Abstract—In the future standardization of the 5G networks, in Long Term Evolution (LTE) Release 13 and beyond, Device-to-Device communications (D2D) is recognized as one of the key technologies that will support the 5G architecture. In fact, D2D can be exploited for different proximity-based services (ProSe) where the users discover their neighbors and benefit from different services like social applications, advertisement, public safety, and warning messages [1]. In such a scenario, the aim is to manage in a proper way the radio spectrum and the energy consumption to provide high Quality of Experience (QoE) and better Quality of Services (QoS). To reach this goal, in this paper we propose a novel D2D-based uploading scheme in order to decrease the amount of radio resources needed to upload to the eNodeB a certain multimedia content. As a further improvement, the proposed scheme enhances the energy consumption of the users in the network, without affects the content uploading time. The obtained results show that our scheme achieves a gain of about 35% in term of mean radio resources used with respect to the standard LTE cellular approach. In addition, it is also 40 times more efficient in terms of energy consumption needed to upload the multimedia content.

Index Terms—Spectrum Allocation, LTE-A, Device-to-Device, Performance Evaluation, Networking and QoS, 5G Systems.

I. INTRODUCTION

The fast growth of data traffic and of enhanced devices in crowded scenarios (i.e., shopping malls, stadiums, concerts etc.) pushes the telecommunications operators to find new paradigms to accommodate the current high demand of users’ multimedia applications [2][3]. In addition, to simply providing faster transmission throughput, 5G networks should meet the requirements and constraint of new use-cases related to novel network environments like the Internet of Things [4]. Machine Type Communications (MTC) [5], broadcast-like services and lifeline communications in times of natural disasters. In order to meet the demands coming from these novel scenarios of interest, 5G networks will need to adopt new technologies such as proximity services (ProSe), whereby devices communicate with each other directly rather than relying on network operators’ base stations (eNodeB). The advantages coming from such a solution are expected to be manifold. For instance, these novelty have the promise to increase the available bandwidth, to allow lower energy consumption, to reduce infrastructure costs, to improve spectral efficiency and increase the resilience of the network. Device-to-Device (D2D) communications are considered as one of the most promising technologies in Long Term Evolution (LTE) systems and beyond (5G), to reach the aforementioned benefits.

D2D communications in wireless network are referred as the direct communication between two devices without the usage of the network infrastructure [6] [7]. The advantages of this novel communication form are manifold: offload cellular traffic [8], [9], decreased battery consumption, increased data-rate and novel applications and services [10]. In fact, D2D communications are of highest interest in scenarios where there is a high density of devices sharing the scarce cellular radio resources or even in vehicular environments where vehicles set up communications for information search and dissemination [11]. As an example, we could consider public safety and disaster scenarios where the network coverage and the connectivity are limited due to the fall of the network infrastructure.

Many works in literature investigate on challenges and practical issues related to the D2D communication configuration, e.g., [12][13]. However, these mainly focus on downlink services and only few works investigate the uplink direction. In addition, most of these works propose new techniques and approaches for D2D open issues (e.g., service discovery, communication set-up), whereas others analyze the impact of D2D interactions in presence of different application scenarios or multimedia applications [14]. Nevertheless, in [15] the authors propose two D2D solutions for content uploading in order to minimize the uploading time with respect to the standard LTE transmission. In addition, the interest for these type of scenarios is also remarked by recent publications, e.g., [16] where a prototype of D2D relaying smartphone is presented to send out emergency messages from disconnected areas as well as information sharing among people gathered in evacuation centers.

The aim of this paper is to propose an efficient spectrum allocation solution that exploits the possibility of D2D communication between User Equipments (UEs) in proximity to each other to minimize the radio resource required to upload some content to the base station (eNodeB). The reference scenario is a single cell in a Long Term Evolution-Advanced (LTE-A) system, where multiple user equipments aim at uploading some data content to a central server or to the Cloud (as shown in Fig. 1).
The traditional uploading technique used in cellular systems, with separate links from each UE to the LTE eNodeB, is compared to an innovative relay-based scheme. To this aim, a novel radio spectrum management is proposed at the eNodeB for an efficient assignment of radio resources to the UEs. The underlying idea for the proposal is that differences in the channel quality experienced by the UEs can be exploited for cooperative content uploading solutions. In particular, the UE with a poor direct link to the eNodeB forwards its data to a nearby node over a high-quality D2D link, and the receiving UE then uploads its own generated data and the relayed data to the eNodeB over a good uplink channel.

