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Review article

A QoS driven adaptive mechanism for downlink and uplink decoupling in 5G

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ABSTRACT

In current cellular networks, cell association is heavily based on the Downlink signal power and all devices are associated with the same Base Station (BS) in Downlink (DL) and Uplink (UL). While as of now this technique has been proven adequate in homogeneous networks where all BSs have similar transmission levels, in increasingly dense heterogeneous networks (HetNets) rate is heavily dependent on the load, which can significantly vary from BS to BS. The introduction of new devices in HetNets, with increased demands in the UL direction, makes the former approach obsolete and poses a threat to the Quality of Service (QoS) rendered by the network. Decoupling Uplink and Downlink is the proposed solution, where the UL cell association is not necessarily based on the same criteria as the DL association. Current implementations of this approach are static, not taking into consideration the network's load. To avoid overloading MBSs, we propose using Signal to Noise Ratio (SINR) and Path Loss with Range Extension (PLRE) as factors for choosing the appropriate BS for connection in DL and UL respectively for every user, taking into consideration the BS's Resource Block availability. We will use simulations to test our approach, with different Path Loss offsets for PLRE, to to favor the expected UL performance and test the scalability of our adaptive mechanism.

1. Introduction

In recent years, with the introduction of extremely capable mobile devices, such as smartphones and laptops, the volume of mobile data traffic generated has increased tremendously and continues to expand each year. These devices are used for a plethora of applications, such as communication applications (voice and video calls), applications for the production and consumption of multimedia and especially browsing the internet. They are also capable of connecting to multiple networks such as 4G mobile networks or Wifi and WiMAX [1]. In order to meet the explosive growth of data traffic demand, the emerge of a new type of dense networks is deemed necessary. Such networks are dense HetNets, promising extremely high Spectral Efficiency and Energy Efficiency [2]. To ensure the achievement of the desired goals, other technologies are used as well such as massive MIMO and mmWave.

The design foundations of past cellular networks are mostly based only on Macro cells (MCells) that featured the same characteristics throughout the network. They were preferred because of their high transmit power, which ensured high

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SINR. The similarities of MCells extend to the number of users they can support [3]. Their focus was centered on improving peak rate and spectral efficiency to offer the best user experience possible. This architecture is commonly referred to as Homogeneous Networks. Until now, this approach was adequate, but with the rise of the volume of network connected devices, the network traffic demands keep rising, making the deployment of HetNets necessary.

Heterogeneous networks consist of Macro cell Base Stations (MBSs) and Small cell Base stations (ScBSs). These two types of BSs, differ substantially both in transmit power and their respective coverage areas. ScBSs are usually scattered among MBS's vicinity [4]. HetNets have already seen implementation in past 4G and even 3G networks, but they were not designed as a part of them from the beginning. This dictates the implementation of fundamental changes in the design of next generation networks, such as fifth generation (5G) networks, to ensure the successful integration of HetNets. With the rise in user demands, 5G networks also need to be user oriented in order to make them accessible from all users and flexible to adjust to the personalized needs of the area they cover.

Generally, Cellular networks up to the fourth generation (4G) consisted only of MBS's, so the DL and UL were coupled, meaning that each user had to associate with the same BS in both DL and UL direction, based on the maximum DL received power. With the shift to HetNets, in order to tackle the challenges of user association, a decoupled access approach, namely Downlink and Uplink Decoupling (DUD) has emerged. With this approach, the connection between UL and DL is differentiated from homogeneous networks and not necessarily based on the same BS [5]. A variety of metrics can be used to identify the best BS association for users in both the DL and UL direction, such as SINR for DL and Path Loss (PL) for UL.

Traditionally the throughput required for DL was vastly higher than the one required in UL, resulting in a lack of symmetry between the resources needed to accommodate network traffic for each direction [6]. Moving on to HetNets, the transmit power of all portable transmitters is almost identical, since most of them are battery powered portable devices with similar capabilities. But considering the amount of such devices in current networks, the collective UL throughput demands keep rising, mostly thanks to applications that make equal use of both uploading and downloading such as social networks and real time streaming or server connection for video games. Separating UL and DL into two different subnetworks that make up our network enables us to individually design a model for each network for the sake of eliminating interference with neighboring cells and increase cell association as well as throughput. In this design, each User Equipment (UE) is able to decide on how to establish connection with the BSs, choosing its preferred one, during UL or DL association either by connecting with the same cell or with different cells (MBSs or ScBSs).

1.1. Motivation

Portable devices can vary in size and specifications. Especially with the rise of Internet of Things (IoT), new types of connected devices such as sensors, are expected to be integrated into the network. IoT is a global network platform that enables dissimilar devices to interconnect over the network. Different kinds of such devices can have their own requirements for various metrics, such as data transfer rate, delay and reliability. They are usually battery powered, with limited capabilities, but they are used for a plethora of applications ranging from Wireless Body Sensor Nodes (WBSNs) [7] to smart farming [8]. Therefore there is a massive need for establishing acceptable data rates, ensuring QoS for the end user and tackle network congestion, to ensure timely delivery of data [9].

