QoS Aware Collaborative Communications with Incentives in the Downlink of Cellular Network : A Matching Approach

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***Abstract*—The demand for data rate is increasing exponentially in the cellular networks due to the emergence of more and more data-driven applications and smart-devices. Currently, these demands cannot be met by cellular networks with any single technology. As a consequence, Quality-of-service (QoS) needs to be sacrificed by some users. To provide guaranteed QoS to the users, researchers are considering massive MIMO, LTE-A, cooperative communications etc as the suitable candidate for the next generation cellular network. In this paper, we propose a collaborative communication mechanism with incentive for downlink in the cellular network for providing guaranteed QoS by utilizing multiple connectivity of the user's smart equipments. We formulate the problem as an optimization problem first and afterwards, we solve this problem with the help of matching theory. Simulation results are shown to represent performance of the technique.**

***Keywords*-Quality-of-Service; Collaborative Communication; Incentives; Matching; Multiple Connectivity;**

I. Introduction

The number of smart devices like smartphone are gaining popularity due to its more powerful multi-functional capabilities and a report [1] predicts that 70% public of the universe will carry a smartphoe by the end of 2020. These smart devices are creating the demand of more data haul applications. A recent study [2] found that mobile subscribers produced 3.7 exabytes of data traffic worldwide per month in 2015 and the amount will reach 30.6 exabytes per month by 2020. The study [1] also prognosticates that 80% of mobile data traffic will generate from smartphones and online video will be the source of 60% of mobile traffic till 2020. The mobile users download the multimedia-rich contents directly from the base station in current cellular network, which leads to huge traffic congestion to networks in the upcoming days.

As a pursuance, new technologies like Long Term Evolution (LTE) or Long Term Evolution Advanced (LTE-A) and WiMAX have been put forwarded with new techniques namely small cell which are susceptible to provide high data rate and guaranteed quality-of-service (QoS) to mobile users [3]. To fulfill the flourishing data demand of users are impossible to meet with the current third or fourth generation (3G or 4G) cellular networks. So, we should think unusually for next generation cellular system as 5G to meet these challenging data greed of the applications.

Massive MIMO (Multiple Input Multiple Output) is one of the exigent postulant technologies for 5G cellular networks [4]. The network can achieve performance many times when both transmitter and receiver employ multiple antennas. However, the cost and complexity of massive MIMO implementation in vast level is a tenacious job in current situation. But the performance of such network can be enhanced significantly with the increase number of receiving antennas [5]. At present, smartphones and tabs are equipped with multiple network connectivities (Wi-Fi 802.11a/b/g/n/ac, Bluetooth 4.0 LE, NFC, 4G LTE (Cat 4)). So, a natural way to handle the traffic congestion labyrinth is to employ multiple connectivity of the receiving devices by means of cooperation. Cooperative communication among these devices commits momentous performance gains in terms of reliability, efficiency and transmission range [6].

In cooperative communication, each device helps others by mixing cellular and device-to-device (D2D) linking facilities. A cellular link sets up between user equipment (UE) and base station (BS) where D2D link establish between the UEs using cellular resources without direct involvement of BS. D2D communication is good at spectral utilization and QoS with low power consumption [7]. Research community ([8],[9],[10],[11],[12],[13],[14],[15],[16]) focus on cooperative content distribution to the group of users who are in close proximity within wireless network by employing different techniques. But most of the case they consider popular contents and similar needs of the users for their model. In reality, this needs are independent from one user to another in most of the cases and problem is to find the best device that can be used as seed nodes. The paper [17] discusses on the mechanism for selecting the best devices for cooperative content distribution in wireless communication. The cooperation among UEs are considered as voluntary job though UEs are usage it's resources (storage, power, computing, time, etc) in most of the previous research works.