![D2D-based content uploading scenario.](image)

Based on such a D2D-based solution, the proposed spectrum allocation is able to reduce the number of resource blocks (RBs) used by the network provider, without introducing any content uploading delay for the UEs. This approach might be of particular interest in those cases, like a disaster scenario, where the efficient use of the radio resources is of utmost or even of vital importance. In fact, in these cases the objective is to serve as many users as possible to gather information from different nodes in the area of interest. In addition, the network provider might force the end-user to accept such a solution even if no further benefit is obtained in terms of energy consumption or transfer delay.

The remainder of the paper is summarized as follows. The system model and LTE assumptions are described in Section II whereas the proposed D2D uploading solution is presented in Section III. The performance evaluation is discussed in Section IV, whereas conclusive remarks are provided in Section V.

II. SYSTEM MODEL

With the focus on a multimedia uploading service, in this paper we consider a basic reference case where some users in a single LTE-A cell are interested in uploading some video content to a central server on the Internet. The eNodeB manages the spectrum, and the Single Carrier Frequency Division Multiple Access (SC-FDMA) is used for assigning the adequate number of RBs to each scheduled user. The available radio spectrum is managed in terms of Resource Blocks (RBs) with each RB corresponding to 12 consecutive and equally spaced sub-carriers. The overall number of available RBs depends on the system bandwidth configuration and can vary between 6 (1.4 MHz channel bandwidth) and 100 (20 MHz).

The Signal to Interference Noise Ratio (SINR) of user \( i \) from a generic BS \( b \) can be evaluated as follows:

\[
SINR_i = \frac{P_{R_{b_i}}}{\sigma^2 + \sum_{c \in \mathcal{B} \setminus b} P_{I_{c_i}}} \tag{1}
\]

where \( P_{R_{b_i}} \) is the useful received power by a user \( i \) (transmitted power of the user and the channel gain are taken into account), \( \sigma^2 \) is the noise power, and \( \sum_{c \in \mathcal{B} \setminus b} P_{I_{c_i}} \) represents the interference power signal due to the adjacent BSs, which are part of set \( \mathcal{B} \).

The capacity achieved by user \( i \) attached to BS \( b \) with a bandwidth \( W \) is given by the well-known Shannon’s formula:

\[
C_i = W \cdot \log_2(1 + SINR_i) \tag{2}
\]

Equations (1) and (2) can be similarly used for D2D communications. The only difference is that we have to replace the BS \( b \) with a generic D2D receiver \( j \) (by considering a D2D link \( i \rightarrow j \)).

The radio resource management procedures are based on the channel quality indicator (CQI) feedback provided by the users to the eNodeB and the corresponding modulation coding scheme (MCS) is chosen by following the CQI-MCS correspondence standardized in [12] and reported in Table I.