The explosive growth in the volume of network connected devices, sets the need for assuring the association of these devices to a BS. Different users can have different demands in data rate that change with time, meaning that the same user can use the network's resources with minor or massive data rate demands at any given time. Taking that into account, it is imperative that the network satisfies as many users as possible simultaneously, with the best QoS possible, to avoid the usage of the network's resources by the same group of users for a prolonged period of time. A massive network with different users, can be quite quite unpredictable, which is why a network that supports adaptive mechanisms that enable real time decisions for user allocation is strongly recommended.

In that regard the mechanisms featured in the network need to be computationally efficient, but also simple and cost effective to be easily and massively introduced in various networks with minor architectural upgrades. The total cost of modern networks, does not only lay on their construction but also on preserving them. The massive scale of modern networks and their infrastructures, leads to an enormous energy consumption. This calls for energy efficient mechanisms that utilize as few BSs as possible and feature energy saving techniques such as sleep mode.

1.2. Highlight

In this paper, trying to alleviate the problems discussed above, we make the following contribution:

- We propose a simple and easy to implement mechanism utilizing the ability for HetNets to support Downlink and Uplink Decoupling. We suggest association on DL and UL based on different metrics, favoring ScBS to offload MBSs and provide better DRs on UL.
- The proposed mechanism also tackles the energy efficiency problem, since it suggests that unused BSs be shut down to minimize resource and energy usage.
- The simplicity of the proposed mechanism enables real time decision, allowing more users to access the network and remains QoS driven, ensuring sufficient data rates.

- The proposed approach is also tested with various positive offsets for the PL to test the mechanism's performance and adaptiveness in different congestion scenarios.

In remaining sectors, we will complete our proposal. Specifically in Sector II we will take a look on the related work, followed by the system model of DUD in Sector III. In Sector IV we will present our proposed efficient mechanism for matching users to the right BS. In Section V we will analyze our simulations setup. In Section VI we will present and analyze the results from our simulations and in Section VII we draw our conclusions. Finally in Section VIII, we propose our suggestions for future work.

2. Related work

Being one of the most promising topologies for 5G networks, HetNets are a matter of extreme scientific interest. In HetNets, MBSs provide wide area coverage, while numerous ScBSs are deployed in their vicinity. By densifying ScBSs, the distance between users and available BSs for association is dramatically shortened. This would lead to a significant improvement in spectral efficiency and energy efficiency for cellular systems[10,11]. HetNets can be easily densified and thus are perfect candidates for applying DUD. In [12] it is suggested that DUD is part of a broader "device centric architectural vision", meaning that the set of network nodes used to connect a certain device in the grid as well as the functions of these nodes in a particular communication session, are tailored to that specific device and its respective needs, during each session. A disruptive architectural design to study the gains of DUD in UL capacity and throughput was proposed in [13], as well as a study on how this approach affected interferences in the network.

Decoupling allows for different metrics to be used on UL and DL association, such as using PL in the UL direction. Worth mentioning is Range Extension (RE) on the UL metric, by adding a positive offset in favor of ScBSs to increase their coverage and redirect traffic from MBSs to ScBSs. Drastic Offsets can cause interference on the DL direction, leading to the development of methods to try and combat these interferences [14]. On the pursuit of energy efficiency for non peak periods, [15] suggests two types of algorithms, for application to any network type, centralized and distributed.

Due to its proposed architecture, UL/DL decoupling allows for energy saving techniques, such as allowing for more flexibility in switching-off some BSs. Studies on energy efficiency such as the study in [16], are necessary considering that network topologies will keep expanding especially with the rise of IoT and network congestion can significantly affect the network's energy requirements. In this regard, [9] has proposed a congestion control algorithm, adapting according to the network congestion. This approach works in different nodes in the network, adjusting the data transfer rate according to the requirements of the IoT devices. This unprecedented rise in the volume of connected devices also poses a threat to the real time communication and decision making capabilities of the network. In [17] a scalable outlier detection methodology was presented, that does not rely on the network nodes' computing capabilities to support instant real time decisions. An analysis of media streaming by [18], explores IoT session protocols, like Constrained Application Protocol (CoAP) and Message Queuing Telemetry Transport Sensor Network Protocol (MQTT-SN), in an attempt to preserve efficient media transport over Low Power Lossy Networks (LLNs).

However, a HetNet topology fundamentally challenges the traditional cellular system design and analysis. One of the most important issues is user association, namely associating a user with a particular serving BS, which may substantially affect the performance. The emergence of HetNets, where MBSs and ScBSs have massive differences in transmit powers and coverage areas, calls for revisiting the coupled access (CA) approach. From the first to the fourth generation of cellular networks, the Downlink (DL) and Uplink (UL) have mostly been coupled, i.e., each user must associate with the same BS in UL as that in DL according to the maximum DL received power. It may lead to severe losses in UL performance of HetNets, especially ultra-dense HetNets since users may associate with far-away MBSs rather than nearby ScBSs in UL according to the coupled association policy. Therefore, in order to improve UL performance in HetNets, decoupled access (DA) which allows access points in UL and DL association to be different has recently emerged [12,19].

3. System model

The extension of cellular networks, increases dramatically the infrastructures needed to accommodate such networks. These changes set the need for smaller cells that can be easily installed to complement existing network infrastructures. Populating the grid with smaller BSs also has significant energy gains, considering that smaller BSs feature smaller serving vicinity but also have significantly less energy demands. In this regard, SCells become smaller (nano, pico etc), so the transmit power differences between MBSs and ScBSs and even among different types of ScBSs, are constantly rising, raising the need to optimally match a UE with the appropriate BS for its UL/DL needs.

