International Journal of Wireless Networks and Broadband Technologies
Volume 9 • Issue 2 • July-December 2020

A Resource-Efficient Approach on User Association in 5G Networks Using Downlink and Uplink Decoupling

Christos Bouras, Computer Engineering and Informatics Department, University of Patras, Patras, Greece
Vasileios Kokkinos, Computer Engineering and Informatics Department, University of Patras, Patras, Greece
Evangelos Michos, Computer Engineering and Informatics Department, University of Patras, Patras, Greece

ABSTRACT

A user-centered network model can significantly optimize connectivity issues between a user and the corresponding base station (BS). This article shall evaluate the user-centric (UC) model targeted for Fifth Generation telecommunication systems and will attempt to optimize communication between users and BSs. The authors suggest a resource-aware mechanism that targets improving coverage through the network decoupling into two separate and independent uplink and downlink networks. The mechanism shall fully respect each user's initially requested throughput demands and aims to solve the network user BS association problem with efficient resource management techniques. Simulations revealed that the mechanism perfectly preserves quality of service (QoS) and offers increased data rates in favor of ultimate user coverage, in both scenarios. Additionally, Frequency Range 2 offers an increased amount of resources, both increased data rates and higher amounts of devices that are covered by the overall network.

KEYWORDS

5G NR, Association, BS, Decoupling, DL, HetNet, MCS, UC, UE, UL

INTRODUCTION

Upcoming 5G networks are expected to enable data transmissions of ultra-high-speeds, nearly x1000 times faster than the speeds of current Long Term Evolution (LTE) networks, support a significantly larger number of user devices (x10 up to x100 times more devices), provide ultra-low latencies ($\leq$ 1ms) that are 5 times lower than existing LTE latencies and prolong device battery lifetimes (x10 times). Such networks should also be capable of satisfying the variant requirements of network services, such as enhanced mobile broadband (eMBB), massive machine type communication (mMTC), and ultra-reliable and low latency communication (URLLC). The fact that each and every one of the aforementioned services are in need of different requirements (e.g., eMBB services require very high bandwidth and mMTC services require ultra-dense connectivity), it goes without saying that homogeneous networks would never be able to efficiently satisfy such services. As a result, 5G networks come into play with sufficient resources by using network function virtualization (NFV) and Software Defined Networking (SDN) technologies, where using network softwarization techniques, network operators may set up, configure and control network slices (International Telecommunication Union, 2015; International Telecommunication Union, 2018).

DOI: 10.4018/IJWNBT.2020070103

Having considered all the above, the authors should be able to comprehend why such big amounts of complex data need to be processed so that operators may efficiently design, construct, deploy and manage network slices to satisfy the users' Quality of Service (QoS) needs. Meanwhile, according to Ghaleb et al. (2018), transmission power limitations in are currently being confronted through very low code rates and modulation schemes of high order, an approach which results in high levels of spectral efficiency (SE). Thus, 5G HetNet architecture should eventually turn from the existing models that are considered network-centric (NC) into models that are user-centric (UC). Such models can provide improved connection between network users and Base Stations (BSs) inside HetNets. What is different is that fact that a HetNet chooses to decouple the homogeneous network into two independent networks, which are the downlink (DL) and the uplink (UL) networks. A User Equipment (UE) takes advantage of this decoupling and now may connect to different BSs in the UL and DL, providing increased freedom to the decoupled networks. Furthermore, HetNets are generally expected to extend the existing macro cell infrastructures though small cell deployments placed close to the macro cell borders, in order to offer extended coverage and data rates for UEs near the macrocell's borders. The optimal Modulation and Coding Scheme (MCS) is necessary to be selected, due to the fact that will define the practical throughput for a user that is linked to a BS.

In this work, the authors will present a resource-aware mechanism that targets at improving network coverage through the decoupling of a dense HetNet into the UL and DL networks. Increased demands and requirements that 5G networks expect are satisfied covered by incorporating and applying the 5G NR radio interface protocol. The proposed mechanism fully preserves users' QoS and provides higher data rates than those initially requested, but in favor of coverage for all network users. The algorithm requires knowledge of the Resource Block (RB) demands for each device and begins iterating, starting from users that have the lowest RB demands, so that the maximum number of users is satisfied. Data throughputs derive from the appropriate selection of the optimal MCS inside each distinct macrocell area. The authors perform the simulations in both applicable 5G physical layer scenarios, which are the settings of Frequency Range 1 (FR1) and Frequency Range 2 (FR2). Simulation results revealed that the proposed mechanism does indeed succeed at respecting users' QoS demands and ends up providing greatly augmented data rates than originally requested, as promised. Furthermore, the fact that Frequency Range 2 offers an increased amount of resources, it is revealed that this equivalent simulation provides both increased data rates and higher amounts of devices that are covered by the overall network.

BACKGROUND

Ghaleb et al. (2018) proposed a UC solution that is power-efficient for dense HetNets and aims reducing the overall energy consumption in the network, while also respecting the requested QoS demands of the users. Using the upcoming UC model, the authors formulated an optimization problem that minimizes total power consumption and suggested a low complexity algorithm that efficiently associates UEs and BSs inside an LTE-A HetNet. Evaluations were carried out by comparing the UC model versus the Network Centric (NC) model and results showed that if the UC model is followed, the HetNet experiences significant energy savings and increased overall system capacity. Coming from Kim (2015), the paper authors studied 5G requirements related to MCS and accepted high SE will be one of the most important requirements for future wireless networks, which generally is obtained through the adoption of a modulation of high order, alongside with very low code rates. The paper also reviewed candidate error correction coding schemes for 5G networks and then evaluated the performances of candidate error correction coding codes. Bouras et al. (2012) studied a total of four different approaches on efficiently choosing the optimal MCS inside the physical layer of the network, so as to optimize over-the-air SE and developed four different scenarios applicable in different real-life situations. In this paper, each approach corresponded to different users' distribution and traffic conditions and during the simulation scenarios, SE measurements dictated if the approach provided the targeted SE for the equivalent scenario. Elshaer et al. (2014) proposed a deployment scenario for a network that adopts the Long Term Evolution (LTE) protocol by decoupling the network into DL and UL and then proposed a DL association solution that was heavily based on the receiving power and on the other hand, an UL association that was based on the pathloss. As for the simulations, the 5G network was simulated based on Vodafone's LTE field trial network in a dense urban area and additionally, realistic traffic maps were accurately based on current network measurement.

Coming from Wang (2017), innovative multiple access technologies for next generation networks were tested in a field trial that was classified as a 5G network. Authors showed the performances of three key 5G technologies as far as SE is concerned (Sparse code multiple access (SCMA), polar codes and filtered OFDM (f-OFDM)). The simulation results showed that by adopting the LTE protocol, Orthogonal Frequency Division Multiple Access (OFDMA) and turbo coding provide increased SE. Mesodiakaki et al. (2016) achieved augmentation of the power and spectral efficiency of the network while also respecting users' QoS demands, followed by a user association algorithm that solves the UE-BS association problem efficiently, regarding the lowest energy consumption per BS. To do so, the problem was formulated as a generalized assignment problem which considered both capacity and energy consumption in the access network and at the direct backhaul links, a problem that was later on classified as NP-hard. Peralta et al. (2018) followed 5G New Radio (NR) wireless communication technical specifications and then studied a variety of channel scenarios that were based on variable bandwidths and sub-carrier spacings. Simulations revealed that achievable user data rates and Block Error Rates (BER) that keep in line with the low-density parity-check (LDPC) approach end up offering augmented performances, if one adopts the LDPC coding scheme.

