Cooperative Radio Resources Allocation in LTE_A Networks within MIH Framework: A Scheme and Simulation Analysis

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Abstract: Heterogeneity and convergence are two distinctive features for new generation networks like the Long Term Evolution-Advanced (LTE-A) system. LTE-A is now being deployed and is the way forward for high speed cellular services. LTE-A enhancements the four areas of capacity, coverage, inter-cells coordination, and cost. Improvements in these areas are based on using several technologies. Multiple-Input Multiple Output along with Orthogonal Frequency Division Multiple Access (MIMO/OFDMA) are two of the base technologies that are enablers. In addition, self-organizing and optimization (SON) technologies have been also developed to enable automatic configuration, optimization of network operations, including the 802.21 Media Independent Handover protocol (MIH), which is designed to optimize the vertical handover process. In this paper, we show the importance of inter-technologies and inter-entities cooperation, which can exploit heterogeneity as an enabler to improve the system capacity as well as the quality of service (QoS) for users. We present a new cooperative radio resource allocation scheme for LTE-A network to coordinate better the utilization of network's available radio resources. We adopted the MIH framework, in order to facilitate the exchange between heterogeneous network entities to insure self-configuration of radio resource management parameters. We worked on allocating the right PRB to the right user at the right time. We also analyze some existing solutions and evaluate our proposed scheme using simulation analysis. Simulation results illustrate the performance gains brought by the proposed optimization, especially for average throughput of macro-cell users comparing to their initial performance within two-tier LTE-A network.

1 INTRODUCTION

Next generation of wireless mobile communication systems, provides to end users several amount of multimedia services. Many of these services are too expensive in terms of resources. In order to deal with this explosive of resources' demands, it is essential to have a huge network capacity. In order to fulfill such requirement, some technologies are chosen to be deployed for the next generation of wireless network, like the LTE-Advanced (ETSI TS 36.300 v10.11.0; Akyildiz et al., 2010) system, such as MIMO, OFDMA, Beamforming, small cells enhancements, macro cells enhancements, HetNets, among others. Coming along with their benefits, these new technologies introduce new challenges in radio resource management (RRM) process, which is the key issue to insure efficient exploitation of the available radio resources including especially interference management and resource allocation (Dehghani et al., 2015). In this paper, we deal with radio resource allocation in downlink in case of the LTE_A systems.

Regarding the literature, we find out several interesting works investigating the problem of radio resource allocation in OFDMA networks, some of which are reviewed below. Some works investigated resource allocation based on an optimization theory approach (Dehghani et al., 2015; Papathanasiou, 2013; Alavi et al., 2013; Tang et al., 2015) and others formulate the problem based on game theory approach about which a survey is offered in Akkarajitsakul, 2011. In Dehghani et al., 2015, a radio resources allocation scheme for MIMO/OFDMA system with the employment of beamforming technique is suggested. In this work, users are classified into two groups: interior and exterior users in the cell. Interior users are those where the interference term satisfies that the sum of received signal in all beams is considerably smaller than the Gaussian noise; all others are

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considered as exterior users. Then the total number of PRB is divided onto Q groups (GPRB) with an equal size. For exterior users, all GPRB are sorted in decreasing order of power. Next, the set of GPRBs that will be allocated to exterior users, which is calculated according to their number in the cell, are those with the minimum power for all eNodeBs. The rest of the GPRBs will be automatically allocated to interior users. In Papathanasiou, 2013, authors considered imperfect channel state information (CSI) in the transmitter, which means that CSI is estimated at the receiver then it is fed back to the transmitter, and they take into account bit error rate, rate requirement and delay requirement as QoS constraints. They proposed a heuristic approach including three steps. In the first one, the resource allocation unit decides the number of subcarriers needed by each user according to the QoS requirements. Secondly, subcarriers are assigned to users according to the corresponding power allocation based on the outcomes of the first step and power constraint. In the third step, they suggested the reallocation of some subcarriers according to user's satisfaction.

The remainder of this paper is organized as follows. We give an overview of the present contribution in section 2. Then in section 3, we describe the system model used in our study. The proposed resources allocation scheme is discussed in section 6 as well as the problem formulation. In section 5 the simulation results are presented and analyzed. Finally, section 6 concludes the paper.