When the needs are different, the requirements of QoS for diverse applications are also variant for users. Typical QoS requirements of multimedia applications are: HD video streaming 800 kbps, Video conferencing 700 kbps, VoIP 512 kbps, Audio streaming 320 kbps and File download 200 kbps [18]. When the QoS of a user is not satisfied with the current rate, it needs help from other UEs to provide a guaranteed

QoS. So, our task is to find out some UEs that can help this UE that requires it. The users are always hoggish in nature and will refuse to contribute their resources in cooperation without getting awarded. Thus the traditional voluntary cooperative communication model is unrealistic and some sort of incentive mechanism should be taken into account for encouraging users in cooperation.

In this paper, we propose a collaborative communication mechanism with incentive for downlink in cellular network when QoS is not guaranteed by itself. First we have formulated the problem as an optimization problem and later solved it by using matching theory. The UE gets benefit of cellular and D2D communication inside the collaboration and helper UEs receive payoff from the system for it's cooperation. The rest of the paper is organized as follows. In Section II, we describe some of the literature review. In Section III, we discuss about system model and problem formulation. DHA as a stable matching is discussed in section IV and V represents payoffs of BS and helper UEs. Experimental results and analysis have been performed in Section VI. Finally the paper is concluded in section VII with some future direction.

II. Literature Review

Contents can be distributed among UEs by using licensed or unlicensed frequency spectrum band in cooperative communications. The article [8] represents an overview of cooperative communication for single-antenna mobile devices to find the benefits of MIMO system. The fundamental idea is to share of antennas by multiple users to form a virtual MIMO system for gaining better throughput. In [9], the authors focus on distribution of dynamic contents over a mobile social network. They consider the optimality and scalability issue in their work first time in cooperation. Whitbeck et al. design a "Push-and-Track" framework for distributing information to mobile users with guaranteed latency to minimize the burden of cellular network in [10]. They consider that most of the users are interested in the same content.

The authors propose a D2D communication framework based upon cooperative relay technique with the usual underlay/overlay D2D communications in the research paper [11]. They consider the performance of both mobile users and D2D users by engaging adaptive mode selection from underlay, overlay or cooperative relay and proper resource allocation by considering it as a weighted bipartite matching problem. In the paper [12], Shalmashi and Slimane represent a skeleton of cooperative D2D communication to overcome the crisis of traffic congestion. Here D2D transmitters are used as an in-band relay for mobile users along with its' normal operations by the help of superposition coding. Overloaded cell can offload the traffic and thus the cell capability can be enhanced. The authors propose cooperative relaying techniques in the paper [13] depending on superposition coding to take advantage of the transmission conveniences of D2D users without degrading the outcomes of the cellular users. By scheduling time and power appropriately, they cancel the interference between D2D pair and cellular equipment and thus provide better outcome.

In the research work [14], the authors first investigate cooperative communication for flourishing system capacity and diversity and then they look at the utilizations of cooperative relaying technique in LTE-A systems. They assess the performance in a intra-cell multi-point environment and find that LTE-A system get benefit in the field of network coverage and capacity by employing such kind of cooperative relay. In this paper [15], the authors first investigate and model the random access procedure on the LTE-A network and attempt to uncover the fall down point in the random access procedure. Then they put forward with a method which engage D2D cooperative relay scheme to mitigate the problem of congestion problem. Finally, they show that their proposal improve the network throughput and congestion of the network with the help of simulation.

Sharafeddine et al look into the capabilities and challenges of employing multiple wireless interfaces simultaneously for smartphones in their paper [16]. Their spotlight was on energy consumption in case of distribution of video in mobile cooperative environment for assessing the performance with the help of experimental technique. They engage different wireless technologies and their combinations for their investigating scenarios.

In our work, we consider QoS requirement of each user for different application as the basic block of collaboration taking into account the selfish nature of the users.

