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Increasing efficiency of resource allocation for D2D communication in NB-IoT context

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Abstract

Internet of things (IoT) and device to device (D2D) communications are among the novel promising technologies in the current releases of 4G and they will play a fundamental role in the next generation 5G as well. In this paper, it is investigated the impact of allocation strategies that take into account the mutual interference in D2D Narrow-Band IoT terminals and cellular terminals transmitting in the same resource block. In a multi-cellular downlink context, the proposed approach and the analysis can serve also as an efficient criterion for selecting the target $SINR$, useful for managing the power control in the uplink. The rate improvement, measured with the proposed approach, is between 10% and 15% w.r.t. conventional techniques.

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Keywords: Device-to-device communications, Narrow band Internet of Things, Resource Management;

1. Introduction

Device to Device (D2D) communication is one of the responses to the current increasing demand for high data rate applications also in challenging environments. Allowing direct communication between devices leads to offloading the base station (eNodeB) and, consequently, to increasing system capacity and spectral efficiency. Some of the applications of D2D communication include vehicle to vehicle (V2V) communication, public safety support in case of damage to the radio infrastructure, applications related to proximity awareness. In D2D, the eNodeB can either be involved or not and the connection within the device pair can either be managed by the base station or by the devices. In this work, we are interested to the former case since we aim to exploit the possibility of reusing the resources allocated to cellular terminals (UEs). Therefore, among the several modes for D2D communication, we are considering the *reuse mode*, where the resources of cellular terminals can be reused and shared with D2D users realizing an improvement in the cell spectral efficiency.

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The narrow band IoT (NB-IoT) is a low power wide area technology for low data rate applications and it is characterized by the use of a single resource block (180 KHz) in both downlink and uplink. NB-IoT can be deployed in LTE systems and this deployment can be *in-band* (within the LTE band), *guard band* (in the guard bands of LTE), or *stand alone* (in other bands, as GSM ones). In this work, coherently with the D2D reuse mode, we are interested in the in-band deployment of a D2D communication between pairs of NB-IoT terminals, with a particular emphasis on the impact of strategies for resource blocks (RBs) allocation.

In the literature, the work on D2D within a NB-IoT context is still scarce. However, it is expected to become more and more popular, because of the crucial role of D2D and NB-IoT technologies in 5G systems. In [1], the focus is on the security enhancements for a better content uploading; in [2], an optimization problem is formulated in order to find the best D2D relay sequence, when the link between the base station and the cellular user (CU) has performance below the requirements. In [3], relaying in vehicular communication is investigated in terms of different performance indicators. On the other hand, resource allocation for D2D has been studied in [4,5] and interference mitigation has been investigated in [6,7]. In [4], a heuristic location based resource allocation has been tested for uplink systems; in [5], in order to have maximum system throughput, the cellular users were given higher priority than D2D users.

In this paper, we exploit a method based on the rate limit computation for LTE users introduced in [8] and the Tab-ID approach for evaluating the multi-user diversity in resource allocation [9]. The proposed method allows to determine if the D2D pair and the cellular terminal can be considered uncorrelated from the point of view of the mutual interference: if this is the case, both of them are assumed to be able to share the same RB, i.e. to reuse the same resources for increasing the overall spectral efficiency. The same principle could be used also in the D2D pairs selection as a criterion that will be more efficient, for example, than the physical distance from the cellular user. Furthermore, by deciding the corresponding rate limit, we can calculate also the maximum feasible signal to interference and noise ratio (SINR), which allows the setup of the target SINR ($SINR_{target}$) parameter used in the power control.

The paper is organized as follow: first, the analytical formulation of the method used for evaluating the correlation between cellular and D2D NB-IoT terminals is introduced in Sect. 2 and then, in Sect. 3, the models of the allocation strategies are explained. Finally, Sect. 4 describes the system model and Sect. 5 reports the simulation results.

