Traffic Offloading with Maximum User Capacity in Dense D2D Cooperative Networks

Nadine Abbas[1], Zaher Dawy[1], Hazem Hajj[1], Sanaa Sharafeddine[2] and Fethi Filali[3]

[1]Electrical and Computer Engineering Department, American University of Beirut, Beirut, Lebanon

[2]Department of Computer Science and Mathematics, Lebanese American University, Beirut, Lebanon

[3]Qatar Mobility Innovations Center, Doha, Qatar

Emails: [1]{nfa23, zd03, hh63}@aub.edu.lb, [2]{sanaa.sharafeddine}@lau.edu.lb, [3]{filali}@qmic.com

***Abstract*—Ultra dense networks and device-to-device communications are expected to play a major role in 5G networks to meet tremendous traffic requirements. In our work, we address traffic offloading in dense device-to-device cooperative heterogeneous networks with focus on use cases where a very large number of users request simultaneously common streaming content from a remote server with quality of service guarantees. We formulate an optimization problem to maximize the number of users served and reduce the number of access points deployed while satisfying a set of system constraints. The solution determines the best strategy for downloading the content either over long range connectivity from the access points or short range connectivity from peer mobile devices. Results are presented for various scenarios in a stadium setting to demonstrate the significant gains of optimized traffic offloading in ultra dense wireless networks.**

I. Introduction

Ultra-dense networks (UDNs) are considered as one of the key scenarios in 5G networks with the need to accommodate massive connections with ultra-fast speeds. Typical UDNs include dense urban areas, open-air assembly and stadiums where a very high number of users request simultaneously large amounts of data [1]. In such scenarios, common content distribution is considered one of the most emerging applications including live and on-demand video streaming. Typically, all the mobile terminals (MTs) receive their data from the base station or access point (BS/AP). However, due to the large traffic demands, macro network resources are becoming more scarce. To address this challenge, 3GPP suggests using device-to-device (D2D) cooperation for traffic offloading [2]. In cooperative networks, the MTs can then cooperate to receive data using different wireless interfaces, either from the BS/AP over long range (LR) links or from other mobile terminals over short range (SR) D2D links.

Existing literature on D2D traffic offloading aims at one or more of several objectives such as: increasing the network throughput [3], [4], decreasing monetary cost [5] or decreasing energy consumption [6–9]. In [10–14], dense cell deployment networks without D2D cooperation are considered to enhance throughput and energy efficiency. The authors in [10] evaluated the performance of UDN in terms of throughput, spectral and energy efficiency and determined their relationship with BS density. In [11], the authors used power control and user scheduling to optimize energy efficiency of UDNs. The authors in [12] and [13] used machine learning including reinforcement learning, bayesian network model, Q-learning, for spectrum sensing and subchannels allocations reducing blocking, retransmission and interruption probabilities in a stadium network model. The authors in [14] analyzed the capacity and coverage of indoor stadiums considering scattering and reflections of signals from human bodies. In [15] and [16], dense cell deployment networks with D2D cooperation are considered. The authors in [15] proposed a hierarchical architecture for channel allocation aiming at minimizing the latency. In [16], an online learning algorithm for spectrum allocation is proposed to increase throughput, spectral efficiency, fairness, and reduce outage ratio.

Our target in this work is to optimize the system capacity in ultra dense networks while maintaining target quality of service for each user in the network. Our system model addresses traffic offloading in dense D2D cooperative heterogeneous networks where a very large number of users request simultaneously a large amount of data, such as real time video replays during a sports game in a large stadium. We aim at finding optimized strategies for common content data download to serve maximum number of users with minimum LR channels while meeting service target rate. We formulate the problem as an optimization problem to find the optimal LR and SR channels allocation constrained by the number of APs, LR and SR channels, users per cooperation cluster, and transmission rate. We solve the optimization problem using AIMMS software and CPLEX as a solver. To evaluate our solution, we focus on a stadium topology to demonstrate the significant gains of optimized traffic offloading in ultra dense wireless networks.

The rest of the paper is organized as follows. The system model is presented in Section II. The optimization problem formulation is detailed in Section III. Performance results are presented in Section IV. Conclusions are drawn in Section V.

II. System Model

In our work, we address traffic offloading in dense D2D cooperative networks where users are downloading common content video streaming data. The mobile terminals can use two wireless interfaces: one interface to communicate with the BS/AP over a long range wireless technology (such as WLAN, UMTS/HSPA, or LTE) and another interface to communicate with other MTs using a short range wireless technology (such as LTE-Direct, WiFi-Direct, Bluetooth or WiFi ad hoc mode). As shown in Figure 1, the network is formed by BSs/APs and clusters served by a cluster head mobile terminal. Accordingly, a mobile terminal may receive its data from a BS/AP over LR wireless technology or from another MT using SR wireless technology.