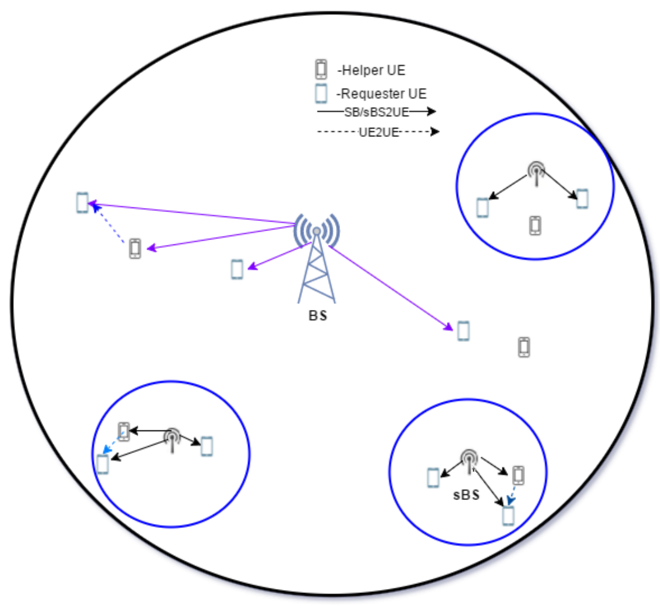

Fig. 1. System Model

III. System Model and Problem Formulation

Consider a circular cellular cell with radius r_0 as shown in Fig. 1 with a traditional BS situated at center of the cell and $\mathcal{B} = \{1, 2, ..., B\}$ sBS with working radius r_b where $b \in \mathcal{B}$ under the coverage of BS. There are M UEs with MIMO facilities distributed randomly within the coverage area of the cell and $\mathbb{M} = \{1, 2, ..., M\}$. The position of BS is considered as $(0,0)$ and location of each UE i with respect to BS is (x_i, y_i). sBS are situated in the periphery of cell coverage area with fixed position. Each user is associated with a sBS if it resides within its coverage area. Otherwise UEs will be associated with macro BS. Let in a particular time t_0, N number of UEs request to the BS/sBS for downloading necessary contents with $\mathbb{N} = \{1, 2, ..., N\}$. The rest $M - N$ UEs represented by $\mathbb{H} = \mathbb{M} \setminus \mathbb{N} = \{1, 2, ..., M - N\}$ are in idle state and can help $\mathbb{N}$ to attain better data rate by contributing there resources. The BS has $\mathbb{S} = \{1, 2, .., S\}$ spectrum resources with $|\mathbb{S}| = S$ and employ orthogonal frequency division multiple access (OFDMA) mechanism for communication with the UEs.

When an UE $i \in \mathbb{N}$ downloads content independently using its own cellular connection through BS/sBS, the data rate it achieves can be calculated by using Shannon's capacity as shown in equation (1).

$$R_{i,dir} = W_d log_2(1 + \gamma^s_{i,b}) \tag{1}$$

where W_d is the cellular down-link bandwidth dedicated for every link $s \in \mathbb{S}$, $\gamma^s_{i,b}$ is the signal to interference noise ratio (SINR) of UE i when downlink communication occurs with BS/sBS and $\gamma^s_{i,b} = \frac{P^s_{i,b} g^s_{i,b}}{P^s_{i',b'} g^s_{i,b'} + W_d N_0}$. Here $P^s_{i,b}$ is the amount of power involved at BS/sBS b to send content to UE i using carrier s, $g^s_{i,b}$ is the channel gain between BS/sBS and UE i when carrier s is used. $P^s_{i',b'} g^s_{i,b'}$ is the interference for UE i due to using the same channel s by some other $b' \neq b$ and N_0 is the white Gaussian noise.