2. Analytical Formulation

Using LTE parameters for NB-IoT means that each D2D user can use just one RB. In addition, in order to increase spectral efficiency, we are assuming that D2D terminals are using RBs already occupied by existing cellular terminals, i.e. in the reuse mode. Therefore, each D2D pair will affect and will be affected by the interference of a single cellular terminal in the same cell. Let us use the following parameters and notations: a link i exists between transmitter TX_i and receiver RX_i and the channel gain between both of them is G_{ii}. A generic channel gain is denoted as G_{ji} and it is defined between TX_j and RX_i. The transmission power of j is denoted as P_j and N_i is the receiver noise power at i, as sketched in Fig. 1. The received SINR is clearly computed as

$$SINR_i = \frac{G_{ii}P_i}{\sum_{j\neq i} G_{ji}P_k + N_i} \tag{1}$$

We are going to define a matrix I whose elements are defined as [10,11]. I can be considered as the ability of a user to achieve a specific SINR given the channel gains (the higher the I the lower the ability):

$$I_{ij} = \begin{cases} 0, & i = j \\ \frac{SINR_{i,min} G_{ji}}{G_{ii}}, & i \neq j, \end{cases} \tag{2}$$

where $SINR_{j,min}$ is the minimum target SINR at the node j.

In order to compute the maximum SINR that both users can achieve, which is used to determine the correlation between the involved terminals and their maximum rate, we use the method derived from [8,10,11], where the Perron-Frobenius theorem for non-negative matrices has been exploited: if the maximum eigenvalue of I is smaller than 1, then we have a possible positive eigenvector, i.e. a feasible solution and, in that case, a feasible SINR for the involved

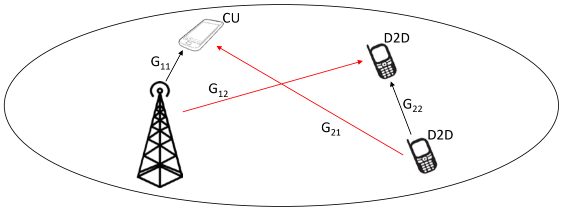

Fig. 1. Interference relations in the downlink. The cellular terminal (CU) suffers from interference produced by a D2D pair and viceversa.

terminals. By calculating the eigenvalues (λ) for the 2 terminal system (the D2D transmitter and the cellular terminal that reuse the same RB), we have

$$I = \begin{bmatrix} 0 & SI\frac{G_{21}}{G_{11}} \\ SI\frac{G_{12}}{G_{22}} & 0 \end{bmatrix}, \tag{3}$$

where SI is the SINR that both users can achieve. For calculating the eigenvalues, we solve the characteristic equation

$$\lambda^2 - SI^2 \frac{G_{21}}{G_{11}} \frac{G_{12}}{G_{22}} = 0 \tag{4}$$

and we obtain, as a function of SI and channel gains, the eigenvalue

$$\lambda = SI \sqrt{\frac{G_{21}}{G_{11}} \frac{G_{12}}{G_{22}}}. \tag{5}$$

Finally, by rearranging (5), SI can be calculated by imposing $\lambda = 1$ since this returns the maximum feasible value, i.e.

$$SI = \frac{1}{\sqrt{\frac{G_{21}}{G_{11}} \frac{G_{12}}{G_{22}}}}. \tag{6}$$

In (6), SI is the maximum SINR that both users (terminal and D2D transmitter) can achieve at the same time, denoted as $uSINR$ (uniform SINR) in[8].

Now we can assume that, if two interfering users can achieve the SINR corresponding to the maximum allowable modulation and coding schemes (MCS), these two users are uncorrelated in practice. Thus, if SI is greater than this SINR level, then both users can achieve the maximum rate without causing performance degradation each other. We remark that this procedure is coherent with the D2D reuse mode application.

3. Multi-user diversity in allocation strategies

The impact of multi-user diversity provided by resource allocation strategies has been simulated using and adapting the Tab-ID approach[9]; then it has been compared with the Round Robin (RR). The advantage of using Tab-ID is that it takes into account the SINR of the users, highlighting the multi-user diversity effect and leaving intact the generality of the numerical results by avoiding the introduction or simulation of specific allocation algorithms .

