

Load Balancing Algorithm within the Small Cells of Heterogeneous UDN Networks: Mathematical Proofs

Mohamad Salhani and Markku Liinajarja

Aalto University, Espoo, 02150, Finland

Email: mohamad.salhani@aalto.fi; markku.liinajarja@gmail.com

Abstract—Ultra-Dense Networks (UDNs) can be used to improve coverage. With limited network capacity and the dense development of wireless networks, heterogeneous ultra-dense networks are set to satisfy the increasing demands of mobile users. However, the dense deployment of small cells in the hotspots of UDN networks generates an uneven traffic distribution. To address this problem, this paper proposes novel load balancing approaches implemented within the small cells, which are formed based on the Radio-over-Fiber (RoF) system. To select the best overlapping zone and then the best candidate user to be handed-over between the access points of the small cells, a common zone approach, a worst zone approach and a mixed approach are suggested. The results indicate that the proposed algorithm improves the performance of UDN networks when the load is unbalanced. The balance improvement ratio can reach on average 89.16%.

Index Terms—UDN, RoF, load balancing algorithm, common zone approach, worst zone approach, mixed approach, Jain's fairness index.

I. INTRODUCTION

As one of the main technologies in 5G, Ultra-dense networks (UDNs) are set to satisfy the increasing demands of mobile users by improving the network coverage. The Radio over Fiber (RoF) system can be used in order to exchange the data between the access points (APs) in UDN networks. This system can improve the network coverage, system capacity, and provides high data rate transmissions. Although the RoF system has attracted much attention, it suffers from load unbalance [1]. In fact, as the coverage of the RoF system is relatively small, the frequent handovers of the users will influence the system's performance [2]. Hence, a load balancing algorithm (LBA) becomes a necessity to redistribute the load among the APs of the UDN network. In studies that have applied the RoF system, the number of handovers was found to be larger than that of traditional cellular networks [3]. This is due to the small coverage area of the APs. Consequently, decreasing handover procedures is a promising solution for UDN networks that are based on an RoF system.

The first load balancing algorithms within wireless networks were proposed by Balachandran and Aleo [4],

[5]. These studies were done on load migration between only two APs and only the users in the overlapping zone could be switched. Other load balancing schemes have been proposed in the previous research. A channel borrowing scheme has been used to offload the overloaded cells by using unused channels from the neighboring unloaded cells in [6]. However, this method without a strict channel locking strategy may result in co-channel interference. Strategies based on cell breathing and power control have been proposed in [7].

A new load balancing algorithm in UDN networks based on a stochastic differential game scheme and an RoF system was suggested in [1], [3]. Additionally, a QoS constraint optimal load balancing scheme for heterogeneous ultra-dense networks was proposed in [8]. However, these previous works did not address the optimization issue of the overlapping zone selection.

In this paper, multiple load balancing approaches within the small cells of UDN networks are proposed based on an RoF system. The proposed approaches aim first to determine the best overlapping zone among several overlapping zones, and then to select the best user to be handed over in order to reduce the number of handovers and thus improve the performance of the whole UDN network.

This paper focuses on UDN hotspots where all the APs of the UDN network are considered to be always active. The user density can be 10 times larger than that of the APs [9], and hence it can reach six users per each small cell. On the other hand, we will assume that the user applications can guarantee that the throughput of the handed-over user remains constant.

The rest of this paper is organized as follows: the system description is proposed in section II. The algorithm is presented in section III. While section IV introduces the different load balancing approaches, section V discusses the simulation results. The mathematical proofs of the relationships between the Jain's fairness indices are introduced in section VI. Finally, a conclusion and perspectives of this work are presented in section VII.

II. SYSTEM DESCRIPTION

The proposed system consists of multiple macrocells, as shown in Fig. 1. Several APs of UDN small cells with overlapping zones are considered. Each set of small cells

constitutes a so-called RoF cluster. The small cells can be integrated with the remote radio heads (RRHs), which are also connected to the central base station (BS) via high speed optical fiber or microwave links [10]. The APs of each cluster are controlled by a virtual base station (VBS) through optical fiber. The VBS is considered as a router of the RoF system. The load distribution system can be either distributed in each VBS or centralized in each virtual BS controller (VBSC)/virtual mobile switching center (VMSC). Each small cell is modeled by a multi-processor queue. To avoid the interference, some small cells are allowed to be inactive (idle mode) in the case of an interference occurring [11]. In this paper, the rates of the users (UEs) are limited by the core network. The proposed system model is assumed to accurately measure the user location from the user reference signals, and thus the location of each user is known [12].