| CQI Index | Modulation Scheme | Efficiency D2D [bit/s/Hz] | Min. Rate D2D [kbps] | Efficiency Cellular [bit/s/Hz] | Min. Rate Cellular [kbps] |
|-----------|-------------------|--------------------------|----------------------|-------------------------------|-------------------------|
| 1         | QPSK              | 0.1667                   | 28.00                | 0.1523                        | 25.59                   |
| 2         | QPSK              | 0.2222                   | 37.33                | 0.2344                        | 39.38                   |
| 3         | QPSK              | 0.3333                   | 56.00                | 0.3770                        | 63.34                   |
| 4         | QPSK              | 0.6667                   | 112.00               | 0.6016                        | 101.07                  |
| 5         | QPSK              | 1.0000                   | 168.00               | 0.8770                        | 147.34                  |
| 6         | QPSK              | 1.2000                   | 201.60               | 1.1758                        | 197.53                  |
| 7         | 16-QAM            | 1.3333                   | 224.00               | 1.4766                        | 248.07                  |
| 8         | 16-QAM            | 2.0000                   | 336.00               | 1.9141                        | 321.57                  |
| 9         | 16-QAM            | 2.4000                   | 403.20               | 2.4063                        | 404.26                  |
| 10        | 64-QAM            | 3.0000                   | 504.00               | 2.7305                        | 548.72                  |
| 11        | 64-QAM            | 3.0000                   | 504.00               | 3.3223                        | 558.72                  |
| 12        | 64-QAM            | 3.6000                   | 604.80               | 3.9023                        | 655.59                  |
| 13        | 64-QAM            | 4.5000                   | 756.00               | 4.5234                        | 759.93                  |
| 14        | 64-QAM            | 5.0000                   | 840.00               | 5.1152                        | 859.35                  |
| 15        | 64-QAM            | 5.5000                   | 924.00               | 5.5547                        | 933.19                  |

A UE in a LTE-A network can either communicate through the serving eNodeB (cellular mode) or it can bypass the eNodeB and use direct communications over D2D links (D2D mode). The eNodeB is in charge of the D2D session setup (e.g., bearer setup), while power control and resource allocation procedures on the D2D links can be executed either in a distributed or in a centralized way. In this paper, we assume that the centralized approach is implemented. Accordingly,
the eNodeB is aware of the cell load and the user channel conditions, and can efficiently allocate dedicated resources to D2D connections so as to improve the session quality. At the beginning of the resource management assignment, the transmitted power is uniformly divided with the respect the number of RBs. Later, the eNodeB packet scheduler virtually allocates the radio resources based on the adopted scheduling policing (i.e., Maximum Throughput (MT), Proportional Fair (PF), Round Robin (RR)). We say that the allocation is virtual due to the fact that it become definitive once that the most suitable transmission mode (i.e., D2D or Cellular mode) is chosen for each users. In addition, we assume that uplink resources are allocated to D2D communications because (i) uplink guarantees a more efficient resources reusing compared to downlink, in the worst case of a fully loaded cellular network, as demonstrated in [10], and (ii) the use of uplink resources gives the possibility of freeing downlink resources to use for other services within the cell. For this reason, we consider TDD and refer to the frame structure type 2 configuration 0 foreseen by 3GPP [12]. This guarantees the highest number of uplink subframes with six out of a total of ten (see Table II) Transmission Time Intervals (TTIs) (one TTI lasts 1 ms).

III. PROPOSED D2D-BASED SOLUTION

The solution proposed in this paper considers a D2D-based solution where the users cooperatively upload their content, by exploiting the best performing uplink channel among the users. To this aim, unicast D2D communication among the involved users is implemented exploiting frequency reuse on the uplink radio resources. To better clarify the benefits introduced by such a solution, we discuss the two solutions through a simple example.

A. Cellular Uploading Solution

Let us consider the case where the eNodeB implements a radio resource allocation policy that equally divides the available RBs \( R \) in the uplink subframes, among all the requesting users. Considering two users and a total number of resources \( R = 50 \), we have that the allocated RBs are \( r_1 = 25 \) and \( r_2 = 25 \). The CQI levels of the two users and the corresponding MCS used for uploading the data, will limit the data rate \( b_c \) (where \( c = 1 \ldots 15 \)) per allocated RB. As an example, assuming that the CQI level of the two users is \( c_1 = 5 \) and \( c_2 = 10 \), we will have (based on [12]) \( b_{c_1} = 147.34 \text{kbps} \), \( b_{c_2} = 458.72 \text{kbps} \). The corresponding uplink data rate for the two users will be respectively equal to \( d_1 = b_{c_1} \cdot r_1 = 3.68 \text{Mbps} \) and \( d_2 = b_{c_2} \cdot r_2 = 11.47 \text{Mbps} \). Consequently, if the content each user wants to upload has a size of \( D = 100 \text{MB} \), the uploading time should be approximately \( t_1 = \frac{D}{d_1} = 217 \text{s} \) and \( t_2 = \frac{D}{d_2} = 70 \text{s} \).