From Cai et al. (2016), a dynamic power control system mechanism was proposed that allowed macro cell BSs to also deal with network issues outside the area covered from small cell installations and when necessary, altered thee operating state of the small cells. By first considering that users were uniformly distributed in the network, the problem was formulated towards a more general case where users are non-uniformly distributed and thus an NP-hard problem, which was tackled by a location-and-density-based operation scheme in order to achieve near-optimum performance losses. Richter et al. (2009) experimented on the different layers of small cell BSs deployed in existing macro cell coverage areas, so as to reduce overall energy levels of consumption. After simulating the deployment strategies on power consumption of mobile radio networks, simulations revealed that when the network's traffic load is full, then using micro BSs only has a moderate effect in the overall system's power consumption. Radwan and Rodriquez (2017) proposed a novel network system that can support multiple network devices with increased data rates, lower latencies and energy levels of consumption through the formulation of a cloud network of small cell deployment. From Ghaleb et al. (2013), network throughput variances are evaluated based on a variety of implemented modes, and finally, Lahad et al. (2018) suggested the use of time-division duplexing (TDD) that can allocate DL and UL resources through dynamic mechanisms over a 5G HetNet.

Extensive work has already been done in the field of QoS provisioning in wireless telecommunication networks. More specifically, Avocanh et al. (2014) acknowledged the fact that LTE was undoubtedly becoming a significant force in mobile Radio Access Technologies (RAT) and developed a two-level packet scheduler that offers strict delay bounds and promised very low packet losses rates for multimedia services. Though the proposed packet scheduling scheme, the simulations revealed that the proposed scheme optimized multimedia services performances and optimal QoS support for LTE networks. Comsa et al. (2018) proposed a scheduling solution based on Reinforcement Learning (RL) in order for the network to be able to satisfy higher QoS demands when facing against unpredictable network conditions and dynamic user congestion in wireless networks. The suggested innovative framework was tested and was revealed that it outperformed conventional packet scheduling strategies regarding packet trop rates and packet delays, while at the same time, it preserved the strict QoS requirements from services and applications. Again, Comsa et al. (2019) performed a research comparison on existent RL mechanisms on schedulers that complied with Orthogonal Frequency-Division Multiple Access (OFDMA). The simulation results showed that the innovative proposed framework again managed to perform optimally, compared to existing scheduling algorithms. Continuing their work, Comsa et al. (2020) tackled the issue of the increasing demand for bandwidth-hungry services and preserving the QoS requirements in HetNets and came forward with the proposal of a smart scheduling framework that aimed to optimize QoS performances via RL and neural networks. After evaluating the framework, it was revealed that the 5MART framework managed to achieve up to 50% improvements regarding time fractions, while simultaneously respecting the heterogeneous QoS demands, compared with existent state-of-the-art scheduling approaches. Khan et al. (2012) considered only DL scheduling in the Medium Access Layer (MAC) that also complied with OFDMA and proceeded at suggesting an Opportunistic Packet Loss Fair (OPLF) scheduling algorithm. The mechanism overperformed existing algorithms, like the Modified Largest Weighted Delay First (M-LWDF), the Proportional Fair (PF) and the Packet Loss Fair (PLF), regarding metrics such as throughput and user fairness. Lastly, Proebster et al. (2010) contributed through a self-optimizing scheduler with adjustable fairness between users. This approach, all user-intended levels of fairness are maintained in scenarios where network are congested with users, resulting in data rates enhancements. Our contribution takes into consideration the aforementioned approaches and especially those related to preserving the strict QoS requirements in situations where the network has to serve extended amounts of users and strives towards efficiently managing physical resources in user-congested situation, while simultaneously persevering the initial QoS user demands.

SYSTEM MODEL

Moving over to the formulation of the system model, the authors focus the interest in an urban 5G HetNet area and suppose that all cells has fixed sizes and radiuses and inside every cell, only one BS exists and is placed in the center of the cell. According to the technical specifications for 5G networks under the NR radio interface protocol (Third Generation Partnership Project, 2018a), in the physical layer of the network, the conventional Orthogonal Frequency Division Multiplexing (OFDM) is used for the DL network with normal cyclic prefix, while the UL network complies with conventional. A uniform distribution of the available system frequency into Resource Blocks (RBs) is also envisioned for the model, supplying each RB with 12 sub-carriers, always according to the specification. The proposed UC model of the network can be seen below in Figure 1.

Now, for the urban deployment scenario, the authors will form the necessary equations for the path loss models, both for the macro cell and the small cell infrastructures, which are considered identical in the DL and UL networks (Third Generation Partnership Project, 2016). The propagation model for the macro cell tier is as accurate as:

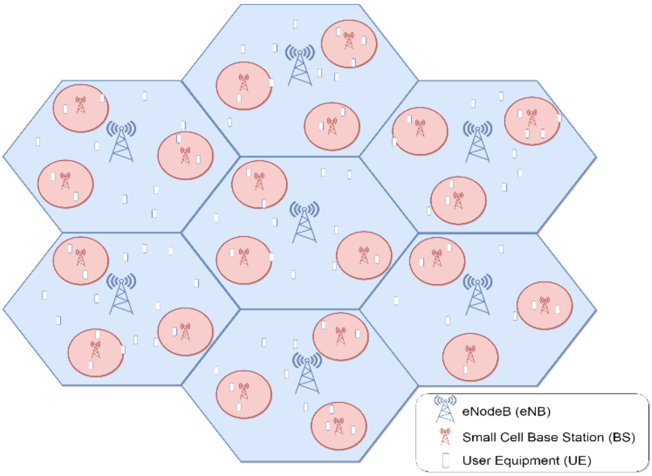
$$PL_{macro} = 128.1 + 37.6 \cdot \log_{10}\left(d\right) \tag{1}$$

where *d* is the norm-2 distance in kilometers between the user and the macro cell BS. The small cells' propagation model is computed as follows (Third Generation Partnership Project, 2013):

$$PL_{small} = 140.7 + 36.7 \cdot \log_{10}\left(d\right) \tag{2}$$

where *d* is again the norm-2 user-small cell distance in kilometers. It should be noted however that the system model considers no wall losses. Both PL_{macro} and PL_{small} are measured in dB. The channel gain is identical for the UL and DL and is calculated as:

Figure 1. The UC model scenario



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

If a user wished to associate himself to an equivalent BS, then this user will be served with a specific number of RB provided by that BS. According to Third Generation Partnership Project (2016), if the initial user demands are pre-determined, the user's RB demands depend a) from the pre-defined throughput demands, b) the available channel bandwidth and c) the Signal-to-interference-plus-noise ratio (SINR). The RB demands are expressed as:

$$rb_{j,i} = \left\lceil \frac{th_j}{B_{RB} \cdot \log_2\left(1 + SINR_{j,i}\right)} \right\rceil \tag{4}$$

where the $\lceil \bullet \rceil$ operator is the function that ceils to the next equal or greater integer, th_j is for the data rate demands of the user, B_{RB} is the RB's bandwidth and $SINR_{j,i}$ is the SINR from the UE' side. Due to the fact that the authors select to round the RB demands towards the next integer, most of the network users will receive more bandwidth than demanded, a factor that will result in preserving the QoS for all the network users served from a BS.

