Resource-Efficient Decoupling in Ultra-Dense 5G Networks

Christos Bouras[1,2], Vasileios Kokkinos[2], Evangelos Michos[2]
[1]Computer Technology Institute and Press "Diophantus", Patras, Greece
[2]Computer Engineering and Informatics Dept., University of Patras, Greece
bouras@cti.gr, kokkinos@cti.gr, emichos@ceid.upatras.gr

***Abstract*—The evolution of 5G mobile networks is expected to be comprised of small cell deployments within spitting distance of existing macrocell infrastructures. The small cells adoption, which promises to offer an economical solution for improved coverage and data rate, appears to be the key factor at improving network cooperation and system performance. In this paper, we evaluate the User-Centric model for 5G networks, targeted at improving communication between user terminal and Base Stations across all layers. We suggest a cost-effective, resource-aware method for improved mobile outdoor coverage and overall network capacity while fully respecting the user's Quality of Service, by decoupling the overall network into downlink and uplink networks. The proposed algorithm determines how the network users in both networks will efficiently connect to a Base Station. The network performances are evaluated in terms of data rates enhancements, association outcome and preservation of the Quality of Service for each user. Our low-complexity algorigthm ultimately manages to serve the vast majority of the users placed inside an ultra-dense network and achieve perfect preservation of Quality of Service, regardless of the number of active users.**

Keywords—small cells, 5G, UC model, cell association, data rates.

I. INTRODUCTION

Throughout the history of mankind, there has been an endless list of technological breakthroughs that shaped our lives to what we are today and undoubtedly, mobile communication is one of the most important innovations in the human history. Since the number of mobile subscribers (User Equipment, UE) increases exponentially each year, we are expecting to find ourselves confronted with 7.6 billion mobile subscribers by the year 2020 and the growing demand for network evolution is not expected to slow down [1].

Existent network-centric (NC) homogeneous networks must be altered to sufficiently withstand the incoming data traffic [2]. The upcoming user-centric (UC) heterogeneous networks (HetNets) will be comprised of multiple Radio Access Technologies (RAT) and will focus on spectral efficiency improvements and different multi-antenna advanced methods [3]. These HetNets will not discard the existing macrocell infrastructures, but will densify and expand them with the use of small cells, which will be mainly placed in areas that the macro Base Stations (MBS) do not cover. The small cell Base Stations (SBS) are an attractive solution for the evolution of 5G mobile cellular networks, since their deployment promises to offer increased network capacities, optimized network performance and improved network cooperation for a very low economic cost, compared to the corresponding cost for the MBS (also known as eNodeBs, eNBs).

A dynamic power control mechanism is introduced in [2] that chooses to allow MBS to continue their functionality of tackling network failures outside the small cells coverage region and alternates the small cells operating states inside the SBS. The authors of [3] formulated a UC energy-saving technique based on the HetNets that supports the LTE-A protocol. This mechanism minimizes the overall power consumption without reducing the user data rate. The authors of [4] managed to deploy an LTE-based dense HetNet infrastructure scenario, decoupling the uplink and the downlink and associated downlink cells based on the receiving power and uplink cells based on the pathloss. In [5], the paper authors studied the different strategic layers for small, low-emitting energy BS placed alongside with existent macrocell sites in order to reduce the network energy consumption. The authors of [6] introduced a mechanism that targeted in optimizing the energy and spectral efficiency of the network and was accompanied by low complexity user association algorithm which ensured the association of all UEs with an available BS candidate which had the lower energy consumption. In [7], a novel system architecture is proposed that promises to support multiple devices by offering increased data rates and system capacity, lower latency and improvements at power consumption, through creating a cloud network of on-demand small cells that connects to the mobile network via front-haul linkage. In [8], the paper authors evaluated the network throughput variances based on different implemented modes, whereas the authors of [9] suggested using time-division duplexing (TDD) so as to allocate uplink and downlink resources dynamically over a 5G HetNet.

In this paper, we study the UE-Base Station (BS) association and provide a context-aware solution for capacity enhancements applicable at LTE HetNets, while respecting the user data rates. We formulate the user association model aimed at increasing the system overall capacity and preserving the Quality of Service (QoS) per network subscriber. By decoupling the network architecture, uplink and downlink will now be considered as two separate networks, each of the two requiring different architectures, interference models and throughputs and a pre-established communication between the small cell sites is assumed.