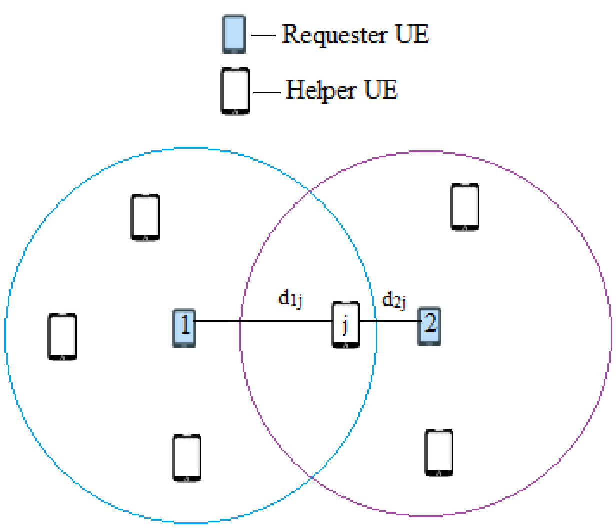

Fig. 2. Overlapping situation of an UE

If the achieved rate $R_{i,dir} \geq QoS_i$ (QoS_i is the minimum rate required for the applications that UE i is using) then it needs no helps from other UEs. Otherwise it requires helps from other UEs to meet the QoS. In that case, our first goal is to find out a set of UEs $H_i \subseteq \mathbb{H}$ that can help UE i for gaining better throughput where $i \in \mathbb{N}$. An UE $j \in H_i$ can assist UE i if it resides in it's local area of activity (LAoA) and is in idle state. If the radius of LAoA of UE i is r_i then UE j can join in cooperation if $d_{ij} \leq r_i$, where d_{ij} is the distance between UE i and UE j. The value of this assistance is the data rate achieved by UE $i \in \mathbb{N}$ in a particular time and reward is given to the members of H_i based on their contribution (data rate). Any UE $j \in H_i$ will help UE i if it gets best benefit that depends on the data rate by investing same amount of resources. Consider the scenario of Fig. 2 where UE j can help both UEs $1, 2 \in \mathbb{N}$. So it is the decision of UE j to whom it will help. From the figure, we find that $d_{1j} > d_{2j}$, where d_{1j} is the distance between UE 1 and UE j and d_{2j} is the distance between UE 2 and UE j, so it is profitable for UE j to support UE 2. The BS/sBS will give this helper UEs a part of their profit for their cooperation and contribution for achieving the better data rate by the requesting UE.

When UE i takes help from H_i then multiple links and connectivities contribute to the data rate gained. Let there are $|H_i| = N_i$ UEs who assist UE i with there resources. So, UE i gets data directly from BS/sBS and also indirectly through other N_i UEs. An UE $j \in H_i$ and $j \neq i$ can get data from BS/sBS with a same rate as in equation (1).

$$R_{j,b} = W_d log_2(1 + \gamma^t_{j,b}), \forall j \in H_i \tag{2}$$

where $t \in \mathbb{S}$ and $t \neq s \neq w$ so that $\exists w$ that has already allocated to any other $k \in H_i$ and $j \neq k$. That is no same sub-carrier will be used for helping UE i. As UEs i and H_i are in close proximity, so this process will reduce interference in the same LAoA. UE $j \in H_i$ can employ it's uplink to send data in the form of D2D communication. The transmission rate of UE j for UE i is shown in the equation (3) where W_u is the uplink bandwidth for any carrier $y \in \mathbb{S}$, $\gamma^y_{i,j}$ is the SINR of between UE i and j and $\gamma^y_{i,j} = \frac{P^y_{i,j} g^y_{i,j}}{\sum_{l \neq i, m \notin H_i} P^y_{l,m} g^y_{i,m} + W_u N_0}$.

$$R_{i,j} = W_u log_2(1 + \gamma^y_{i,j}) \tag{3}$$

Now helper UE j has two data rate namely $R_{j,b}$ and $R_{i,j}$ and minimum of these two rate will be the achievable rate for UE i that is shown in equation (4).