Moving to the DL network, the authors adopt the OFDM protocol. Supposing that $SINR_{i,j}^{DL}$ be the SINR measured from an i^{th} BS to a j^{th} UE, the SINR, according to Goldsmith (2015), can be expressed as:

$$SINR_{i,j}^{DL} = \frac{P_i^{rad} \cdot G_{i,j}}{N_0 \Delta f + \sum_{i'} P_{i'}^{rad} \cdot G_{i',j}} \tag{5}$$

where P_i^{rad} is the power emitted from the BS, $G_{i,j}$ refers to the UE-BS channel gain, N_0 depicts the white noise power spectral density and Δf corresponds to the sub-carrier spacing (SCS).

Furthermore, $\sum_{i'} P_{i'}^{rad} \cdot G_{i',j}$ refers to the summation of the power that radiates from every other BSs except the i^{th} BS that multiplies with the channel gain for these BSs and the equivalent j^{th} UE. It should be noted that all measurements are made over RBs and not over sub-carriers.

In order to optimally make good use of the channel's bandwidth capacity, the authors propose that adaptive MCS must be followed. When the j^{th} UE links up with an i^{th} BS, user demands derive from the amount of RBs it and the equivalent SINR. If the authors consider $R_{j,i}^{DL}$ as the user's throughput in the DL network, then from Bouras et al. (2012):

$$R_{j,i}^{DL} = \left|r\right| \cdot \sum_{r \in RB} W_{RB} \cdot cr_{SINR} \cdot \left(1 - BLER_{SINR}\right) \tag{6}$$

where $\left|r\right|$ corresponds to the cardinality of the RBs needed for the user's demands, W_{RB} is RB's bandwidth, cr_{SINR} corresponds to the code rate of the MCS and $BLER_{SINR}$ denotes the SINR-dependent BER.

For the UL network that also adopts OFDM, let $SINR_{j,i}^{UL}$ be the SINR measured from an i^{th} BS to a j^{th} UE measured as (see Ghaleb et al. 2018):

$$SINR_{j,i}^{UL} = \frac{P_j^{rad} \cdot G_{j,i}}{N_0 \Delta f + \sum_{j'} P_i^{rad} \cdot G_{j',i}} \tag{7}$$

where P_j^{rad} is the UE's emitted power, $G_{j,i}$ is the channel gain between the UE and the BS, N_0 and Δf are as stated in the DL model and $\sum_{j'} P_i^{rad} \cdot G_{j',i}$ is the summation from each network user except the j^{th} one, of the multiplication between the emitted power from the UE and the channel gain between the user and the BS. If $R_{j,i}^{UL}$ denotes the user's throughput in the UL network, then:

$$R_{j,i}^{UL} = W_s \cdot \left|N_s^{UL}\right| \cdot cr_{SINR} \cdot \left(1 - BLER_{SINR}\right) \tag{8}$$

where W_s is the bandwidth of the sub-carrier, N_s^{UL} corresponds to the cardinality of the sub-carriers that are necessary in the UL network, cr_{SINR} is the modulation's code rate and last but not least, $BLER_{SINR}$ refers to the BER that depends on the SINR of the UL network.

In order to transform the SINR measurements in (dB), the authors transform Equations (5) and (7) into:

$$SINR_{(dB)}^{DL} = 10 \cdot \log_{10}\left(SINR_{i,j}^{DL}\right) \tag{9}$$

$$SINR_{(dB)}^{UL} = 10 \cdot \log_{10}\left(SINR_{j,i}^{UL}\right) \tag{10}$$

PROPOSED MECHANISM

Main Architecture

The suggested algorithm allows a UE to associate with different BSs in the DL and UL separated networks, depending on which connection is optimal in the now decoupled DL an UL networks. The algorithm targets at maximizing the average user data rates inside the macro cell area, but without necessarily providing optimal coverage towards all users (achieving both of them as of now is quite a task). The proposed mechanism takes into consideration the users' initial RB demands iterates from the UEs with the lowest RB demands. This happens so that both networks can satisfy as many network users as possible. As far the MCS is concerned, the authors attempt to link each user with the appropriate MCS and later on, each MCS will be mapped its corresponding Channel Quality Indicator (CQI). This will provide in overall 15 MCS-CQI sets, as described in Third Generation Partnership Project (2019).

The algorithm requires information about the available RBs of each BS, SINR calculations from each BS to each UE and vice-versa and the initial user RB demands. Al this information is needed in both decoupled UL and DL networks. Then, repetitively, every device will attempt to link with the best available BS candidate up until its initial throughput demands are satisfied. Upon connection, all users will experience higher data rated than requested, due to the fact that each user's RB demands are rounded towards the next integer, so the vast majority of the users will eventually be supplied with more bandwidth than what they requested. Each UE-BS association is possible only if the BS has the required amount of remaining RBs. If this isn't the case, the authors iterate the next best BS candidate, up until the next best BS is located. The association mechanism is presented below for both the cases of the DL and the UL networks:

PERFORMANCE EVALUATION

In this section, the authors will thoroughly present the MATLAB simulation and its results that derive from the proposed mechanism, under the 5G NR specifications. As for the geographical area, the authors consider a two-level ring topology, where the main 7 macro cells in the center of the topology are the macro cells where users spawn and the authors are interested at and a total of 12 additional macro cells added around the main macro cells. This is necessary in order to simulate a real-life scenario, where actual interference is experienced from neighboring cells (ignoring neighboring interference from other cells would never provide objective results). All macro cell BSs are situated at the cell center and surrounded by 3 small cells. The decision to place all small cells close to the macro cell borders is due to the fact that users that are close to the cell borders experience poor network coverage, alongside with increased interference levels from neighboring cells. Such problems are envisioned to be tackled through small cells deployments. In order to provide the maximum applicable data rates to the network users, the authors set all BSs to operate at maximum power levels.

Network users will most probably be randomly placed inside macro cell infrastructures in which the authors are interested in the simulations and initial user throughput demands are randomly assigned to UL and DL network users. More specifically, UEs are given a 90% chance of spawning inside the macro cell area of interest that and a 10% chance to spawn in areas covered by additional rings. This is necessary so that the authors study scenarios that cells have to cope with augmented amounts of users inside our area of interest, which is the central macrocell deployment (macrocells 1-7). The idea of placing the network devices uniformly (with equal possibilities) inside all macrocells was discarded, simply because the interest is in studying the behavior of the decoupled networks that deal with extensive user congestion and how well the mechanism could respond to such networking scenarios. Studying the decoupled DL network, UEs have a 10% chance of demanding 8 Mbps, 40% chance of demanding 4 Mbps and 50% chance of demanding 2 Mbps. As far as the UL network is concerned, users have a 10% of demanding 4 Mbps, 30% chance of demanding 2 Mbps and 60%