2 MAIN CONTRIBUTION

In this paper, we attempt to present a dynamic and cooperative solution to the problem in order to satisfy the LTE-A network features. We considered both network and mobile users constraints. As presented in Figure 1, in the first step we classify users to edge and central users, in both cases users will be collected to M-UE teams according to their localization, velocity and QoS requirements. On the other side, PRBs are assigned by user's M-UE team. We estimate the required number of PRBs by each M-UE team. Then the total available band will be divided into sub-bands of the required estimated value and one of them will be assigned to the corresponding M-UE team of users. The sub-band selection is based on the resolution of optimization problem to maximize the capacity provided by the sub-band for the M-UE team of users. We also study the case when the M-UE team requirement risks overloading the cell, in such case the cell will collaborate with neighbors one to serve the group of users.

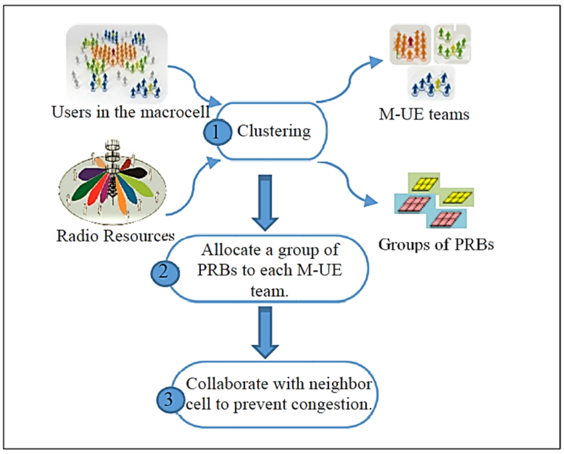

Figure 1: Contribution overview.

When developing the proposed approach, we focus on the selection of the best action by the radio resources allocation scheme to assign the right sub-band to the right M-UE team of users at the right time. We also integrate the congestion control aspect in order to maintain system stability and users required QoS. In fact, when the cell becomes close to overload state, the eNodeB selects a neighbor cell or one of the existing RAT to collaborate with based on information collected about different existed technologies; thanks to MIH deployment (IEEE Std for Local and metropolitan area networks Part 21, 2008).

3 SYSTEM MODEL

In this work, we investigate radio resource allocation for multi-cell downlink OFDMA communication scenario in LTE-A systems. With the OFDM scheme, the total band is equally divided into P physical resource blocks (PRBs) and each user can allocate an integer number of PRBs according to its requirements. Consider MIMO as key technology of LTE-A, where each eNodeB is equipped with Me transmit antennas and users devices are equipped with M_r receive antennas. Each eNodeB transmits a single data stream to each user with zero forcing beamforming. We mean by M_t , the total number of transmit antennas which is equal to $\sum_{i=1}^{E} Me_i$ where E denotes the total number of eNodeB. Figure 2 illustrates the downlink coordinated beamforming

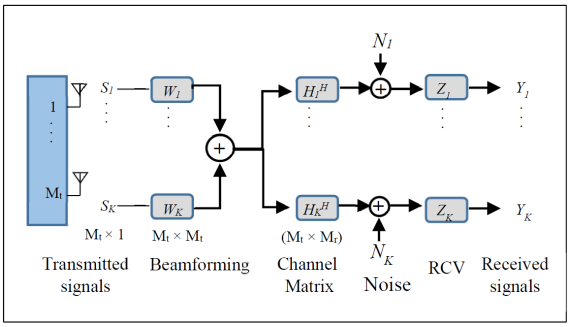

Figure 2: Illustration of downlink coordinated beamforming.

transmission process. Thus, the received signal Y_k^p at user k in the set of K user scheduled in PRB p is modeled in equation (1) below.

$$Y_k^p = Z_k\left(\sum_{i=1}^{E} H_{k,i}^p W_{k,i}^p S_{k,i}^p + \sum_{j=1, j\neq k}^{K} \sum_{i=1}^{E} H_{k,i}^p W_{j,i}^p S_{j,i}^p + N_k^p\right) \quad (1)$$