The remainder of this paper is organized as follows. Section II describes the system model for the aforementioned small cells deployment scenario. Section III provides a thorough analysis of the proposed scheme and Section IV offers a summary of the simulation formulas and results that evaluate our system model. Finally, in Section V we present our summarized conclusions for this paper and provide insights over future works.

978-1-7281-1244-2/19/$31.00 ©2019 IEEE

II. System Model

We focus our analysis on a geographical area that incorporates an LTE HetNet where equal-size cell division is already assumed. The area includes both small cells, microcells, femtocells and picocells, placed either within the macrocells or to bridge coverage gaps. Each cell contains a BS placed at its center. Since the UC model requires different approaches for the decoupled networks, we comply with the Orthogonal Frequency Division Multiple Access (OFDMA) for the downlink architecture and with the Single-Carrier-Frequency Division Multiple Access (SC-FDMA) for the uplink architecture. The available frequency in LTE networks is divided into resource blocks (RBs) and each RB consists of 12 consecutive subcarriers for a fixed duration of 1 ms. SC-FDMA is used in order to achieve higher terminal-related power ratings by supplying the network with augmented peak-to-average power ratio [8]. The suggested UC model deployment scenario is depicted in Fig. 1.

We will first examine the power model for both BSs and UEs and then we will calculate the overall power consumption for the network infrastructure. Then, we will evaluate the channel model and construct the data rates model in both the decoupled networks, which heavily depends on the number of subcarriers and the quality measuring of the wireless network, denoted as Signal-to-interference-plus-noise ratio (SINR).

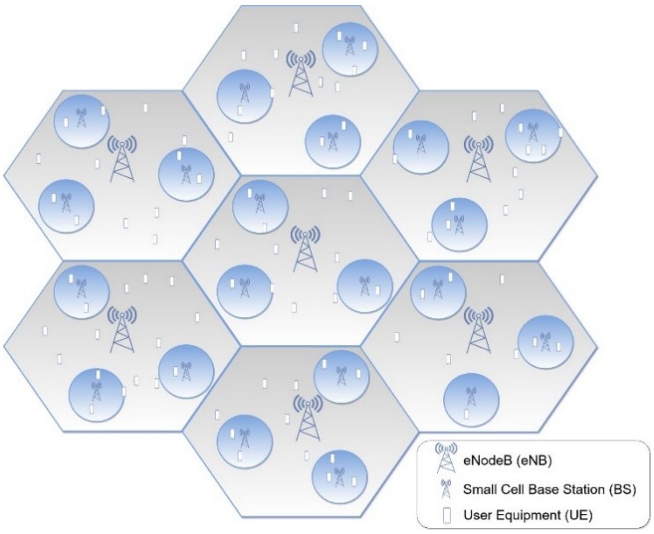

Fig. 1. A network instance of the UC model scenario.

A. Power Consumpion Models

For simplicity reasons, we consider that all BSs operate at their maximum power. Given that each BS is positioned at the center of each cell, let P_i^{BS} be the power consumed by the i^{th} active BS in our system. P_i^{BS} is computed as follows [5]:

$$P_i^{BS} = a_i \cdot P_i^{rad} + b_i \, , \tag{1}$$

where P_i^{rad} equals the outgoing radiated power from the i^{th} active BS, a_i is the consumed radiated power due to feeder/amplifier losses and b_i the consumed power depending on the BS type.

As for the UEs, let P_j^{UE} be the consumed power active mobile user that is connected to a different set of BSs at the downlink and at the uplink, since in the UC model they are decoupled and considered as separate networks. P_j^{UE} is computed as follows [3]:

$$P_j^{UE} = c_j^{\lambda} \cdot \left(\sum_{\lambda \in \mathrm{N_j^{ant}}} \sum_{\mathrm{i} \in \mathrm{N}_{BS}^{\mathrm{UL,i}}} P_{j,i}^{rad,\lambda} \right) + n_i \, , \tag{2}$$

where c_j^{λ} denotes the radiated power consumed due to system losses for each of the λ antennas connected to, N_j^{ant} represents the number of different antennas that the j^{th} user is equipped with, $N_{BS}^{UL,i}$ corresponds to the set of antennas in a specific uplink BS, $P_{j,i}^{rad,\lambda}$ is the radiated power of the λ^{th} antenna for the j^{th} user that is connected in the i^{th} BS and lastly, n_i is the static energy consumption needed for the mobile user to be active. It should be noted that according to [10], the LTE protocol requires that the amount of RBs that a subscriber has acquired for the uplink connection shall first, be consecutive and second, distribute the energy equally over the 12 subcarriers of each RB. In the downlink network however, since the implemented architecture is OFDM-based, the set of subcarriers differentiates over different cell infrastructures.