Traditional cell association suggests that both UL and DL are based on the maximum DL Received Power (RP) as measured at the UE [15]. With DUD, a UE will now be able to effectively choose Small or Macro Cells to connect to, based on its requirements. That means that even if it is connected to a certain BS in one direction, it can still choose a different BS to connect to for the other direction, based on a different metric. In our research as well, we assume that association on the DL direction is no longer tied with the UL association. We assume that DL association is based on SINR, while UL association is based on PL, where we also apply Range extension (PLRE). Each user calculates their desired rate and then computes the number of RBs necessary from the BSs to achieve such rate, and tries to connect with their desired BSs. We will also test the proposed mechanism with different PL offsets, in order to measure the mechanism's adaptive capabilities Fig. 1.

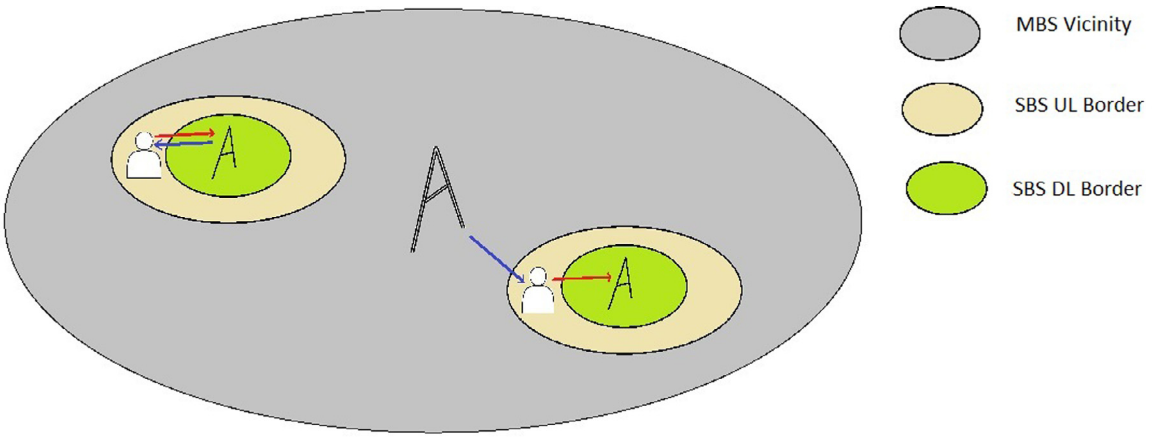

Fig. 1. DUD enables users to connect to different BSs for DL,UL based on different metrics.

We consider a multi-tier HetNet that consists of MBSs, ScBSs and a varying plethora of UEs. Suppose that we have a set of MBSs (M=1,....,$|M|$), a set of SMSs (S=1,....,$|S|$) and a set of UEs (U=1,....,$|U|$). All users want to send and receive data to both directions (UL,DL) that can be considered as different channels in the network. We consider that users are arranged in space following homogeneous Poisson point process (PPP) ϕ of intensity λ_S, λ_N. Finally each BS has a maximum number of users that it can serve simultaneously quoted as n_i, i=1,....,$|U|$ and also features a number of available Resource Blocks (RBs)

The main focus of UL/DL Decoupling is to offload MBSs and distribute load among other ScBSs in the MBSs vicinity, enabling better performance for users and consequently providing improved QoS. In a traditional coupled example each user would link to a single BS, based solely on best DL performance regardless of UL performance. In decoupled models each user will connect to the best possible BS for DL and UL respectively, based on the proposed metric. In our case users connect to a MBS for DL based on DL SINR and to a ScBS based on PLRE, seeking the BS that can provide their desired Data Rate (DR) with the higher QoS. The positive offset is tested on different network congestion scenarios.

For the simulations, we will assume a typical metropolitan area network scenario. We assume that MBSs reach above rooftop levels in order to provide continuous uninterrupted coverage for users, regardless of their relevant position. In regard to their capabilities, ScBSs are based below rooftop levels city-wide and even indoors, for femtocells, to cover up for various conditions that users may experience, such as Non-Line-Of-Sight (NLOS) and interference. These conditions are especially harsh for indoor users, even users roaming the streets, especially in crowded areas with tall buildings. These ScBSs are able to enable higher throughput in areas with high user density especially for indoor terminals, by increasing spatial reuse and thus reducing the number of users per cell[16].

In the simulations, we assume that there are no signs of interference between two users located within the same cell as they can each be assigned to non-interfering sets or resource blocks (RB). A RB is a flexible resource structure, consisting of 12 sub-carriers contiguous in frequency over one slot in time. Sub-carriers are the smallest time-frequency resource unit used for DL/UL transmission[3]. First, we calculate Data Rate as:

$$DR = B_{\mathrm{RB}} * log_2(1 + SINR_{\mathrm{j,i}}), \tag{1}$$

where B_{RB} corresponds to the bandwidth of a specific RB and $SINR_{\mathrm{j,i}}$ is the signal to interference and noise ratio between user j and Base Station i. The total DR for the whole system is equal to the sum of the DR_M (Mcell DR) and DR_S (Scell DR).

