Resource Allocation for D2D Communications in Mobile Networks

Bassam Hussein and Abed Ellatif Samhat

Lebanese University, Faculty of Engineering - CRSI, Campus Hadath, Beirut, Lebanon
bassam.hussein@net.usj.edu.lb, samhat@ul.edu.lb

***Abstract* — To improve the network capacity without additional costs, Device-to-device (D2D) communication technology establishes direct links between users while reusing the same spectrum of traditional communication between base station and cellular users. In this paper, an efficient resource allocation scheme is proposed for D2D communications to overcome the interference caused by the presence of multiple connections sharing the same spectrum. The capacity of the network is optimized by maximizing the number of all served users while considering a tradeoff between quality of service and power consumption. Simulations of the proposed scheme in different radio conditions showed that the number of D2D communications increases significantly which indicates the efficiency of the novel resource allocation scheme.**

Keywords—D2D communications, Resource allocation, optimization.

I. INTRODUCTION

Global mobile data traffic will increase nearly eightfold between 2015 and 2020 according to Cisco [1]. Mobile data traffic will grow at a compound annual growth rate (CAGR) of 53 percent, reaching 30.6 Exabyte’s per month by 2020 and there will be 11.6 billion mobile connected devices exceeding the world’s projected population at that time [1].

Research is being conducted to accommodate this significant growth in traffic and number of users. The proposed techniques seek to minimize the number of users in each cell by running handovers from one dense cell to another. Other techniques aim to enlarge the band used by a cell through the aggregation of several scattered bands and by introducing the cloud radio access network architecture. However, considering the huge increase in demand for cellular services, these techniques may not be sufficient. In this context, D2D technology serves to maximize network capacity without increasing the number of channels in a cell and without decreasing the number of traditional connected users.

D2D is used to establish direct link between two users under the control of mobile core network. Several approaches are under investigation to apply D2D; most of them consider that D2D service can be specified for users who suffer from lack of coverage. In this case, a user can act as a relay between the base station and another uncovered user as shown in Figure 1 [2]. Others assume that D2D can be adopted for direct communication between two users who are at a close distance as in the case of calls, messages and social networks applications [3-4].

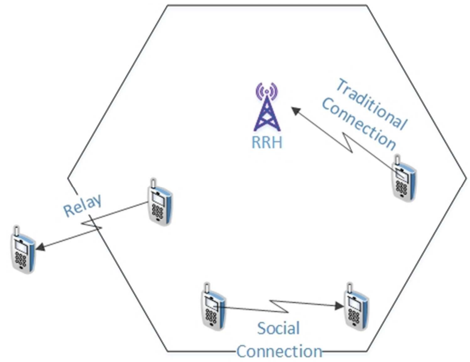

Fig. 1. D2D communications use cases.

In addition, some works proposed D2D for “Location-based Applications" and others suggested D2D as an alternative solution in case the network goes down [5].

In this context, several resource allocation methods and interference management schemes are developed in the literature. Most of them are specialized to indicate the frequency or channel for each D2D pair to be used in uplink or downlink [6-7]. Those methods are proposed with dynamic power allocation for D2D transmitters as in [8] or with transmission power in a static manner like in [9]. In general, most schematics assume that the system consists of a single cell and ignore the external interference from other cells. Some cases considered multicellular system but they assume that the two users who must communicate in D2D mode are located in the same cell [10]. The majority of existing approaches did not determine which user could communicate directly with the other, but they assume that the D2D pairs are already known.

The existing resource allocation schemes for D2D have worked on allocating a single or a maximum of two resources. The problem in this paper is formulated to allow the allocation of three resources for each communication.

In this paper, a novel resource allocation scheme is proposed for D2D communications. The main factor of the proposed scheme is the service. The service is what the user requests from the mobile operator. This work aims to allocate the service required by a user from another user that can serves him. D2D connection can only be done if the service requested by a user is available from another user. The problem is formulated to allow the allocation of three resources for each user requiring a service: The suitable transmitter that have the required service, the appropriate channel that avoids strong interference and the transmission power that guarantees minimum energy consumption.