Where, $H_{k,i}^p \in C^{M_r \times M_e}$ is the channel matrix between user k and eNodeB i at PRB p. $s_{j,i}^p \in C^{M_e \times 1}$ is the data vector transmitted by the eNodeB i for user j employing the beamforming vector $W_{j,i}^p \in C^{M_e \times 1}$ with $\mathrm{E}\left[s_{j,i}^p (s_{j,i}^p)^H\right] = 1$. N_k^p is the additive white Gaussian noise with zero mean and covariance matrix $\sigma^2 I_{Mr}$. Furthermore Z_k denotes the received combining vector employed at user k. So, the SINR for user k connected to eNodeB e at PRB p is modeled as shown below:

$$SINR_{k,e}^p = \frac{\left|Z_k H_{k,e}^p W_{k,e}\right|^2}{\sum_{i=1, i\neq e}^{E}\left|Z_k H_{k,i}^p W_{k,i}^p\right|^2 + \sum_{j=1, j\neq k}^{K}\sum_{i=1}^{E}\left|Z_k H_{k,i}^p W_{j,i}^p\right|^2 + \left|Z_k \sigma_k\right|^2} \quad (2)$$

Moreover, the interference expression in (2) includes the interference introduced from other eNodeBs as well as inter-user interference. However, with Joint Transmission (Bjornson et al., 2011), interference between macro and small base station can be neglected; thanks to the coordination between all of them when serving all covered users.

In practice, the uncertainty of CSI makes the cancellation of inter-users interference an impossible task. The zero forcing beamforming strategy can give inter-users interference relaxation by being limited to some threshold value γ>0 instead of being cancelled (Lee et al., 2011), which means that:

$$\sum_{j=1, j\neq k}^{K}\sum_{i=1}^{E}\left|Z_k H_{k,i}^p W_{j,i}^p\right|^2 \leq \gamma \quad (3)$$

According to the description above, the SINR at user k can be formulated as:

$$SINR_{k,e}^p = \frac{\left|Z_k H_{k,e}^p W_{k,e}\right|^2}{\sum_{j=1, j\neq k}^{K}\sum_{i=1}^{E}\left|Z_k H_{k,i}^p W_{j,i}^p\right|^2 + \left|Z_k \sigma_k\right|^2} \geq \frac{\left|Z_k H_{k,e}^p W_{k,e}\right|^2}{\gamma + \left|Z_k \sigma_k\right|^2} \quad (4)$$

The achieved data rate by user k in its served cell e for one PRB p *is given by*:

$$R_{k,e} = \frac{1}{N_p}\sum_{p=1}^{N_p} \log_2\left(1 + SINR_{k,e}^p\right) \quad (5)$$

Where N_p denotes the number of allocated PRB to user k in by eNodeB e. And the total system capacity is modeled as:

$$C_T = \sum_{e=1}^{E}\sum_{k=1}^{K} R_{k,e} \quad (6)$$

4 RADIO RESOURCES ALLOCATION

To meet expectations of 5G telecommunication systems, an efficient resource allocation scheme is needed, that should be able to provide a capable real time solution. In this paper, we look to find a solution of the problem, while maximizing system capacity and maintaining end users required QoS. As mentioned above we focus on LTE-A RAT, but it could be extended to other RATs. Our approach includes four steps. In the first step, we focus on active users classified into central and edge users. For both cases we collect users into M-UE teams to form what we called M-UE teams, such idea can replace the deployment of small cells in order to cancel inter small cell interference. In addition, it aims to resolve problems with edge users like interference and Ping-Pong effect. The result of step 2 gives the selected group of PRBs that will be allocated to each M-UE team of user, based on CQI indicator. In this step, we also propose a linear problem that maximizes the system capacity under QoS constraints. In next step, we aim to prevent a congestion state in the cell. Hence, we propose to collaborate overloaded cells with neighbor ones that are under-loaded and can serve some M-UE teams of users. Finally, in the last step we track the allocation to check whether the M-UE teams requirements are satisfied or not, or if there is an over served M-UE teams and both cases need a reallocation to improve the efficiency; we consider also new coming call. Next, we describe details of each of these steps.

Step 1:

In the macro cell, users are classified to edge and central one. Then, they are collected into groups to form M-UE teams according to three metric: localization, user's application and user's velocity. The role of M-UE team leader can be assigned to one UE at the same time according to an agreement with the operator. However, this role is not limited to a single user; another one can fill it when principal leader is down, in order to maintain the M-UE team. The number of mobile users by each M-UE team is fixed taking into consideration the capacities of the leader equipment.