Algorithm 1. Association algorithm for the DL network

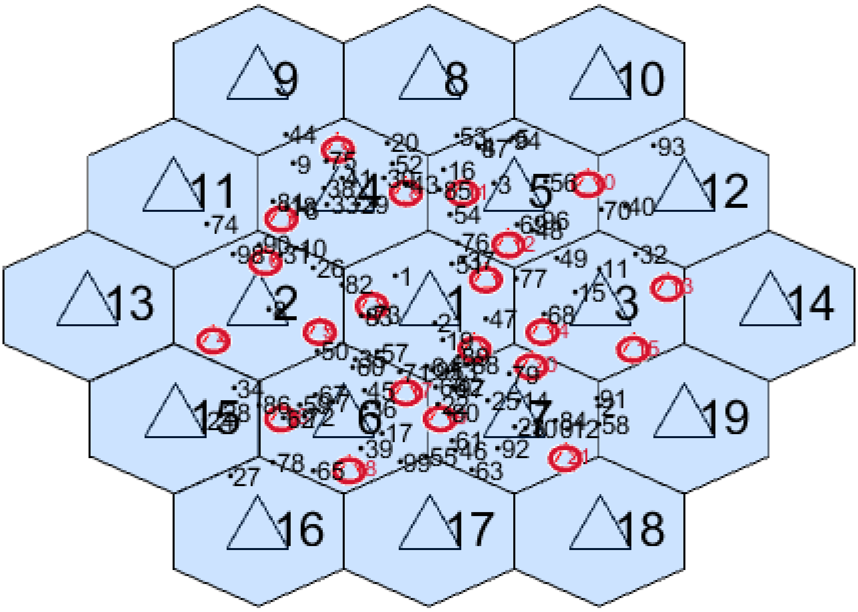
```
function association_DL_mode($r_{user,BS}$, $SINR_{BS,user}^{DL}$)
    for each macrocell BS
        for each CQI = 1:15
            for each UE
                calculate user data rates(CQI);
            end
            calculate average data rates(CQI) for macrocell area;
        end
        calculate optimal average data rates(CQI) for macrocell area;
        select MCS based on average CQI;
        for each UE
            select UE with min($r_{user,BS}$);
            select optimal BS by finding max($SINR_{BS,user}^{DL}$);
            if RBs of this BS are enough
                link UE - BS;
                calculate user data rates(CQI);
                update available RBs of this BS;
            else
                try next best BS by finding new max($SINR_{BS,user}^{DL}$);
            end if
        end for
    end for
end
```

Algorithm 2. Association algorithm for the UL network

```
function association_UL_mode($r_{user,BS}$, $SINR_{user,BS}^{UL}$)
    for each macrocell BS
        for each CQI = 1:15
            for each UE
                calculate user data rates(CQI);
            end
            calculate average data rates(CQI) for macrocell area;
        end
        calculate optimal average data rates(CQI) for macrocell area;
        select MCS based on average CQI;
        for each UE
            select UE with min($r_{user,BS}$);
            select optimal BS by finding max($SINR_{user,BS}^{UL}$);
            if RBs of this BS are enough
                link BS - UE;
                calculate user data rates(CQI);
                update available RBs of this BS;
            else
                try next best BS by finding new max($SINR_{user,BS}^{UL}$);
            end if
        end for
    end for
end
```

chance of demanding 1 Mbps. In the simulations, users may start from 100 and can reach up to 400 in order to study dense 5G HetNet scenarios. Figure 2 presents the MATLAB simulation deployment scenario that assumes 100 network users, where black dots represent UEs, black triangles represent macro cell stations, red triangles represent small cell stations and red circles represent the coverage area of each small cell installation.

Figure 2. MATLAB deployment scenario for the case of 100 UEs



As far as the simulation scenarios as concerned, the authors consider the maximum applicable transmission bandwidth levels for both 5G NR deployment scenarios (FR1 and FR2). This results in to the FR1 configuration of 100 MHz and the FR2 configuration of 200 MHz. The amount of RBs each BS possesses derives is as accurate as stated in Mesodiakaki et al. (2016). the authors will simulate the proposed algorithms for both 5G NR deployment settings that best simulate a 5G network. According to Peralta et al. (2018), using larger SCS shortens the slot duration and enables fast data transmission and because of that, the authors consider as possible SCSs only the settings that maximize the number of RBs for both networks (the authors have already stated that the mechanism would be efficient in terms of resource allocation/management inside both decoupled networks). More specifically, for the FR1 setting, the authors select the 30 kHz as applicable SCS and the 60 kHz for the configuration of the FR2 deployment scenario. As stated in Release 15, the available amount of RBs per BS depends on the sub-carrier configuration and may differ across different sub-carrier settings.

In terms of evaluating the mechanism, the authors will be implementing the mechanism inside a dense urban HetNet and checking whether it reaches the throughput goals through optimal MCS selection inside each distinct macro cell area. Evaluation metrics include a) calculating UE-BS successful associations over both networks, b) data rates measurements and c) SINR comparisons. All metrics are measured for both the decoupled UL and DL networks. The simulation parameters are as accurate as the technical specifications of the 3GPP organization (Third Generation Partnership Project, 2013; Third Generation Partnership Project, 2016; Third Generation Partnership Project, 2018a; Third Generation Partnership Project, 2018b). The overall information is summarized below in Table 1.

In Figures 3 and 4, one may see the total number of macro cell and small cell connections during the FR1 and FR2 deployment simulation scenarios for the cases of 30 kHz and 60 kHz for the SCS, respectively. The only way for a UE to successfully connect to a BS inside each decoupled network is when the BS has the resources needed to provide the available RBs to that specific UE. These demands derive from Equation (4) and pretty much depend on the user's initial throughput demands. For the DL network, when the number of simulated network UEs augments, it is getting harder and harder for UEs to efficiently connect to the optimal BS and as a result, they are eventually forced to

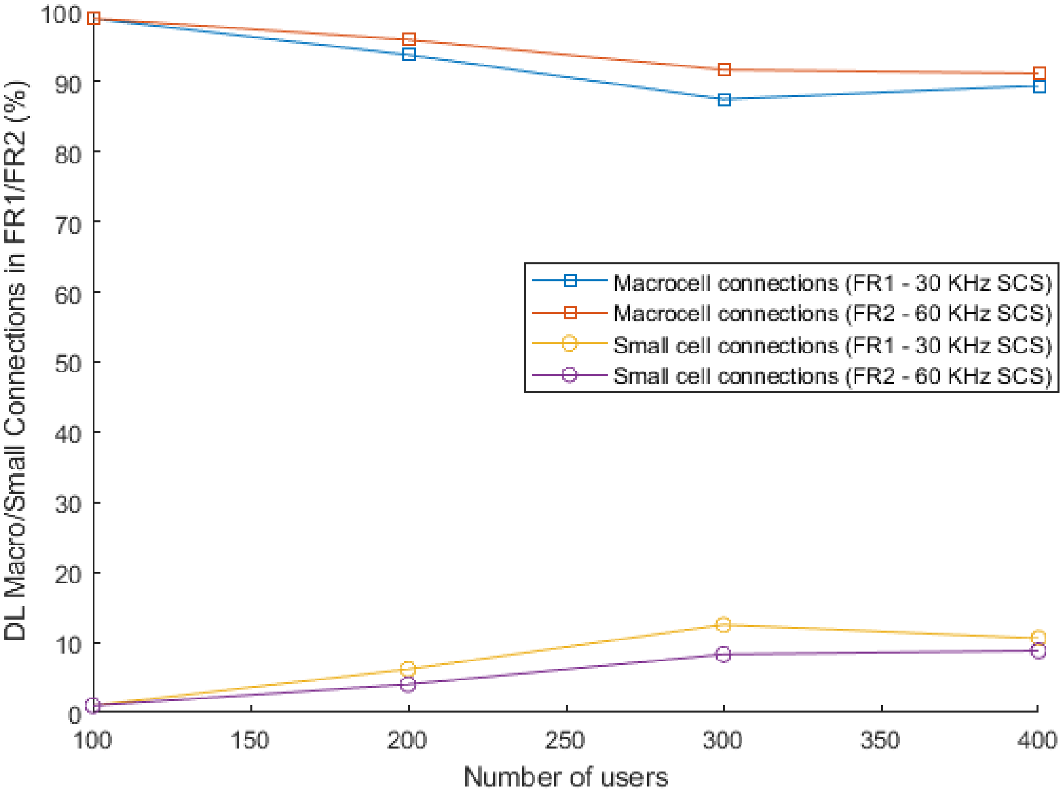
Table 1. Simulation parameters from the deployment scenarios