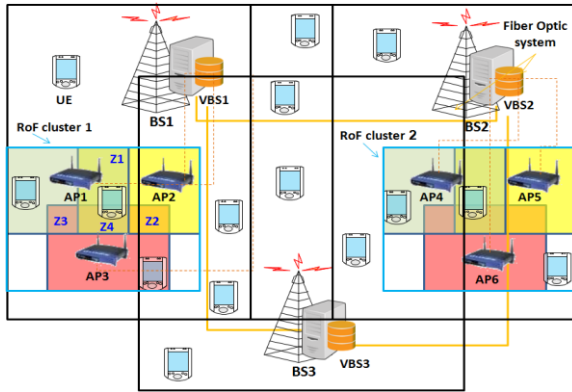


Fig. 1. Distributed system model.

In the simulation model, we consider two macrocells and each group of three square overlapping small cells forms an RoF cluster. The tolerance parameter α is chosen to be 5%. The dimensions of each square small cell are 20x20 m² and the dimensions of each square macrocell are 0.5x0.5 km². The inter-sites distance is 15m. The user density ρ is on average equal to six users per small cell. Therefore, the density threshold ρ_{Th} is equal to 18 users per cluster. Each user selects a specific throughput in the range from 0 to 350 Mbps [13]. Note that in this paper we will only present the important results of the simulation model and will focus on the mathematical proofs.

III. LOAD BALANCING ALGORITHM

The proposed load balancing algorithm (LBA), which is depicted in Fig. 2, **first** starts checking the user density (ρ) within each cluster and comparing the density of the cluster with the highest density to the density threshold ρ_{Th} . If the user density does not exceed the threshold, the algorithm is stopped and it waits for the next trigger. Otherwise, the algorithm sets the throughput of each user, its zone and the tolerance parameter α (explained later). After that, the algorithm calculates the throughput of each AP ($T_{AP(i)}$) as a summation of throughputs of all users (j) connected to the AP(i), as given by

$$T_{AP(i)} = \sum_{j=1}^{m(i)} T_{user(i,j)} \quad (1)$$

where $m(i)$ is the number of users connected to AP(i). Next, the algorithm calculates the average network load (ANL) of the whole cluster as follows:

$$ANL = (T_{AP1} + T_{AP2} + \dots + T_{AP(n)}) / n \quad (2)$$

where n is the maximum number of APs. Meanwhile, the LBA determines the state of each AP by using the transfer policy. This policy verifies which AP must exclude a user (overloaded AP) and which one must include this user (underloaded AP). For that, two thresholds (δ_1 and δ_2) are needed as follows:

$$\delta_1 = ANL + \alpha \times ANL, \quad \delta_2 = ANL - \alpha \times ANL \quad (3)$$

According to the transfer policy, an underloaded AP can accept new users and handed-over users from an overloaded AP. While a balanced AP can only accept new users, an overloaded AP does not receive any new or handed-over users.

With regard to the tolerance parameter α , the critical value of α is calculated before applying the LBA by setting the throughput of the most overloaded AP equal to δ_1 as follows:

$$\alpha_{critical} = (T_{AP_{most-overloaded}} - ANL) / ANL \quad (4)$$

Then, the result is divided by 10 to obtain the required value of α . Note that increasing the value of α widens the balance zone and thus reduces the handovers. Therefore, this shortens the running time of the LBA and benefits the users with real time applications. In practice, the desired value of α can be empirically calculated so that the average value of α can be tuned based on the state and the location of the network.

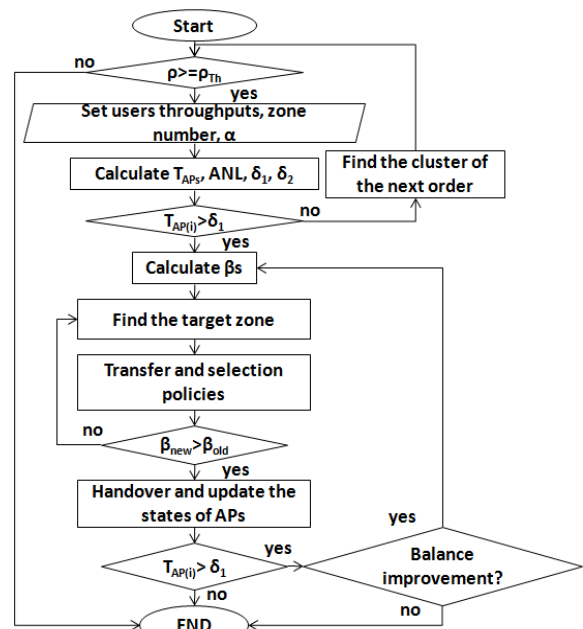


Fig. 2. Flowchart of the load balancing algorithm (LBA)