Our system model considers an ultra dense network with an area of A m^2 and a high attendants density per 1 m^2. In general, a network is considered dense when more than 1 mobile terminal exists per 1 m^2 [1]. Our network is formed by M BSs/APs and a large number of mobile terminals K. A MT i requests a common content data such as live and on-demand video streaming with a specific transmission target rate $R_{\mathrm{T},i}$. A MT receiving over LR from BS and re-transmitting data to other MTs over SR is considered a cluster head. Each small cell composed of mobile terminals served by the same mobile terminal is considered a cluster. Accordingly, one cluster head exists per cluster or group. The users should be served with LR or SR rates higher than the target transmission rate.

We assume that the rate adaptation is based on M-QAM modulation. The rates $R_{\mathrm{L},ij}$ and $R_{\mathrm{S},ij}$ are the rates achievable on LR and SR channels between transmitter i and receiver j, respectively, computed as $R_{ij} = \log_2 M_{ij} \cdot W$, where W is the passband bandwidth of the channel and assuming the symbol rate is equal to the passband bandwidth, and M_{ij} is the highest possible order of the M-QAM modulation scheme selected based on the following expression [17]:

$$P_{\mathrm{e}} \leq 0.2e^{-1.5\gamma_{ij}/(M_{ij}-1)} \quad (1)$$

where P_{e} is the target probability of error, and γ_{ij} represents the signal-to-noise ratio (SNR) assuming the LR and SR channels are orthogonal: $\gamma_{ij} = P_{\mathrm{r},ij}/\sigma^2$, where σ^2 is the thermal noise power and $P_{\mathrm{r},ij}$ is the received power linked to the transmit power $P_{\mathrm{t},ij}$ of the transmitter i as follows:

$$\left(\frac{P_{\mathrm{r},ij}}{P_{\mathrm{t},ij}}\right)_{dB} = 10\log_{10}\kappa - 10\alpha\log_{10}\frac{d_{ij}}{d_0} + (h_{ij})_{dB} \quad (2)$$

where κ is a pathloss constant which depends on the antenna characteristics and wireless environment, α is the pathloss exponent, d_0 is a reference distance (typically 1 or 10 meters in indoor or short range outdoor scenarios), d_{ij} is the distance between transmitter i and receiver j, and h_{ij} is a random variable representing channel fading [17].

Accordingly, based on the transmit power, distance and channel conditions between the receiver and the transmitter, the transmission rate is estimated. The goal is to serve the maximum number of users, while meeting the service target rate for all the served MTs subject to system constraints and network bandwidth limitations.

III. Traffic Offloading Optimization Problem Formulation

The goal is to maximize the capacity of the system by offloading the data traffic to D2D communication. In this section, we present the problem formulation in the first subsection including objective function, decision variables and constraints. In the second subsection, we present solution methodology and complexity analysis.

A. Problem Formulation

We aim at serving the maximum number of mobile terminals with minimum number of LR channels while maintaining

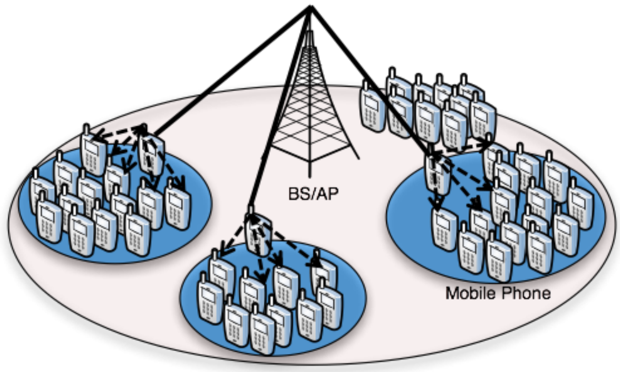

Fig. 1. Dense D2D cooperative network formed by one BS/AP and three clusters.

system target performance for every user. The problem is formulated as an optimization problem aiming at determining the download strategy for every user while meeting target transmission rate. The outcome of the solution determines the mobile terminal connectivity for downloading data either from BS/AP via long range connectivity or from another MT via short range connectivity. The decision variables (Table I) are presented as follows:

- z_i: a binary variable that indicates whether mobile terminal i is served, i.e., receiving data via LR from a BS/AP or via SR from another mobile terminal. In general, users might not be served due to capacity and/or coverage limitation.

$$z_i = \begin{cases} 1 & \text{if MT } i \text{ is served} \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

- y_{mi}: a binary variable that indicates whether mobile terminal i is receiving data over LR from BS/AP m.

$$y_{mi} = \begin{cases} 1 & \text{if MT } i \text{ receives data from BS/AP } m \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

- v_{ij}: a binary variable that indicates whether mobile terminal j is receiving data over SR from MT i.

$$v_{ij} = \begin{cases} 1 & \text{if MT } i \text{ transmits data to MT } j \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

- u_i: a binary variable that indicates whether mobile terminal i is a cluster head, i.e., receiving data over LR and transmitting over SR to other mobile terminals.

$$u_i = \begin{cases} 1 & \text{if MT } i \text{ is a cluster head} \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

Accordingly, the decision variables are: $\mathbf{y}$ a matrix of size $M \times K$, $\mathbf{v}$ a matrix of size $K \times K$, $\mathbf{u}$ and $\mathbf{z}$ vectors of length K. The traffic offloading problem is subjected to several constraints in terms of capacity and coverage limitations. The problem is formulated as follows:

$$\underset{\mathbf{y},\mathbf{v},\mathbf{u},\mathbf{z}}{\text{argmin}} \quad \sum_{m=1}^{M}\sum_{i=1}^{K} y_{mi} - \beta \sum_{i=1}^{K} z_i \tag{7}$$

subject to

$$v_{ij} \le \sum_{m=1}^{M} y_{mi}, \forall i, \forall j \tag{8}$$

$$\sum_{i=1, i\neq j}^{K} v_{ij} + \sum_{m=1}^{M} y_{mj} = z_j, \forall j \tag{9}$$

$$z_i \ge \sum_{m=1}^{M} y_{mi}, \forall i \tag{10}$$

$$z_i \ge v_{ij}, \forall i, \forall j \tag{11}$$

$$\sum_{m=1}^{M}\sum_{i=1}^{K} y_{mi} \le N_{\text{LR}} \tag{12}$$

$$\sum_{i=1}^{K} y_{mi} \le K_{\text{L}}, \forall m \tag{13}$$

$$\sum_{j=1, j\neq i}^{K} v_{ij} \le K_{\text{c}}, \forall i \tag{14}$$

$$u_i \le \sum_{m=1}^{M} y_{mi}, \forall i \tag{15}$$

$$u_i \ge v_{ij}, \forall i, \forall j \tag{16}$$

$$\sum_{i=1}^{K} u_i \le N_{\text{SR}} \tag{17}$$

$$\sum_{m=1}^{M} R_{\text{L},mi} \cdot y_{mi} + \sum_{i'=1, i'\neq i}^{K} R_{\text{S},i'i} \cdot v_{i'i} \ge R_{\text{T},i} \cdot z_i, \forall i \tag{18}$$

$$y_{mi} \in \{0,1\}, v_{ij} \in \{0,1\}, u_i \in \{0,1\}, z_i \in \{0,1\} \tag{19}$$

