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Radio resource management scheme and outage analysis for network-assisted multi-hop D2D communications☆

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ABSTRACT

In a cellular network it's very difficult to make spectrum resource more efficiently. Device-to-Device (D2D) technology enables new service opportunities, and provides high throughput and reliable communication while reducing the base station load. For better total performance, short-range D2D links and cellular links share the same radio resource and the management of interference becomes a crucial task. Here we argue that single-hop D2D technology can be used to further improve cellular networks performance if the key D2D radio resource management algorithms are suitably extended to support multi-hop D2D communications. Aiming to establish a new paradigm for the analysis and design of multi-hop D2D communications, We propose a radio resource allocation for multi-hop D2D routes based on interference avoidance approach in LTE-A networks. On top of that, we investigate the outage probability of D2D communication. We first introduce a new definition of outage probability by considering the maximum distance to be allowable for single-hop transmission. Then we study and analyze the outage performance of a multi-hop D2D route. We derive the general closed form expression of outage probability of the multi-hop D2D routes. The results demonstrate that the D2D radio, sharing the same resources as the cellular network, provide higher capacity compared to pure cellular communication where all the data is transmitted through the base station. They also demonstrate that the new method of calculation of D2D multi hop outage probability has better performance than classical method defined in the literature.

1. Introduction

The next generation LTE-Advanced (LTE-A) network is expected to adopt technologies that not only improve system performance but also build up foundation for new type of services. Direct communication with short range or Device-to-Device (D2D) communication [1,2] is a candidate to satisfy this requirement and has become one of the study items under investigation in releasing 12 of 3GPP LTE. D2D communication allows devices to transmit data directly without passing it through eNodeB(eNB). D2D communication provides high throughput, reduce power consumption [3], and enables new service opportunities and reliable communication while reducing the Base Station (BS) load.

Spectrum sharing is one way of reusing spectrum and has been frequently used to improve the performance of wireless networks [4,5]. D2D communication in LTE shares the licensed radio resource with regular LTE links [6]. It has significant advantages on spectral efficiency and power consumption [7]. Furthermore, it is possible to gain higher spectrum usage by letting the D2D links utilize the spectrum resource of cellular links [8] without causing substantial performance degradation to each other. Such way of communication requires a smart design on radio traffic management [9].

Knowing that the ideas of integrating multi-hop relaying systems into cellular networks is not new [10,11]. The advantages of D2D communications in cellular spectrum have been identified and analyzed only recently [12]. Specifically, it has been found that Single-Hop (SH) D2D communication can increase the spectral and energy efficiency of cellular networks by taking advantage of the proximity, reuse, and hop gains. Another line of research suggests that network-assisted Multi-Hop (MH) communications, including mobile relays and relay assisted D2D communications, can not only enhance the achievable transmission capacity, but also improve the coverage of cellular networks. In this paper, we argue that single-hop D2D technology can be applied to further increase the spectral efficiency and energy if the key D2D radio resource management algorithms [13] are suitably extended to support cellular network assisted multi-hop D2D communications. In this work, we consider multi-hop D2D communication underlaying a 3GPP LTE-A network. For better total performance, D2D links and cellular links share the same radio resource and the management of interference becomes a crucial task. We propose a radio resource allocation for multi-hop D2D links based on interference

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avoidance approach. The problem is to optimize the transmitting power levels of D2D users in order to maximize the cell throughput while preserving the SINR performance for the cellular user [14].

We introduce the scenario of multi-hop communications, and discuss that how to build multi-hop communication, how D2D Users Equipment (UEs) are distributed, and how to reduce the outage probability in D2D enabled cellular network [15]. In this context, the outage probability is an important metric that can improve the network QoS [7]. As a major contribution, we derive outage probability closed form expressions for the D2D link. Then we study and analyze the outage performance of a multi-hop D2D route. We derive the general closed form expression of outage probability of the multi-hop D2D routes. We discuss that how to build multi-hop communication, how D2D UEs are distributed, and how to reduce the outage probability in D2D-enabled cellular network. We analyze and compare the proposed scheme and many others schemes in terms of system throughput for DL and outage probability according to the distance constraint. Simulation results show that the proposed scheme has better performance than the other resource allocation schemes performance in terms of the system throughput and outage probability. The paper will be organized as follows. In Section 2, we present the scenario description and system model. In Section 3, we propose a novel scheme to realize DL resources sharing avoiding interference ARIA for network assisted ad-hoc D2D communications. Section 4 presents the new way to determine the multi-hop D2D outage probability that is able to enhance the system performance. Finally, performance evaluation and discussions are presented in Section 5 and conclusion is given in Section 6.