D2D communications can be used by applications including call, social application, relay, etc. The most interesting application in this approach is the cache offloading between users through client-server model.

The rest of this paper is organized as follows. The system model is introduced in section II. The problem formulation is presented in Section III and the simulation results are finally given in Section IV.

II. SYSTEM MODEL

We consider a C-RAN environment with hexagonal distribution of cells. Cellular User (CU) is defined as a user operating in traditional mode, D2D-Tx and D2D-Rx are users operating in D2D mode as transmitter and receiver respectively. The network management is centralized and direct connection between users located in two different cells can also be allocated as shown in Figure 2.

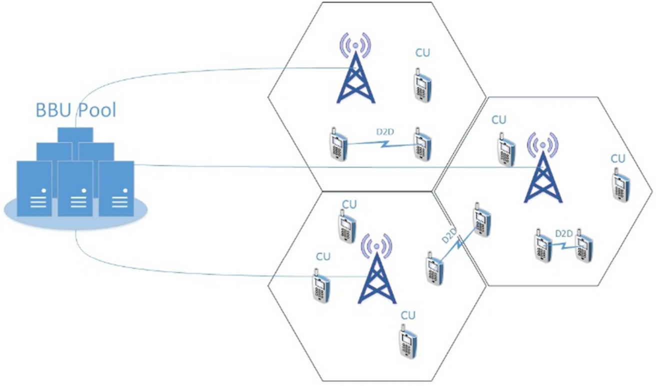

Fig. 2. CUs and D2Ds in C-RAN architecture.

The band specified for D2D communications in this work is the Uplink part for two main reasons:

1- The user transmission power is much smaller than that of the base station. Thus, on the uplink, the D2D-Tx is in competing with a CU and not with the base station RRH (Radio Remote Head).

2- The sensitivity of RRH is rather better than that of user device. It is preferred to have RRH as receiver to maintain the quality of service among CUs.

Noting that one can use the two bands Uplink and Downlink, but with priority for the uplink.

A. Channel Characteristics

Assuming all channels are orthogonal to each other in each cell and a channel is associated with a single CU at a given time. Hence, the internal interference between CUs in the same cell is negligible. Nevertheless, the interference exists between D2D's and CU's connections because they share the same channels in the same cell as shown in Figure 3.

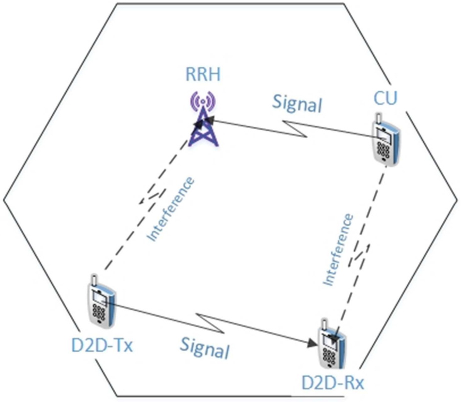

Fig. 3. Internal interference .

It is worth knowing that one can apply this approach regardless of the channel type used in the system frequency-division multiple access FDMA, time-division TDMA, code-division CDMA or orthogonal frequency-division OFDMA… However, the allocation period must be short to better adapt the system against changes in the radio environment conditions. In addition, it is preferable that the period of resource allocation for D2Ds be the same as that of CUs to ensure synchronization.

B. Applications

Researchers have specified many interesting applications for D2D such as relay, calls, social applications and location based applications. The aim is to create a general model that meets the needs of most applications. The request of a user is noted as a service regardless of the type of the application used. If the service S requested by a user R is available at another user T, then probably a D2D connection between R and T can be allocated unless if all conditions are not met. The network gives an order to T to send the service S using the channel n, and likewise to R to receive S on the same channel n. Each user requesting a service will be a candidate to be a D2D-Rx and each user who owns a service will be a candidate to be a D2D-Tx.

The most interesting application is Caching. Practically, this idea is used to turn every user in the system into a Cache Server. Each user saves its services in his memory; if another user requests the same service, the network has the choice to give the already backed-up service directly through the D2D option. The available services in case of caching are much more: web pages, images, videos, multimedia… It is remarkable that by 2020, 75 percent of the world's mobile data traffic will be video. Mobile video will increase 11-fold between 2015 and 2020 [1].