This allows for more flexible resource allocation schemes enabling us to achieve higher spectral efficiency. To compute the number of RBs that a user (suppose user j) needs from a specific Base Station, in order to achieve the desired rate, we will use the following equation:

$$R_{\mathrm{j,i}} = [\frac{g_j}{B_{\mathrm{RB}} * log_2(1 + SINR_{\mathrm{j,i}})}], \tag{2}$$

where g_j denotes the UE throughput demands and DR_i the desired Data Rate for the user j.

Next we shall define the parameters suggested for DUD, PL and SINR. We will define PL for the distance dependent Path loss model, when a user is connected with MBSs (PL_M) as well as ScBSs (PL_S). PL is a metric to measure the signal loss in our wireless communication network. The equations that describe them are given below, both for UL and DL:

$$PL_M = 128.1 + 37.6 * log_{10}d \tag{3}$$

$$PL_S = 140.7 + 36.7 * log_{10}d \tag{4}$$

And SINR for DL can be calculated as:

$$SINR^{\mathrm{DL}}_{\mathrm{i,j}} = \frac{P_j g_{\mathrm{i,j}} d^{\mathrm{-a}}_{\mathrm{i,j}}}{\Sigma_{\mathrm{kB}}}, \tag{5}$$

4. Matching algorithm

4.1. Our approach

Taking into consideration that each BS has an upper bound on its RB capacity we consider as W the number of Resource Blocks (RBs) available for each BS. In this research, we consider that all users are equal, with no user having a priority for serving, even though they have different needs and requirements from their respective matched BS. All users, have defined needs for data transmission, the want to receive and send data and do so with a desired Rate. We consider that all served users that achieve their desired data rate, enjoy full QoS. In our network, we consider that all MBSs share the same capacity and all ScBSs are of the same type, sharing the same capacity as well. Allocating users on BSs in the network, greatly resembles the Knapsack Problem (KP), on which each BS resembles a knapsack, while users are different objects. In KP, each object has a specific value (profit) and a specific weight. We want to maximize Data Rate (DR), so DR can be considered as the profit for selecting a user and the RBs that each user asks for, can be considered as the weight of each user. We will analyze the Knapsack problem for a complete overview later.

The main focus of our research is the UL performance of the network, thus we apply Range Extension only on PL (our metric for UL association), trying to satisfy as many users as possible. Applying PLRE, means that while each BS has their own UL border and DL border, now all ScBSs are provided with a positive offset in the UL direction, an advantage over MBSs to expand their UL border. This method is expected to associate more users with ScBSs, resulting in less congested MBSs. Prioritizing ScBSs over MBSs in Uplink is expected to yield positive results in the total number of users satisfied and lead to a more uniform distribution of user association with BSs over the network.

4.1.1. The knapsack problem

In the KP we have a set of objects, each one with a specific value (v_i) and its respective weight (w_i). We also have a knapsack, with a limited space of W and the goal is to fit as many objects in the knapsack as we can in order to achieve the maximum profit. Each object can either be selected or not selected, so the problem is usually referred to as the 0–1 Knapsack Problem. Obviously since the carrying capacity of the knapsack is limited, subsequently the amount of objects we can carry is limited.

Given a set of items (suppose n items) we want to maximize our profit [20]:

$$\sum_{i=1}^{n} U_i X_i \tag{6}$$

Suppose that we can carry a set of m ($m < n$) objects. For all all objects we define (X_i) and $X_i = 1$ when an object belongs in the set of chosen objects or $X_i = 0$, when an object is not selected. Obviously for our set of selected objects:

$$\sum_{i=1}^{n} U_i X_i \leq W \tag{7}$$

4.2. The associations

An association denotes a connection between a user and BSs. This connection can be either on UL or on DL and a user can be connected to different BS for their UL and DL connections, or the same BS for both.

Each user i $\supseteq$ N, can sign a "contract" which includes the identities of the BSs associated with the user for UL and DL connection. Think of a two BS example. Let possibilities for association be the following: user 1 prefers an association with BS 1 in the UL direction and BS 2 in the DL direction based on the utility function we use, so user 1 has a preferred association of $\{UL1, DL2\}$. For the two BS example, we define the preferences as following: $\{UL1, DL2\} > \{UL1, DL1\} > \{UL2, DL1\} > \{UL2, DL2\}$.

For each BS j $\supseteq$ B,we define two separate lists of preferred relations for UL and DL direction, over the set of possible associations.

4.3. The algorithm

The proposed algorithm aims to provide a stable algorithm that produces optimized results, regardless of the congestion of the network. The network starts with a plethora of users, with no associations between users and BSs. Furthermore, we consider that there are no limitations to the assignments of users, each user has an equal chance to connect to all BSs based on the values of the metrics used. Each user creates a list consisting of pairs, one BS for their UL connection and one for their DL connection. In our mechanism, each user selects their preferred BS for UL based on PL with a positive offset, and for DL based on SINR. Range Extension on the UL channel, results in ScBSs being favored over MBSs for user association. Range extension is applied if the user attempts a connection with a SMBs only, to offload MBSs. In the matter of user selection, BSs accept users, providing they have enough RBs available. Users should communicate their RBs demands to each BS, they try to associate to.

When a user's (let's assume user i) connection with a BS (assuming BS j) is accepted in the UL direction, we use UL_j to suggest an association. Respectively, DL_j suggests associations on the DL direction. In other words, each BSs is faced with a list of users for association, both on UL and DL direction. This list states possible connections, a possible contract, with each user. At an initial stage we can assume that neither users nor BSs have a reason to drop a possible connection.