2. Scenario description and system model

In this section, an integrated framework is proposed to support opportunistic networking scheme which underlies an LTE-A cellular network. In LTE-A system, bandwidth is divided into equal size of Physical Resources Blocks (PRBs). Each PRB physically occupies (0.5 ms) 1 slot in the time domain and 180 kHz in the frequency domain with subcarrier spacing of 15 kHz [16]. Each PRB is assigned exclusively to one user at any time within a given cell. However, neighboring cells may reuse the same PRB for different users. Over recent years, the latest approved standard for LTE-A, includeing the support for discovery and direct communication between devices that are in proximity of each other [17], developed under the name of Proximity based Services (Pro-Se). However, D2D communication is sharing authorized frequency SubBand (SB) with cellular communications by the way of orthogonal method or multiplexing method.

As shown in Fig. 1, we consider a system topology with 3 hexagonal cells, in the center of each one of them it contains an eNB noted by eNB_j where $j \in \{1, 2, \ldots, J\}$. Each cell is individually characterized by U users denoted as $\Omega_u = \{1, 2 \ldots, U\}$, sharing V PRBs represented as $A = \{1, 2 \ldots, V\}$. The users are grouped into two types: the first type is called cellular user who apply services from system servers, and thus merely need communicating via eNB denoted as $\Omega_c = \{1, 2 \ldots, C\}$. The second type is two users who need to exchange data with each other, as a D2D Transmitter-Receiver (Tx-Rx) pair (see Fig. 1). This category of users is denoted as $\Omega_{D2D} = \{1, 2 \ldots, D\}$. Obviously,it is composed by two UEs: $n \mapsto m$. The transmission link between n and m refers to a single-hop D2D transmission denoted as $l(n, m) \in \{1, 2 \ldots, \mathbf{L}\}$. Let us define a D2D route, based on D2D single-hop link, as the concatenation of one or more D2D links that denotes as $i \in \{1, 2 \ldots, I\}$. As a consequence of single-hop D2D concatenation, we can obtain a multi-hop D2D routes (see Fig. 2).

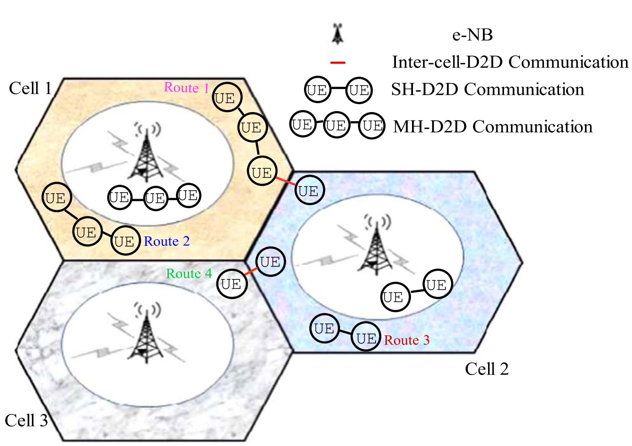

Fig. 1. System Topology.