Parameter	FR1 Scenario	FR2 Scenario
Macro cells	19	19
Small cells	21	21
Modulation Scheme	Adjustable	Adjustable
DL Bandwidth	100 MHz	200 MHz
UL Bandwidth	100 MHz	200 MHz
Resource Blocks (per BS)	273	264
Carrier Frequency	3.5 GHz	30 GHz
RB Bandwidth	360 KHz	720 KHz
Cycle Prefix	Normal	Normal
SCS	30	60
White noise density	-174dBm/Hz	-174dBm/Hz
Macro Cell inter-site distance	750m	750m
Macrocell Radius	375m	375m
Small Cell Radius	50m	50m
BS Antenna Type	Omni-directional	Omni-directional
UE Antenna Type	Omni-directional	Omni-directional
Macro BS $P_{i,max}^{rad}$	30 Watt	30 Watt
Small BS $P_{i,max}^{rad}$	1 Watt	1 Watt
UE $P_{j,max}^{rad}$	0.2 Watt	0.2 Watt

rely on a small cell to server their needs (with a large amount of devices, macro cell RBs run out at higher rates). This phenomenon can be seen in Figure 3, where while network UEs tend to augment, the percentage of user connections to macro cells decreases, but the percentage of user connections to small cell increases, just as the authors expected in a theoretical level.

Moving over to evaluation the different SCS setups, the selection of 60 KHZ seems to be the dominant case for macro cell connections, whereas the setup of 30 KHz is preferable for small cell connections. Again, focusing on the DL network, the reason why the 30 KHz configuration is optimal for macro cells while the 60 KHz configuration is optimal for small cells is directly linked to the number of RBs of the equivalent SCS setup. In more detail, Table 1 suggests a total of 273 available RBs for the FR1 60 KHz setup and each RB is equipped with a bandwidth of 360 KHz. For the 60 KHz setup in the FR2 scenario, the available RBs are equal to 264, but carry augmented bandwidth of 720 KHz (per RB). Since the suggested algorithm rounds the RB demands towards the next integer and UEs that eventually link up with a BS use all the RBs they demanded, when users have increased demands and only macro cells to cover them, it would be preferable for the approach more to supply the BSs with more resources than to reduce them and increase the bandwidth. But, this isn't always the case, simply because when users manage to link up with small cells, this specific associations happens because the RB demands of these users can be already met by small cells, which have less

Figure 3. [DL] Macro cell-small cell connections for FR1/FR2 scenarios



available RBs compared to macro cells (in this case, the 30 KHz configuration of FR2 is evaluated as preferable).

If the authors wanted to compare the performances of both DL and UL networks, then the authors can clearly see that the UL network offers augmented small cell associations. This occurs because in the decoupled UL network, users have significantly less throughput demands than the users of a DL network. This results in less needs for RB demands and later on, to better chances of locating the most efficient/optimal small cell that can server them. Also, the decoupled UL network offers almost identical performances in for both FR1 and FR2 scenarios, regardless of the SCS selection. This result reveals a hidden fact, which is no other than the fact that an optimal SCS selection is efficiently applicable in scenarios where users have significantly increased throughput demands (mostly referring to DL networks).

Figure 5 and Figure 6 present the average user throughput in both FR1 and FR2 scenarios (the authors only take into account users that have successfully established a connection with a BS). From Equations (6) and (8), the authors are aware that user throughput is dependent from the amount of received RBs, the RB bandwidth and the coding rate from the average optimal MCS selected for the macro cell area. After simulating and evaluation the proposed mechanism, the MCS selection of ‘64QAM’ was deemed preferable, because the CQI set that comes along with this modulation scheme manages to maximize user data rates inside a specific macro cell geographical area.

As far as average SINR is concerned, in the DL network, SINR is higher for macro cell connections compared to small cell connections (see Figure 7). This occurs because of the fact that in the DL network, user RB demands are significantly higher than the UL network and as a result, devices shall rely more on macro cell BSs, because macro cell BSs offer higher frequency resources due to their