In the main phase, users will rank their preferences (with the available contracts) using the proposed scheme (UL: PLRE, DL: SINR). At this point each user has created a preference list. Each user will need to submit a request at their desired BS for acceptance in both directions. It is obvious that each user wants to connect with its most preferred BS in each direction, namely the first match in their matching list, but BSs may refuse such an association. As some BSs may not accept some users' connection, each rejected user attempts to connect with their next most preferred BS on the list based on the same parameters, meaning that their list of preferences is taken into account in descending order. Network BSs will have to prioritize their available connections, accept a user, if they have enough available RBs to satisfy their demands, or decline them if they lack the necessary RBs.

It is essential that all users must connect to some station, both on UL and on DL direction. This means that for any user i there should be at least two connections with any BS, (let's assume BS j and BS k, where j and k are not necessarily different). After each user produces its preference list, they calculate the number of RBs needed to achieve their desired rate. Each UE transmits to its preferred BS their needed RBs and awaits confirmation (or not) of the contract. Each BS builds its preference list over the available set of connections, taking into consideration the number of RBs that each user requests. All BSs accept users, until they can no longer accept any more users. Therefore, all BSs have an upper limit in the number of users they can accept Algorithm 1.

Algorithm 1 Pseudocode for the Matching Algorithm .

```
U: Denoting all users
MB: Denoting all Macrocell Base Stations (29)
SB: Denoting all Smallcell Base Stations (45)
for num of users= 100, 200, 500, 1000,2000 do
  for i = 1 to MB do
    ACCM(i): Empty;
  end for
  for i = 1 to SB do
    ACCS(i): Empty;
  end for
  for i = 1 to U do
    Create BS preference list for DL over SINR;
    Create BS preference list for UL over PL,
    applying RE in favor of SBs;
    Transmit request to most preferred BS for DL, UL;
    Calculate number of RBs to achieve wanted Rate;
  end for
  for J = MB and J = SB do
    for i = 1 to J do
      If total BS RBs < user wanted RBs => accept;
      If(best PL BS accepts user) then subtract user given RBs from total BS RBs
      If(no BS accepts user) then check next user
    end for
  end for
  for i = 1 to MB do
    If MBS(i) serves no users
    Then shutdown;
  end for
  for i = 1 to SB do
    If MBS(i) serves no users
    Then shutdown;
  end for
end for
```

The proposed algorithm can be seen above. As users are rejected by a BS, then they submit a contract proposal to their next set of preferred BSs for connection. Again each BS shall create a new waiting list (consisted of all the users that can connect with them). The algorithm only concludes when there are no users left unassociated with a BS, provided the network is not congested. Given the simulated network should mimic a real scenario, it is possible that some users may

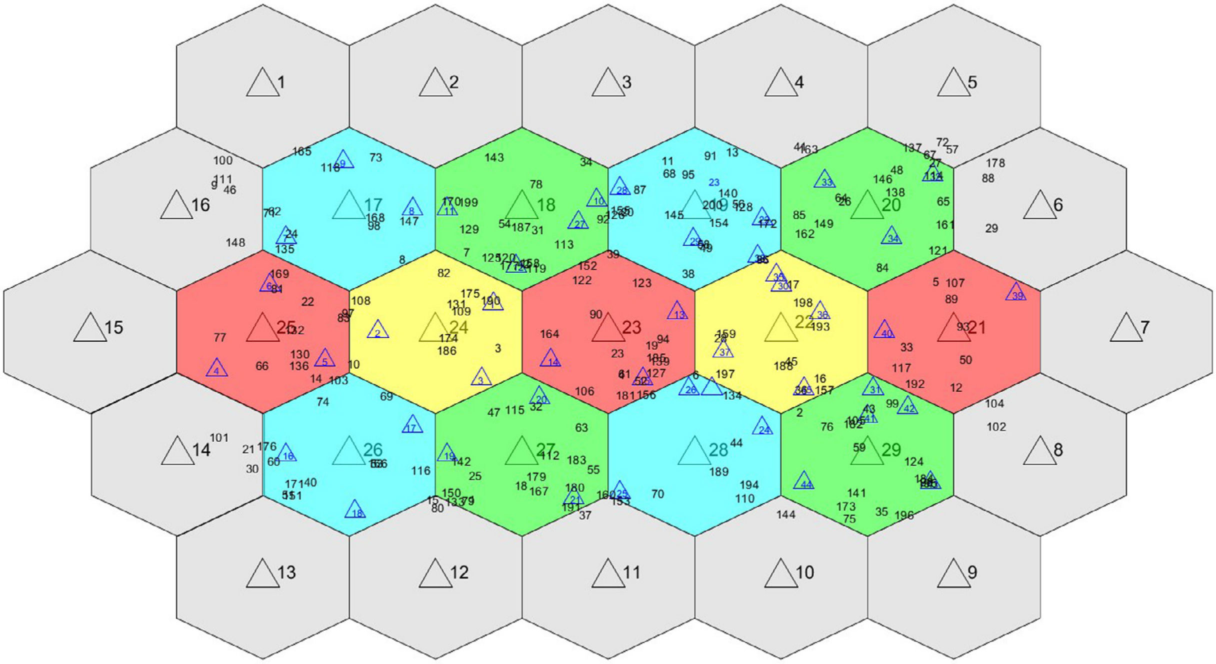

Fig. 2. Our MATLAB simulated network, consisting of 29 MBSs, 45 BSs and a total of 200 users.

be left unassociated. In the case where no network congestion happens, BSs with no users matched to them, shut down to reduce energy waste.

