring cell and experience a degraded performance.

It can be observed through simulations that scaling the number of RUs is impacting the performance of the network because of users competing in terms of accessing the resources from the RUs.

B. *Performance Behaviour Insight*

Based on RB level analysis, which is the reflection of channel fading conditions, and RU level analysis, which conveys the level of competition for users, we could analyze the cell-less network performance gain behavior as follows.

RU level performance analysis: The notable fact is that all the users are competing to access the resources providing good channel conditions. The more competition for resources with higher gain will create the more space to allocate resources efficiently in order to achieve more network capacity. Therefore, in general, the more RUs will cause increased resource reuse possibility. However, this would cause inter RUs user competition to happen in less share of the entire RUs. Thus, a lower capacity gain could be obtained as the result of efficient resource allocation.

RB level performance analysis: In order to analyze the RB (channel fading) level, we will categorize the RU level in two categories. The scales with low number of RUs will provide higher resource reusing efficiency per RU. The more time-frequency varying channel (i.e., outdoor environment) will eliminate the more need of competition on high gain resources. Therefore, significantly it will avoid the gain of efficient resource allocation from taking competition as an opportunity. While in the setups with higher number of RUs, as the resource reusing efficiency per RU is already low, so there will be no much difference between the frequency selective fading channels (coherence bandwidth of the channel is smaller than the bandwidth of the signal) and flat fading channels (coherence bandwidth of the channel is larger than the bandwidth of the signal).

UE level performance analysis: At the end, moving toward the user level performance comparison, we will create two categories of channel fading in RB level. In the flat fading channel conditions, particularly, for the indoor environments with less time-frequency varying channel, there will be more resources providing good channel conditions. In such cases, there might not be too much benefit from user competitions in resource allocations. However, the higher performance gain could be obtained through competition for accessing a major number of these resources. Consequently, more resources being allocated per user, which means the lower number of users could be

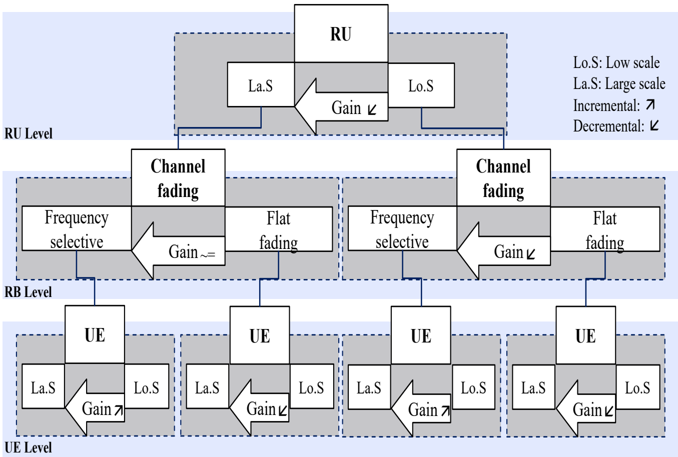


Fig. 4: Performance behaviour insight of the proposed scheme.

associated per RU, will provide more impact of benefiting by using the efficient resource allocation. Therefore, the higher achievable capacity gain will be provided. In the case of frequency selective channels, for outdoor environments, as there are lower numbers of radio resources providing good channel conditions within the entire bandwidth, the behavior would be opposite. The more number of the users will give the more opportunity for allocation of resources providing good channel conditions. Therefore, more users could benefit from efficient resource allocation for frequency selective fading environments. As a result, the higher system capacity gain would be achieved from the cell-less network serving more number of users.

The summary of the performance behavior insight is shown in Fig. 4. Understanding this behavior which is proved in Fig. 3a and Fig. 3b, makes the implementation strategy for the cell-less network clear. It is observed from the outdoor environment in Fig. 3b that the more number of users per RU would let the system achieve higher system capacity due to the higher gain through the resource allocation algorithm at the cell-less RAN controller. As can be seen from the Fig. 3b, there is an optimal number of served users per RU which in our setup is around 10 times the number of RUs at around more than 80% of simulations. Therefore, increasing the ratio of number of serving users to RU more than such optimal scale will lower the per-user performance gain. It is due to the fact that each user would not have sufficient resources for effective gain from competition to improve the system capacity. In these special circumstances, we can only satisfy allocating a number of resources for minimum throughput requirements of the user. However, from the indoor environment simulation in Fig. 3a, it is observed that the lower user density setup provides more gain in system capacity considering the effect of channel fading.

V. Conclusion

In this letter, we propose a cell-less networking approach for capacity improvement of NG-RAN in future 6G networks. We highlight the potential benefits of our proposed design through several numerical simulations. The simulation results clearly indicate that we are achieving significant system capacity performance improvement by shifting legacy cellular RAN design paradigm towards the proposed cell-less RAN design. In this work, we only investigate the behavior of our proposed cell-less RAN design to maximize the system capacity of the networks. Future work will investigate the behavior of cell-less networking approaches to optimize the above-mentioned KPIs such as e.g., energy efficiency, reliability, and latency.

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