$$R_{i,ind_j} = min(R_{j,b}, R_{i,j}), \forall j \in H_i \tag{4}$$

So, UE i gets the total data rate directly from BS and indirectly from N_i UEs as a cooperation is shown in equation (5).

$$R_i = R_{i,dir} + R_{i,ind} \tag{5}$$

where

$$R_{i,ind} = \sum_{j=1}^{N_i} R_{i,ind_j} = W log_2 \prod_{j=1}^{N_i} D_{i,j} \tag{6}$$

Here $W_d = W_u = W$ and $D_{i,j} = 1 + \gamma^s_{i,j}$ or $D_{i,j} = 1 + \gamma^y_{j,b}$ based on equation (4). Now substitute the value of equations (1) and (6) in equation (5) and letting $D_{i,b} = 1 + \gamma^s_{i,b}$, we find the total data rate gained by UE i.

$$R_i = W log_2 D_{i,b} + W log_2 \prod_{j=1}^{N_i} D_{i,j} = W log_2 \prod_{j \in \{b, H_i\}} D_{i,j} \tag{7}$$

Given a fixed sets of UEs $\mathbb{N}$ and $\mathbb{H}$, one needs to periodically find best $H_i \subseteq \mathbb{H}$ that can help $i \in \mathbb{N}$ to gain better outcome because of the mobility nature of the mobile UEs. We now formulate the Dynamic Helper Assignment (DHA) problem as an optimization problem. Our goal is to find the minimum number of helper UEs so that QoS of UE i can be guaranteed. Mathematically we have the following formulation of the DHA problem:

$$\begin{aligned} \min_{H_i} \quad & |H_i|, \ \forall i \in \mathbb{N} \\ \text{s.t.} \quad & R_i \geq QoS_i \\ & d_{ij} \leq r_i, \ \forall j \in H_i \\ & N_i(t) + 1 \leq L_i \\ & s^p \neq t^q, \ \exists\{p,q\} \in H_i \cup \{i\}, \{s,t\} \in \mathbb{S} \end{aligned} \tag{8}$$

The first inequality in problem (8) ensures that QoS of every UE i is guaranteed. Second inequality tell us that every $j \in H_i$ must be inside the LAoA of UE $i \in \mathbb{N}$. The third inequality assures no to violate the link capacity of UE i and fourth one conserves not of using same sub-carrier in $H_i \cup \{i\}$. This problem (8) is a variation of the multi-objective generalized assignment problem [19] which is NP-hard. Furthermore, scale of the problem is large when you consider the real cellular network environment. The algorithm needs to be computationally proficient for dynamic nature of mobile cellular environment, traditional methods for solving large scale multi-objective optimization (LSMOO) problem is not real. In this paper, we adopt stable matching to encounter such kind of problem which have been regarded as an effective alternative.

IV. DHA as a Stable Matching

To study the DHA problem, we use the skeleton of stable matching namely college admission problem [20] that can be solved by the deferred acceptance algorithm (DAA)[21]. There are two disjoint sets, exemplary requesting UEs $\mathbb{N}$ (acting as colleges) and helping UEs $\mathbb{H}$ (acting as students). By employing preferences over the other sets and blocking pairs, we deduce this phase of DHA problem as a many-to-one stable matching problem. Every UE $i \in \mathbb{N}$ wants to avail guaranteed QoS for it's application by engaging minimum number of UEs $H_i \subseteq \mathbb{H}$ and every UE $j \in \mathbb{H}$ wants to get better payoffs by providing higher data rate for $i \in \mathbb{N}$. We use the traditional notation $b \succ_a c$, means a prefers b than c.

Definition 1: The preference list of the UE $i \in \mathbb{N}$ is represented by $\mathcal{P}_i = \{j, ..., \}$, with helper UEs which reside within the LAoA of i i.e. $d_{ij} \leq r_i, \forall j \in \mathbb{H}$ and also associated in the same BS/sBS as with i. The elements of preference list $\mathcal{P}_i$ are ranked in an ascending order of distance from UE i.