5. Simulation setup

For the evaluations performed in this paper, we will model a 5G System in a MATLAB based network simulator following the distance dependent PL model for Mcells and Scells. MATLAB provides a set of standard functions and an intuitive GUI for the design, simulation and verification of Advanced Communication Systems such as mobile networks. It is widely preferred for research and educational use. MATLAB simulations allow us to perform evaluations that are more difficult or impossible to perform on real life systems and study the behavior of our mechanism in a highly controlled, reproducible environment.

We executed simulations for a set of users, as low as 100 users and as high as 2000 users for a network approach of 29 (fixed position) MBSs and a 45 ScBSs. An instance of our network can be seen on the picture below. The network consists only of the colored hexagons, and all gray colored hexagons are not considered part of our simulation network. At the center of each hexagon we encounter the MBSs displayed as a large triangle and a set of small triangles that represent ScBSs, scattered among the MBSs vicinity.At first we will conduct a simulation with 29 MBSs and 45 ScBSs to produce the first set of results, with SINR as the metric of DL association and PL with a small offset for the UL association. In order to test the adaptive capabilities of out mechanisms, we configure network's parameters (e.g. PL offset) to see how the mechanism adapts to the scale of the network Fig. 2.

In our simulations we will consider an area that consists of MBSs (omni-directional with an inter-site distance of 375m) and ScBSs (omni-directional with a radius equal to 50m). As for our simulation deployment scenario, we will simulate a network and model its performance for different numbers of users. That way we hope to create a model to study the network's scalability potentials. At first, we consider 100 users that seek to use the resources of our network and later this number escalates to 200, 500, 1000 and finally 2000 users. All users are randomly generated with a personalized chance of appearing inside our area of interest that is served from a cell and a small chance to appear beyond our network. In the DL network as well as the UL network, all users have their personalized demands for DRs that range from 2048 (Kbps) to 32,768 (Kbps) for the DL and for the UL, their demands range from 2048 (Kbps) to 16,384 (Kbps). All our simulation parameters will be presented in the following array: Table 1.

6. Simulation results

We begin with comparing our mechanism with an approach that relies only on PL for association on the UL direction, without any offset whatsoever. Applying Range Extension on PL with a positive offset, results in an increased number of successful user associations, as seen in Fig. 3. This increase in total associations, shows that adopting this approach in next generation networks, can lead to denser networks with increased capacities in user association. While SCells are relatively

Table 1
Simulation Parameters.

Parameter	Setting
Propagation Model	macro cell propagation model
DL Bandwidth	100MHz
UL Bandwidth	100MHz
User distribution	Poisson Point Process
Network Deployment	29 Mcells and 45 Scells
Number of users	100/200/500/1000/2000
Carrier frequency	3.5 GHz DbM,
Modulation UL Scheme	64QAM

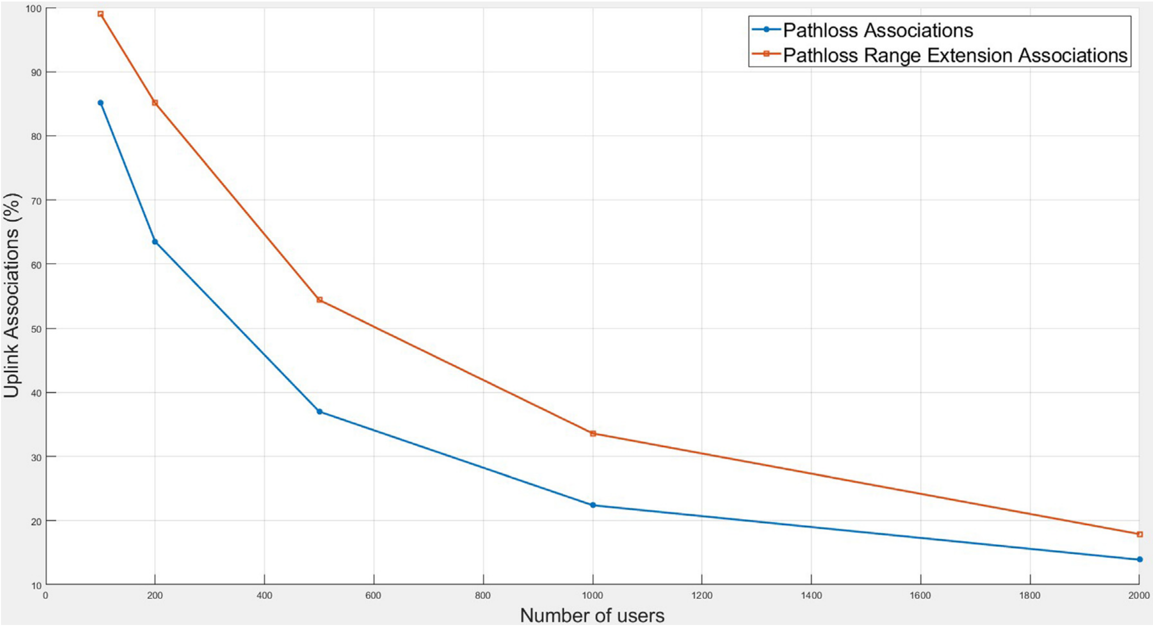

Fig. 3. Association percentage for PLRE over PL as UL metric.

ineffective on satisfying UEs' demands on DL association, they offer significant coverage in the UL and they are in fact, able to satisfy a respectable amount of users Fig. 3.