In the **second step**, the algorithm checks if there is at least one overloaded AP within the cluster with the highest user density (cluster of first order). If not, the algorithm transits into the cluster of second or third order successively and rechecks the density condition. If this condition is not satisfied in these three clusters, the algorithm is stopped. Otherwise, the algorithm calculates Jain's fairness index (β) [14], which is determined by

$$\beta = \frac{\left(\sum_{i=1}^n T_{AP(i)} \right)^2}{n \times \sum_{i=1}^n T_{AP(i)}^2} \quad (5)$$

where n is the number of small cells that overlap on the zone in question, i.e., each overlapping zone has its own β . When all the APs have exactly the same throughput, β is equal to one. Otherwise, β approaches $1/n$, so $\beta \in [1/n, 1]$. The **third step** is to apply the selection policy in order to determine the best candidate user (BC) to be handed-over as follows. First, the difference (delta Δ) between the chosen overloaded AP and the ANL is calculated by

$$\Delta = T_{overloadedAP} - ANL \quad (6)$$

Of all the users located in the overlapping zone in question and connected to the chosen overloaded AP, the BC is the one for which the difference of the user throughput and delta has the smallest absolute value as follows:

$$BC_j = |T_{user_j} - \Delta| \quad (7)$$

The **fourth step** is to determine the new β if the best candidate is handed-over. This step is so-called distribution policy. The aim of determining new β is to ensure that the expected handover will definitely improve the balance before doing the handover (to avoid the ping-pong problem). Thus, the handover of the candidate user will be carried out if and only if $\beta_{new} > \beta_{old}$. If the latter condition is satisfied, the algorithm selects this candidate and the handover occurs. Otherwise, the algorithm transits into the next target zone. It is one of the overlapping zones, which changes or not according to the selected load balancing scheme. After that, the algorithm repeats the last policies with the new target zone. The **fifth step** is to check again if there is still an overloaded AP within the selected cluster and also if the balance improvement is still valid. If so, it evaluates the enhancement of the load balancing within the new target zone by updating all the values of β (β_s) and so on. Otherwise, the algorithm waits for the next trigger.

IV. LOAD BALANCING APPROACHES

In order to accomplish the load balancing, the following approaches are proposed:

A. Common Zone (CZ) Approach

In this approach, the load is only balanced by the users located in Z4, which is the common zone between the

three overlapping cells. This zone is always the target zone. This approach is quick and simple, as it does not require much processing. In contrast, it is not very convenient in the case of UDN networks, since the user density is relatively low and the possibility to find many users located in the common zone might be limited.

B. Worst Zone (WZ) Approach

The balancing is executed in the worst zone, which is the target zone with the smallest value of $\beta(i)$. Thus, the CZ approach is less complicated than the WZ approach as the latter one calculates the different $\beta(i)$ to determine the worst zone for each handover. Therefore, the CZ approach might shorten the running time of the algorithm.

C. Mixed Approach (MA)

A hybrid approach that combines the CZ approach and the WZ approach. It starts balancing the load in the common zone, then it transits into the worst zone with or without returning to the CZ approach. Therefore, the target zone alternates between the common zone and the worst zone according to the chosen policy. In this regard, we suggest the following five policies:

- **2nd-AP policy** tries to hand over all the available users in the CZ as long as there are users of first order (connected to the most overloaded AP) and second order (connected to the next most overloaded AP). Then, it converts into the WZ approach.
- **Early WZ policy** only executes one handover for a user of first order in the CZ and then transits early into the WZ approach.
- **Persist 1st-users policy** only hands over the users of first order in the CZ before transiting into the WZ approach. Once there are more than one overloaded AP and the handovers for the first order users in the CZ are over by using the persist 1st-users policy, does the algorithm come back to the CZ or not? What are the potential policies in this case? To answer to these questions, two additional policies are proposed:
- **Persist WZ policy** only hands over one user of second order in the CZ, after handing over all the users of first order by the persist 1st-users policy, then it converts into the WZ approach.
- **Persist CZ policy** is opposite to the persist WZ policy, meaning that after handing over all the users of the first order, it only hands over one user by the WZ approach and then it transits into the CZ approach and tries to not return to the WZ approach. Note that the existence of one or all of these policies depend on the throughput of the users and APs in the common zone.

V. SIMULATION RESULTS

We found by the simulation study that the best balancing results are achieved by the MA approach using the 2nd-AP and the persist WZ policies. These policies search for the best handovers in the common zone, then they continue the improvements in the worst zone. Furthermore, the WZ approach is better than the CZ

approach. The more overlapping zones the more candidate users to be handed-over in the load balancing perspective. Actually, the WZ approach immediately goes to the worst zone and deals with the unbalancing problem. It has the higher probability to select the best candidates located in many zones.

On the other hand, we observed that the WZ approach hands over the least number of users compared to others, this indicates that it is a selective approach, i.e., it tries to hand over the users with the highest throughputs in order to achieve the balancing with a minimum number of users. In fact, the most efficient approach is the one that requires the least handovers and shows the best balancing results. In this view, the 2nd-AP policy and the persist WZ policy are the most efficient policies. Alternatively, the CZ approach shows the worst balance efficiency.

A comparison between the different approaches was carried out, the MA approach achieves better balancing results than the WZ approach or the CZ approach. Furthermore, the policies of the MA approach achieve the highest balance improvement ratio, which is on average 91.24%. Conversely, this ratio is 89.94% and 86.29% in the case of WZ approach and CZ approach, respectively.

