A Fairness-based Cell Selection Mechanism for Ultra-Dense Networks (UDNs)

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Received: 7 June 2023 | Revised: 2 July 2023 | Accepted: 17 July 2023

 DOI: https://doi.org/10.48084/etasr.6106

ABSTRACT

A typical 5G Ultra-Dense Network (UDN) comprises different types of Base Stations (BSs) in its structure. Dense deployment of small-cell BSs within a macrocell BS's coverage offers significant benefits, as the distance between a User Equipment (UE) and its small-cell BS is shorter with robust signals. Thus, the network capacity will increase dramatically. However, selecting an appropriate small-cell BS for a particular UE becomes a challenge in 5G UDNs. This study proposed a mechanism to address the cell selection problem and maximize fairness among UEs when making the cell selection decision. The proposed mechanism considered different parameters. The load balance for each small-cell BS was considered to fairly distribute UEs and avoid traffic congestion. Moreover, the signal strength was considered with the achievable data rate for all small-cell BSs to stimulate idle small-cell BSs to be in operating mode. A simulation was carried out in MATLAB to evaluate the proposed mechanism. Signal-to-Interference-Ratio (SINR) and Signal Strength (SS) -based strategies were also simulated for comparison. The proposed solution outperformed the other schemes in terms of fairness, as the UEs attached to the system were fairly distributed among small-cell BSs. Furthermore, the proposed mechanism achieved the best radio resource distribution in terms of fairness compared to the two other schemes.

Keywords-cell selection; UDN; small cells; fairness

I. INTRODUCTION

The fifth generation (5G) of wireless networks enables data to be shared and information to be accessed at any time, anywhere, and for any purpose [1]. Abundant new applications and service domains, such as smart transportation, smart cities, and the Internet of Things (IoT), must be supported by 5G technologies [2-3]. 5G provides high data rates, efficient use of energy, greater reliability, low latency, and extended coverage [4]. Technologies such as millimeter wave (mmWave) and Heterogeneous Ultra-Dense Networks (HUDN) are the most promising approaches to meet these requirements [5-6]. The density growth in current wireless cellular networks has brought some challenges that need to be resolved [7]. It is expected that the number of small cells installed will increase rapidly in the next few years [8]. An Ultra-Dense Network (UDN) is a network in which the number of active UEs is less than the number of small cells in the network [9]. UDNs have a high density of small cells, where the UE distribution would reach approximately 600 active users per kilometer [10]. Picocells and femtocells are examples of small low-power cells that make up HUDNs, while high-power legacy macrocells make up the majority of the network [4].

A typical UDN consists of various types of cells in its structure. Four distinct types of networks could be identified, depending on different coverage areas and application scenarios, as shown in Table I [11]:

- Macrocell: Typically, cellular networks use a macrocell architecture when a powerful BS serves a wide coverage area. The macrocell is always located in a high place, such as the apex of a mountain or a skyscraper. Therefore, it has a clear visibility of the surrounding environments and barriers, allowing for long transmission distances and wide coverage areas, with a cell radius that expands from 1 to 25 km. However, shadow fading and multipath interference have a significant impact on the Quality of Service (QoS) for UEs at cell edges. Additionally, the QoS for attached indoor UEs is affected when served by the macrocell, as a result of uneven service request distribution.
- Microcell: A microcell is served by a low-power BS in densely crowded urban areas. Its range is between 200 m and 1 km. This network is much more limited in scope than the much more widespread macrocell system. As the frequency reuse distance of low-power BS decreases, the number of channels and traffic density increase.
- Picocell: The coverage of a picocell network is less than the coverage of a microcell, as it ranges from 100 to 200 m. Indoor areas are frequently covered by picocells.
- Femtocell: A femtocell is a small, low-power BS designed to improve the quality of communications in residential or small business places. Compared to other cell types, femtocells are much easier to install and an efficient and cost-effective choice. Furthermore, femtocells could cover the gaps left by picocells and reduce signal loss.

TABLE I. TYPES OF UDN NETWORKS

Type	Transmission power (W)	Coverage
Macrocell	20-160	1 km -25 km
Microcell	2-20	300 m – 1 km
Picocell	0.25 - 2	100– 250 m
Femtocell	0.01 – 0.05	10 – 50m

The deployment of dense small-cell systems in existing macrocells offers significant benefits to traditional networks. With a short distance between a user and the BS, the level of signal strength will be robust and capacity will increase. Small cells can be deployed by end users, reducing the overall cost of deployment. Incoming network traffic can be balanced and offloaded over multiple cells. Small cells can be configured in a variety of ways to reduce interference and increase energy efficiency [12]. It is also possible to improve spectral efficiency by making efficient use of the spectrum and reusing frequencies over short distances [13-14]. However, HUDNs face difficulties such as transmission power management, radio resource allocation, cell selection, interference mitigation, and overhead signaling to coordinate among small cells [15].