Algorithm 1: M-UE Teams Conception.

```
Initialization
L: List of active users in the sector/cell
B: Number of M-UE teams, B=0
V_k: Velocity of user k
R_av: Available data rate
RR_k: Required rate by user k
while Stop=false
   if length (L) >1
   a. Select a leader l, L= L/{l}, B = B +1
   b. Define the max number of user in the M-UE
      team N_max
      while i< N_max and k≤ length (L)
           if | V_k –V_l|< threshold
                Add the mobile terminal to the M-UE team.
                L= L/{k}
                i=i+1
           end
           k=k+1
      end
    if i< N_max
         Stop=true
      end
   else
         Stop=true
    end
end
for b=1 to B
    for k=1to N #N is the number of user in the team
        if | V_k –V_l|> threshold
              So this user will be removed from the M-UE team
        end
    end
    while i< N_max and k≤ length (L)
        if | V_k –V_l|< threshold
            if RR_k < R_av
                 Add the mobile terminal to the M-UE team.
             R_av = R_av- RR_k
                 L= L/{k}
                 i=i+1
            end
        end
            k=k+1
      end
      Liberate unused resources
end
```

The radio resources allocation for each M-UE team of users will be communicated with the eNodeB by the team leader only, which will decrease signalization traffic in the cell.

Step 2:

In the network side, we work on the selection of the best radio resources to be allocated to each M-UE team of users. Therefore, the first issue is the estimation of the number of required PRBs by all users in the M-UE team, according to the required QoS for each user in the team, which depends on the type of traffic. In our work, we considered both real-time and non-real-time traffic (Rysavy). For users with real-time applications, fixed rate are required and for those with non-real-time services only minimum rate requirements are demanded.

The required number of PRBs for user i is calculated as follow:

$$n_i = \left\lfloor \frac{RR_i}{R_{PRB}} \right\rfloor \tag{7}$$

With $\lfloor a \rfloor$ denotes the floor of the fraction, RRi denotes the required rate of user i and R_{PRB} denotes the peak capacity of one PRB. Assume 64QAM modulation without coding, over 2 time slot (1ms) a single PRB has 12 subcarriers and 14 symbols, or

12 x 14 = 168 resource elements (REs). Some of those REs are occupied by the PDCCH and the downlink reference signals, leaving about 120 REs per PRB to carry data on the downlink. And with 64QAM each RE holds 6 data bits, so the maximum data rate delivered by one PRB is equal to:

$$R_{PRB} = M_t \times 720 \ Kb/s \tag{8}$$

Then the total number of required PRBs of the M-UE team *k* is equal to:

$$N_k = \sum_i n_i \tag{9}$$

Next, the available band will be divided into sub-bands each one with a number of successive PRBs equal to the estimated number of required PRBs. Our goal is to maximize the cell capacity. Mathematically, we can present this maximization problem as:

$$\begin{aligned}
&\text{maximize } C_T \\
&\textit{subject to} \\
&C_1: \sum_{\substack{j=1 \\ j\neq k}}^{K} \sum_{i=1}^{E} \left| Z_k H^p_{k,i} W^p_{j,i} \right|^2 \leq \gamma,\ \forall i \in \{1..E\},\ j \in \{1..K\} \\
&C_2: R^{RT}_{k,i} = \gamma_{RT},\ \forall k \in \{1..K^{RT}\} \\
&C_3: R^{NRT}_{k,i} \geq \gamma_{NRT},\ \forall k \in \{1..K^{NRT}\} \\
&C_4: C_T \leq C_{threshold}
\end{aligned} \tag{10}$$

Algorithm 2: PRB Allocation.

Result: Obtain the group of PRBs G_b^* to be allocated to each M-UE team *b*.
Input: Available bandwidth
Input: User's M-UE teams list with leader localization and QoS requirements for each M-UE team.
For each M-UE team b
1. Define Set of users with real time services
Define Set of users with non real time services
2. Initialize G_b*
3. Resolve the problem (10)
End for
Update the available bandwidth to B= B- G_b*
If B <=threshold
Execute the MIH collaborated cell
B= available bandwidth in the new collaborated cell
End

The selected GPRB will be allocated to the correspondent M-UE team of users. In order to maximize system throughput, we adopt downlink beamforming vector for each GPRB (Alavi et al., 2013) and also for each M-UE team of users.