All D2D connections follow the client-server model. However, it is necessary to distinguish between two directions: Server- client is D2D-Downlink and client- server is D2D-Uplink. Each direction needs to allocate resources separately.

C. Proposed scheme

Most resource allocation schemes for D2D focused on allocating a single or a maximum of two resources. The problem in this paper is formulated to allow the allocation of three resources for each communication. Each resource is allocated in order to optimize a specific performance factor. The first resource is the suitable transmitter. The transmitters are classified according to the service that each one has. When a user requests a service S, the network will look in class S for the best D2D-Tx to allocate that satisfy the constraints. D2D-Txs are allocated in order to maximize the number of connected users in the system. Noting that a D2D-Tx can be in several classes.

The second resource is the appropriate channel. The channels are allocated in order to maximize the sum of SINR in the system, knowing that more than one D2D connection can be allocated on the same channel in the same cell if conditions are met.

The third resource is the transmission power. The objective is to distribute it in order to minimize the aggregation power in the system and consequently minimize the energy consumption and total cost of transmission.

III. PROBLEM FORMULATION

The following sets are defined in the system:

- Set of orthogonal channels for uplink $N = \{1 \ldots, N_n\}$.

- Set of CUs $C = \{1 \ldots, N_C\}$, noting that a CU uses at least one channel.

- Set of receivers D2D-Rx $R = \{1 \ldots, N_r\}$.

- Set of transmitters D2D-Tx $T = \{1 \ldots, N_t\}$.

- Set of services $S = \{1 \ldots, N_S\}$.

User can be included in both sets of D2D-Tx and D2D-Rx simultaneously according to its role, server or client.

A. Gain Model

The gain between two users is calculated as follows:

$$G = K \,.\, F \,.\, S \,.\, L^{-\alpha} \quad (1)$$

- K: Pathloss Constant ($K = 10^{-2}$).

- F: Fast fading - exponential distribution with a unit average.

- S: Slow fading - log-normal distribution with a unit mean and standard deviation of 8.

- L: Distance between D2D-Tx and D2D-Rx (m).

- α: Pathloss exponent ($\alpha = 3$).

This equation was adopted because it takes into consideration slow fading that represents the main radio conditions index. In addition, fast fading make the system suitable with the high-speed channel allocation expected in 5G. We also assume white Gaussian noise in the system $\sigma = -114$ dBm.

B. Optimization parameters

Let us define the following parameters:

$\rho_{r,t,n,s} \epsilon \{0, 1\}$: This parameter represents the acceptance index of the communication D2D considering the service s between a receiver r and a transmitter t on the channel n. $\rho = 1$ if a connection exists between the transmitter t and the receiver r on channel n while the service is s. $\rho = 0$ otherwise.

$SC_{c,n}$: Current SINR at base station due to the transmission of CU c on channel n.

$SCt_{c,n}$: SINR-Target at base station due to the transmission of CU c on channel n.

$SD_{r,t,n}$: Current SINR at D2D-Rx r due to the transmission of D2D-Tx t on channel n.

$SDt_{r,t,n}$: SINR-Target at D2D-Rx r due to the transmission of D2D-Tx t on channel n.

$Set_{t,s}$: Service s existed at D2D-Tx t.

$Ser_{r,s}$: Service s requested by D2D-Rx r.

$Gcc_{c,n}$: Transmission gain between CU c and the base station on channel n.

$Gdd_{r,t.n}$: Transmission gain between D2D-Tx t and D2D-Rx r on channel n.

$Gcd_{c,r.n}$: Interference caused by CU c to D2D-Rx r on channel n.

$Gdc_{t,c,n}$: Interference caused by D2D-Tx to the base station on channel n.

$Pc_{c,n}$: Power of transmission from CU c on channel n.

$Pd_{t,n}$: Power of transmission from D2D-Tx t on channel n.

Pcm_c : Maximum power of CU c.

Pdm_t : Maximum power of D2D-TX t.