Figure 4. [UL] Macro cell-small cell connections for FR1/FR2 scenarios

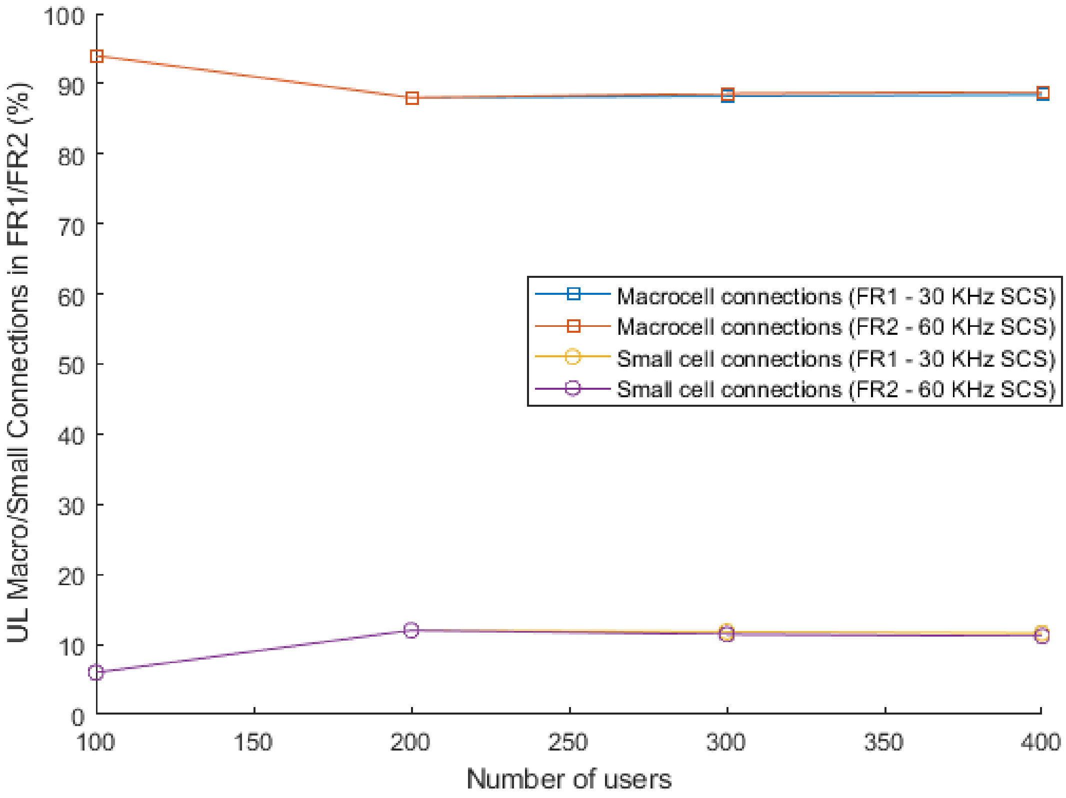


Figure 5. [DL] Average data rates for FR1/FR2 scenarios

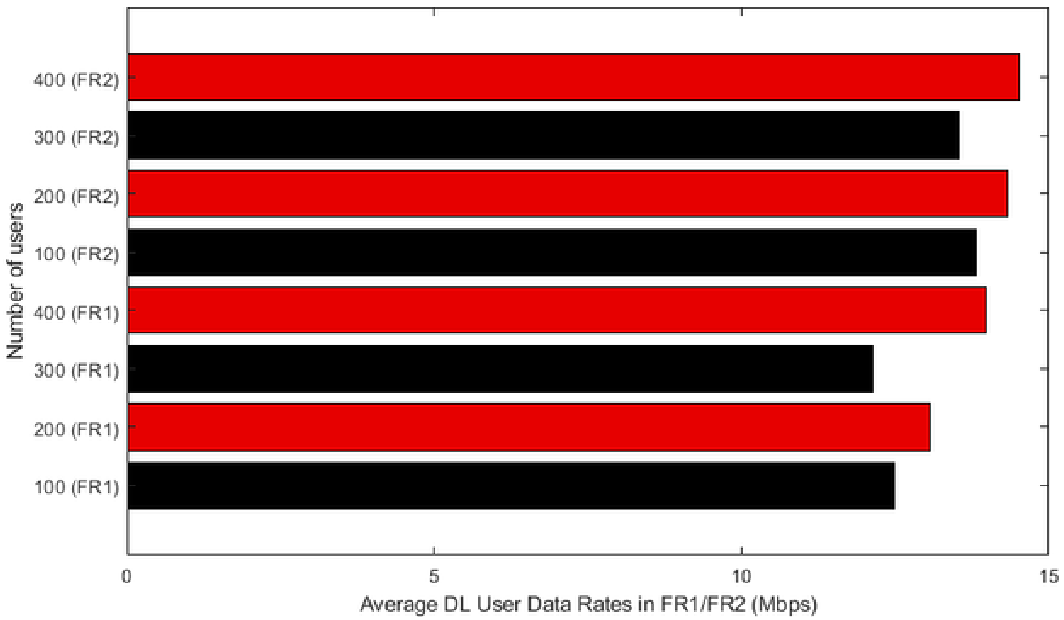


Figure 6. [UL] Average data rates for FR1/FR2 scenarios

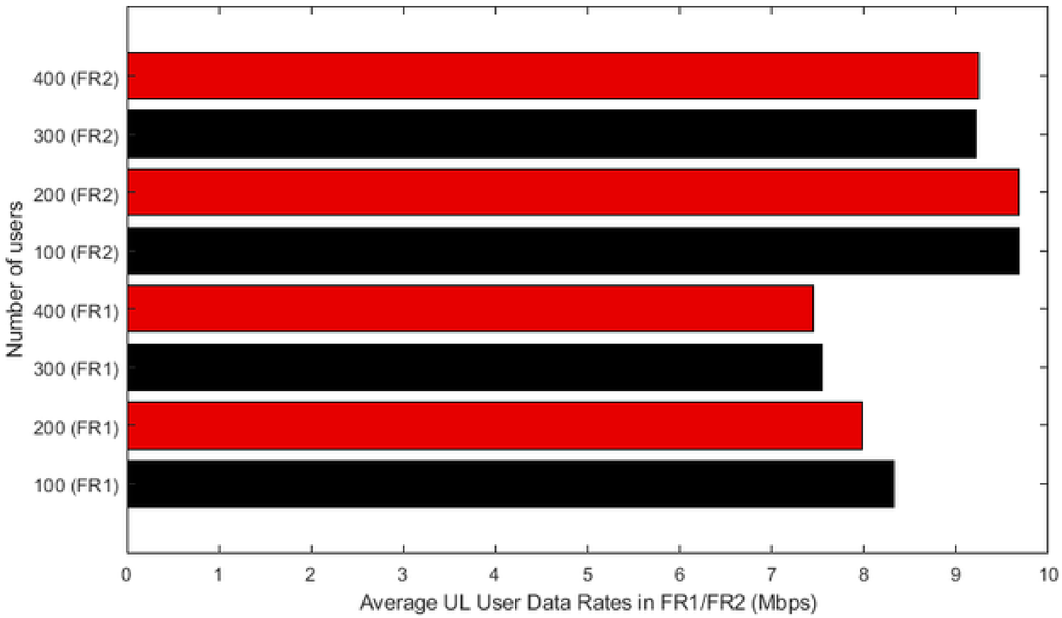
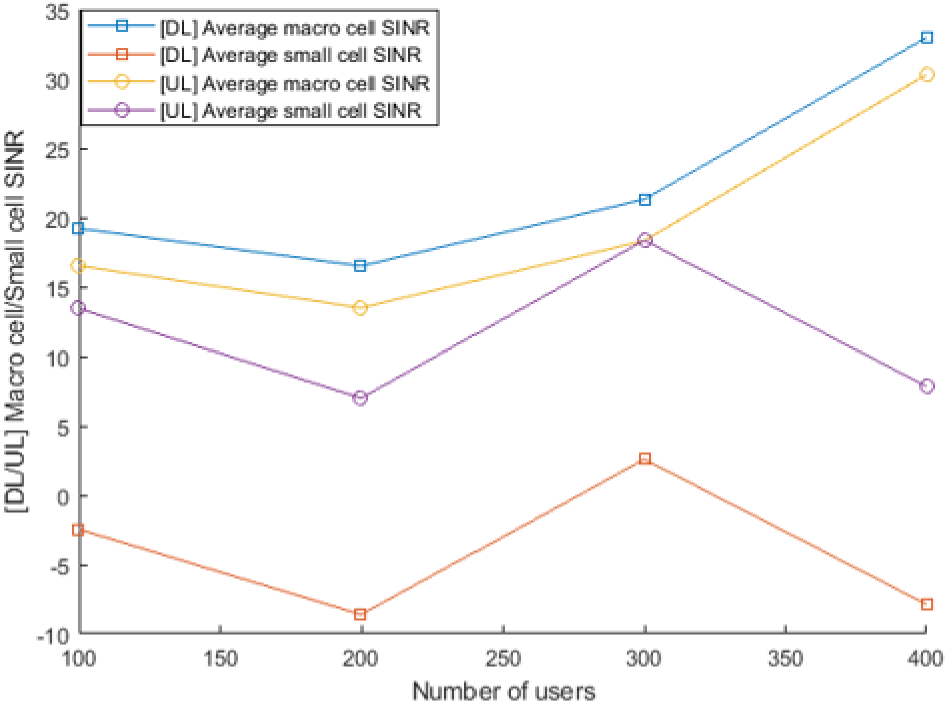


Figure 7. Macro cell and small cell average SINR in DL and UL



power emissions. On the other hand, in the UL network, user RB demands are lower and thus, many users can be served from small cells installations. This does not alter the fact that also in the UL network, more users are served from macro cells rather than from small cells, but it highlights the need for small cells, since the macro cell – small cell difference in the DL network is significantly higher from the difference in the UL network, suggesting that small cells proved very effective, especially for UL deployments.