Increasing the amount of ScBSs in HetNets is relatively easy and can be proven effective in increasing the amount of user associations, especially if we apply techniques to utilize ScBSs and associate more users with them. This is critical on the UL direction, where ScBSs face a plethora of association demands with smaller desired DRs coming from a wide range of devices. This can be seen in Fig. 4, where we see that more users are connected with ScBSs in comparison to simple DUD with PL set as the desired metric for UL association Fig. 4.

Increasing the number of network ScBSs is a viable option, considering that the cost of installing new ScBSs, is extremely low. Following this approach, ensures a more homogeneous distribution of UEs between the network nodes and results in less congestion on Mcells. This, in turn, leads to a better distribution of the network resources. ScBSs are utilized increasingly and steadily by our proposed method, which, combined with the increased total user associations, can prevent network congestion in extreme scenarios. Obviously every network has an upper limit on the volume of concurrent UEs it can satisfy. In our network, we see some signs of congestion after 1000 users.

Regarding the DR performance of our mechanism, the average DRs, are proven to be lower in PLRE with a stable offset, by a small margin in comparison to simply applying PL in the UL channel, as seen in Fig. 5. Individual DRs, show signs of scaling between users, since some users are more favored by range extension than others. The DRs are limited by the overall channel quality and topology and the fact that UEs are not necessarily connected to the BS that the have the lowest PL. With an optimized offset, users will be provided with a improved UE SINR allowing the use of higher modulation schemes. Even though we use a tight offset, we see a minor effect on DRs, which inevitably calls for the implementation of Interference management schemes. The similar DRs with the increased number of associations, result in an increased total network throughput and leads to higher user satisfaction. Channel quality is quite important in the overall satisfaction of throughput demands and as the number of users increases, it is all the more difficult for a large percentage of users to connect to a BS, let alone their preferable BS, which results in setting an upper bound for the total produced DR Fig. 5.

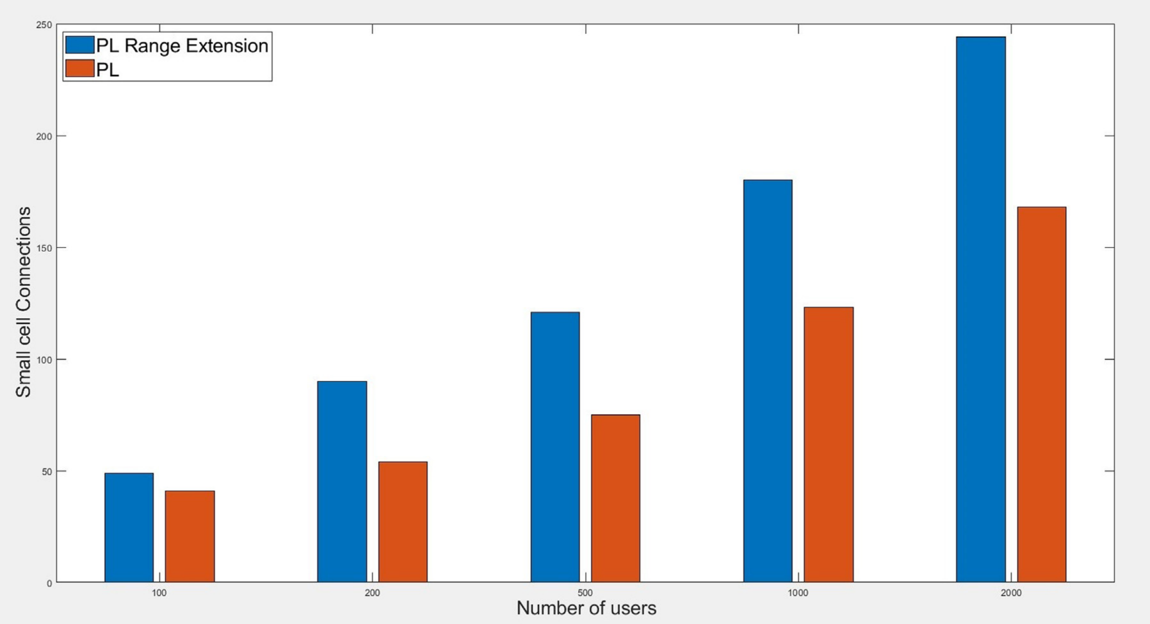

Fig. 4. Number of Small Cells Associations for PLRE vs PL as UL metric.