Moreover, the average balance improvement ratio of all the approaches reaches 89.16%. Conclusively, the MA approach shows the best balancing results; however, the WZ approach does not require signaling as the MA approach.

VI. MATHEMATICAL PROOFS

In this section, we discuss and find the relationships between the different Jain's fairness indices in the three intersecting cell model with four overlapping zones (Z1, Z2, Z3 and Z4), as shown in Fig. 1. We first determine the mathematical relationship between the global β (β_4 in the common zone: Z4) and the partial β s ($\beta_1, \beta_2, \beta_3$) in the different overlapping zones. After that, we find the mathematical relationships among the partial β s. The purpose is to prove the benefit of the load balancing approaches. In particular, we want to discuss the impact of the balance improvement in each overlapping zone on the others. Indeed, by simulation tool, we found that the balance improvement in any overlapping zone positively and quickly reflects on the other overlapping zones among them the common zone. In the following, we will confirm this result by the mathematical proof.

As we previously mentioned, the Jain's fairness index is expressed using (5), thus, the different values of $\beta(i)$ in each overlapping zone are given as follows:

$$\beta_1 = \frac{(T_1 + T_2)^2}{2 \times (T_1^2 + T_2^2)} \quad (8)$$

$$\beta_2 = \frac{(T_1 + T_3)^2}{2 \times (T_1^2 + T_3^2)} \quad (9)$$

$$\beta_3 = \frac{(T_2 + T_3)^2}{2 \times (T_2^2 + T_3^2)} \quad (10)$$

$$\beta_4 = \beta = \frac{(T_1 + T_2 + T_3)^2}{3 \times (T_1^2 + T_2^2 + T_3^2)} \quad (11)$$

A. Determining β_4 as A Function of the Partial β s

In the following, we find β_4 as a function of β_1, β_2 and β_3 , i.e., $\beta_4=f(\beta_1, \beta_2, \beta_3)$. For that, (8) is reformulated:

$$\beta_1 = \frac{1}{2} + \frac{T_1 \cdot T_2}{(T_1^2 + T_2^2)} = \frac{1}{2} + \frac{T_1/T_2}{1 + (T_1/T_2)^2} \quad (12)$$

Let $x=T_1/T_2$, hence $\beta_1 = \frac{1}{2} + \frac{x}{1+x^2}$ (13)

Similarly, $\beta_2 = \frac{1}{2} + \frac{y}{1+y^2}$ (14)

and $\beta_3 = \frac{1}{2} + \frac{z}{1+z^2}$ (15)

where $y=T_1/T_3$ and $z=T_2/T_3$. Consequently,

$$x \times z = \frac{T_1}{T_2} \times \frac{T_2}{T_3} = \frac{T_1}{T_3} = y \Rightarrow x = \frac{y}{z} \quad (16)$$

Hence, (11) can be written as follows:

$$\beta_4 = \beta = \frac{T_1^2 + T_2^2 + T_3^2 + 2 \times (T_1 T_2 + T_1 T_3 + T_2 T_3)}{3 \times (T_1^2 + T_2^2 + T_3^2)}$$

$$\beta_4 = \frac{1}{3} + \frac{2}{3} \times \frac{\left(\frac{T_1 T_2}{T_3^2} + \frac{T_1 T_3}{T_3^2} + \frac{T_2 T_3}{T_3^2}\right)}{\left(\frac{T_1^2}{T_3^2} + \frac{T_2^2}{T_3^2} + \frac{T_3^2}{T_3^2}\right)} = \frac{1}{3} + \frac{2}{3} \times \frac{\left(\frac{T_1 T_2}{T_3^2} + \frac{T_1}{T_3} + \frac{T_2}{T_3}\right)}{\left(\frac{T_1^2}{T_3^2} + \frac{T_2^2}{T_3^2} + 1\right)}$$

$$\beta_4 = \frac{1}{3} + \frac{2}{3} \times \left(\frac{yz + y + z}{y^2 + z^2 + 1}\right) \quad (17)$$

Considering (13) and (16), we deduce the following:

$$\beta_1 = \frac{1}{2} + \frac{y/z}{1+(y/z)^2} = \frac{1}{2} + \frac{yz}{y^2 + z^2} \quad (18)$$

From (14), we find the following equation:

$$(2\beta_2 - 1)y^2 - 2y + (2\beta_2 - 1) = 0 \quad (19)$$

Thus, $\Delta = 4 - 4(2\beta_2 - 1)^2$
 $\Delta = 16(\beta_2 - \beta_2^2)$

Subsequently, the solutions of (19) are the following:

$$y_1 = \frac{1 + 2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \quad (20)$$

$$y_2 = \frac{1 - 2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \quad (21)$$

where $\beta_2 \in]0.5, 1]$. Similarly, based on (13) and (15), we deduce the following solutions:

$$x_1 = \frac{1 + 2\sqrt{\beta_1 - \beta_1^2}}{2\beta_1 - 1} \quad (22)$$

$$x_2 = \frac{1 - 2\sqrt{\beta_1 - \beta_1^2}}{2\beta_1 - 1} \quad (23)$$

$$z_1 = \frac{1 + 2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \quad (24)$$

$$z_2 = \frac{1 - 2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \quad (25)$$