The increased amount frequency resources that FR2 setup can offer plays a far more important role in user data rates than in associating users and BSs (see Figure 3 and Figure 4). In order to maximize user throughput (and this applies in both DL and UL decoupled networks), the maximum available SCS selection must be applied, which is of course the selection of the 60 KHz for the FR2 deployment scenario. This can also be seen in Figure 5 and Figure 6, where the maximum selection of 60 KHz that FR2 provides as SCS is optimal for both DL and UL networks. The reason behinds this lies to the fact that the FR2 setup, according to the 5G NR specifications, can augment the available bandwidth of each RB from 360KHZ (FR1) to 720 KHz and according to Equations (6) and (8), higher bandwidth results in higher user data rates.

From the experiments, all simulation results for all experiments are presented below in Table 2. As promised, the proposed algorithm managed to preserve each user's initial QoS demands, supplying them with increased data rates from their initial demands. Last but not least, it can be easily observed that deciding to go along with the FR2 setup will result in increased average user data rated and more successful associations, factors that are critical for the upcoming 5G network installations.

CONCLUSION AND FUTURE WORK

In this paper, the authors studied the UC approach for the future wireless 5G networks, an approach that targeted at improving channel quality and provide efficient association options between users and BSs. This approach considered the decoupling of the original homogeneous network into two decoupled and independent networks, the DL and the UL networks. The proposed algorithm from the authors offered optimal average user data rates for each macro cell area through the optimal selection of the modulation scheme that maximizes average user throughput inside this area. The simulations were conducted for both applicable 5G NR scenarios (namely FR1 and FR2). The simulations firstly revealed that the phenomenon where the amount of network devices starts to rise, the user connections to macro cells percentage tends to decrease, whereas the percentage of user connections to small cell increases, something that the authors expected in a theoretical level. Furthermore, the selection of an SCS equal to 60 KHZ proved to be the dominant case for macro cell connections, whereas the setup of 30 KHz was preferable for small cell connections. Additionally, the fact that in the decoupled UL network, users have significantly less throughput demands than the users of a DL network resulted in the UL network offering increased small cell associations, thus taking better advantage of existing small cell deployment. In overall level, the simulations revealed that the algorithm indeed offers perfect QoS preservation and increased data rates for user, higher than those originally requested. By using the FR2 setup instead of the FR1, both networks experienced increased user data rates and increased UE-BS associations.

Future work can include additional mechanisms or algorithms applicable for interference mitigation from neighboring cells or simulation scenarios for high-mobility users, where handover is extremely important. The promising results that derive from the simulation can generate interest in Machine Learning technologies that can be incorporated in 5G networks and used in order to predict (through appropriate datasets) user placement/movement inside the HetNet and distribute the resources to the BSs dynamically according to the user needs. Last but not least, Game Theory is undoubtedly a field that can be used in order to model existing or innovative scenarios that efficiently help towards resource allocation inside HetNets.

Table 2. Simulation parameters from the deployment scenarios

Users	100	200	300	400
FR1 Setting (SCS 30 KHz)				
[DL] Macro cell associations	99	167	196	245
[DL] Small cell associations	1	11	28	29
[DL] Unsupported devices	0	22	76	126
[DL] Selected MCS	64QAM	64QAM	64QAM	64QAM
[DL] Average throughput (Mbps)	12.48	13.06	12.23	13.99
[DL] QoS preservation	100	178	224	274
[DL] QoS preservation (%)	100	100	100	100
[DL] Average macro cell SINR	19.21	16.50	21.30	32.97
[DL] Average small cell SINR	-2.47	-8.61	2.59	-7.87
[UL] Macro cell associations	94	176	254	132
[UL] Small cell associations	6	24	34	41
[UL] Unsupported devices	0	0	12	47
[UL] Selected MCS	64QAM	64QAM	64QAM	64QAM
[UL] Average throughput (Mbps)	8.32	7.98	7.55	7.45
[UL] QoS preservation	100	200	288	353
[UL] QoS preservation (%)	100	100	100	100
[UL] Average small cell SINR	16.51	13.49	18.32	30.30
[UL] Average small cell SINR	13.43	7.00	18.35	7.85
FR2 Setting (SCS 60 KHz)				
[DL] Macro cell associations	99	191	243	300
[DL] Small cell associations	1	8	22	29
[DL] Unsupported devices	0	1	35	71
[DL] Selected MCS	64QAM	64QAM	64QAM	64QAM
[DL] Average throughput (Mbps)	13.82	14.33	13.53	14.52
[DL] QoS preservation	100	199	265	329
[DL] QoS preservation (%)	100	100	100	100
[DL] Average macro cell SINR	19.21	16.50	21.30	32.97
[DL] Average small cell SINR	-2.47	-8.61	2.59	-7.87
[UL] Macro cell associations	94	176	264	326
[UL] Small cell associations	6	24	34	41
[UL] Unsupported devices	0	0	2	33
[UL] Selected MCS	64QAM	64QAM	64QAM	64QAM
[UL] Average throughput (Mbps)	9.68	9.68	9.21	9.24
[UL] QoS preservation	100	200	298	367
[UL] QoS preservation (%)	100	100	100	100
[UL] Average small cell SINR	16.51	13.49	18.32	30.30
[UL] Average small cell SINR	13.43	7.00	18.35	7.85

REFERENCES

Avocanh, F. T. S., Abdennebi, M., & Ben-Othman, J. (2014). An Enhanced Two Level Scheduler to Increase Multimedia Services Performance in LTE Networks. In *Proceedings of the 2014 Institute of Electrical and Electronics Engineers International Conference on Communications (ICC)* (pp. 2351-2356). Academic Press. doi:10.1109/ICC.2014.6883674

Bouras, C., Alexiou, A., Papazois, A., Kokkinos, V., & Tsichritzis, G. (2012). Modulation and coding scheme selection in multimedia broadcast over a single frequency network-enabled long-term evolution networks. *International Journal of Communication Systems*, *25*(12), 1603–1619. doi:10.1002/dac.1326

Cai, S., Che, Y., Duan, L., Wang, J., Zhou, S., & Zhang, R. (2016). Green 5G Heterogeneous Networks Through Dynamic Small-Cell Operation. *Institute of Electrical and Electronics Engineers Journal on Selected Areas in Communications*, *34*(5), 1103–1115.