The process of selecting adequate small cell BSs to provide services for a particular UE is recognized as the cell selection problem [16-17]. This is identified as an NP-hard optimization problem, and its computational complexity grows exponentially with the size of the network [18-19]. The effective and efficient use of a spectrum is a critical prerequisite for UDN 5G networks [20].

II. RELATED WORKS

Investigating cell selection involves multiple criteria, such as performance measurements and knowledge of mobility information. Information about mobility, such as the velocity and direction of the UEs, provides the foundation for many different applications. Most of the research focused on UEs with traveling vehicles. Instead, this study considered pedestrian UEs where their velocity does not have a critical impact on the cell selection decision. In [21] a topology-aware skipping technique was proposed, which analyzed the detrimental influence of UE speed on the achieved capacity in UDNs. This study was carried out to determine how to maximize network throughput. The location of the user and the size of the cell were taken into account when making a handover decision. The simulation results showed that the proposed scheme was more effective than the conventional one in terms of the average UE data rate. In [22], a cell selection technique for 5G UDNs was presented, employing a non-cooperative game theory with two players, one representing UE and the other representing BS. The simulation results showed that the proposed technique reduced the blockage rate experienced by users and increased the performance of 5G UDNs.

In [23], a cell selection method was proposed for 5G UDNs named Handover based on Resident Time Prediction (HO RTP). This scheme aimed to predict the amount of time spent inside a cell. Afterward, small-cell BS was selected considering two facts: First, the small-cell BS with the highest RSSI value was considered, and second, a resident duration that is longer than a predefined threshold value was considered for selection. In terms of achievable mean user throughput, the simulation results showed that this method was better than the traditional one. In [24], Adaptive Cell Selection (ADA-CS) was proposed for 5G UDNs, choosing the optimal BS by considering various characteristics of UDNs and vehicular motions. The proposed scheme consisted of six steps: configuration, decision-making, filtering, narrowing, selecting, and HO triggering. The simulation showed that the ADA-CS method outperformed the conventional and current related approaches in terms of the median number of handovers, the median feasible downlink data rates, and the median spectral efficiency.

In [25], the Q-learning algorithm was presented for the cell selection problem, supporting UEs to select their appropriate BS autonomously. UEs could learn to attain equilibrium without centralized control for collecting information from other UEs. The simulation results demonstrated the convergence of the proposed algorithm and its efficiency. A novel strategy for the cell selection problem was presented in [26]. This method classified all cells into distinct groups based on priority levels. Then, the cell with the highest priority degree would be selected. As a result, the probability of triggering a cell selection decision was reduced. The problem of cell selection was discussed in [27]. The proposed scheme presented two Hidden Markov Model (HMM)-based Machine Learning (ML) algorithms. The proposed HMM-based ML systems had multiple goals, and the main goal was to improve the dependability and availability of network resources. The simulation results demonstrated that the proposed strategy could overcome the random cell selection method in terms of channel availability and dependability. A flexible and hard cell selection method was proposed for non-uniform HetNets in [28], considering the position of the UE. The positions were classified into three categories: inner region, annular region, and outer region. The hard cell selection decision was used in both the inner and outer regions, but the flexible cell selection decision was used in the annular region. The results of the analysis showed that both the coverage and user throughput improved greatly. In [29], Movement-Aware Coordinated multipoint Handover (MACH) and improved MACH (iMACH) were proposed to manage handover and cell selection issues in 5G UDNs. The MACH approach considered the UE's stay time at a specific cell BS. The iMACH approach considered two factors: dwell time and nearest BSs. The simulation results showed that the proposed strategies could overcome the compared ones in terms of handover probability minimization, coverage probability, and throughput increases.

In [18], a deep learning cell selection strategy was suggested, representing the challenge of user association as a segmentation issue in an image, based on pixel-scale categorization. A traditional U-Net network model was built to perform the cell selection task while complying with the requirements of load balancing and UE fairness. The suggested U-Net model took the channel gain matrix as input and considered factors such as path loss, shadowing, and gain. The BS-associated matrix would be determined according to the trained model when it was demodulated. The network was designed as a two-tier UDN, including two macro-BSs and eight small BSs. The BSs were randomly dispersed within a region measuring 600 m on each side. The simulation results showed that the UDN-based deep learning approach surpassed the asymptotically optimum Genetic Algorithm (GA) in terms of the time needed for computation and the degree to scale with the size of the network. A mobility-aware cell selection method for mmWave networks was introduced in [30], considering the distribution of loads in small cells to prevent cell congestion. This method addressed issues of non-line-of-sight propagation effects, blocking, and directionless while decreasing the frequency of handovers between small-cell BSs. In addition, it could accommodate changes in network topology and channel conditions. In [31], the QoS of high-speed mobility in LTE was discussed, measuring handover performance while UEs moved at high speed. The results were classified into multiple classes according to UE speed, showing that it could be determined when handover could fail and the call could be dropped.