By substituting (20), (21), (24) and (25) for (17), the possible solutions of β_4 as a function of β_2 and β_3 are given by

$$\beta_4(y_1, z_1) = \frac{1}{3} + \frac{2}{3} \times \frac{\left(\frac{1+2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right) \left(\frac{1+2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right) + \left(\frac{1+2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right) + \left(\frac{1+2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)}{\left(\frac{1+2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right)^2 + \left(\frac{1+2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)^2 + 1} \quad (26)$$

$$\beta_4(y_1, z_2) = \frac{1}{3} + \frac{2}{3} \times \frac{\left(\frac{1+2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right) \left(\frac{1-2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right) + \left(\frac{1+2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right) + \left(\frac{1-2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)}{\left(\frac{1+2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right)^2 + \left(\frac{1-2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)^2 + 1} \quad (27)$$

$$\beta_4(y_2, z_1) = \frac{1}{3} + \frac{2}{3} \times \frac{\left(\frac{1-2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right) \left(\frac{1+2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right) + \left(\frac{1-2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right) + \left(\frac{1+2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)}{\left(\frac{1-2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right)^2 + \left(\frac{1+2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)^2 + 1} \quad (28)$$

$$\beta_4(y_2, z_2) = \frac{1}{3} + \frac{2}{3} \times \frac{\left(\frac{1-2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right) \left(\frac{1-2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right) + \left(\frac{1-2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right) + \left(\frac{1-2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)}{\left(\frac{1-2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right)^2 + \left(\frac{1-2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)^2 + 1} \quad (29)$$

Initially, the four solutions of β_4 are acceptable; however, we want to find the best one. On the other hand, we notice from the previous equations that β_4 is independent of β_1 . This means that the global β (β_4) is only related to two overlapping zones at a given time. In other words, *the intersecting cell model can reduce the complexity of the balancing problem from four overlapping zones to three overlapping zones.*

B. Finding β_1 as A Function of the Other Partial β s

In the following, we determine β_1 as a function of β_2 and β_3 . Due to the β_1 equation given by (18) and considering the different solutions of y and z , which are given by Eq. 20, Eq. 21, Eq. 24 and Eq. 25, the different solutions of β_1 are the following:

$$\beta_1(y_1, z_1) = \frac{1}{2} + \frac{\left(\frac{1+2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right) \left(\frac{1+2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)}{\left(\frac{1+2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right)^2 + \left(\frac{1+2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)^2} \quad (30)$$

$$\beta_1(y_1, z_2) = \frac{1}{2} + \frac{\left(\frac{1+2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right) \left(\frac{1-2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)}{\left(\frac{1+2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right)^2 + \left(\frac{1-2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)^2} \quad (31)$$

$$\beta_1(y_2, z_1) = \frac{1}{2} + \frac{\left(\frac{1-2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right) \left(\frac{1+2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)}{\left(\frac{1-2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right)^2 + \left(\frac{1+2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)^2} \quad (32)$$

$$\beta_1(y_2, z_2) = \frac{1}{2} + \frac{\left(\frac{1-2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right) \left(\frac{1-2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)}{\left(\frac{1-2\sqrt{\beta_2 - \beta_2^2}}{2\beta_2 - 1} \right)^2 + \left(\frac{1-2\sqrt{\beta_3 - \beta_3^2}}{2\beta_3 - 1} \right)^2} \quad (33)$$

In order to clarify the relationships between the different solutions of β_4 , we present the curves of the diverse solutions of β_4 as a function of β_2 and β_3 . In addition, we illustrate the curves that represent the different solutions of β_1 as a function of β_2 and β_3 . For that, let us consider the following study cases:

- **Improving the balance in an overlapping zone more than in another one**

In this study case, we increase the value of β_2 at a step of 0.05 and the value of β_3 at a step of 0.02. Both β_2 and β_3 are increased in the range [0.52, 1]. Hence, we have 25 different values at most to trace the β curves. Presumably, the load balancing algorithm has improved the balance in Z2 more than in Z3. Then, we observe the impact of this balance improvement on the other zones. This scenario may result from assuming that Z2 is the worst zone.

Fig. 3 shows that β_4 is improved with the four solutions: ($\beta_4(y_1, z_1)$, $\beta_4(y_1, z_2)$, $\beta_4(y_2, z_1)$ and $\beta_4(y_2, z_2)$). The best solution is $\beta_4(y_2, z_2)$, then $\beta_4(y_1, z_2)$. The $\beta_4(y_2, z_2)$ solution outperforms the three other solutions. This means that this solution follows up the balance improvement in the worst zone (Z2) faster than the other solutions, which are still acceptable solutions, as they reach in the end the optimal balance value, $\beta_4=1$. On the other hand, we observe that $\beta_4(y_1, z_2)$ and $\beta_4(y_2, z_2)$ converge to the β_2 curve and they coincide when $\beta_2=1$. In contrast, $\beta_4(y_1, z_1)$ and $\beta_4(y_2, z_1)$ solutions coincide when $\beta_2=1$; however, they converge to the β_3 curve.