Comsa, I.-S., Trestian, R., Muntean, G.M., & Ghinea, G. (2020). 5MART: A 5G SMART Scheduling Framework for Optimizing QoS Through Reinforcement Learning. *Institute of Electrical and Electronics Engineers Transactions on Network and Service Management, pp. 1-14*. IEEE Transactions on Network and Service Management. DOI: 10.1109/TNSM.2019.2960849

Comsa, I.-S., Zhang, S., Aydin, M., Kuonen, P., Trestian, R., & Ghinea, G. (2019). A Comparison of Reinforcement Learning Algorithms in Fairness-Oriented OFDMA Schedulers. *Information (Switzerland)*, *10*(10), 1–28. DOI: https://doi.org/10.3390/info10100315

Comsa, I.-S., Zhang, S., Aydin, M. E., Kuonen, P., Lu, Y., Trestian, R., & Ghinea, G. (2018). Towards 5G: A Reinforcement Learning-Based Scheduling Solution for Data Traffic Management. *Institute of Electrical and Electronics Engineers Transactions on Network and Service Management*, *15*(4), 1661–1675. DOI: https://doi.org/10.3390/info10100315. DOI: 10.1109/TNSM.2018.2863563

Elshaer, H., Boccardi, F., Dohler, M., & Irmer, R. (2014). Downlink and uplink decoupling: a disruptive architectural design for 5G networks. In *Proceedings of the 2014 Institute of Electrical and Electronics Engineers Journal on Selected Global Communications Conference* (pp. 1798–1083). Academic Press. doi:10.1109/GLOCOM.2014.7037069

Ghaleb, A., Chieng, D., Ting, A., Abdulkafi, A., Lim, K.-C., & Lim, H.-S. (2013). Throughput performance insights of LTE release 8: Malaysia's perspective. In *Proceedings of the 2013 9th International Wireless Communications and Mobile Computing Conference* (pp. 258-263). Academic Press. doi:10.1109/IWCMC.2013.6583569

Ghaleb, A. M., Mansoor, A. M., & Ahmad, R. (2018). An Energy-Efficient User-Centric Approach for High Capacity 5G Heterogeneous Cellular Networks. *International Journal of Advanced Computer Science and Applications*, *9*(1), 405–411.

Goldsmith, A. (2015). *Wireless Communications*. Cambridge: Cambridge University Press.

International Telecommunication Union. (2015). IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond Recommendation International Telecommunication Union-Radiocommunication Sector M.2083-0.

International Telecommunication Union. (2018). Framework of IMT-2020 network Recommendation International Telecommunication Union-Telecommunication Standardization Sector Y.3102.

Khan, N., Martini, M. G., Bharucha, Z., & Auer, G. (2012). Opportunistic Packet Loss Fair Scheduling for Delay-Sensitive Applications over LTE Systems. In Proceedings of the 2012 Institute of Electrical and Electronics Engineers Wireless Communications and Networking Conference (WCNC) (pp. 1456-1461). IEEE Press. doi:10.1109/WCNC.2012.6214010

Kim, H. (2015). Coding and Modulation Techniques for High Spectral Efficiency Transmission in 5G and Satcom. In *Proceedings of the 2015 23rd European Signal Processing Conference (EUSIPCO)* (pp. 2746–2750). Academic Press. doi:10.1109/EUSIPCO.2015.7362884

Lahad, B., Ibrahim, M., Lahoud, S., Khawam, K., & Martin, S. (2018). Analytical Evaluation of Decoupled Uplink and Downlink Access in TDD 5G Hetnets. In *Proceedings of the 2018 Institute of Electrical and Electronics Engineers 29th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*. Academic Press. doi:10.1109/PIMRC.2018.8580698

Mesodiakaki, A., Adelantado, F., Antonopoulos, A., Alonso, L., & Verikoukis, C. (2016). Energy and spectrum efficient user association in 5G heterogeneous networks. In *Proceedings of the 2016 27th Institute of Electrical and Electronics Engineers Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*. Academic Press. doi:10.1109/PIMRC.2016.7794877

Peralta, E., Levanen, T., Ihalainen, T., Nielsen, S., Hung Ng, M., Renfors, M., & Valkama, M. (2018). 5G New Radio Base-Station Sensitivity and Performance. In *Proceedings of the 2018 15th International Symposium on Wireless Communication Systems (ISWCS)*. Academic Press.

Proebster, M., Mueller, C. M., & Bakker, H. (2010). Adaptive Fairness Control for a Proportional Fair LTE Scheduler. In *Proceedings of the 2010 21st Institute of Electrical and Electronics Engineers Annual International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC)* (pp. 1504-1509). Academic Press. doi:10.1109/PIMRC.2010.5671970

Radwan, A., & Rodriguez, J. (2017). Cloud of Mobile Small-cells for Higher Data-rates and Better Energy-efficiency. In *Proceedings of the 2017 23rd European Wireless Conference*. Academic Press.

Richter, F., Fehske, A., & Fetwweis, G. (2009). Energy efficiency aspects of base station deployment strategies for cellular networks. In *Proceedings of the 2009 Institute of Electrical and Electronics Engineers 70th Vehicular Technology Conference*. Academic Press. doi:10.1109/VETECF.2009.5379031

Wang, J., Jin, A., Shi, D., Wang, L., Shen, H., Wu, D., ... Wang, J. (2017). Spectral Efficiency Improvement With 5G Technologies: Results from Field Tests. *Institute of Electrical and Electronics Engineers Journal on Selected Journal on Selected Areas in Communications*, *35*(8), 1867–1875.

Third Generation Partnership Project. (2013). Small Cell Enhancements for E-UTRA and E-UTRAN-Physical layer aspects. Third Generation Partnership Project Technical Requirements 36.872, v12.1.0, Release 12.

Third Generation Partnership Project. (2016). Radio Frequency (RF) requirements for LTE Pico Node B. Third Generation Partnership Project Technical Specifications 36.931, v13.0.0, Release 13.

Third Generation Partnership Project. (2018a). 5G NR Overall Description; Stage 2. Third Generation Partnership Project Technical Specifications 38.300, v15.3.1, Release 15.

Third Generation Partnership Project. (2018b). Base Station (BS) radio transmission and reception. Third Generation Partnership Project Technical Specifications 38.104, v15.1.0, Release 15.

Third Generation Partnership Project. (2019). Evolved Universal Terrestrial Radio Access (E-UTRA)-Physical layer procedures. Third Generation Partnership Project Technical Specifications 36.213, v15.5.0, Release 15.

Christos Bouras is a Professor at the University of Patras, Department of Computer Engineering and Informatics. Also, he is a scientific advisor of Research Unit 6 in Computer Technology Institute and Press - Diophantus, Patras, Greece. His research interests include the analysis of performance of networking and computer systems, computer networks and protocols, mobile and wireless communications, telematics and new services, QoS and Pricing for networks and services, e-learning, networked virtual environments and WWW issues. He has extended professional experience in the design and the analysis of networks, protocols, telematics, and new services. He has published more than 400 papers in various well-known refereed books, conferences and journals. He is a co-author of 9 books in Greek and the editor of one in English. He has been member of editorial board for international journals and PC member and referee in various international journals and conferences. He has participated in R&D projects.

Vasileios Kokkinos obtained his diploma from the Physics Department of the University of Patras in October 2003. Next, he was accepted in the postgraduate program "Electronics and Information Processing" in the same department and in March 2006 he obtained his master's degree. In 2010 he received his PhD on Power Control in Mobile Telecommunication Networks from the Computer Engineering and Informatics Department. His research interests include data networks, next generation mobile telecommunications networks, multicast routing, radio resource management and wireless networks measurement and verification. He has published several research papers in various well-known refereed conferences and scientific journals.

Evangelos Michos was born in 1995 in Athens, Greece. He entered the Department of Information and Communication System Engineering at University of Patras in 2013 and is currently an undergraduate student. He has obtained the Michigan Certificate of Proficiency in English and the Diplome D' Etudes en Langue Francaise B2. His interests involve web development and next generation mobile telecommunications networks. He has published two research papers in various well-known refereed conferences.