where

- Equation (7) is the objective function which aims to minimize the usage of long range channels and force more cooperation between mobile terminals. The aim is to serve the largest number of users while using the minimum LR channels. β is a positive coefficient indicating the impact of maximizing the number of users served. Since our primary goal is to serve the maximum number of users, β parameter should have a high value. We assume β is equal to the number of active users to give very high impact for serving users instead of minimizing the use of LR channels.
- The first constraint (8) guarantees that only a mobile terminal receiving over LR can forward data to other mobile terminals over SR. For instance, MT j can receive data from MT i ($v_{ij} = 1$) only if MT i receives data over LR from a BS/AP m $\left(\sum_{m=1}^{M} y_{mi} = 1\right)$. Otherwise, if MT i does not receive over LR $\left(\sum_{m=1}^{M} y_{mi} = 0\right)$, MT j cannot receive data from MT i ($v_{ij} = 0$).
- The second constraint (9) makes sure any MT j that is served by the system ($z_j = 1$), receives data either on LR from BS/AP m $\left(\sum_{m=1}^{M} y_{mj} = 1\right)$ or SR from mobile terminal i $\left(\sum_{i=1,i\neq j}^{K} v_{ij}\right)$.
- Constraints (10) and (11) guarantee that any MT i receiving data over LR or SR is considered served.
- Constraint (12) ensures that the number of LR channels used is less than the maximum number of LR channels N_{LR}.
- Constraint (13) guarantees that the number of users served by every BS/AP is less than K_{L}.
- Constraint (14) guarantees that the number of users in a cluster is less than the maximum allowed number K_{c}.
- Constraints (15), (16) and (17) guarantee that the number of SR channels used by cluster heads is less than N_{SR}. We assume that each cluster head uses one SR channel to send data to other MTs. The variable u_i defines if MT i is a cluster head. The value of u_i is determined based on constraints (15) and (16). Constraint (15) guarantees that MT i can be a cluster head ($u_i = 1$) if it receives over LR (one of the y_{mi} variables is equal to 1), constraint (16) ensures that MT i can be a cluster head if it transmits data over SR (one of the v_{ij} variables is equal to 1). Constraint (17) limits the number of cluster heads to N_{SR}.
- Constraint (18) ensures that the throughput for every mobile terminal (considered served, i.e., $z_i = 1$) is greater than target rate $R_{\text{T},i}$. If a MT is receiving data over LR, its rate R_i will be equal to $R_{\text{L},mi}$ with one of y_{mi} variables equals to 1 and $v_{i'i} = 0, \forall i'$. If the mobile terminal i is receiving over SR from another MT i', R_i will be equal to $R_{\text{S},i'i}$ with $y_{mi} = 0, \forall m$ and $v_{i'i} = 1$.
- The last constraint sets the decision variables **y**, **v**, **u** and **z** to be binary.

TABLE I
MAIN PARAMETERS AND VARIABLES

Parameters	
K	the set of requesting MTs, where a MT is referred to as MT i, $i = 1, ..., K$
M	the set of BSs/APs, where a BS/AP is referred to as BS/AP m, $m = 1, ..., M$
β	positive coefficient indicating the tradeoff between maximizing the number of users served and minimizing the number of LR channels
d_{ij}	distance between transmitter (BS/AP or MT) i and MT j
$R_{\text{S},ij}$	transmission rate on SR from the MT i to MT j
$R_{\text{L},mj}$	transmission rate on LR from the BS/AP m to MT j
$R_{\text{T},i}$	target transmission rate to MT i to meet video application requirements
N_{LR}	maximum number of LR channels in the network
N_{SR}	maximum number of SR channels in the network
K_{L}	maximum number of MTs served by a BS/AP
K_{c}	maximum number of MTs served over SR by a cluster head MT in a cluster
Variables	
z_i	a binary variable that indicates whether MT i is receiving data
y_{mi}	a binary variable that indicates whether MT i is receiving data over LR from BS/AP m
v_{ij}	a binary variable that indicates whether MT j is receiving data over SR from MT i
u_i	a binary variable that indicates whether MT i is a cluster head

B. Solution Methodology

The problem is a binary linear programming problem. The number of binary variables is $MK + K^2$ composed of: $\mathbf{y}$ a matrix of size $M \times K$, $\mathbf{v}$ a matrix of size $K \times K$, $\mathbf{u}$ and $\mathbf{z}$ vectors of length K that can be computed using values of variables $\mathbf{y}$ and $\mathbf{v}$. The problem is NP-complete. Starting with the first two constraints, the problem is divided into two directions or directed graphs whether the mobile terminal is receiving data over LR or SR. Each graph is composed of different subgraphs based on the problem constraints. The problem is similar to Minimum Dominating Set problem in Directed Graphs which has been shown as NP-Hard [18] [19]. It can be shown that solution for the optimal offloading problem can be verified in polynomial time, thus the problem is NP-complete.

We solved the optimization problem using Advanced Interactive Multidimensional Modeling System (AIMMS) software which is designed for modeling and solving large-scale optimization and scheduling-type problems. CPLEX optimization software package in AIMMS was used as a solver [20]. CPLEX uses the simplex algorithm to solve very large linear programming problems, convex and non-convex quadratic programming problems, and convex quadratically constrained problems.

IV. Results and Analysis

In this section, we present first the simulation setup including case study topology, assumptions and main system parameters. In Subsection IV-B, we present the performance of the network without D2D cooperation. In Subsection IV-C, we present solutions with D2D cooperation as a function of user density level.

A. Simulation Setup

As a case study, we consider a stadium with a capacity of 100,000 seats. Our topology is close to the topology of Camp nou stadium, located in Barcelona, Spain. Camp nou, with a seating capacity of 99354, is considered the largest stadium in Europe in terms of capacity. The considered dimensions of the stadium are assumed to be $280m \times 240m$ as shown in Figure 2. Due to the high complexity of the problem and the large number of users, we divided the area into small sections of $20m \times 20m$. The main system parameters are summarized in Table II.