The limitations of the recent cell selection methods can be summarized as follows:

- Fairness issues have not been studied in depth in recent cell selection strategies. The issue of UE fairness must be considered when making the cell selection decision. Fair distribution of radio resources among UEs is also necessary to maintain user satisfaction.
- Most contemporary studies give the highest priority to cells that have the strongest reception power to maximize the amount of data rate.
- The issue of starvation, which can be faced by distributed UEs, has not been considered in most current studies. Starvation occurs when more UEs are congested in a single small-cell BS, where the radio resources of a small-cell BS are limited and might not satisfy UE requests.
- Most studies used static and nonadaptive methods when making the cell selection decision. Since HetNets have several tiers, adaptive selection is preferable.
- Most strategies have focused on selecting an adequate cell for a high-speed moving vehicle. However, small-cell BSs can be deployed in areas that have pedestrian UEs, where the handover decision might not be necessary because the UEs are stationary or move very slowly.

This study aims to:

- Propose an adaptive cell selection mechanism to maximize fairness among UEs. The proposed scheme aimed to map UEs to adequate small-cell BSs under the fairness constraint, considering load balance, signal strength, Signal-to-Interference-Ratio (SINR), and achievable throughput.
- Evaluate the proposed mechanism in a 5G UDN model, simulating a real-time environment.
- Conduct a MATLAB simulation to evaluate the proposed mechanism, using different performance metrics, such as data rate and fairness, to investigate its feasibility. The average throughput of the whole system was also considered. Furthermore, Jain's fairness index was used to evaluate the achievable fairness of the proposed mechanism. The process of distributing UEs among small-cell BSs, which depends on the cell selection decision, was evaluated in terms of fairness, and the fairness of distributing radio resources among UEs was investigated.

III. SYSTEM MODEL

A 5G UDN was considered, consisting of small high-density 5G cells, deployed within the range of a single macrocell. Small cells operated with different subbands of the available spectrum to avoid and mitigate interference. The division of the available spectrum was performed based on the method proposed in [32]. The small BSs operated on a carrier frequency of 28 GHz with a bandwidth of 500 MHz. The available bandwidth N consisted of multiple subchannels, where N=[n_1, n_2, n_3,…,n_n]. Small cells were randomly distributed within the macrocell area. X and Y were the coordinates of the macro-BS. The distribution of the small BSs depends on those coordinates, as their locations would be maintained to not be placed out of the macrocell's range. The set S comprises all BSs of small cells in the system S=[s_1, s_2, s_3, …, s_n]. Additionally, UEs were distributed randomly. The system would insert a new UE for each run and apply the cell selection strategy. The set U comprises all UEs that request resources in terms of downlink, where Ui=[UE_1, UE_2, UE_3,…, UE_n]. Location information for all small BSs, UE, and macrocell is necessary to calculate the distance between UEs and their serving small BSs, and the between UEs and other small BSs. This information was used to calculate the necessary propagation models, such as path loss.

It was assumed that $Tx_{s,UE,n}$ indicates the transmission power for a specific sub-channel n_i for a particular UE UE_i, which is associated with a small cell BS s_i. The transmission power dedication matrix of a particular s_i small cell BS is denoted by Tx=[$Tx_{s,UE.n}$]$_{s\times UE\times n}$. The sub-channel scheduling indicator matrix is denoted by CH=[$ch_{s,UE.n}$]$_{s\times UE\times n}$. If the subchannel n_i would be allocated to a UE UE_j in small-cell BS s_k, $CH_{\mathrm{s.UE.n}}$, otherwise $CH_{\mathrm{s.UE.n}}$=0. The capacity of subchannel n, which is assigned for UE by a small cell BS s, is calculated as follows [33]:

$$C_{s,UE,n} = \Delta f\, log_2\left(1 + \alpha SINR_{s,UE,n}\right) \tag{1}$$

where Δf and a indicate the subcarrier spacing and the target BER set to 10^{-6}, respectively. The SINR would be calculated according to the following formula [33]:

$$SINR_{UE,n} = \frac{Tx_{s,n}\, G_{s,UE,n}}{\sum_{MBS} Tx_{MBS,n} G_{MBS,UE,n} + \sum_{s'} Tx_{s',n}\, G_{s',UE,n} + N_0 \Delta f} \tag{2}$$

where $Tx_{s,n}$ represents the transmission power of the serving small cell BS s on sub-channel n, $G_{s,UE,n}$ indicates the channel gain between the serving small cell BS s and its UE on subchannel n, $Tx_{MBS,n}$ indicates the transmission power of macrocell BS MBS on subchannel n, $G_{MBS,UE,n}$ indicates the channel gain between MBS and UE on subchannel n, $Tx_{s',n}$ indicates the transmission power of the adjacent small cell BS s' on subchannel n, $G_{s',UE,n}$ indicates the channel gain between adjacent small cell BS s' and UE on sub-channel n. The channel gain is calculated as follows [33]:

$$G = 10^{-PL/10} \tag{3}$$

where *PL* is the path loss calculated based on two considerations: First when the small cell BS is installed indoors and its associated UEs are in the same environment. In this case, it is calculated according to [33]:

$$PL_{indb} = 38.46 + 20log_{10}\,(D) + 0.7d_{2R,in} + 18.3^{((n+2)/(n+1)-0.46)} + V_x * L_{inwall} \quad (4)$$

where D is the distance in meters, $0.7d_{2R,in}$ is the penetration loss caused by the walls inside buildings, the floors are accounted as n, V indicates the total number of walls between the small cell BS and its attached UEs, and L_{inwall} is the penetration loss caused by walls that separate adjacent buildings. The second consideration assumed that small-cell BS is installed in an indoor environment and its associated UEs are positioned outdoors. In this case, the path loss would be calculated according to [33]:

$$PL_{indb} = max\big(15.3 + 37.6\,log_{10}\,(D), 38.4 + 20log_{10}\,(D)\big) + 0.7d_{2R,in} + \backslash 18.3n^{((n+2)/(n+1)-0.46)} + V_x * L_{inwall} + L_{outwall} \quad (5)$$

IV. PROPOSED SOLUTION

Usually, UEs periodically scan and inspect the received signals from all adjacent small-cell BSs. Additionally, all small-cell BSs would be aware of the number of attached UEs. Moreover, the information about the achievable data rates for each UE attached to a particular small-cell BS is known by the serving small-cell BSs. In addition, SINR information is also known for small-cell BSs. All of this information can be used to design a novel strategy for cell selection in which UEs are attached to a proper small-cell BS. The proposed solution was designed to improve the cell selection decision using the aforementioned information and assist small-cell BSs to serve their attached UEs appropriately. The proposed scheme aims to improve spectrum utilization and fairness among UEs. Fairness includes the fairness of radio resource distribution among UEs and the fairness of UEs distribution among small-cell BSs Accordingly, information about load balance for each small-cell BS, the achievable data rate for each UE, Received Signal Strength Indicator (RSSI), and SINR were used to form the proposed solution.

A. Load Balance

The load balance that considers the number of UEs assigned for each small-cell BS needs to be configured in the proposed solution. In addition, an indication of the utilization of all resources in UDN would be known and used during the cell selection decision process. In this context, load balance consists of both the total number of UEs in each small-cell BS and the total number of UEs served represented as u. Moreover, the total number of UEs in a particular small cell BS is represented as u_{s_i}. Those two facts are needed to determine both α_{s_i} and β_{s_i}, which are calculated as follows:

$$\alpha_{s_i} = \frac{u_{s_i}}{u} \quad (6)$$

Every small cell BS s_i has a predefined target τ for the total number of UEs that would be served, which is used to calculate β_{s_i} as follows:

$$\beta_{s_i} = \frac{u_{s_i}}{\tau} \quad (7)$$

where the range of τ is maintained as follows:

$$4 < \tau < 12 \quad (8)$$

B. Channel Condition

The second step of the proposed strategy was to evaluate the channel condition between distributed small-cell BSs and their UEs. SINR provides knowledge about the channel condition between the UE and small-cell BS s_i in terms of interference. This knowledge is necessary for the proposed strategy when making the cell selection decision. Equation (2) describes the SINR formula. Another significant factor to inspect the channel condition is RSSI, which represents the strength of the received signal. However, RSSI discards the interference temperature, which would be propagated by neighboring small-cell BSs. Thus, the aforementioned factors are used in the second step according to the following:

$$\gamma_{s_i,ue_j} = \frac{SINR_{s_i,ue_j}}{\delta} \quad (9)$$

where δ represents the target SINR, which is predefined as a target interference avoidance value in the system, and ue_j indicates the newly inserted UE. Accordingly, the channel condition indicator in this system is calculated by:

$$\varepsilon_{s_i,ue_j} = \left(\gamma_{s_i,ue_j} \times RSSI_{s_i,ue_j}\right) \quad (10)$$

C. Achievable Data Rate

The third step of the proposed strategy is to investigate the achievable data rate for every small-cell BS. Knowledge about the achievable data rate would be key to supporting fairness among UEs. In this system, idle small-cell BS might also be stimulated to operate and accept UEs. From (1), the average data rate for a group of UEs attached to a particular small-cell BS s_i can be extracted. Consequently, the average data rate can be configured as follows:

$$\zeta_{s_i} = \frac{\Sigma_{ue=1}^{n} C_{s_i,UE}}{u_{s_i}} \quad (11)$$

Afterward, the average data rate for all installed small cell BSs in the system would be considered. In this case, the idle small cell BS would influence the decision of selecting a target BS when a new UE requests resources. The following formula provides the average small cell BSs' capacity:

$$\Theta = \frac{\Sigma_{s=1}^{k} \zeta_S}{S} \quad (12)$$

where S is the number of small cell BSs in the system. This equation is used to realize the proportional utilization of the distributed small cell BSs. The result shows whether distributed small-cell BSs are fully used or if there are idle small-cell BSs. Thus, the cell selection decision would be affected by the result of the following formula:

$$\lambda = \frac{\Theta}{\psi} \quad (13)$$

where ψ is the target average capacity for all small cell BSs in the system. In this target, all small cell BSs are operated with all available resources under good channel conditions.