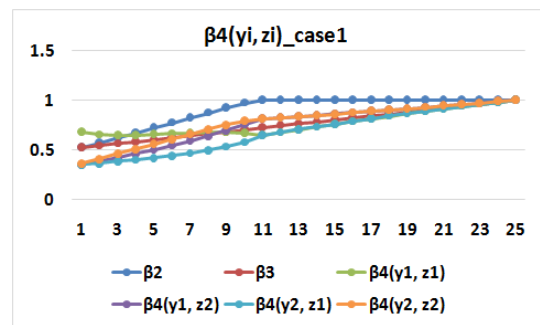


Fig. 3. Improving the balance in Z2 more than Z3.

Fig. 4 shows that all the β_1 solutions converge to the β_3 curve and they coincide when $\beta_2=1$, and then follow the balance improvement that is carried out in Z3, not in Z2. This confirms that *the highest balance improvement*

in any overlapping zone reflects significantly on the value of β in the common zone. Conversely, the lowest balance improvement reflects on the values of β s in the other overlapping zones. This clarifies the importance of achieving the load balancing in starting by the common zone, the case that is adopted by the MA approach. Note that the MA approach indicated the best balancing results by simulation tool in the majority of the study cases.

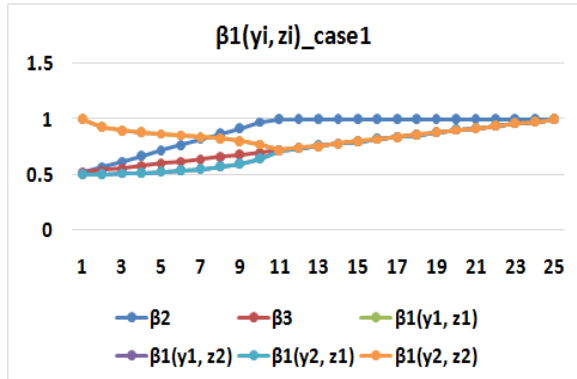


Fig. 4. Improving the balance in Z2 more than Z3.

On the other hand, we noticed that there are always two solutions in all study cases regarding the function $\beta_1=f(\beta_2, \beta_3)$. In other words, the $\beta_1(y_1, z_1)$ solution is equivalent to $\beta_1(y_2, z_2)$ solution and the $\beta_1(y_2, z_1)$ solution is equivalent to $\beta_1(y_2, z_1)$ one. In the current study case, the $\beta_1(y_1, z_1)$ and $\beta_1(y_2, z_2)$ solutions outperform the $\beta_1(y_2, z_1)$ and $\beta_1(y_1, z_2)$ solutions. As a result, the partial β s are function of the balance improvement of β in the worst zone, i.e., the balance improvement in the worst zone benefits the balance in other zones and reflects positively on them. The opposite case is studied, in which the balance in Z3 is improved more than in Z2 and the same results are deduced.

• **Improving the balance in an overlapping zone with the existence of an optimal balance zone**

An optimal case of load balancing is considered in Z3, i.e., $\beta_3=1$ and the load balancing is only improved in the worst zone (Z2). Fig. 5 depicts that the four solutions of β_4 converge in the end to reach the optimal balance value in the common zone, $\beta_4=1$. In addition, the results of the $\beta_4(y_1, z_1)$ and $\beta_4(y_1, z_2)$ solutions are identical and in such a way for $\beta_4(y_2, z_1)$ and $\beta_4(y_2, z_2)$ solutions, which are the best solutions in this study case.

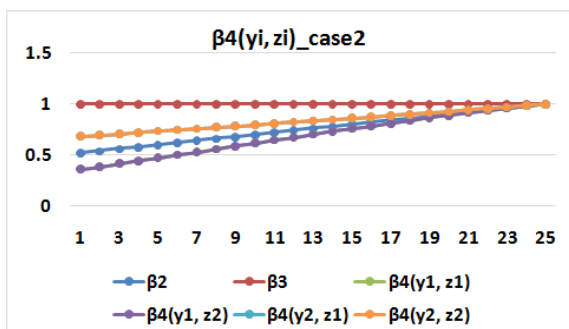


Fig. 5. One optimal zone (Z3) and one improved zone (Z2).

Fig. 6 reveals that all the β_1 solutions are identical. The curves of these solutions and the β_2 curve are superimposed. As a result, the balance improvement in the worst zone similarly reflects on the other zones, even if one of the zones might be optimally balanced. Furthermore, the opposite case with $\beta_2=1$ and the balance improvement in Z3 is also studied. The same previous results are deduced for β_1 and β_4 .