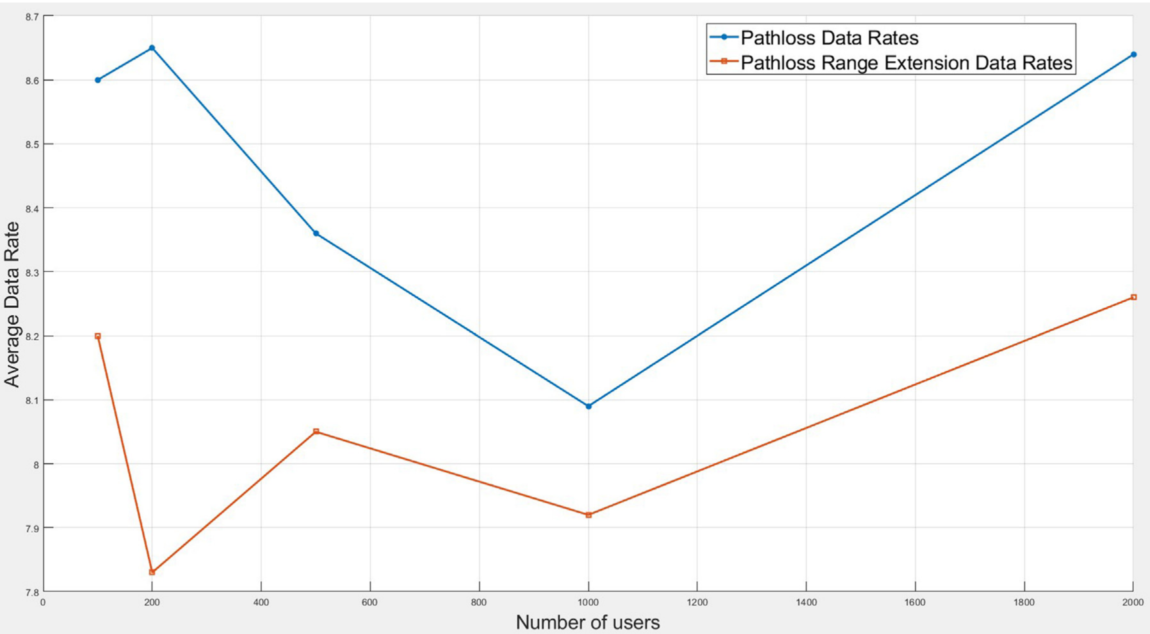

Fig. 5. Average DRs for PLRE over PL as UL metric.

Following Fig. 5, as the number of users increases, we notice that the DR for PLRE is following the same pattern as the DR based on simple PL association. It is important to note how DRs seem to increase and decrease as the number of users increases. This is not only due to channel quality but it also indicates the need for Adaptive Range Extension (ARE) with different offsets dependent on the BS load or the number of users populating the network and possibly indicates that each network should feature different numbers of ScBSs dependent on the expected user load and topography. Different networks might dictate possible routes for users, so ScBSs placement should be based on the network topography.

Testing the mechanism with different offsets for the PL on UL direction, presents the most promising results right before we face network congestion (between 500 and 1000 users) for our simulation. Increasing the offset during these tests, showed an increase in DRs, total network throughput and user associations. As seen in Fig. 5, when the network only has a small amount of users, a negligible offset is preferable because, in these conditions users will receive the highest QoS possible, anyway, and in cases with extreme network congestion, increasing the positive offset only results in higher interference levels, while the number of user and BS associations seems to marginally rise. This result is promising, provided that the right interference management tools are applied. Increasing the number of ScBSs, increases the range where higher offsets are effective, and drastically reduces interferences.

Concerning the energy efficiency of our mechanisms, in the DUDe case, UEs are distributed more evenly between the nodes. As the number of UEs increases, all the available nodes are heavily congested in extreme scenarios, but for lower congestion scenarios, some BSs may be able to shut down, and since PLRE favors ScBSs, MBSs can lower their transmit power for energy efficiency. Even in congestion scenarios, an increased amount of ScBSs, allows the network to cope with the volume of users easily, leading back to no congestion scenarios. The produced results indicate that ARE in PL seems promising in DUD, provided the offset is tied with the network conditions. These results are critical, especially in future IoT networks where the network load is expected to drastically increase in the UL.

7. Conclusion

From the produced results, we see that as the number of network users rises, Base Stations are increasingly having problems satisfying most of the users. In this regard, we applied Range Extension on Path Loss for association in the Uplink channel, with different offsets to valorise Small cell Base Stations over Macro cell Base Stations. The results are promising, with a homogeneous user distribution across the network and higher association rates. Higher offsets, produce better results only on scenarios with high traffic, but no apparent congestion. In low traffic scenarios the offset is best kept minimal, while on congestion scenarios, the offset must be adjusted to the desired interference levels. Individual Data Rates of the proposed mechanisms are more vulnerable to the distance of the user from the associated Base Station, while the average DR is a bit lower on PLRE. We conclude that Adaptive Range Extension on Path Loss is key to more stable, energy efficient and congestion proof networks, especially with the rise of IoT where the volume of portable devicess is expected to massively utilize the UL direction.

8. Future work

User association on wireless mobile networks is a matter of intense scientific research activities, which makes it essential to study this matter along with other study fields. As possible candidates, we expect Machine Learning and Game Theory to help us understand the mechanics behind overcomplicated network scenarios, to refine existing mechanisms and radically increase efficiency in these networks. Game Theory can model existing and possible congestion scenarios and model user behavior in networks. This enables us to provide different allocation mechanisms for different scenarios based on the users' needs and strategies. Machine Learning can support these Game Theory mechanisms. It can provide us with the tools to alternate these mechanisms in real time or predict various scenarios and model our network accordingly. Machine Learning is also expected to play an important role in choosing the best placement for ScBSs. By predicting user influx and placement, we can find the best placement for Small cells to offload congested network areas.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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