When a j^{th} UE selects to associate with an i^{th} BS, the UE may select a BS which has the lowest number of RBs but can satisfy the UE-BS association demands. The UE's RB demands are proportional to its throughput demands and inversely proportional to the bandwidth of a specific RB and the SINR between the UE and the BS. The equation for the number of RBs needed for a UE-BS association derives from Shannon's theorem [11] and is computed as:

$$r_{j,i} = \left\lceil \frac{g_j}{B_{RB} \cdot \log_2(1+SINR_{j,i})} \right\rceil , \tag{3}$$

where $\lceil \cdot \rceil$ is the operator for the ceiling function, g_j denotes the UE throughput demands, B_{RB} corresponds to the bandwidth of a specific RB and $SINR_{j,i}$ the wireless connection quality between the UE and the BS.

B. Path Loss Models

Based on the macro cell propagation model for urban areas stated in [12], to measure the signal power losses in our wireless network, we formulate the equation for the distance-dependent path loss model (denoted as PL_{macro} and PL_{small} in the equations below and measured in dB) is the same for both the uplink and the downlink network and equal to:

$$PL_{macro} = 128.1 + 37.6 \cdot \log_{10}(d) \, , \tag{4}$$

where d denotes the distance between the transmitter and the receiver (in kilometers). As for the urban-based small cell propagation model, the equivalent path loss model is as follows [13]:

$$PL_{small} = 140.7 + 36.7 \cdot \log_{10}(d)\,, \tag{5}$$

where d again corresponds to the transmitter-receiver propagation distance (in kilometers). Thus, the channel gain G can be expressed as

$$G = 10^{-PL/10} \tag{6}$$

Both models are calculated provided that all BS sites have an antenna height equal to 15m and the carrier frequency is set to 2 GHz (see Table I). Any additional wall losses are exluded from our model formulation.

C. Data Rates Model

1) Downlink Network: For the downlink network model, we consider $s_{j,i}$ as the subcarrier that the j^{th} UE is assigned with from the i^{th} BS and as for the overall set of subcarriers, we assume that $S^{DL}_{s,j,i}$ denotes the sum of downlink subcarriers that the j^{th} UE is assigned with from the i^{th} BS. Since we decided to use the OFDMA architecture for the downlink, the i^{th} UE which is connected to the j^{th} BS has a data rate of:

$$R^{DL}_{j,i} = \sum_{s \in S^{DL}_{s,j,i}} B_s \cdot \log_2\left(1 + SINR^{DL}_{j,s,i}\right)\,, \tag{7}$$

where B_s denotes the subcarrier bandwidth and $SINR^{DL}_{j,s,i}$ is the SINR of the downlink, transmitted from the j^{th} BS to the i^{th} UE via a subcarrier s. BLER is assumed to be equal to 10^{-4} in both networks. The $SINR^{DL}_{j,s,i}$ is computed as [14]:

$$SINR^{DL}_{j,s,i} = \frac{P^{rad}_{s,i} \cdot G^{DL}_{j,s,i}}{N_0 \Delta f + \sum_{i'} P^{rad}_{s,i'} \cdot G^{DL}_{j,s,i'}}\,, \tag{8}$$

where $P^{rad}_{s,i}$ corresponds to the radiated power from the i^{th} BS over a subcarrier s, $G^{DL}_{j,s,i}$ is the channel gain between a j^{th} UE and an i^{th} BS (over a subcarrier s), N_0 denotes the white noise power spectral density, Δf is the subcarrier spacing and last but not least, $\sum_{i'} P^{rad}_{s,i'} \cdot G^{DL}_{j,s,i'}$ is the overall summation of every power from an i'^{th} BS that causes interference multiplied with the channel gain between the interfering BS and the j^{th} UE.