B. D2D-Based Uploading Solution - Resource Blocks Minimization

In this section we present the D2D-based solution named D2D-based uploading - resource block minimization (DBU-RBM). The aim of the proposed approach is to decrease the number of used RBs needed under the constraint of matching a given uploading time. In particular, in our approach the reference uploading time is the time required by the standard cellular solution. Starting from the cellular uploading solution described in the previous subsection, below we provide a practical description of the D2D-based uploading scheme in order to improve the understanding of the reader. Following the rationale of the DBU-RBM solution, the best of the two channel conditions between the users (i.e., \( c_2 \)) is exploited to upload all data, whereas the user with worst channel conditions (i.e., \( c_1 \)) will first forward its data to the second user over a D2D link. Then the target data delivery time for the two users is set to be equal to the transfer time in the basic cellular mode, i.e., \( t_1 = 217 \text{s} \) and \( t_2 = 70 \text{s} \). Then the minimum number of RBs is computed so that a transfer time \( t'_1 \leq t_1 \) and \( t'_2 \leq t_2 \) is guaranteed, when considering CQI level for user 2, \( c_2 = 10 \) for the uplink towards the eNodeB. Clearly, when uploading the data, user 2 will give priority to its own traffic. Thus, to guarantee \( t'_2 \leq t_2 \), it will still use \( r_2 = 25 \) RBs for 70 seconds of time. Then it will upload the data for user 1. Considering the minimum data rate per RB for user 2, \( b_{c_2} = 458.72 \text{kbps} \), the objective is to obtain \( t'_1 = 70 \text{s} + \frac{D_2}{D_1} b_{c_2} \leq 217 \text{s} \). Reorganizing the equation we obtain: \( r'_2 = \frac{D_2}{b_{c_2}} \leq \frac{D_1}{b_{c_1}} = 11.86 \), that is \( r'_2 = 12 \) RBs for additional 147 seconds. Thus, in this case we will have that \( r'_1 = 0, r'_2 = 25 \) for 70s and \( r'_2 = 12 \) for additional 147s, and we guarantee that \( t'_1 \approx t_1 \) and \( t'_2 = t_2 \).

IV. SIMULATION RESULTS

A numerical evaluation is conducted by using MATLAB®, to assess the main performance of the novel D2D scheme. In particular, we investigate three different system metrics given by (i) the average number of RBs used, (ii) the mean uploading time, and (iii) mean energy consumption. We consider an LTE cell with a radius equal to \( R = 100 \text{m} \) and \( N = 2 \) users. The packet scheduler implemented in the eNodeB is Round Robin, which means that all the available RBs are equally divided among the users. The transmitted power for a generic LTE UE is equal to 23dBm whereas the transmitted power on a D2D link is 10dBm. In this work, we consider that the users want to upload a low quality video file to remote server (or Cloud) and the size of the video is fixed to 100MB. The effective SINR, estimated according to the Exponential Effective SIR Mapping, is mapped onto the CQI level ensuring a Block Error Rate smaller than 10%. In addition, all the results shown are

### Table II

| Uplink-Downlink configuration | Downlink-to-Uplink Switch-point periodicity | Subframe number | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-------------------------------|-------------------------------------------|----------------|---|---|---|---|---|---|---|---|---|---|
| 0                             | S mi                                      | D             | S | U | U | D | S | U | U | D | S | U |
| 1                             | S mi                                      | D             | S | U | D | S | U | D | S | U | D | U |
| 2                             | S mi                                      | D             | S | U | D | S | U | D | S | U | D | U |
| 3                             | S mi                                      | D             | S | U | D | S | U | D | S | U | D | U |
| 4                             | S mi                                      | D             | S | U | D | S | U | D | S | U | D | U |
| 5                             | S mi                                      | D             | S | U | D | S | U | D | S | U | D | U |
| 6                             | S mi                                      | D             | S | U | D | S | U | D | S | U | D | U |