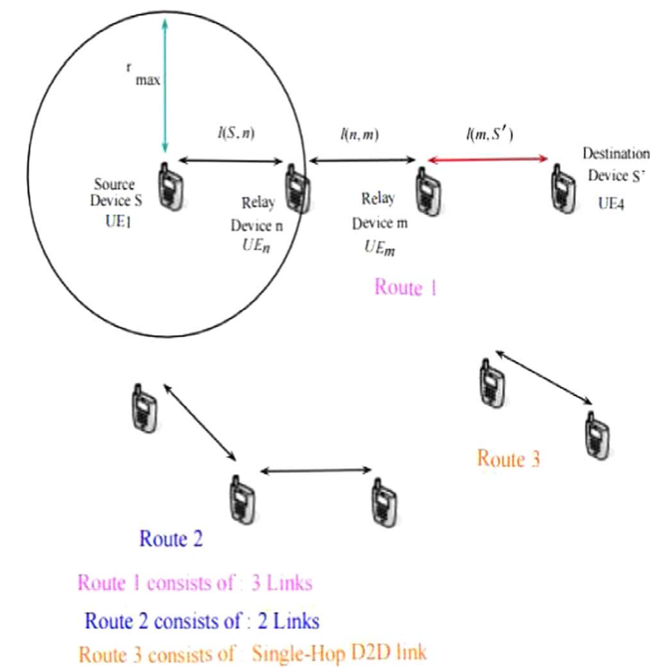

Fig. 2. An example of a network with 3 routes, where Route 1 and Route 2 are MH-D2D routes, and Route 3 consists of a SH-D2D route.

A D2D pair can be a D2D Tx node transmitting to a D2D Rx node in single-hop D2D mode, a D2D Tx node transmitting to a D2D intermediate node or a D2D intermediate node transmitting to a D2D Rx node. The whole frequency resources are divided into V PRBs, which are classified into two groups: common SBs (CSB) and uncommon SBs (USB). For each cell, one group of SBs are CSBs, the other group of SBs are USBs. The CSBs of all the cells are the same, while the USBs should be carefully planned to prevent from using the same SBs in neighboring cells. Whereas the CSBs are transmitted with the maximum power P_{max}, the USBs are transmitted with the minimum power P_{min}. D2D communication uses the same allocated SBs with the cellular communication. Thereby the utilization of the spectrum can be increased and D2D communication must generate interference to the cellular network. The SINR of the cellular communication link between eNB and UE c denoted as [18]:

$$\gamma_{B,c} = \frac{P_B G_{B,c} r_{B,c}^{-\alpha}}{N_0 + I_{cell} + \sum_{m \in \Omega_{D2D}} x_c^m P_m G_{m,c} r_{m,c}^{-\alpha}}, \tag{1}$$

The SINR of the D2D of a link from UE n to UE m can be written as follows [18]:

$$\gamma_{n,m}^{D2D} = \frac{P_n G_{n,m} r_{n,m}^{-\alpha}}{N_0 + I_{cell} + \sum_c x_c^m P_B G_{c,m} r_{c,m}^{-\alpha}}, \tag{2}$$

P_B represents the transmitting power offered by eNB to user c. P_n is the transmitting power of D2D UE n. When D2D devices reuses DL

Table 1
An example of how the network in Fig. 2 can be described using the Functions defined above.

Functions	Description	Example in the Network ofFig. 2
LL(i)	Number of link in route i	LL(1)=3
Ind(i,l)	Index of D2D Tx-Rx nodes which are formed the link l in route i and the index of the eNB that controls each one of them	Ind(1,3)=$(m-S')_{1,2}$

frequency resources, any D2D pair causes interference to cellular user c while using resource frequency assigned to it. x_c^m represents a binary variable which satisfies $x_c^m = 1$ if UE m uses resource frequency assigned to cellular user c. α is the pathloss distance exponent. I_{cell} accounts for Inter Cell Interference (ICI), N_0 is the receiver noise power. $G_{B,c}$ denotes the Rayleigh fading channel power gain of the link from the eNB and UEs c. $G_{n,m}$ and $r_{n,m}$ are the Rayleigh fading channel power gain and distance of the link from UE $n \to m$, respectively. Let us define the rates $\tau_{B,c}$ and $\tau_{n,m}^{(i)}$ corresponding to the $\gamma_{B,c}$ and $\gamma_{n,m}^{D2D}$ as determined by the Shannon capacity model. $\tau_{n,m}^{(i)}$ denotes the rate for the D2D communication between UE n and UE m that forms the link $l(n,m)$ of route i. To describe the association of links with routes, we define the following two functions. Let $LL(i)$ denote the total number of links in the route i. $Ind(i,l)$ denotes the index of (Tx-Rx) nodes that form the link number l in route i. $(Tx-Rx)_{jk}$ where j and k denote the index of the eNB that controls each one of them. $LL(i) = 1$ represents a route i that is formed by just one link (single-hop D2D pair). Table 1 gives an example of how these functions help to describe the relationship between routes, links and devices that formed. The problem is formulated to maximize the total system throughput under two different constraints. The optimization problem can be expressed as follows:

$$\text{Max } \mathbf{T} = \sum_{c=1}^{C} \nu_c \tau_{B,c} + \sum_{i}^{I} \sum_{l(n,m)}^{LL(i)} \sum_{c=1}^{C} x_c^m \nu_c \tau_{n,m}^{(i)}, \tag{3}$$

$$\text{st} \quad : \begin{cases} \gamma_{B,c} \geq \gamma_{th}^{c} \quad \text{and} \quad \gamma_{n,m}^{D2D} \geq \gamma_{th}^{D2D}, \quad \forall\, n, m \in \Omega_{D2D} & (a) \\ \sum_c x_c^m \leq 1 \quad \text{and} \quad \sum_{m \in \Omega_{D2D}} x_c^m \leq 1 & (b) \\ x_c^m \in \{0, 1\} & (c) \end{cases}$$

here, ν_c denotes the number of PRBs allocated to the cellular user c at each time slot during the DL period. Constraints in (3.a) guarantee the target SINR of the cellular and D2D transmission. The D2D links are allocated such that the interference at each involved device is below a threshold. In a multi-hop D2D communication case, the SINR targets of each link in a specific route must be the same, in line with the so-called solidarity property. Constraints in (3.b) ensure that each device shares at most one user's PRB(s). And ensure that at most one D2D pair shares any user's PRB(s).

3. Resource Allocation and Interference Avoidance (RAIA) for network assisted Ad-hoc D2D communications

In this paper we propose and analyze some of the key design challenges in coping with the interference between cellular and D2D communication. We propose a simple resource allocation scheme that is applicable in cellular networks integrating multi-hop D2D communications in LTE-A networks. The resource allocation proposed scheme is divided into two parts, the first part is a resource allocation approach for the single-hop D2D pair which is detailed in [18]. Likewise, the second part represents a resource allocation approach, but this time for the multi-hop D2D pairs. The idea is to extend the key enabling technology components of single-hop network assisted D2D communications to multi-hop D2D communications.

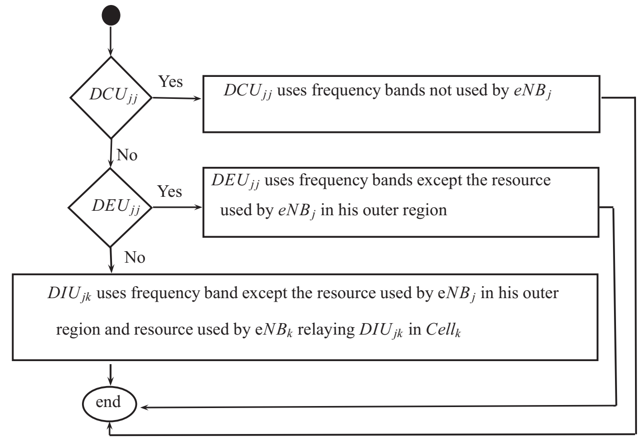

Fig. 3. Intra-Inter D2D Frequency Reuse Scheme.