C. Optimization problem

Three different objective functions are defined and discussed in the following:

1- Maximize the capacity of the system:

$$Max \sum_{r\epsilon R} \sum_{t\epsilon T} \sum_{n\epsilon N} \rho_{r,t,n,s} \quad \forall\, s\epsilon S \quad (2)$$

Maximizing the sum of ρ factors serves to maximize the number of successful D2D communications in the system and then the total capacity of the system because ρ is the acceptance index.

2- Maximize the quality of service in the network in terms of SINR:

$$Max \sum_{c\,\epsilon C} \sum_{r\epsilon R} \sum_{t\epsilon T} \sum_{n\epsilon N} (SU_{c,n} + \rho_{r,t,n,s} * SD_{r,t,n}) \;\forall\, s\epsilon S \quad (3)$$

3-Minimize energy consumption in the system in term of power:

$$Min \sum_{c\,\epsilon C} \sum_{r\epsilon R} \sum_{t\epsilon T} \sum_{n\epsilon N} (Pc_{c,n} + \rho_{r,t,n,s} * Pd_{t,n}) \;\forall\, s\epsilon S \quad (4)$$

Note that is this work the main concern is the first objective, but as long as there is no impact on it, an improvement is executed based on tradeoff between the two other objectives as discussed in the next section. Several scenarios could be investigated:

In scenario 1, one cell is considered with no external interferences as shown in Figure 4.

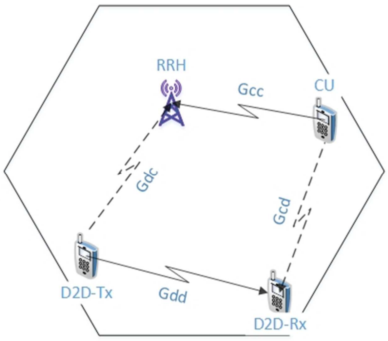

Fig. 4. Signal and interference gains in one cell system.

In scenario 2, a multicellular system is considered as shown in Figure 5. Note that in figure 5, the considered cell as example of cell in multicellular system is the cell 1 where the external interference links on cell 1 are showed in red color.

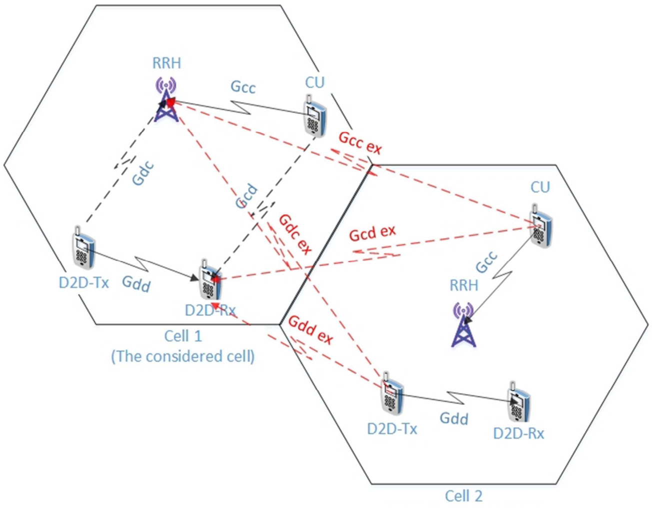

Fig. 5. Signal and interference gains in multicellular system.

In scenario 3, a multicellular system is considered with the possibility that users belong to two different cells can communicate with each other through D2D communications. In addition, the allocation of several D2D connections is allowed in the same cell at the same time on the same channel from which it is necessary to take into consideration the internal interference between the D2D connections. Therefore, in this scenario the maximum capacity of the system is relatively not limited.