D. UE and Small Cell BS Match Table

In the last step, every small cell BS would be aware of the variable value of its function computed according to (14). This formula measures the current load balance for each small-cell BS, the channel condition between the small-cell BS and the candidate UE, and the data rate of distributed UEs and their serving small-cell BSs:

$$\psi_{s_i,ue_j} = \frac{\left(\beta_{s_i} \times \lambda\right)}{\left(\alpha_{s_i} \times \varepsilon_{s_i,ue_j}\right)} \tag{14}$$

This equation depends directly on (6), (7), (10), and (13). The parameters β_{s_i} and α_{s_i} are used to balance the expression output. Table II shows the match between a newly inserted UE and all small-cell BSs based on (14). Accordingly, the small cell BS s_i with the highest value will be assigned for the new user ue_j. However, if the small cell BS s_i that has the highest value reaches the predefined target number of UEs τ, the new UE ue_j will not be assigned for this matched small-cell BS s_i. Instead, it will be assigned to a small-cell BS s_x , which has the next highest value of the function in (14). The pseudo-code for the proposed mechanism is illustrated in Algorithm 1.

TABLE II. UE/SMALL CELL BS MATCH TABLE

UE	s_1	s_2	s_3	………	s_i
ue_j	ψ_{s_1,ue_j}	ψ_{s_2,ue_j}	ψ_{s_3,ue_j}	………	ψ_{s_i,ue_j}

Algorithm 1 Proposed Mechanism
Inputs← $S, u, u_{s_i}, \psi, \delta, \tau$
FOR i = 1 to S do
  compute α_{s_i}
  compute β_{s_i}
  FOR j = 1 to ue_{s_i} do
    $\text{capacity}_{s_i,UE_j}$
  End FOR
  compute ζ_{s_i}
  Θ, λ
  compute: ψ_{s_i,ue_j}
END FOR

V. SIMULATION RESULTS AND DISCUSSION

A simulation was carried out in MATLAB to evaluate the performance of the proposed method on a 5G UDN, comprised of high-density 5G small-cell BSs. A single macrocell BS was implemented with randomly distributed small-cell BSs within its coverage, considering the concept of a two-tier network. Accordingly, small cells shared different subbands from the available spectrum to alleviate interference. The division of the available spectrum was performed based on the method proposed in [32]. The small cell BSs operate on a carrier frequency of 28 GHz with a bandwidth of 500 MHz. The available bandwidth N consists of multiple subchannels, where N=[n_1, n_2, n_3, …, n_n].

The Orthogonal Frequency-Division Multiple Access (OFDMA) transmission method was adopted, and multiple subcarriers formed the frequency band. A particular Resource Block (RB) was constructed from 12 adjacent subcarriers. RB is a basic unit that can be allocated to a particular user. The UEs were distributed randomly within the macrocell BS coverage. The number of UEs served should not exceed the predefined target. Path loss, SINR, and noise influence on channel gain between any UE and its serving small-cell BS were considered. Thus, the channel condition varies from one UE to another. Table III presents the simulation parameters.

TABLE III. SIMULATION PARAMETERS

Parameter	**Value**
Number of small cell BSs S	40
Number of Distributed UEs u	200
Small cell BS Transmission Power	30 dBm
Macrocell BS Transmission Power	46 dBm
Carrier Frequency	28 GHz
Bandwidth	500 MHz
Small Cell BS Radius	25 m – 100 m
White Noise Power Density	174 dBm/Hz
Carrier Spacing	15 kHz

The performance of the system was evaluated in terms of average throughput and fairness among the distributed UEs. The proposed scheme was compared with two other schemes. The SINR-based scheme directed the cell selection decision toward interference mitigation since UE was assigned to its small-cell BS according to SINR. In this case, the channel condition and interference were both considered when making the cell selection decision. The other scheme was the Signal Strength (SS)-based scheme, where the cell selection decision was made according to the strength of the received signal. Thus, a particular UE would be assigned to the small-cell BS having the strongest received signal regardless of interference.