Step 3:

This step is executed by the MIIS server, which aims to form a group of cooperative heterogeneous cells to extend the available capacity. Heterogeneity here describes not only macro or small cells, but also different radio access technologies deployed by the operator in the area, which explain our choice of using MIH technology (IEEE Std for Local and metropolitan area networks Part 21, 2008) to ensure a simple communication between heterogeneous network equipment. The selection of a collaborative cell or collaborative RAT is mainly based on the load of each. This step is executed when one of the LTE cell risks depleting its available resources, which can lead to a congested cell. In order to prevent such scenario, the MIIS is charged to collect information about all neighbors of the current cell in a limited area. Then, it communicates the list of candidates to the eNodeBs. If the eNodeBs find LTE-A cell among the candidates list, it will be selected automatically to establish a collaboration with through direct communication between eNodeBs via X2 interface. Otherwise, one of the least loaded RAT takes the place, and the two stations will exchange direct messages; thanks to the MIHF sub layer. We called the selected cell/RAT the "grandmother cell/RAT", because all new connections in addition to some M-UE teams, if needed, will be served by the "grandmother cell/RAT" via the intermediate of the mother cell which is considered like a remote node when serving new calls/or handover. As soon as possible, the mother eNodeBs interrupt the connection with the "grandmother cell/RAT" and continue by itself to serving all connected users.

Following, is the detailed algorithm for the inter-cell/RAT collaboration establishment executed by the eNodeBs.

Algorithm 3: MIH-Cooperation management.

e_c: Current eNodeB
C_{ec} : Available capacity in the current LTE-A cell
MIH-RR-Coop: list of cooperative cells/RATs
$C_{MIH\text{-}RR\text{-}Coop}$: Total available capacity of the cooperative
group of cells/RATs
Initialization:
MIH-RR-Coop ={e_c};
$C_{MIH\text{-}RR\text{-}Coop}$ =C_{ec};
Stop=false;

While $C_{MIH\text{-}RR\text{-}Coop}$ < threshold and Stop=false
- ♦ Sending a request to MIIS for searching a cooperative cells
- ♦ Neighbors' capacity state request
- ♦ Select under loaded LTE cells / RATs
- ♦ Response by the list of candidate L_c sorted in ascending by load

  If L_c not empty
  - Select the first cell/RAT in the list
  - Establish collaboration via X2 or MIH.
  - $\mathcal{C} = \mathcal{C}$ + available capacity in the collaborative cell
  - MIH-RR-Coop = MIH-RR-Coop ∪{selected cell}

  Else

  Stop=true

  end

End

If stop=true

Reject new call

Decrease the rate for some users

End

End.

We define a new MIH primitive of service "MIH-Cooperate.req" to be exchanged between the MIH information server and the eNodeBs to ensure the collaborative resources allocation between LTE-A macro-cells. This primitive has as a parameter the minimum required capacity and we use also the users' applications to verify that they are supported or not. The syntax of this primitive is given follow:

MIH-Cooperate.req:

{Available capacity

Users applications }

Step 4:

This step deals with allocation track to see if there is over served M-UE teams, so as to withdraw unused resources to be reallocated to underserved M-UE teams or to incoming calls independently or seeing the possibility to include new users to one of the existing M-UE team according to the proposed scheme described above. We also take into account resources as soon as they become available after a terminal leaving.

5 SIMULATION RESULTS

This section illustrates simulation results to evaluate our proposed algorithms in terms of system throughput. We worked with the Matlab-based LTE-A System Level simulator developed by the TU Wien Telecommunications Institute (Mehlfuhrer et al., 2011). The simulator allows both link level and system level simulations. We used also the Matlab-based convex modeling framework CVX (Becker et al., 2011) for the resolution of the optimization problem (10). The LTE-A system parameters used in simulations are presented in Table 1.

Table 1: Simulation Parameters.

Parameter	Description
Duration of simulation	200 TTIs
Number of users per macro cell	100 UEs/MC; 591 in total
M_r	4
M_t	2
User velocity	5m/s
Cell radius	250m
System bandwidth	20 Mhz
Number of PRBs	100 RBs
PRB Bandwidth	180 KHz
Real time requirement [11]	384 kbps
Non real time requirement [11]	32 kbps

In this paper, we compare results of two simulated scenarios:
- An interfered system and no optimization is performed with femtocell deployment only;
- An interfered system with joint MUE-team and femtocell deployment.