Definition 2: The preference list of the helper UE $j \in \mathbb{H}$ is represented by $\mathcal{P}_j = \{i, ..., \}$ which contains requesting UEs $i \in \mathbb{N}$ within who's LAoA j resides i.e. $d_{ji} \leq r_i$. The elements of preference list $\mathcal{P}_j$ are ordered in ascending of their distance from j.

Definition 3: A matching $\mathcal{M}$ is stable when there exists no blocking pair. In matching, a pair (i, j), $i \in \mathbb{N}$ and $j \in \mathbb{H}$, is a blocking pair if $i \succ_j \mathcal{M}(j)$ and $j \succ_i \mathcal{M}(i)$, where $\mathcal{M}(j)$ illustrates UE j's partner in $\mathcal{M}$ and $\mathcal{M}(i)$ represents UE i's partner in $\mathcal{M}$.

Algorithm 1 Stable Matching

Input: $\mathbb{N}$ and $\mathbb{H}$
Each UE $i \in \mathbb{N}$ sends request to the BS/sBS for downloading the contents and also broadcast the intension
Each UE $j \in \mathbb{H}$ makes a preference list based on the received broadcast information of every $i \in \mathbb{N}$, and Definition 2 and send to the BS/sBS
BS/sBS builds a preference list for every $i \in \mathbb{N}$ depending on the received information from $\mathbb{H}$ and Definition 1
repeat
    Each UE $j \in \mathbb{H}$ proposes to its most preferred UE $i \in \mathbb{N}$ according to its preference list
    if All the proposals don't violate the link capacity constraint of $i \in \mathbb{N}$ **then**
        Every UEs $i \in \mathbb{N}$ holds temporarily all the proposals
    else
        Depending upon the preference list, every $i \in \mathbb{N}$ holds the most preferred proposals that don't violate of it's link capacity constraint i.e. quota
        Every UE $i \in \mathbb{N}$ rejects other unacceptable proposals
    end if
until There is no proposals from the UEs $\mathbb{H}$ or the respective quotas are fulfilled
Output: $\mathcal{M}$

A. Stable Matching Algorithm

We employ DAA method to produce a stable matching between UEs $\mathbb{N}$ and $\mathbb{H}$. We choose helper UEs $\mathbb{H}$ as the proposing side, which yields a stable matching with the requester UEs $\mathbb{N}$. The process is shown in Algorithm 1. Particularly, each side constructs the preference list based on the Definition 1 and 2, UEs $\mathbb{H}$ begin to propose to their most favorable UEs of $\mathbb{N}$. Each UE of $\mathbb{N}$ receives the proposals, chooses its most preferred UEs of $\mathbb{H}$ under the constraints shown in problem formulation (8) and refuse the others. The procedure is reiterated until no proposal can be made anymore.

B. Sub-channel Allocation Algorithm

Algorithm 2 will find minimum number of helpers for guaranteeing QoS with allocated sub-channel by taking into consideration the output $\mathcal{M}$ from the stable matching algorithm.

V. Payoffs of BS/sBS and helper UEs

UE j contributes R_{i,ind_j} data rate for UE i, so it should get a fair proportion of profit from BS/sBS. Profits made by the BS/sBS from UE i is shown in the equation (9).

$$P_i = R_i p \tag{9}$$

Here p is the profit for unit data and same for all of the UEs. The payoff UE j gets from this profit is given by equation (10) where ω is the fraction of profit that will be shared with the helper UEs in the coalition and $\omega \in (0,1)$ and c is the cost of resources of UE j for helping to transmit per unit of data. So, total payoff got by H_i for helping $i \in \mathbb{N}$ is illustrated in the equation (11).