2) Uplink Network: For the uplink for a j^{th} UE that has the ability to choose the best BS to connect to is given by [3]:

$$R^{UL}_{j,i} = B_{subc} \cdot |N^{UL}_{subs}| \cdot \log_2\left(1 + SINR^{UL}_{s,j,i}\right)\,, \tag{9}$$

where B_{subc} denotes the bandwidth for the associated subcarriers, $|N^{UL}_{subs}|$ is the cardinality of the uplink subcarriers (equal to the number of subcarriers in the associated set) that the i^{th} BS provided to the j^{th} UE and $SINR^{UL}_{s,j,i}$ is the SINR as experienced from the j^{th} UE's point of view. The $SINR^{UL}_{s,j,i}$ is almost identically computed in the same manner as with the $SINR^{DL}_{j,s,i}$ and is equal to [14]:

$$SINR^{UL}_{j,s,i} = \frac{P^{rad}_{j,s} \cdot G^{DL}_{s,i,j}}{N_0 \Delta f + \sum_{j'} P^{rad}_{s,j'} \cdot G^{DL}_{s,i,j'}}\,, \tag{10}$$

where $P^{rad}_{j,s,i}$ corresponds to the radiated power from the j^{th} UE over a subcarrier s, $G^{UL}_{j,s,i}$ is equal to $G^{DL}_{j,s,i}$ and refers to the channel gain between a j^{th} UE and an i^{th} BS (over a subcarrier s). N_0 denotes the white noise power spectral density, Δf is the subcarrier spacing and $\sum_{j'} P^{rad}_{s,j'} \cdot G^{DL}_{j',s,i}$ is the overall multiplication of every power from an i^{th} BS that causes interference and the channel gain between the interfering BS and the j'^{th} UE.

To calculate SINR in (dB), we will have to transform the equations derived from (8) and (10) into the equations below:

$$SINR^{(DL)}_{(dB)} = 10 \cdot \log_{10}\left(SINR^{DL}_{j,s,i}\right)\,, \tag{11}$$

$$SINR^{(UL)}_{(dB)} = 10 \cdot \log_{10}\left(SINR^{UL}_{j,s,i}\right)\,, \tag{12}$$

III. Proposed Scheme

The proposed mechanism assumes pre-defined context information for the network subscribers and favors UE-BS association through UE's decision to establish connection with different cells in the uplink and downlink networks. Aiming at maximizing the spectrum efficiency of the UC model while respecting the user data rates, the aforementioned problem transforms into a minimization of required RBs. The association algorithm is formulated and presented below:

Algorithm 1: UE-BS Association Algorithm

Input: $SINR^{DL}_{j,s,i}$, $SINR^{UL}_{s,j,i}$, $Arch^{DL}$, $Arch^{UL}$, RBs^{DL}, RBs^{UL}

1: **begin**
2: **for each** j in N_{UE} **do**
3:     **for each i** in N_{eNB} **do**
4:         calculate $r_{j,i}$ using (3);
5:     **end for**
6: **end for**
7: **for each** j in N_{UE} **do**
8:   choose UE candidate with min $(r_{j,i})$;
9:   select best BS by finding max $(SINR^{DL}_{j,s,i})$;
10:   **if** the available downlink BS RBs are enough **then**
11:       associate j^{th} UE and i^{th} BS;
12:       update available downlink RBs;
13:   **else**
14:       select best BS by finding new max $(SINR^{DL}_{j,s,i})$;
15:   **end if**
16: **end for**
17: **repeat** steps 7-16 for uplink network
18: **end**

As we can see from Algorithm 1, the proposed low-complexity algorithm requires the following context-aware information: the SINR of the decoupled networks, the system architecture (in our case, this means the uplink and downlink architectures) and the RBs of every available BS in our network. To achieve maximization of spectrum efficiency, we consider as possible BS candidates for the UEs all those who have the lowest RB requirements. As a result, we are ensuring spectrum efficiency for the UE-BS association problem. Repetitively, each UE will select the best available BS candidate so that its data rate transmission demands are met. Each UE-BS association is possible only if there exist remaining RBs, otherwise, we decide to select the next best candidate. As for any remaining BSs, which are not needed for either the uplink or the downlink network, they are simply discarded.