3.1. Proposed scheme for single-hop D2D communication

In [18], the authors propose a simple resource allocation scheme for single-hop Intra-Inter-Cell D2D communication. The proposed approach, in the first step, determines whether D2D candidates in the proximity of each other should communicate in direct mode using the D2D link or in cellular mode. Two classes of users are considered, cellular users and D2D users. As well as, this last class is already divided into two categories: Intra-Cell D2D communication and Inter-Cell D2D communication. The first category is called Intra-Cell-D2D communication, two users $(Tx-Rx)_{jj}$ are identified physically as belonging to the same $cell_j$ and who need to exchange data with each other. The second category considers, called Inter-Cell-D2D communication, two users $(Tx-Rx)_{jk}$ are belonging to the edge of two different adjacent cells, $cell_j$ and $cell_k$, as it is shown in Fig. 1. The Center User (CU) category contains two subgroups: Cellular Center User (CCU) and D2D Center User (DCU). The same goes for the Edge User (EU) that contains two subgroups: Cellular Edge User (CEU) and D2D Edge User(DEU). DEU class is already divided into two under-classes: Intra-Cell-D2D and Inter-Cell-D2D. Thus, by the end of the D2D users grouping, there will be three D2D classes: D2D Edge User(DEU), D2D Center User (DCU) and D2D Inter-Cell User(DIU). After finishing the user grouping to get access to the different users categories, then you go to evaluate the SINR and throughput for every user u (see Algorithm 1). During this evaluation, account must be taken of the user's type and the users's position in the cell. The idea is to start by serving the cellular users by the CSBs, the CSBs are exclusively reserved to the CCUs. The PRB ν will be affected to the CCU which is going to maximize the throughput. When the CSBs are done, we move to the USBs which are deserved to the remaining users while also taking into account the maximization of the throughput (see Algorithm 2). Once, we have finished cellular users allocation, we move to the single-hop D2D users' allocation. Fig. 3 shows the procedure how eNBs allocate the frequency resources to single-hop D2D users. If D2D users are located in the inner region of $cell_j$, they therefore belong to the category of DCUs, who are noted by DCU_{jjk}, and can use the frequency band which eNB_j do not use. In case that D2D UEs are in the outer region of $cell_j$, so it is noted by DEU_{jj}, they can use the frequency resources except for the resources used by eNB_j in identical $cell_j$ outer region. Again, in the latter case, Inter-Cell-D2D UEs are in cell outer region, but each one of them belongs to a cell apart. Inter-Cell-D2D that is located between the extremity of $cell_j$ and $cell_k$ is noted by DEU_{jk}, so they can use the radio resources except the resource used by eNB_j in his outer region and resource used by eNB_k in his outer region.

Algorithm 1. SINR and Throughput Evaluation

for $v = 1: V$; **do**
  for $u = 1: U$; $u \in CU$, $P_B = P_{max}$ **do**
    if $u \in CCU$ **then**
      evaluate $\gamma_{B,u}$ using Eq.(1)
      $\tau_{B,u} = \frac{B}{V}\log_2(1 + \frac{\gamma_{B,u}}{\Gamma})$
    else
      evaluate $\gamma_{n,m}^{D2D}$ using Eq.(2)
    end if
  end for
  for $u = 1: U$; $u \in EU$, $P_B = P_{min}$ **do**
    if $u \in CEU$ **then**
      evaluate $\gamma_{B,u}$ using Eq.(1)
      $\tau_{B,u} = \frac{B}{V}\log_2(1 + \frac{\gamma_{B,u}}{\Gamma})$
    else
      evaluate $\gamma_{n,m}^{D2D}$ using Eq.(2)
    end if
  end for
end for

Algorithm 2. Cellular Users Allocation

for $v = 1: V$; $v \in CSB$ **do**
  $u^* = \text{argmax}_{u \in U}\tau_{B,u}$
  if $u^* \in CCU$ **then**
    Affect v to u^*
  end if
end for
for $v = 1: V$; $v \in USB$ **do**
  $u^* = \text{argmax}_{u \in U}\ \tau_{B,u}$
  Affect v to u^*
end for

3.2. Proposed scheme for multi-hop D2D communication

As shown in Fig. 1, a hybrid network with a fixed number of nodes is depicted. The idea is to extend the key enabling technology components of single-hop network-assisted D2D communications to multi-hop D2D communications. The idea is to (re)group D2D communications into i routes, regardless of routes formed by D2D single-hop or multi-hop communications. Each route is the concatenation of one or more links, each link $l(n, m)$ is represented by a single-hop D2D communication. The idea is to divide the routes which are formed by multi-hop D2D pair into single-hop D2D pair and treat thereafter link by link (see Fig. 2). This single-hop D2D pair can be a Intra-Cell D2D Communication or Inter-Cell D2D Communication. Therefore, in order to allocate SB to each route, you just need to allocate the SB to the various links that form this route. Therefore use the proposed algorithm in [18] on each D2D single-hop pair (see Algorithm 3).