Algorithm 2 Allocating Sub-channels to minimum $\mathbb{H}i$

```
Input: M
Each BS/sBS allocate sub-channel to each UE i ∈ ℕ who
    requests for accessing application
Each BS/sBS calculate achievable rate R_{i,dir} for corre-
    sponding UE i ∈ ℕ
for each UE i ∈ ℕ do
    if R_{i,dir} ≥ QoS_i then
        Mark i as satisfied and label the sub-channel as
        allocated
        set M^i_{min} = ∅
    end if
end for
set j=1
repeat
    Allocate j different sub-channel(s) to j number helper
    UE(s) from M for each unsatisfied UE i ∈ ℕ and
    calculate achievable rate R_{i,dir} and R_{i,ind}
    if R_{i,dir} + R_{i,ind} ≥ QoS_i then
        Mark i as satisfied and label the sub-channel as
        allocated
        Take first j helper UE to M^i_{min}
    end if
    set j=j+1
until There is no unsatisfied UE i ∈ ℕ or no elements
    in M for unsatisfied i
Output: M_{min} with sub-channel allocation list
```

$$P_{j,i} = \omega P_i \frac{R_{i,ind_j}}{R_i} - cR_{i,ind_j} = (\omega p - c)R_{i,ind_j} \tag{10}$$

$$P_{H_i} = \sum_{j=1}^{N_i} P_{j,i} = (\omega p - c)\sum_{j=1}^{N_i} R_{i,ind_j} = (\omega p - c)R_{i,ind} \tag{11}$$

The system profit is shown in the equation (12) and the total payoffs got by the helpers UEs $\mathbb{H}' \subseteq \mathbb{H}$ is represented in equation (13).

$$P_{\mathbb{N}} = \sum_{i \in \mathbb{N}} P_i = p \sum_{i \in \mathbb{N}} R_i \tag{12}$$

$$P_{\mathbb{H}'} = \sum_{i \in \mathbb{N}} P_{H_i} = (\omega p - c)\sum_{i \in \mathbb{N}} R_{i,ind} \tag{13}$$

VI. Simulation and Performance Evaluation

For the simulation, we model the location of the BS to be fixed in the center of radius 1km and the locations of the UEs to be uniformly and independently distributed over coverage space. We take four sBS in the fixed locations $(300,300)$,$(-300,300)$,$(-300,-300)$ and $(300,-300)$ respectively with coverage radius 200m. Here we have 200 helper UEs and varying number (20 to 70) of requester UEs. Each UE has three connectivities: one for direct communication and other two for indirect communication. We consider 49dBm for macro BS and 20dBm for sBS as the transmit power with 10MHz bandwidth and 50 sub-carrier for DL and same for UL. For sketching the propagation environment, we use a path loss $L(d) = 34 + 40log(d)$ and $L(d) = 37 + 30log(d)$ for macro cell and sBS respectively. We assume lognormal shadowing with a standard deviation of 8dB for macro cell and 4dB for LAoA. The power density of thermal noise power is $-114dBm/Hz$. We use same model of sBS for UE2UE communication. We consider the data demanding applications as indicted in [18] here for evaluation and requests are uniformly distributed among them. We use MATLAB for simulating the environment and producing the output. The values represented in the figures are average of 10 runs.