3.1. Tab-ID strategy (Tab-ID)

Allocation strategies based on SINR can be described approximately by a single parameter I_D[9], which represents the degree of multi-user diversity exploited by the algorithm. This approach allows to make the analysis independent from a particular allocation algorithm choice, focusing on the impact of the first order parameter of any allocation algorithm for multiple access wireless networks. The rationale of Tab-ID is to assign a sub-group of I_D terminals to each sub channel and select, in each sub-group, the user with the best SINR. The Tab-ID algorithm divides the users into these sub-groups in order to give each user more chances to be assigned a RB; with N_S RBs, each user is included in at least $\lfloor N_S/I_D \rfloor$ sub-groups, increasing the fairness when I_D decreases, correspondingly to the concept of multi-user diversity. The user sub-channel assignment process is really easy and it is done by means of a matrix composed of N_S rows and I_D columns and filled with $\lceil N_S I_D = N_U \rceil$ repetitions of an ordered list of users, where N_U is number of active terminals in each cell[9].

3.2. Tab-ID strategy with D2D management (Tab-ID-D2D)

Table 1 describes the modified Tab-ID in presence of D2D terminals. First, for cellular terminals, the Tab-ID is used and each RB is allocated to a user with the best SINR within a group of I_D ones. Secondly, for the D2D terminals, for each RB already assigned to a cellular terminal, a group of I_{D2D} pairs is selected and the SI between each of these and the cellular terminal in that RB is computed according to (6): therefore, the parameter I_{D2D} becomes the multi-user diversity factor for the D2D allocation and the D2D transmitter with the highest SI is selected. Since the allocation strategy is tuned for NB-IoT systems, each D2D transmitter will take just one RB. The algorithm is implemented in a way that guarantees that all the D2D users are allocated a RB.

It is worth noting that, as already mentioned, if the SI between the selected terminals is high, these two terminals can be considered independent from the interference point of view. This means that they can coexist together in the reuse mode as already stated.

Table 1. Algorithm for Tab-ID with D2D management.

Resource allocation algorithm
1.**Run the Tab-ID for cellular terminals** • Take I_D users' SINR for each RB. • Assign the RB to the user with highest SINR. 2.**Run the modified Tab-ID for D2D terminals** • Compute I_{D2D} users' SI for each RB as in (6). • Assign the RB to the D2D pair / transmitter with highest SI. • Check if all D2D terminals have taken a RB. • In case of multiple RB assignment, select the RB that maximizes the total rate.

4. System Model

The resource allocation is simulated under the following conditions and model assumptions: 19 hexagonal cells, bandwidth equal to 10 MHz, equivalent to 50 RB, maximum transmit power (D2D) 24 dBm and $I_{D2D} = 2$. All the 19 cells in the 2 tiers have the same parameters and performance targets. Terminals and D2D pairs are uniformly distributed in the environment with a cell radius equal to 250 m. All the resource allocation algorithms operate with a full traffic queue. In the D2D pairs, no power control is used (full power transmission) and the maximum distance between D2D terminals is 50 m. Finally, in order to apply the procedure in Sect. 2, it is assumed the knowledge of the channel gains between D2D NB-IoT terminals and the CU terminals involved in the same RB; this knowledge is supposed to be acquired, for example, in a centralized way by the eNodeB.

5. Simulation results

According to the system model in Sect. 4, we report the results of simulations focused on the impact of the allocation strategies in presence of NB-IoT devices operating in D2D reuse mode. In particular, the main objective of

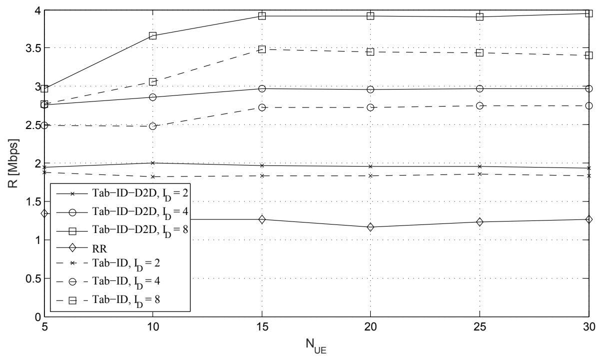

Fig. 2. Rate per cell as a function of the number of terminals in presence of 2 D2D NB-IoT pairs with the allocation strategies.