\( t_1 = \frac{D}{d_1} = 217 \text{s} \) and \( t_2 = \frac{D}{d_2} = 70 \text{s} \).
obtained with a 95% confidence interval. The main simulation parameters are listed in Table III.

| Parameter          | Value                      |
|--------------------|----------------------------|
| Cell radius        | 100 m                      |
| Frame Structure    | Type 2 (TDD)               |
| TTI                | 1 ms                       |
| Cyclic prefix/Useful signal frame length | 16.67 µs / 66.67 µs |
| TDD configuration  | 0                          |
| Carrier Frequency  | 2.5 GHz                    |
| eNodeB Tx power    | 46 dBm                     |
| LTE UE node Tx power | 23 dBm                  |
| D2D UE node Tx power | 10 dBm                  |
| Noise power        | -174 dBm/Hz                |
| Path loss (cell link) | $128.1 + 37.6 \log(d), d[km]$ |
| Path loss (D2D link, NLOS) | $40 \log(d) + 30 \log(f) + 49, d[km], f[Hz]$ |
| Path loss (D2D link, LOS) | $16.9 \log(d) + 20 \log (f/5) + 46.8, d[m], f[GHz]$ |
| Shadowing standard deviation | 10 dB (cell mode); 12 dB (D2D mode) |
| Sub-carrier spacing | 15 kHz                     |
| BLER target        | 10%                        |
| # of Runs          | 500                        |

We considered a varying number of RBs in the system and a random distribution of the CQI levels for the UEs. The simulative analysis leads to the performances reported in Fig. 2, Fig. 3, and Fig. 4 where the proposed DBU-RBM solution is compared to the traditional cellular-mode data uploading. As it can be noticed, the proposed solution does not introduce performance losses in terms of uploading time for the UEs (the cellular mode and the DBU-RBM actually overlap), see Fig. 2. This is an expected result of the proposed approach, as the target uploading time for the users is the time obtained in the classic cellular mode. In fact, the aim is to decrease the number of RBs without performing worst with respect the case of the standard cellular solution.

When instead analyzing the performance for the proposed approach in terms of the average number of RBs used in the system, we observe important benefits being obtained. In particular, the results plotted in Fig. 3 reveal that the DBU-RBM solution is outperforming the standard cellular-mode solution in terms of mean number of RBs used in the system. As observed from the plots, the DBU-RBM solution reaches a maximum of 50% for the resources usage when 100RBs are available, whereas the cellular-mode reaches about a 85% value. This improvement is introduced by the proposed approach thanks to the exploitation of a better channel quality which requires a lower number of RBs to serve the UEs with the target uploading time. This shows how with the efficient management of the radio spectrum, the eNodeB can preserve some RBs to be used for other scopes, e.g., to assist UEs with worst channel conditions or reduce its own transmission power. In addition, since the uploading time does not change either for the cellular and D2D approach, our proposed solution results transparent to the system users.

Additional results are presented in terms of energy consumption in Fig. 4. As it is shown in the plots, the proposed solution has a very low energy consumption with respect the standard cellular solution. In particular, with a limited set of available RBs (about 10 RBs), the DBU-RBM scheme performs 40 times better then the cellular solution. Further, even if the achieved gain decreases proportionally with the increase of the RBs, in case of full available bandwidth (100 RBs) the gain of the D2D-RBM is 7 times more with respect to the cellular scheme.

V. CONCLUSIONS

In this paper the enhancements provided by the usage of D2D-based solutions in content uploading environments are investigated. We considered the performance of D2D communications by taking into account a scenario where the users want to upload a multimedia file to a remote server and
we evaluated the system performance in term of uploading time, average RBs used, and energy consumption. In particular, we compared our proposed D2D-based solution with respect to a standard LTE uploading scheme. The obtained results show that D2D communications are able to decrease the average number of RBs needed in a data uploading process without affecting the standard uploading time given by the LTE system. In addition, we analyzed also the battery consumption of each device in terms of required energy consumption. As the results showed, the D2D-RBM scheme outperforms the traditional LTE cellular scheme and provides a better management of the battery life to the system users.

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