1) Mobile terminal demands: Every $20m \times 20m$ section is composed of 700 seats, assuming the seat width to be $0.5m$, and the space between rows to be $1.14m$ [21]. The attendants density is then equal to 1.75 users per $1m^2$. We based our study on an area of $40m \times 40m$ composed of four $20m \times 20m$ sections, with total of 2800 seats and five deployed BSs/APs as presented in Figure 2. In our work, we refer to user activity A as the probability of users out of 2800, located in the target $40m \times 40m$ area and are simultaneously requesting common content distribution. The number of active mobile terminals K can then be computed as follows: $A \times 2800$. Non active users are not considered present in our model. The active mobile terminals are randomly distributed. In our considered scenarios, the MTs are assumed to download common content real-time video streaming with 1 Mbps target rate requirement.

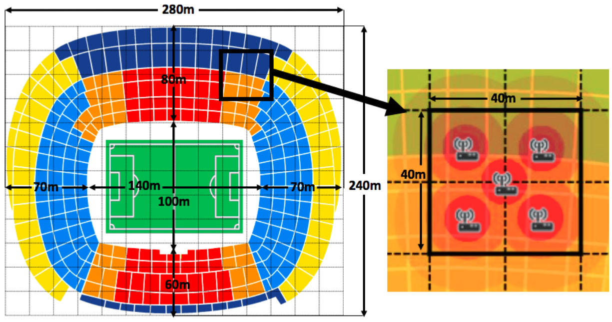

Fig. 2. Stadium with dimensions $280m \times 240m$, divided into $20m \times 20m$ sections, each composed of 700 seats. An area of $40m \times 40m$ area is composed of four sections, 2800 seats and five deployed BSs/APs.

TABLE II
NETWORK PARAMETERS AND ASSUMPTIONS

Parameters	Values
Section area	40m $\times$ 40m
Seats capacity C	2800 seats/section
A	0.1 - 1
K	$C \times A$
$R_{\mathrm{T},i}$	1 Mbps
K_{L}	30 connections/AP
K_{c}	10 connections/cluster head
N_{LR}	$K_{\mathrm{L}} \cdot M$
N_{SR}	$N_{\mathrm{LR}} \cdot K_{\mathrm{c}}$
P_{tLR}	10 Watts
P_{tSR}	0.5 Watts
W	0.5 MHz
P_{e}	10^{-3}
σ^2	10^{-3} Watts
κ	-31.54 dB
α	3.71
d_0	10 m

2) Long range channels capacity and coverage: In our model, we assume the BSs/APs are using 2.4 GHz IEEE 802.11n WLAN. Assuming an overhead of 35%, interference of 35% and a maximum PHY rate of 72.2 Mbps, the estimated AP aggregated throughput will be around 30 Mbps. The maximum number of users served by one AP to meet the target requirements of 1 Mbps will be 30 users/AP. In our model, the transmit power of an AP is assumed to be 10 Watts.

3) Short range channels capacity and coverage: In our model, we assume the MTs are using 5GHz IEEE 802.11n WLAN. The maximum number of users K_{C} served by one cluster head is limited to a maximum of 10 users/cluster. The transmit power of a mobile terminal is assumed to be 0.5 Watts.

B. Performance Results: Conventional Model Without D2D Cooperation

In conventional networks, users download their data from BSs/APs using LR channels. In ultra dense networks, large number of users are requesting data simultaneously. Due to the limitation of capacity and bandwidth, a large number of BSs/APs is then required. Table III presents the number of BSs/APs required to serve simultaneously different user density and network activity. For a network with 0.1 low user activity, 10 BSs/APs are required to serve 280 users within a $40m \times 40m$ area. Our considered stadium is composed of

36 sections of $40m \times 40m$, accordingly, 360 BSs/APs are needed to serve low activity user density of 0.1 in a total $280m \times 240m$ area. The number of BSs/APs increases with the increase of the traffic demand and user activity due to the limitation of LR channels and users served per BS/AP. The number of APs reaches 94 to serve a high density network composed of 2800 users. A total of 3384 BSs/APs are then needed to serve the high user density stadium. Deploying large number of APs is expensive and causes high interference due to the limit on the number of available IEEE802.11n orthogonal channels.