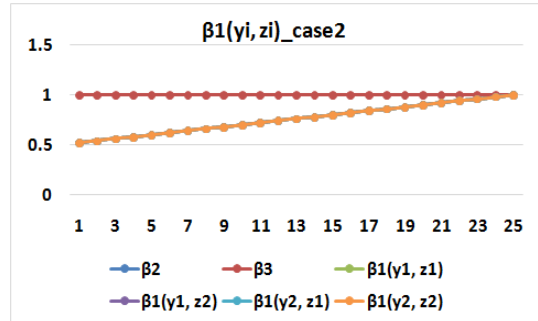


Fig. 6. One optimal zone (Z3) and one improved zone (Z2).

• **Improving the balance in an overlapping zone with the existence of a worst zone**

Consider an overlapping zone with the smallest value of $\beta_3=0.52$ and the load balancing is only improved in another overlapping zone (Z2). In fact, this case is not real case, because the proposed algorithms of the WZ approach and the MA approach transit from a zone into another in view of enhancing the load balancing, and hence the algorithms will improve the load balancing in Z3. The purpose of this study case is just to discover if the β_4 solutions will converge to β_3 in the worst zone (Z3) or these solutions will improve and pursue the balance improvement that is achieved in Z2. Fig. 7 depicts that the $\beta_4(y_1, z_2)$ and $\beta_4(y_2, z_2)$ solutions follow up the balance improvement in Z2. The values of these two solutions are similar; however, $\beta_4(y_2, z_2)$ solution is slightly better. Alternatively, the other solutions ($\beta_4(y_1, z_1)$ and $\beta_4(y_2, z_1)$) show worse values than β_3 value, which is the value of the worst zone. In any case, if this study case is applicable, the $\beta_4(y_1, z_1)$ and $\beta_4(y_2, z_1)$ solutions are rejected.

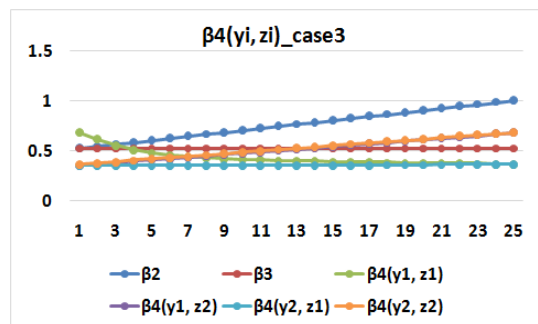


Fig. 7. One WZ with $\beta_3=0.52$ and one improved zone (Z2).

Fig. 8 clarifies that the $\beta_1(y_1, z_1)$ and $\beta_1(y_2, z_2)$ solutions are identical and better than the $\beta_1(y_1, z_2)$ and $\beta_1(y_2, z_1)$ solutions, which are also identical. Additionally, we notice that all these solutions converge

to β_3 of the worst zone; however, we previously observed that β_4 converge to β_2 of the zone that is improving with the $\beta_4(y_1, z_2)$ and $\beta_4(y_2, z_2)$ solutions. This reflects the robustness of the MA approach that starts balancing the load in the common zone and then transits into the worst zones. In that way, the MA algorithm quickly reaches the best balancing results. Moreover, the opposite case with $\beta_2=0.52$ and the balancing improvement in Z3 is also studied and achieved the same results for β_1 and β_4 .

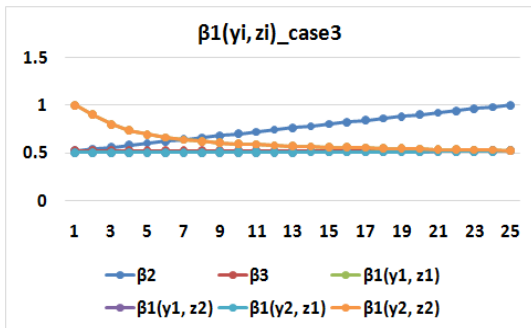


Fig. 8. β_1 in the case of one WZ with $\beta_3=0.52$ and one improved zone (Z2).

To conclude, the intersecting cell model reduces the complexity of load balancing problem from four to three overlapping zones. The load balance improvement in the worst zone positively and quickly reflects on the other overlapping zones, particularly on the common zone. Accordingly, in the most cases, the MA approach would be the best approach, as it starts balancing the load in the common zone, then transits into the worst zones. Finally, regarding the proposed load balancing algorithm in the intersecting cell model, the best solution for the global β is $\beta_4(y_2, z_2)$ and the best solution for β_1 is $\beta_1(y_2, z_2)$, which is equal to $\beta_1(y_1, z_1)$. Thanks to the selection and distribution policies, it turns out that the proposed algorithm, particularly the one of the WZ and MA approaches, is able to select the best solution.