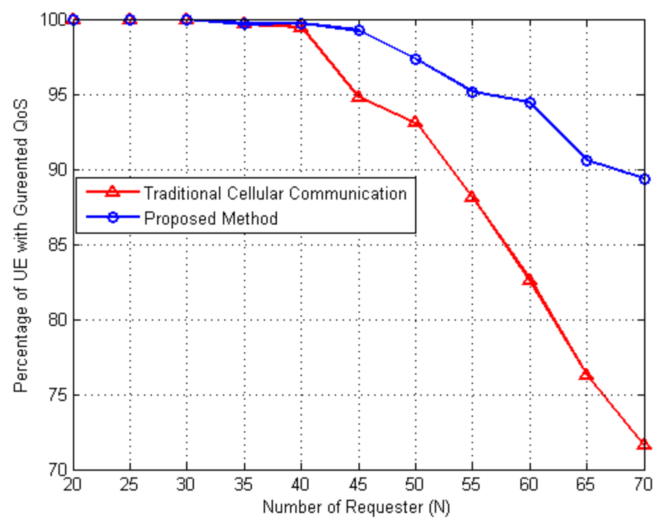

Fig. 3. Satisfied Users when $H = 200$ and $LAoA = 50$m

Fig. 3 shows the percentage of satisfied users in case of cellular communication and in proposed method. From the figure, we see that the proposed method can provide guaranteed QoS to many users than traditional cellular communication. The performance gap between two method is about 18% when there are 70 users accessing different applications as mentioned before.

Fig. 4 represents the system payoffs due to collaboration over the cellular communication technique and collaboration gives better payoff to the system. From the figure, we find that after $N = 55$ the payoff decreased because of interference causing data rate decreased with increasing number of users. Fig. 5 depicts the users' payoffs due to cooperation over mobile communication. It shows that users' net payoffs is better excluding all the cost due to cooperation.

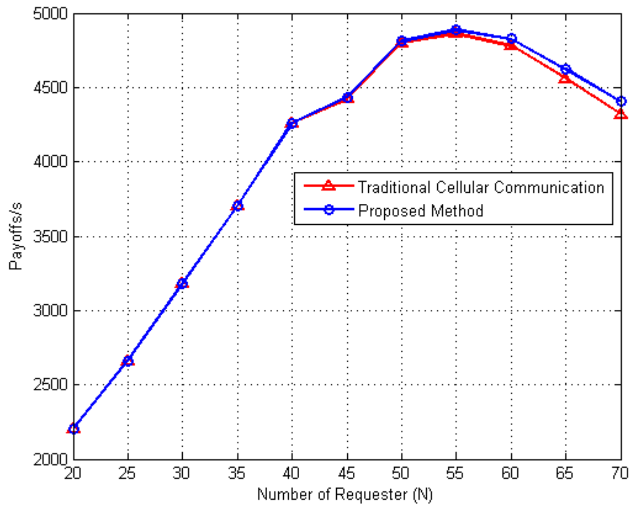

Fig. 4. System payoffs when $p = .02$/unit and $\omega = 30\%$

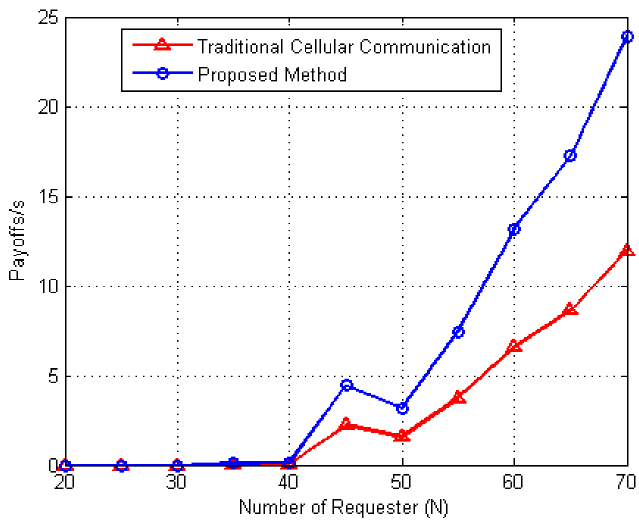

Fig. 5. Helper UE's payoffs when $p = .02$/unit, $c = 0.002$/unit and $\omega = 30\%$

VII. Conclusion

Collaborative communication can be an effective alternative for guaranteeing QoS of the cellular users specially in case of data demanding applications. The paper has considered multiple connectivity of smart devices for communication and incentives to helper UEs on behalf of their assistance. we have solved the helper assignment problem as a many-to-one matching game. Simulation results has shown the effectiveness of the collaborative communication over traditional cellular communication in case of data demanding applications.

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