C. Performance Results: System Capacity Increase with D2D Cooperation

Figure 3 shows the outage probability for different scenarios with and without D2D cooperation while varying the user activity representing the density of the users requesting common content simultaneously within $40m \times 40m$ area. The outage probability is very high when no D2D cooperation is considered. The system capacity is limited to 150 and 270 possible connections over LR channels when 5 APs and 9 APs are deployed, respectively. This leads to an outage reaching 94.64% when the network density is very high.

The outage probability decreases when D2D cooperation is considered. The coverage range and capacity of the conventional network are extended by the cluster heads acting as providers to other MTs. When the network density increases within a specific area, the MTs are closer and tend to use SR channels for data download. Accordingly, the number of clusters formed increases to serve more users. The outage will then decrease with the increase of the network density to reach a capacity limited by the number of LR channels K_{L} and the maximum number of users within a cluster K_{c} which is 1650 when 5 APs are deployed. For this reason, the outage probability increases for user activity more than 0.6 (1680 users). Increasing the transmit power $P_{\mathrm{t,LR}}$ of the APs from 5 Watts to 10 Watts decreases the outage percentage from 15.35 to 6.07% for low user activity (A=0.1) , and from 6.13 to 1.78% for high user activity (A=0.6). Deploying 9 APs in the $40m \times 40m$ area allows the network to serve high user density. The outage probability is less than 1% when 2800 users are simultaneously requesting data.

Figure 4 shows the resource allocation of LR and SR channels for low density (0.3) and high density (0.7) network activity. The number of LR channels is very high when no D2D cooperation is used. The number of LR users is reduced from 840 (28 APs) when no D2D is considered to 75 (5 APs) and 76 (9 APs) with D2D cooperation while achieving an outage less than 3% in a low activity scenario. In a high activity scenario, the solution for the optimization problem showed that 9 APs with only 179 LR connections were able to serve 99.95% of the dense network when D2D cooperation is used instead of 66 APs providing 1960 LR connections when no D2D cooperation is considered.

To illustrate the solution for the proposed traffic offloading optimization problem, Figures 5, 6 and 7 show resource allocation of SR and LR connections in $40m \times 40m$ dense area composed of 1960 users (0.7 user activity) for three scenarios: (1) area composed of 5 APs without D2D cooperation, (2) area composed of 5 APs with D2D cooperation, and (3) area composed of 9 APs with D2D cooperation, respectively. As shown in Figure 5, 5 APs can only serve 150 LR users which leads to a very high outage percentage of 92.34% with no D2D cooperation due to LR capacity limitation. The outage probability is reduced to 15.81% when D2D cooperation is used (Figure 6). 14.54% of users are not served due to capacity limitation (maximum possible capacity is 1650 users) and 1.28% due to coverage limitation. To increase the capacity of the dense network, 9 APs were deployed as shown in Figure 7. The outage probability was reduced to 0.05%; only one user was out of coverage.

TABLE III
NUMBER OF BSS/APS NEEDED WITHOUT D2D COOPERATION

Activity A	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Active users in 40mx40m area	280	560	840	1120	1400	1680	1960	2240	2520	2800
BSs/APs needed in 40mx40m area	10	19	28	38	47	56	66	75	84	94
BSs/APs needed in 280mx240m area	360	684	1008	1368	1692	2016	2376	2700	3024	3384

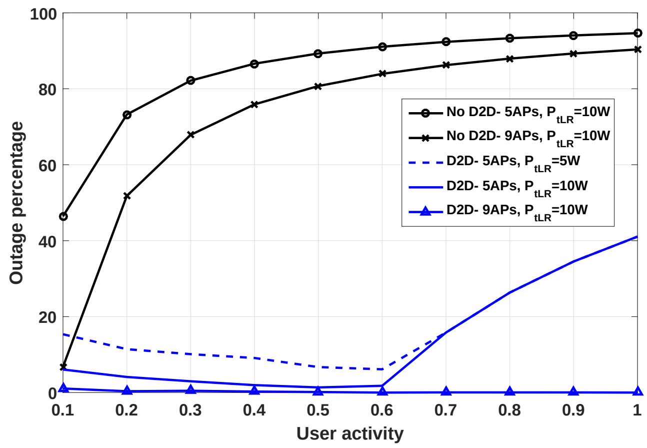

Fig. 3. Outage percentage variation with user activity probability for different network scenarios composed of 5 or 9 APs with/without D2D cooperation.