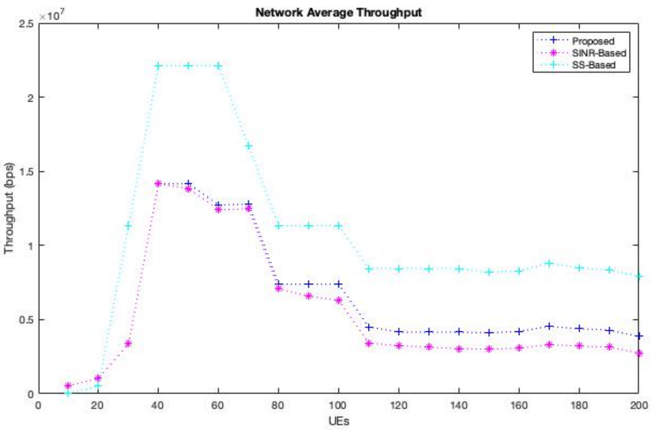

Fig. 1. Small cell network average throughput.

Figure 1 shows the average throughput of the whole network during the cell selection decision for different strategies. The three schemes were evaluated by increasing the number of UEs. The SS-based scheme outperformed the other two schemes because the cell selection decision was made with the best channel condition. Signal strength influences the quality of the received data, and thus the data rate increases. However, in this case, some of the small-cell BSs might be unused or have less number of associated UEs. As a result, this will impact the full utilization of the available resources. The average throughput would decrease as more UEs are inserted into the system. The SINR-based scheme had the worst average throughput. The cell selection decision for the SINR-based scheme was made according to the SINR value received for each UE. Then, the cell selection decision would be made to match the small-cell BS with the best received SINR value with the UE. The channel condition was used to alleviate the undesired impact of interference, but this will affect the capacity of the network. Average throughput decreased as the number of UEs increased. In contrast, the average throughput of the proposed scheme was between the SINR- and SS-based schemes, as the proposed scheme does not only tend only adopt the strength of the signal or to only focus on alleviating the interference. Instead, the proposed scheme acknowledges both factors by considering both signal strength and interference mitigation. In addition, the load balance for all small-cell BSs was considered. Finally, the average throughput of all three schemes decreased as the number of UEs increased. This became obvious after inserting 40 UEs into the system.

The Jain fairness index was used to evaluate the fairness among the distributed UEs. Figure 2 shows the fairness among the UEs for all three schemes. The proposed scheme exhibited the best fairness index result compared to the others. Fairness in this context was derived from the achievable throughput for all UEs in the system. According to Figure 2, the results of the fairness index can be distinguished when more UEs are inserted into the network. Achieving fairness among UEs is applicable with fewer and a limited number of UEs. However, the fairness results were not precise because the number of UEs was limited and there were no distinguished differences for achievable throughput of the limited number of UEs. When the number of UEs increased, especially over 100, the proposed scheme outperformed the SINR-based and SS-based schemes. The proposed scheme considered the load balance, channel condition, and achievable throughput. Thus, the cell selection decision attempted to increase capacity under a fairness constraint. On the contrary, the fairness index results showed lower fairness among UEs for both SINR-based and SS-based schemes.

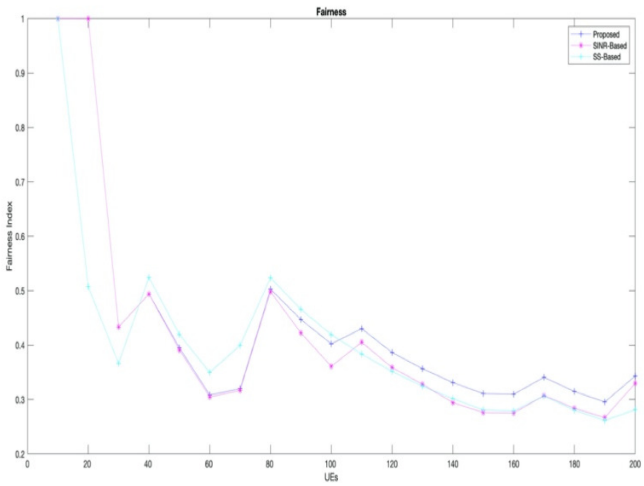

Fig. 2. Fairness index.

Figure 3 shows the fairness distribution of radio resources among UEs, depicting the radio resource allocation for the UEs distributed in the system. The SS-based scheme achieved the worst fairness distribution of radio resources compared to the proposed and SINR-based schemes. This is because the SS-based scheme assigns UEs to the small-cell BS that has the strongest signal. In this case, the load balance and the number of UEs attached to a particular small-cell BS would not be recognized. Consequently, over-limited UEs will share the radio resources of a single small-cell BS, reducing the allocated portion of radio resources for each attached UE. This fairness index result decreased as the number of UEs inserted increased. In contrast, the proposed scheme achieved the best result in the fair distribution of radio resources. Moreover, fairness increased when the number of attached UEs increased due to consideration of the load balance for small-cell BSs and the definition of a target threshold number of UEs for each small-cell BS. The result of the fairness index became more obvious when the number of attached UEs increased. Additionally, the fairness result of the SINR-based scheme for the distribution of radio resources was worse than that of the proposed scheme.