IV. Performance Evaluation

In the simulations we executed in MATLAB, we considered an area that includes 19 macro cells with an inter-site distance of 375m and 21 small cells with a radius equal to 50m. Our area of interest are the 7 macro cells positioned in the center of the ring (colored in Fig. 2 using darker grey) and the small cells they include. Yet, we have included an additional ring of BSs to take into consideration the interference factor as experienced from macro cell infrastructure outside our area of study. Each macro BS is placed at the center of the cell and each cell includes 3 small cells, all of them placed close to the cell borders. We selected to place the small cells near the cell borders, since cell-borders users are prone to poor network coverage from the macro cell infrastructure or excessive interference from neighboring cells, issues that can be tackled by the installation of small cells. UEs in our decoupled networks have pre-defined QoS demands that alternate in each simulation based on probab, based on the demands stated in [15]. For our area of interest, we chose to simulate both decoupled networks for different numbers of active users. Initially, we are presented with 50 users in our networks and this number reaches up to 250 users.

Fig. 2 presents the simulation deployment scenario for the case of the 50 network users. Black triangular markers represent macro cell BSs, blue markers are for the small cell BSs and the red markers depict the randomly generated UEs. Users have a 90% chance of appearing inside our area of interest that is served from a cell and 10% to be placed in areas covered by additional rings, so that we study scenarios that cells have to cope with extensive workload. In the downlink network, we set the possibility to 40% for the users to have demands equal to 2048 (Kbps), 30% for the users to have demands equal to 4096 (Kbps) and 10% for their demands to reach up to 8192 (Kbps). For the uplink network, users have 60% possibility of demanding 1024 (Kbps), 30% possibility of demanding 2048 (Kbps) and the remaining 10% is the possibility of demanding 4096 (Kbps). Simulation parameters according to the macro cells are accurate as the parameters stated in [12] and as for the small cells and the UEs, the parameters that were declared in [3] and [13] were used. Table II summarizes the default simulation parameter settings for our overall defined network.

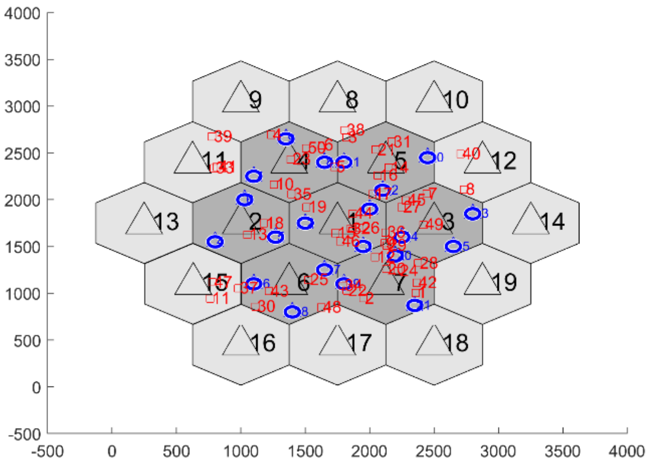

Fig. 2. Deployment scenario for 50 network users.

TABLE I. Default Parameters

Parameter	Setting
Area	19 Macro Cells
Traffic Direction	Downlink/Uplink
Transmission	SISO
Modulation Scheme	64QAM
Duplexing Mode	FDD
Downlink Bandwidth	60MHz
Uplink Bandwidth	40MHz
Carrier Frequency [10]	2GHz
RB Bandwidth [10]	180KHz
Subcarrier spacing [10]	15KHz
White noise density [10]	-174dBm/Hz
Macro Cell inter-site distance [10]	750m
Macrocell Radius	375m
Small Cell Radius [11]	50m
BS Antenna Type [3]	Omni-directional
UE Antenna Type [3]	Omni-directional
BS Antenna Gain [10]	15dBi
UE Antenna Gain [10]	0dBi
Macro BS $P_{i,max}^{rad}$ [10]	40Watt/46 dBm
Small BS $P_{i,max}^{rad}$ [11]	1Watt/30 dBm
UE $P_{j,max}^{rad}$ [11]	0.2Watt/23 dBm

UEs can be associated with one BS in the downlink and another BS in the uplink. As for the MATLAB simulations, we evaluate the performance of the UC architecture in terms of data rates enhancements and successful associations in the separated networks. Simultaneously, our target is to preserve the demanded QoS by using the maximum achievable bandwidth possible, which according the aforementioned standards, results in offering the maximum data rates possible.