Besides, the optimization constraints are as follows:

- The first optimization constraint is that the service *s* transmitted by D2D-Tx *t* must be the same service requested by D2D-Rx *r*.

$$Set_{t,s} = Ser_{r,s} \quad \nabla\, r\epsilon R\ ,\ \nabla\, t\epsilon T\ ,\ \nabla\, s\epsilon S \qquad (5)$$

-The second constraint is that SINR at the RRH must be larger than target SINR already determined by the operator. Noting that SINR is calculated by dividing the signal gain power in the sum of noise and interferences gain powers sharing the same channel while gains are calculated according to equation (1).

$$SU_{c,n} = \frac{Gcc_{c,n} * Pc_{c,n}}{\sigma + \sum_{r\,\epsilon R} \sum_{t\,\epsilon T} \rho_{r,t,n,s} * Gdc_{t,c,n} * Pd_{t,n}} \geq SUt_{c,n,s}$$

$$\nabla\, c\epsilon C\ ,\ \nabla\, r\epsilon R\ ,\ \nabla\, t\epsilon T\ ,\ \nabla\, n\epsilon N\ ,\ \nabla\, s\epsilon S \qquad (6)$$

-The third constraint is that SINR at the D2D-Rx must be larger than target SINR already determined by the operator. Noting that SINR target value can be determined as a variable factor that depends on the user priority.

$$SD_{r,t,n} = \frac{Gdd_{r,t\,.n} * Pd_{t,n}}{\sigma + Gcd_{c,r.n} * Pc_{c,n} + \sum_{\substack{k\epsilon R\\ k\neq r}} \sum_{\substack{j\epsilon T\\ j\neq t}} \rho_{r,t,n,s} * Gdd_{r,n} * Pd_{t,n}}$$

$$\geq SDt_{r,t,n,s}$$

$$\nabla\, c\epsilon C\ ,\ \nabla\, r\epsilon R\ ,\ \nabla\, t\epsilon T\ ,\ \nabla\, n\epsilon N,,\ \nabla\, s\epsilon S \qquad (7)$$

-The fourth constraint is that the transmission power of each CU must be smaller or equal to its maximum transmission power.

$$0 \leq Pc_{c,n} \leq Pcm_c \qquad \nabla\, c\epsilon C,\ \nabla\, n\epsilon N \qquad (8)$$

-The fifth constraint is that the transmission power of each D2D-Tx must be smaller or equal to its maximum transmission power.

$$0 \leq Pd_{t,n} \leq Pdm_t \qquad \nabla\, t\epsilon T,\ \nabla\, n\epsilon N \qquad (9)$$

IV. SIMULATION RESULTS

The optimization problem is of type mixed integer linear programming (MILP) which is very hard to solve. A heuristic solution is proposed as shown by the flowchart in figure 6. Our approach consists of spliting the problem into three phases. In the first phase, for each Rx request all the suitable Txs that have the same service required by Rx are identified. This phase serves to reduce the complexity of the problem in a very efficient way by classifying the receivers and transmitters according to the service. This classification leads to minimize the area of useful solutions because the system tests only the transmitters with the same service of the receiver which leads to construct a small set of suitable transmitters for each receiver.

In second phase, for each couple Rx-Tx the system investigates all suitable channels and then calculates the smallest possible power for each channel. The main constraint in this phase is that all SINR values at all receivers should be satisfied. Practically, in most cases there is only a small number of channels that satisfy the constraints. For each acceptable channel, the best value of transmission power is specified.

After finishing the two first phases, for each receiver that requests a service, there are several choices of triplets: Transmitter – Channel – Power. In third phase, for each receiver the system selects the triplet that guarantees the best results, i.e. the triplet that maximizes the following performance factor to guarantee the trade-off between the quality of service in term of SINR and the energy consumption in term of power:

$$\sum_n \frac{SINR}{SINR\ average} - \sum_n \frac{P}{P\ average} \qquad (10)$$

This heuristic approach reduces the complexity of solution in very efficient way compared to solving the MILP problem while respecting the same constraints.

The simulations presented in this paper are based on scenario 3 mentioned above since it covers all other cases with 7 cells. We consider a scenario where the number of CUs $\mathrm{N_c}$ = 50, number of channels $\mathrm{N_n}$ = 50, number of D2D-Txs = 30, number of D2D-Rxs = 30, number of services Ns = 10, radius of the cell R = 500 m, target SINR for CUs = 3 dB and target SINR for D2Ds = 2 dB. Figure 7 shows a hexagonal cell surrounded by cells on all sides. The traditional CUs are represented in red color, the D2D-Rxs candidate in blue and the D2D-Txs candidate in green.