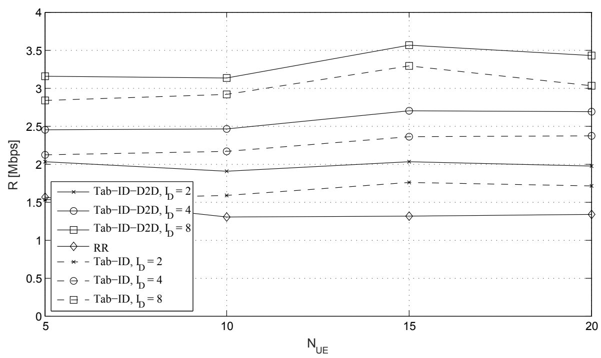

Fig. 3. Rate per cell as a function of the number of terminals in presence of 10 D2D NB-IoT pairs with the allocation strategies.

the simulations is to evaluate the advantage provided by the allocation strategies based on the analytical formulation in Sect. 2. As a term of comparison, we have used the algorithm Tab-ID in presence of D2D users also without the specific strategy described in Sect. 2 and 3.2; in this case, the D2D transmitters are allocated without evaluating the interference impact on the other terminals, but just selecting the best SINR according to the I_{D2D} parameter (in other words, the information about the mutual interference between D2D NB-IoT terminals and the other cellular terminals is ignored).

Figs. 2 and 3 show the rate per cell, including the D2D terminals, obtained by the application of the allocation strategies: it is possible to notice the performance advantage provided by the specific D2D resource allocation (Tab-ID-D2D), which can be estimated between 10% and 15%. On the other hand, in the specific scenario, the algorithms have not a significant impact on the percentage of users that remain not served at the end of the allocation process since the outage depends strongly on the occurrence of negative shadowing conditions for the terminals, mainly at the edge of the cells (Fig.4). Finally, Fig. 5 shows performance as a function of the number of D2D pairs: the relative improvement between simple Tab-ID and Tab-ID-D2D tends to increase with the number of D2D pairs since their interference impact on cellular terminals becomes more relevant.

6. Conclusions

In this paper, we have investigated the potential impact on performance of multi-user diversity typically guaranteed by allocation strategies enhanced by the possibility of including, in the allocation process, an evaluation of the mutual interference impact between cellular terminals and D2D NB-IoT pairs. The numerical results show that, in presence of cells with increasing densities of users and D2D Nb-IoT pairs, it is possible to expect a rate improvement between

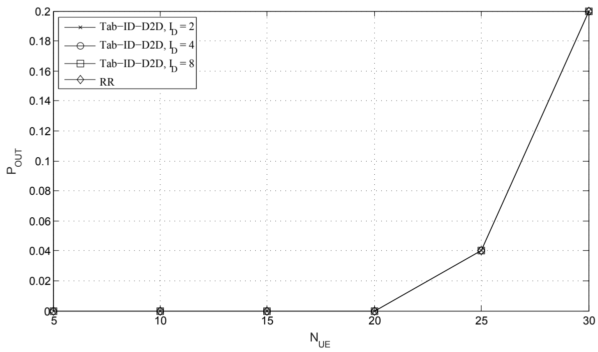

Fig. 4. Outage probability in presence of D2D NB-IoT pairs.

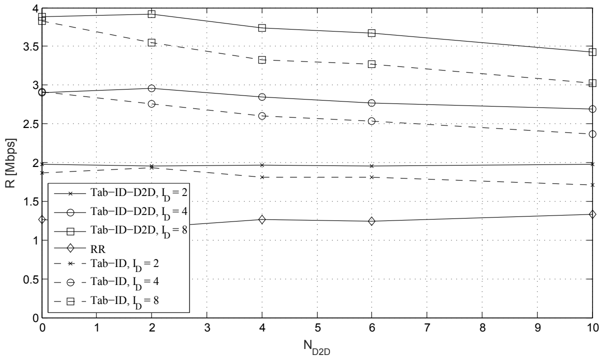

Fig. 5. Rate per cell as a function of the D2D NB-IoT number of pairs with the allocation strategies and $N_{CU} = 20$.

10% and 15% w.r.t. approaches ignoring the impact of mutual interference. Additional investigation is needed for extending the results to heterogeneous scenarios with overlapping macro and micro cells.

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