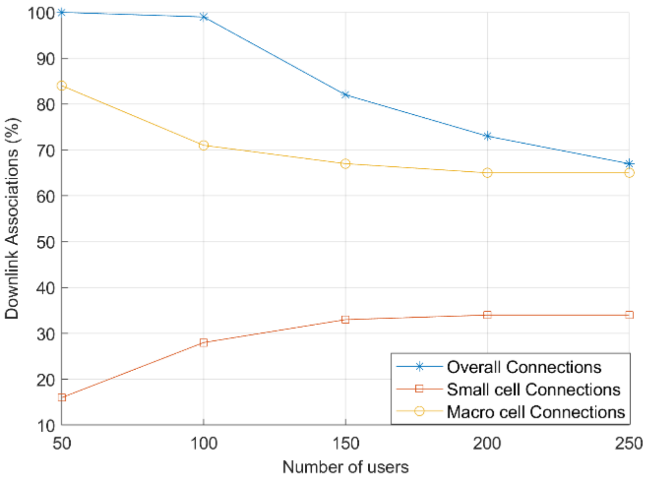

Fig. 3. Succesful UE-BS associations in the DL network (%).

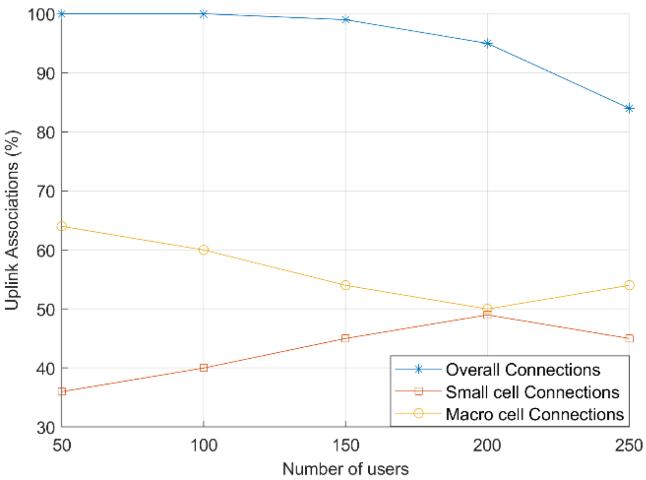

Fig. 4. Succesful UE-BS associations in the UL network (%).

In Fig. 3 and Fig. 4, we see that the proposed algorithm manages to achieve high rates of users that are eventually accepted and served from the network. Beginning from a perfect 100% of DL/UL association percentage when we have a low amount of users (50 in total), in time we find ourselves confronted with a lower percentage of completed associations and this is totally understandable (see Table II). Because each BS in our network has a fixed value for radiated power, the available RBs in the network that derive from the pre-selected bandwidth are equally distributed in the macro cell and the small cell infrastructure. Since the number of users keeps growing but the available RBs in each BS remain the same, eventually it will be a bit of a challenge to manage to serve all the users inside an ultra-dense area, based on their RB demands as stated in equation (3). This eventually results in an decreasing portion of successful associations in both downlink and uplink networks.

For the UE-BS associations in both networks, the graphs above show that the uplink network seems to be working more efficiently than the downlink network and this is because the uplink user throughput demands are significantly lower than the downlink user demands. So, equation (3) will produce lower RB demands for the users in the uplink and this will result in a better chance for a user in the uplink to connect to a BS very nearly its location rather than in the downlink, where throughput demands are significantly higher.

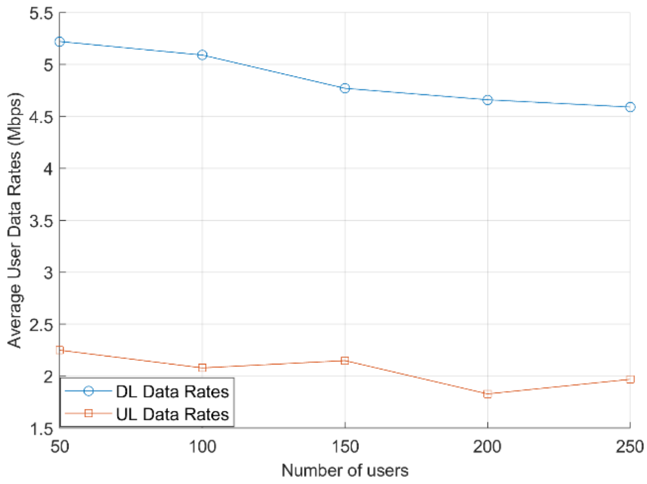

Fig. 5. Average user throughputs in both DL/UL networks.