Figure 8 shows only the D2D pairs accepted after the resolution of the heuristic code. Only served receivers located in the middle cell are shown. Taking the example in figure 8, 21 out of 30 D2D-Rxs are served. This means that the number of served users in the cell is increased from only 50 CUs to 71 users: 50 CUs, 21 D2D-Rxs, and the gain including D2D-Rxs is about 70%.

Further, it is worth to note that on a well-defined channel, a CU link is far from the D2D link that shares the same channel as shown in Figure 9. The simulations results with different conditions are presented in the following figures. Figure 10 shows the number of accepted D2D-Rxs as a function of the number of services. Note that for a fixed number of TXs and Rxs; if the number of services in the system increases the number of successful D2D communications decreases because some receivers do not find suitable transmitters that possess the requested service.

In Figure 11, the number of D2D-Rxs is shown as a function of the number of Txs in the system. Note that the acceptance rate of D2D communications is high, and for a fixed number of Rxs, if the number of Txs increases, the number of successful D2D communications increases because the number of Txs choices for each Rx increases. Hence, some non-served receivers find the right choice through the addition of transmitters.

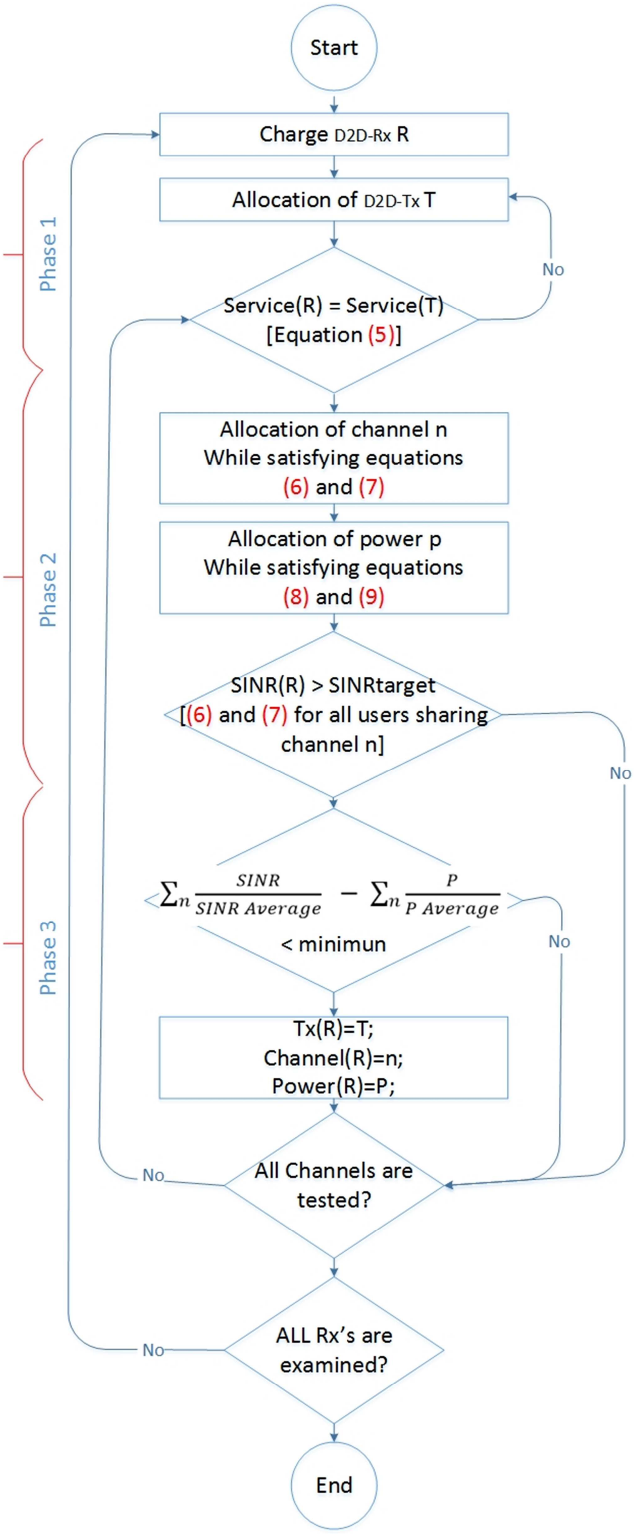

Fig. 6. Solution Flowchart.