First result is shown in Figure 3 that depicts the empirical Cumulative Distribution Function (CDF) for all users' throughput to compare performance when considering macrocells and femtocells with and without the integration of our optimization algorithms. We observe that MUE-teams deployment besides femotocells offer a higher average throughput in comparison to the initial configuration. Indeed, the maximum achieved throughput when deactivating the proposed optimization algorithms is about 9.4 Mb/s. While, when performing our algorithms 20% of users exceed this value with the possibility of achieving 11.8 Mb/s.

Figure 4 shows performance of scheduling SINR in form of the empirical CDF when performing the proposed schemes. By examining the curve we conclude that, for 90% of users our scheme is able to find a better choice of resources allocation than with the initial configuration case.

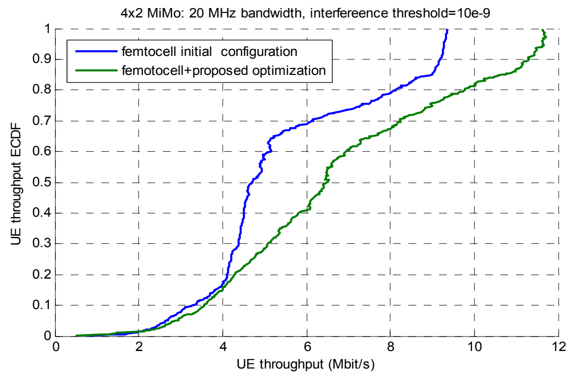

Figure 3: Empirical CDF of global throughput.

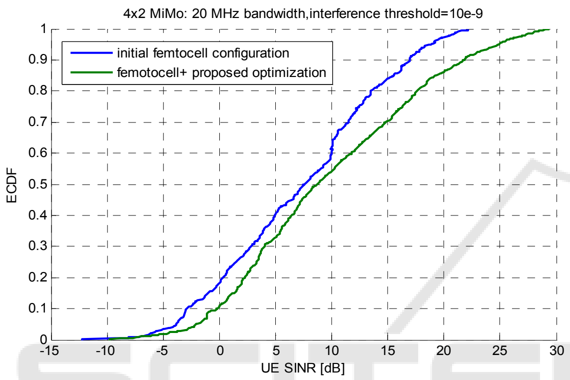

Figure 4: Wideband SINR.

Figure 5 shows the variation of the average throughput in the macro cell with the interference threshold value when using our scheme. This performance is presented for two different concentrations of femotocells. For each simulation run, we fixed three values of threshold interference when maintaining the same configuration. We can clearly observe that there is no major difference between the two cases, even more femotocells means more interference inside the macro cell.

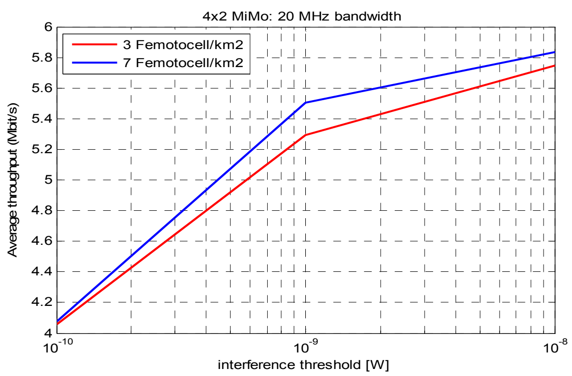

Figure 5: Average throughput vs. interference threshold.

We can conclude that our optimization solution maintains the UE throughput level in various densities of small cells.

6 CONCLUSIONS AND PERSPECTIVES

We developed in this paper a cooperative RR allocation approach for LTE-A systems as multi-RAT environment and highlight the importance of inter-cell and inter-RAT cooperation. The proposed solution makes the heterogeneity an enabler to improve system capacity. We also provide a new way to manage active mobile users in the macro cell, in order to minimize inter user's interference and improve their QoS. We further propose a novel PRBs selection and allocation technique that optimizes resources exploitation. Simulation results show that the proposed scheme maximizes the system throughput while guaranteeing QoS for users. As future work, we attempt to integrate new features like D2D communication technique inside MU-teams. We also intend to deploy radio network virtualization in order to extend system capacity.

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