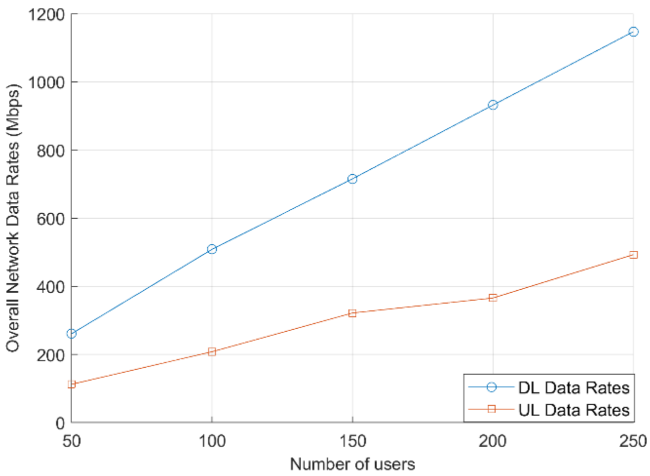

Fig. 6. Overall network throughputs in both DL/UL networks.

Fig. 5 and Fig. 6 depict the data rates as measured from the users' point of view and the overall throughput inside the network infrastructures in the uplink and downlink networks. The throughput of each user is inextricably linked to the number of RBs it demands and the SINR of the BS it connects to, so the higher the SINR is, the higher the data rates will be. Since the majority of the UEs select to connect to a macro cell, each user will probably connect to the BS to which it has the best SINR and so will gain high data rates. But the more users we add to the network, users keep finding it more and more challenging to find an optimal BS for association and will eventually have to connect to a BS that is at a larger distance than the optimal, if the initial attempt to create an optimal UE-BS association is not possible. Eventually, we see that the average user data rates tend to decrease if we add more users to the network and densify it. Yet, since UC model promises to offer more freedom due to the ability to connect to different BSs on the downlink and uplink model and better link quality, we are confronted with higher data rates that we would experience if the network followed a NC approach. As for the overall network data rates, they show an astonishing increase, since they are calculated as the sum of all active UE data rates in both the downlink and uplink networks.

By looking at Table II, we can see that the uplink network performs better than the downlink network by satisfying a larger number of user throughput demands, because the demands in the uplink network are much lower than in the downlink network. Uplink users can more efficiently be served, since they present lower RB demands due to their lower throughput demands. This affects our simulation in many ways, such as the uplink network to present higher successful associations and lower number of unsupported users. Even though there are differences between the number of users that preserve their QoS in both networks, the success rate remains at 100% simply because from equation (3), users that ultimately connect to a BS have equal or higher available RBs than requested, so their demands will always be satisfied.

TABLE II. SIMULATION RESULTS

UEs	50	100	150	200	250
DL Unsupported Users	0	1	26	54	81
DL Macro Cell Connections	42	71	83	96	111
DL Small Cell Connections	8	28	41	50	58
UL Unsupported Users	0	0	1	9	39
UL Macro Cell Connections	32	60	81	97	115
UL Small Cell Connections	18	40	68	94	96
DL Preserved QoS	50	99	124	146	169
UL Preserved QoS	50	100	149	191	211
Average DL UE throughputs (Mbps)	4.92	4.81	4.80	4.73	4.73
Average UL UE throughputs (Mbps)	2.14	2.15	2.04	1.84	1.99
DL Network Data Rates (Mbps)	246.25	481.04	719.95	945.43	1183.25
UL Network Data Rates (Mbps)	107.08	214.63	305.37	367.34	497.69

V. CONCLUSION AND FUTURE WORK

In this paper, we studied the UC model for next generation networks, which enables connections to a BS for at least one direction (uplink or downlink), giving our decoupled networks freedom over managing UE-BS associations.We formulated the problem as a UC model instead of existant NC models and proposed an context-aware association algorithm which decides the BS to connect to for each UE in both networks, provided that the remaining RBs are enough for the association. After evaluating the network performances, the results showed that regardless of the congestion caused by the number of users in a specific area of interest, our algorithm managed to achieve a QoS preservation rate of 100% in both the decoupled networks, for the users that were ultimately served from the network. Also, we experienced more association successes and less unsupported users in the uplink network, due to the users having significantly lower throughput demands (which results in lower RB demands) than the ones in the downlink network. This was a result of users selecting more small cells for association in the uplink network rather than the downlink network, thus showing us the advantages of deploying small cells in crowded areas. Future work may include UC model adjustments and advanced coding schemes for interference mitigation between neighboring cells in the network.