VII. CONCLUSION

We have proposed a load balancing algorithm within the UDN hotspots based on the RoF model. Several load balancing approaches are suggested by taking into account the zone of start and the policy of load balancing. While the mixed approach achieves the best balancing results, the worst zone approach proven its efficiency in balancing the load.

The mathematical proofs showed that the load balancing based on the mixed approach could be a promising concept with the objective of improving the performance of 5G mobile systems.

Perspective works deal with the load migration mechanism in order to transfer the extra users from the small cells to the macrocells. This could be an alternative solution to improve the performance of UDN networks. The impact of the small cells configuration on the load balancing can be studied. The device-to-device (D2D)

communications of the users could be also addressed. In addition, the design structure matrix (DSM) method can be employed in view of reducing the end-to-end delay and balancing the load at the same time.

REFERENCES

- [1] Z. He and J. Wang, "Non-cooperative differential game based load balancing algorithm in radio-over-fibre system," *China Communications*, vol. 11, no. 14, pp. 79-85, Supplement 2014.
- [2] A. J. Cooper "Fiber/Radio' for the provision of cordless/mobile telephony services in the access network," *Electron. Lett.*, 1990.
- [3] H. Xu, Z. He, and X. Zhou, "Load balancing algorithm of ultra-dense networks: A stochastic differential game based scheme," *KSII Transactions on Internet and Information Systems*, vol. 9, no. 7, pp. 2452-2467, 2015.
- [4] A. Balachandran, P. Bahl, G. M. Voelker, "Hotspot congestion relief and service guarantees in public-area wireless networks," *ACM SIGCOMM Computer Communication Review*, vol. 32, no. 1, pp. 59-59, 2002.
- [5] V. Aleo, "Load distribution in IEEE 802.11 cells," Master of Science Thesis, KTH, Royal Institute of Technology, March 2003.
- [6] S. S. M. Patra, K. Roy, S. Banerjee, *et al.*, "Improved genetic algorithm for channel allocation with channel borrowing in mobile computing," *IEEE Transactions on Mobile Computing*, vol. 5, no. 7, pp. 884-892, 2006.
- [7] S. V. Hanly, "An algorithm for combined cell-site selection and power control to maximize cellular spread spectrum capacity," *Journal on Selected Areas in Communications*, vol. 7, no. 13, pp. 1332-1340, 1995.
- [8] Y. Wang, X. Xu, Y. Jin, *QoS constraint optimal load balancing for Heterogeneous Ultra-dense Networks*, WPMC 2016, pp. 317-323.
- [9] M. Ding, D. L. Perez, and G. Mao, "A new capacity scaling law in ultra-dense networks," arXiv: 1704.00399v1 [cs.NI], 3 Apr. 2017.
- [10] M. Peng, Y. Li, Z. Zhao, and C. Wang, "System architecture and key technologies for 5G heterogeneous cloud radio access networks," *IEEE Network*, vol. 29, no. 2, pp. 6-14, Mar.-Apr. 2015.
- [11] H. Claussen, I. Ashraf, and L. T. W. Ho, "Dynamic idle mode procedures for femtocells," *Bell Labs Tech. J.*, vol. 15, no. 2, pp. 95-116, 2010.
- [12] M. Koivisto, A. Hakkarainen, M. Costa, P. Kela, K. Leppanen, and M. Valkama, "High-Efficiency device positioning and location-aware communications in dense 5G networks," *IEEE Communications Magazine*, vol. 55, no. 8, pp. 188-195, 2017.
- [13] P. Kela, *Continuous Ultra-Dense Networks, A System Level Design for Urban Outdoor Deployments*, Book 1799-4942 (electronic), Aalto University Publication Series Doctoral Dissertations, 2017.
- [14] M. Huang, S. Feng, and J. Chen, "A practical approach for load balancing in LTE networks," *Journal of Communications*, vol. 9, no. 6, pp. 490-497, June 2014.



Mohamad Salhani is an associate professor at the Department of Computer and Automation Engineering (CAE), Faculty of Mechanical and Electrical Engineering (FMEE), Damascus University since 2016. He received his B.S degree in Electrical Engineering. from the FMEE in 2000, M.Sc degree

from National Polytechnic Institute of Lorain (INPL), France in 2005 and Ph.D degree from National Polytechnic Institute of Toulouse (INPT), France in 2008. He was an assistant professor at the CAE, FMEE, Damascus University in 2009. In 2016, he was a vice-dean for Administrative and Scientific Affairs at the Applied Faculty, Damascus University. He is currently a visiting professor at the Department of Communications and

Networking, School of Electrical Engineering, Aalto University, Espoo, Finland. His research interests include 5G mobile communication systems, Ultra-dense networks (UDNs), Internet of Things and LoRa technology.



Markku Liinajarja received the D.Sc (Tech.) degree in communications engineering from Helsinki University of Technology in 2006. He is currently working as a research fellow at the Department of Communications and Networking within the School of Electrical Engineering, Aalto University, Espoo, Finland. His main research

interests are in radio communications and error control coding.