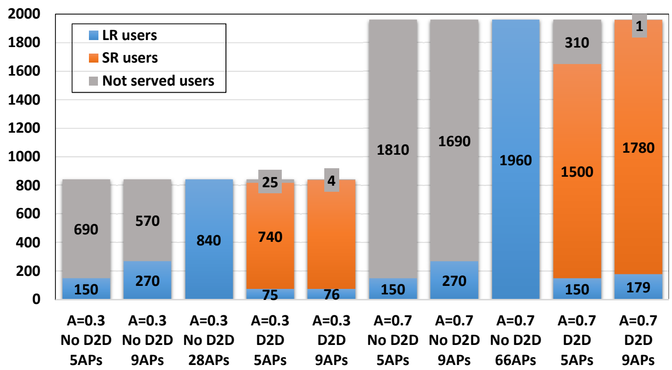

Fig. 4. LR and SR channels allocation for low density (A = 0.3) and high density (A = 0.7) scenarios with/without cooperation.

V. CONCLUSIONS

This paper addressed D2D traffic offloading in dense heterogeneous networks where very large number of users request common content distribution. The problem was formulated as

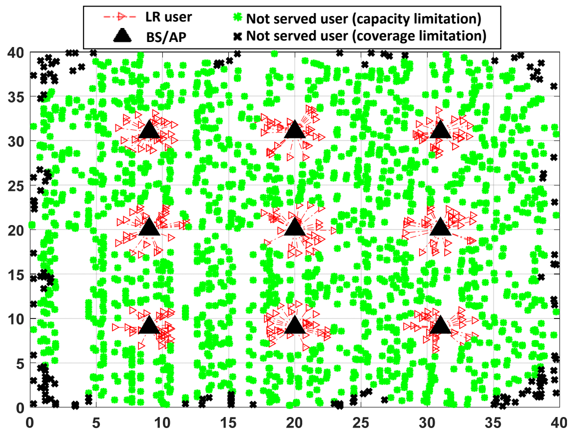

Fig. 5. Resource allocation for $40m \times 40m$ area composed of 1960 users (0.7 user activity) and 9 APs without D2D cooperation. Outage = 92.34%.

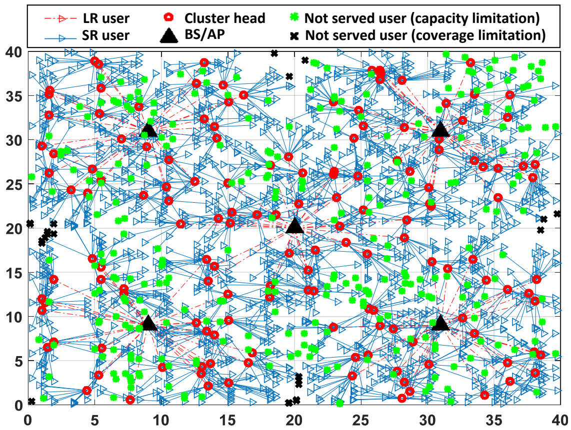

Fig. 6. Resource allocation for $40m \times 40m$ area composed of 1960 users (0.7 user activity) and 5 APs with D2D cooperation. Outage = 15.81%.

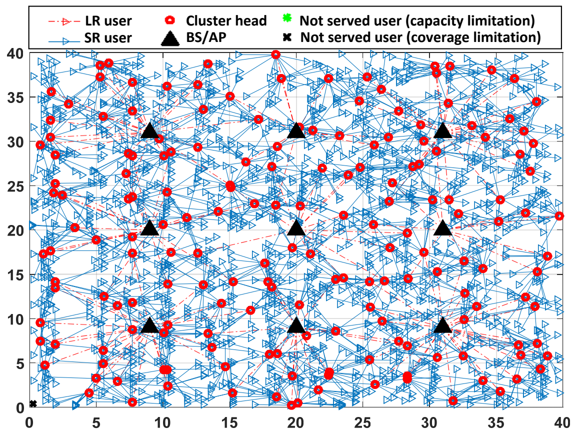

Fig. 7. Resource allocation for $40m \times 40m$ area composed of 1960 users (0.7 user activity) and 9 APs with D2D cooperation. Outage = 0.05%.

an optimization problem to serve the maximum number of users with minimum long range connections. We present a realistic use case for a stadium scenario with detailed performance assessment as a function of various system parameters. Results demonstrate significant performance gains, reflected by both reduction in outage probability and reduction in the number of simultaneously needed LR connections.

VI. Acknowledgments

This work was made possible by NPRP grant 7-1529-2-555 from the Qatar National Research Fund (a member of The Qatar Foundation). The statements made herein are solely the responsibility of the authors.