REFERENCES

[1] M. H. Alsharif, and R. Nordin, "Evolution towards fifth generation (5G) wireless networks: Current trends and challenges in the deployment of millimetre wave, massive MIMO, and small cells", Telecommunication Systems Journal, Springer, 64(4), pp. 617-637, 2017.

[2] S. Cai, Y. Che, L. Duan, J. Wang, S. Zhou, and R. Zhang, "Green 5G Heterogeneous Networks Through Dynamic Small-Cell Operation", IEEE Journal on Selected Areas in Communications, 34(5), pp. 1103-1115, 2016.

[3] A. M. Ghaleb, A. M. Mansoor, and R. Ahmad, "An Energy-Efficient User-Centric Approach High-Capacity 5G Heterogeneous Cellular Networks", International Journal of Advanced Computer Science and Applications (IJACSA), 9(1), pp. 405-411, 2018.

[4] H. Elshaer, F. Boccardi, M. Dohler, and R. Irmer, "Downlink and uplink decoupling: a disruptive architectural design for 5g networks", IEEE Global Commucations Conference, pp. 1798-1083, 2014.

[5] F. Richter, A. Fehske, and G. Fetwweis, "Energy efficiency aspects of base station deployment strategies for cellular networks", 2009 IEEE 70th Vehicular Technology Conference Fall, Anchorage, AK, pp. 1-5, 2009.

[6] A. Mesodiakaki, F. Adelantado, A. Antonopoulos, L. Alonso, and C. Verikoukis, "Energy and spectrum efficient user association in 5G heterogeneous networks", in Proc. IEEE 27th Annu. Int. Symp. Pers., Indoor, Mobile Radio Commun. (PIMRC), pp.1-6, 2016.

[7] A. Radwan and J. Rodriguez, "Cloud of Mobile Small-cells for Higher Data-rates and Better Energy-efficiency", 23rd European Wireless Conference, pp. 1-5, 2017.

[8] A. Ghaleb, D. Chieng, A. Ting, A. Abdulkafi, K.-C. Lim, and H.-S. Lim,"Throughput performance insights of LTE release 8: Malaysia;s perspective", in 9th International Wireless Communications and Mobile Computing Conference, pp. 258-263, 2013.

[9] B. Lahad, M. Ibrahim, S. Lahoud, K. Khawam, and S. Martin, "Analytical Evaluation of Decoupled Uplink and Downlink Access in TDD 5G Hetnets", 2018 IEEE 29th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Bologna, pp. 1-7, 2018.

[10] 3rd Generation Partnership Project (3GPP), "3GPP TS 36.211 3GPP TSG RAN Evolved Universal Terrestrial Radio Access (E-UTRA) Physical Channels and Modulation, version 8.3.0, Release 8", 3GPP, Tech. Rep., 2008.

[11] H. Holma and A. Toskala, Eds., "LTE for UMTS: OFDMA and SC-FDMA based radio access", John Wiley & Sons, pp. 213-257, 2009.

[12] 3rd Generation Partnership Project (3GPP), "3GPP TS 36.931, v13.0.0, Radio Frequency (RF) requirements for LTE Pico Node B, (Release 13)", 2016.

[13] 3rd Generation Partnership Project (3GPP), "3GPP TR 36.872, v12.1.0, Small cell enhancements for E-UTRA and E-UTRAN-Physical layer aspects, (Release 12)", 2013.

[14] A. Goldsmith, "Wireless Communications", Cambridge University Press, pp. 24-57, 2005.

[15] 3rd Generation Partnership Project (3GPP), "3GPP TR 36.842, v12.0.0, Study on Small cell enhancements for E-UTRA and E-UTRAN; Higher layer aspects, (Release 12)", 2013.