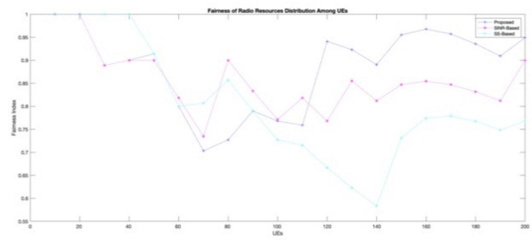

Fig. 3. Radio resources distribution among served UEs.

The process of mapping UEs for their appropriate small cell BS depends on the cell selection mechanism. Figures 4-7 present the distribution of UEs among small-cell BSs. Figure 4 shows the fairness index for distributing UEs and selecting their serving small-cell BSs for all three schemes. The proposed scheme showed the best fair distribution of UEs compared to the other two schemes, achieving a fairness index of 0.9. This was because the decision on cell selection was made considering parameters, such as load balance, received signal strength, and SINR. If load balance was considered in the cell selection decision, the UEs would be evenly distributed among small-cell BSs. Moreover, an idle small-cell BS will have an opportunity to operate, and thus the utilization of the available resources will be improved. Additionally, there should be a target threshold, which should not be exceeded, for the number of UEs that small-cell BS would accept to serve. This threshold depends on different factors, such as the available spectrum, the number of small-cell BSs serving, and the expected number of future attached UEs. When UEs are distributed fairly among small-cell BSs, each UE would have the same portion of the shared spectrum. In contrast, the SINR-based scheme achieved the lowest degree of fairness and the SS-based scheme gained a moderate degree of fairness. This can influence the random distribution of UEs across the grid and shows that UEs are randomly distributed throughout macrocell coverage.

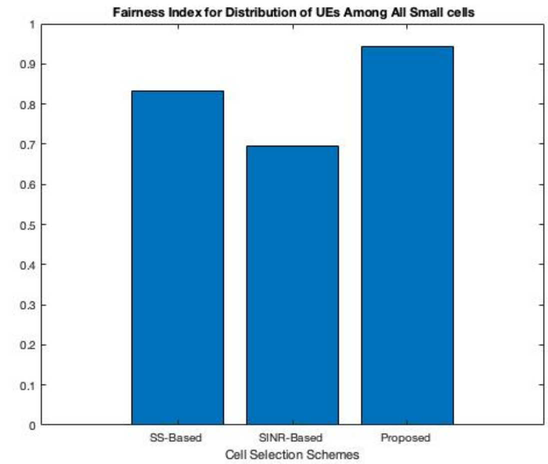

Fig. 4. UE distribution fairness index.

In addition, the cell selection strategy reflects the case of UE distribution among all small-cell BSs in the system. UE distribution varies according to the adopted cell selection strategy. The coverage of the macrocell was divided into four subregions, obeying the following strategy: a center cell subregion and three outer subregions. Consequently, small-cell BSs were distributed and implemented in different subregions. Accordingly, all small-cell BSs positioned in the same subregion were grouped in one cluster. Thus, cluster one represents small-cell BSs positioned in the center subregion. The other clusters, clusters 2, 3, and 4, represent small-cell BSs positioned in the outer subregions.

Figure 5 represents the UE distribution among small-cell BSs with their clusters for the SINR-based scheme. According to Figure 5, the SINR-based scheme never assigns UEs for small-cell BSs positioned in the center subregion (cluster 1). This is because all small-cell BSs in the center subregion experience a high temperature of undesirable interference. The main source of interference is the macrocell BS because it is very close to this subregion. Thus, all UEs were assigned to small-cell BSs in the outer subregions. This explains why UE distribution among small-cell BSs gained a worse fairness degree for this scheme compared to the other two. For example, the average of distributing 200 UEs among four clusters would be 50, while it was 30 according to Figure 5. The gap is obvious in this case where cluster 1 had zero UE and clusters 2 and 3 had 80 UEs. Figure 6 shows the UE distribution across all four clusters for the SS-based scheme, showing a nearly fair UE distribution when the number of UEs is less than 50. However, the gap between the number of UEs assigned for each cluster expanded when the number of UEs increased to over 50. For example, the gap reaches 50 when the number of UEs becomes 150. In this case, 80 UEs were assigned only for small-cell BSs located in the center subregion, while 70 UEs were distributed among the three other subregions. When the number of UEs became 200, this gap became huge. In this situation, only 20 UEs were assigned for small-cell BSs positioned in cluster 3, while 80 were assigned to small-cell BSs in cluster 1. Consequently, the gap between 80 and 20 is still unfavorable.