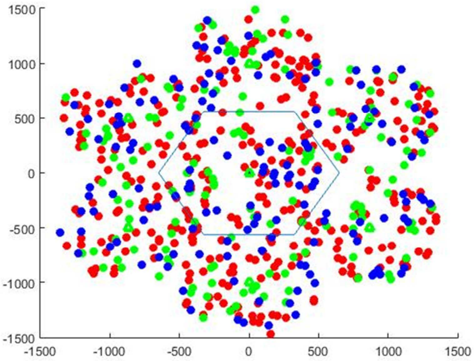

Fig. 7. System cells and users distribution example.

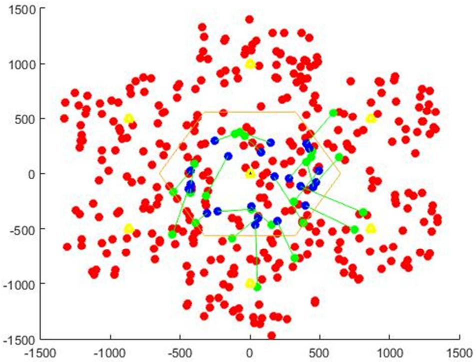

Fig. 8. Accepted D2D links in the middle cell.

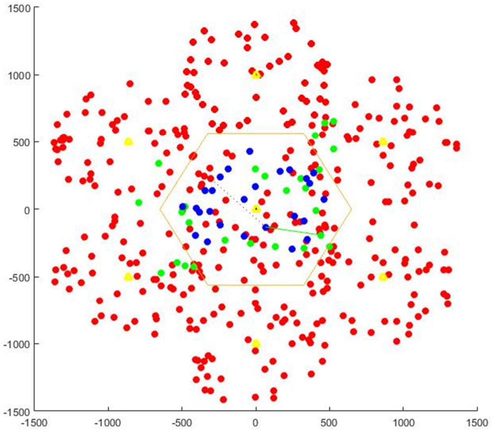

Fig. 9. D2D and interference links sharing same channel example.

Figure 12 shows that the case with different SINR targets. As expected, if the required target SINR increases, the number of accepted D2D communications decreases. We note that the number of accepted D2D users is affected by the nature of the network, cell size, number of users, type of services and required quality of service but in general, the simulation results shows that in various circumstances D2D communications is useful to improve capacity.

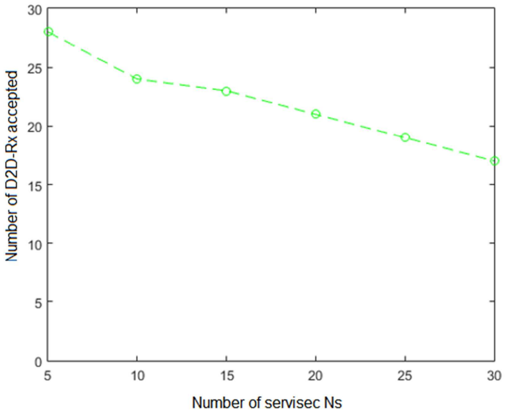

Fig.10. Number of D2D-Rxs as a function of the number of services/Nr=30, Nt=30.

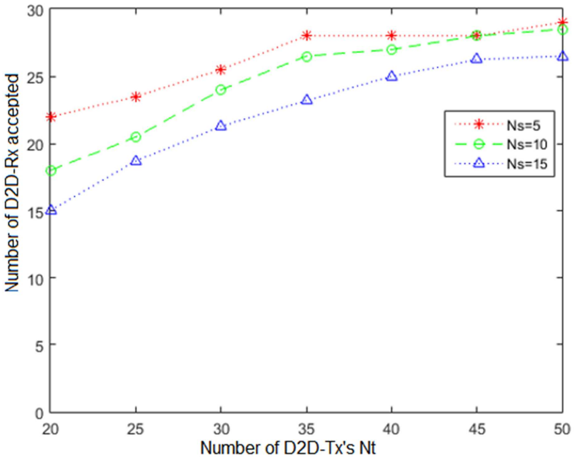

Fig. 11. Impact of number of services on the number of successful D2D-Rxs/Nr=30.