References

[1] IMT-2020 (5G) Promotion Group, "5G Vision and Requirements," 2014.
[2] 3GPP TR 36.843 version 0.2.0 Release 12, "Study on LTE Device to Device Proximity Services; Radio Aspects," 2013.
[3] H. Al-Tous and I. Barhumi, "Resource Allocation for Multiuser Improved AF Cooperative Communication Scheme," *IEEE Transactions on Wireless Communications*, vol. 14, no. 7, pp. 3655–3672, 2015.
[4] E. Yaacoub, F. Filali and A. Abu-Dayya, "QoE Enhancement of SVC Video Streaming Over Vehicular Networks Using Cooperative LTE/802.11p Communications," *IEEE Journal in Selected Topics in Signal Processing*, vol. 9, no. 1, pp. 37–49, 2015.
[5] M.-F. Leung, and S.-H. G. Chan, "Broadcast-Based Peer-to-Peer Collaborative Video Streaming Among Mobiles," *IEEE Transactions on Broadcasting*, vol. 53, no. 1, pp. 350–361, 2007.
[6] C. Korn, D. S. Michalopoulos and R. Schober, "Power Saving Potential of Cooperative Communication: A Two-Dimensional Approach," *in Proceedings of the 10th International Conference on on Systems, Communications and Coding*, February 2015.
[7] L. Al-Kanj, H. V. Poor and Z. Dawy, "Optimal Cellular Offloading via Device-to-Device Communication Networks With Fairness Constraints," *IEEE Transactions on Wireless Communications*, vol. 13, no. 8, pp. 4628–4643, 2014.
[8] E. Yaacoub, L. Al-Kanj, Z. Dawy, S. Sharafeddine, F. Filali, A. Abu-Dayya, "A Nash bargaining solution for energy-efficient content distribution over wireless networks with mobile-to-mobile cooperation," *in Proceedings of the 4th IFIP/IEEE Wireless and Mobile Networking Conference*, October 2011.
[9] S. Sharafeddine, K. Jahed, N. Abbas, E. Yaacoub, and Z. Dawy, "Exploiting Multiple Wireless Interfaces in Smartphones for Traffic Offloading," *in Proceedings of the First International Black Sea Conference on Communications and Networking*, July 2013.
[10] Q. Ren, J. Fan, X. Luo, Z. Xu and Y. Chen, "Analysis of Spectral and Energy Efficiency in Ultra-Dense Network," *in Proceedings of the IEEE International Conference on Communication Workshop*, June 2015.
[11] S. Samarakoon, M. Bennis, W. Saad, M. Debbah and M. Latva-aho, "Ultra Dense Small Cell Networks: Turning Density Into Energy Efficiency," *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 5, pp. 1267–1280, 2016.
[12] N. Morozs, T. Clarke and D. Grace, "Distributed Heuristically Accelerated Q-Learning for Robust Cognitive Spectrum Management in LTE Cellular Systems," *IEEE Transactions on Mobile Computing*, vol. 15, no. 4, pp. 817–825, 2016.
[13] N. Morozs, T. Clarke and D. Grace, "Intelligent Dynamic Spectrum Access in Cellular Systems with Asymmetric Topologies and Non-Uniform Traffic Loads," *in Proceedings of the 82nd Vehicular Technology Conference*, September 2015.
[14] M. N. Islam, S. Subramanian, A. Partyka and A. Sampath, "Coverage and Capacity of 28 GHz Band in Indoor Stadiums," *in Proceedings of the IEEE WCNC*, April 2016.
[15] S. Krishnasamy and S. Shakkottai, "Spectrum Sharing and Scheduling in D2D-Enabled Dense Cellular Networks," *13th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks*, May 2015.
[16] I. AlQerm and B. Shihada, "A Cooperative Online Learning Scheme for Resource Allocation in 5G Systems," *in Proceedings of the IEEE International Conference on Communication*, May 2016.
[17] A. Goldsmith, *Wireless Communications*. Cambridge University Press, 2005.
[18] G. Chartrand, F. Harary, and B. Q. Yue, "On the Out-Domination and in-Domination Numbers of a Digraph," *Discrete Mathematics* , vol. 197198, pp. 179 – 183, 1999.
[19] G. Chartrand, P. Dankelmann, M. Schultz and H. C. Swart, "Twin Domination in Digraphs," *Ars Comb.*, 2003.
[20] M. Bay and Y. Crama, "Introduction to AIMMS," November 2004.
[21] British Association of Seating Equipment Suppliers, "Recommendations for the Specification and Use of Telescopic and Other Spectator Seating," 2008.