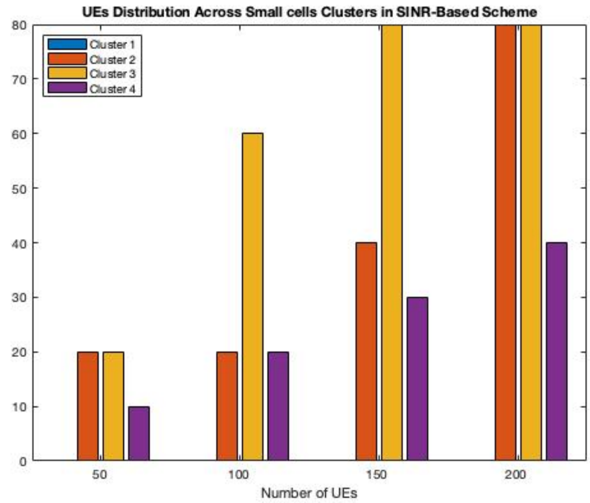

Fig. 5. UE distribution for the SINR-based scheme.

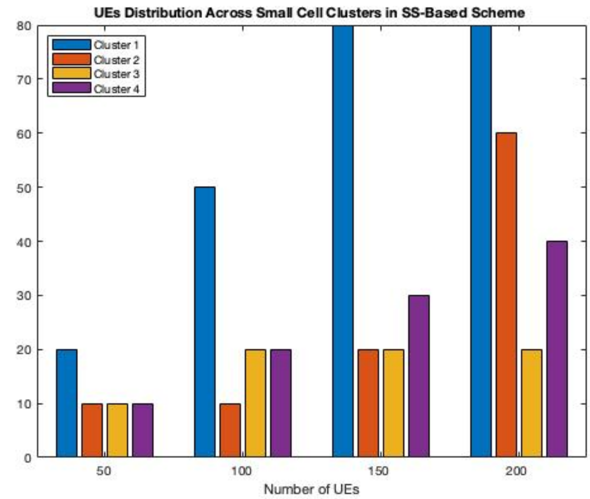

Fig. 6. UE distribution for the SS-based scheme.

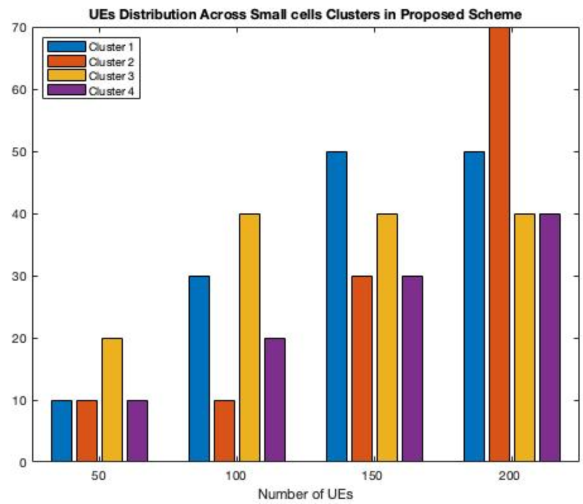

Fig. 7. UE distribution for the proposed scheme.

Figure 7 shows the UE distribution across the different clusters for the proposed scheme. According to Figure 7, the gap decreased as the number of UEs inserted increased. This became clearer when the number of UEs was 150 or 200. When the number of UEs was 150, the gap shrank between 10-20. Also, when the number of UEs reached 200, the gap degree resided approximately between 20-30. This gives an advantage in limiting the served UEs with a predefined target threshold and sheds light on the necessity of considering the load balance for each small-cell BS to allow fair distribution of UEs among serving small-cell BSs. Additionally, including load balance in cell selection decisions would support fairness among served UEs, as it would attempt to preserve as much network capacity as possible. Moreover, the spectral efficiency would also be enhanced.

VI. CONCLUSION

This study investigated the cell selection problem in a 5G UDN environment. A typical UDN consists of different cell types in its structure: macrocell, microcell, picocell, and femtocell. The deployment of dense small-cell BSs within the extent of a macrocell BS provides significant benefits. The distance between a serviced UE and its mapped small-cell BS is short. This will increase the capacity of the network because the received signal would be in good condition. However, UDNs face challenges, such as the cell selection problem. The basic process of cell selection decision is to map UEs with their appropriate small-cell BS based on predefined parameters and strategies. This study proposed a mechanism to address the cell selection problem, intending to maximize fairness among UEs when making the cell selection decision. The proposed mechanism considers different parameters and aspects. The load balance of each small-cell BS was considered to fairly distribute UEs among small-cell BSs. In addition, it was used to avoid congestion for a particular small-cell BS. Signal strength was also considered and the achievable data rate for all small-cell BSs was investigated and analyzed to stimulate an idle small-cell BS to be in operating mode. All these factors were considered when the cell selection decision was made for the proposed mechanism. A simulation was performed in MATLAB to evaluate the proposed mechanism, incorporating both the SINR-based and SS-based schemes for comparison. The proposed solution outperformed the other two schemes in terms of fairness, and the attached UEs were fairly distributed among small-cell BSs. Moreover, the proposed mechanism achieved the best radio resource distribution in terms of fairness. In future work, handover and mobility issues would be further studied and incorporated into this scheme.

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