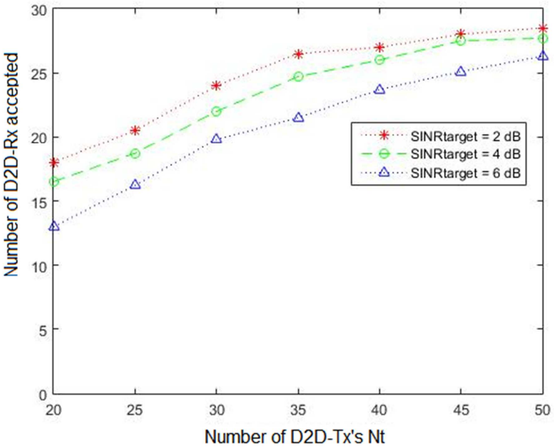

Fig. 12. Impact of SINR target level on the number of successful D2D-Rx/Nr=30.

V. CONCLUSION

In this paper, a novel optimal resource allocation scheme is proposed for D2D users in network with C-RAN architecture. The proposed scheme increased the total capacity of the system. The problem is formulated to allow each D2D user who requests a service to specify the appropriate transmitter, channel, and transmission power. The main objective had been to increase the capacity of network and the second objective had been to balance between quality of service in term of SINR and energy consumption in term of power.

REFERENCES

[1] Cisco, Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2015-2020, February 2016.

[2] Ki. Vanganuru, S. Ferrante, and G. Sternberg, “System Capacity and Coverage of a Cellular Network with D2D Mobile Relays,” *Miitary Communications Conference, 2012 - MILCOM 2012*.

[3] Y. Zhang, E. Pan, L.Song, W. Saad, Z. Dawy, and Zhu Han, “ Social Network Aware Device-to-Device Communication In Wireless Networks,” *IEEE Transactions on Wireless Communications (Volume: 14, Issue: 1, Jan. 2015)*.

[4] B. Zhang, Y. Li, D. Jin, P. Hui, and Z. Han, “Social-Aware Peer Discovery for D2D Communications Underlaying Cellular Networks,” *IEEE Transactions on Wireless Communications (Volume: 14, Issue: 5, May 2015)*.

[5] J. Seppal, T. Koskela, T. Chen, and S. Hakola, “Network Controlled Device-to-Device (D2D) and Cluster Multicast Concept for LTE and LTE-A Networks,” *Wireless Communications and Networking Conference (WCNC), 2011 IEEE*.

[6] H. S. Chae, J. Gu, B. G. Choi, and M. Y. Chung, “Radio Resource Allocation Scheme for Device-to-Device Communication in Cellular Networks Using Fractional Frequency Reuse,” *Communications (APCC), 2011 17th Asia-Pacific Conference on*

[7] M. Belleschi, G. Fodor, and A. Abrardo, “Performance Analysis of a Distributed Resource Allocation Scheme for D2D Communications,” *GLOBECOM Workshops (GC Wkshps), 2011 IEEE*.

[8] J.Gu, S. J. Bae, B. G. Choi, and M.Y. Chung, “Dynamic Power Control Mechanism for Interference Coordination of Device-to-Device Communication in Cellular Networks,” *Ubiquitous and Future Networks (ICUFN), 2011 Third International Conference on*.

[9] S. WEN, X. ZHU, X.ZHANG and Dacheng Yang, “QoS-Aware Mode Selection and Resource Allocation Scheme for Device-to-Device (D2D) Communication in cellular networks,” *Communications Workshops (ICC), 2013 IEEE International Conference on*.

[10] J. M. B. da Silva Jr, T. F. Maciel, R. L. Batista, Carlos F. M. e Silva and Francisco R. P. Cavalcanti, “UE Grouping and Mode Selection for D2D Communications Underlaying a Multicellular Wireless System,” *Wireless Communications and Networking Conference Workshops (WCNCW), 2014 IEEE*.