Algorithm 3. Multi-Hop D2D Allocation

for $i = 1: I$ **do**
  if $LL(i) = 1$ **then**
    $(Tx - Rx)_{jk} = Ind(i, 1)$
    Execute the Intra-Inter D2D Frequency Reuse Scheme in Fig. 3 with $(Tx - Rx)_{jk}$
  else
    for $l = 1: LL(i)$ **do**
      $(Tx - Rx)_{jk} = Ind(i, l)$
      Execute the Intra-Inter D2D Frequency Reuse Scheme in Fig. 3 with $(Tx - Rx)_{jk}$
    end for
  end if
  $\tau_{(Tx,Tr)}^{(i)} = \frac{B}{V}\log_2\left(1 + \frac{\gamma_{(Tx,Tr)}^{D2D}}{\Gamma}\right)$
end for

4. Outage probability for multi-hop D2D routes with distance constraint

The outage probability is an important metric that can improve the network QoS [7]. In this part, we study the outage probability of multi-hop D2D communications. In this section, we derive new closed-form expressions for the outage probabilities of the D2D link for the relay aided strategy. Let us define the outage probability of the D2D link l between nodes n and m denoted as $(P_{out_{l(n,m)}})$ where the received $\gamma_{n,m}^{D2D}$ is below the threshold $\boldsymbol{\gamma}_{th}^{D2D}$. In this section, we denote by $f_X(\gamma)$ and $F_X(\gamma)$ the Probability Density Function (PDF) and the Cumulative Density Function (CDF) of x, respectively.

4.1. Classical D2D outage probability approach

The classical outage probability approach is based on the calculation of probability that the instantaneous SINR is below the SINR threshold over a certain fading model. The outage probability of the D2D link $(P_{out_{l(n,m)}}^{D2D})$ is defined as the probability that the instantaneous $\gamma_{n,m}^{D2D}$ falls below a predetermined ratio γ_{th}^{D2D}. As a result, the outage probability of of D2D link l between nodes n and m can be obtained by integrating the PDF of γ_{th}^{D2D} as [11]:

$$P_{out_{l(n,m)}}^{D2D} = \mathbf{Pr}(\gamma_{n,m}^{D2D} \leq \gamma_{th}^{D2D}) \tag{4}$$

As mentioned above, because $G_{n,m}$ follows Rayleigh distribution, then $\gamma_{n,m}^{D2D}$ is an exponential random variable and this is the typical and classical approach that almost everyone uses [11,19].

4.2. Single-hop D2D outage probability

Short range direct communication or D2D communication is a candidate to satisfy this requirement. This could allow large volumes of media or other data to be transferred from one device to another over short distances and using a direct connection. Here, a new definition of outage probability by considering the maximum distance to be allowable for single-hop transmission. We denote $r_{n,m}$ the distance between D2D nodes n and m which forms the link l. Knowing that above this distance we are going to have a connection failure between D2D UE n and UE m when the condition $r_{n,m} \geq r_{max}$ is realized. Hence the D2D link outage probability can be defined as:

$$\begin{aligned}\mathbf{P}_{out_{l(n,m)}}^{D2D} &= Pr(\gamma_{n,m}^{D2D} \leq \gamma_{th}^{D2D},\ r_{n,m} \geq r_{max}),\\ &= Pr\left(\frac{P_n G_{n,m} r_{n,m}^{-\alpha}}{N_0 + \daleth} \leq \gamma_{th}^{D2D},\ r_{n,m} \geq r_{max}\right)\end{aligned} \tag{5}$$

where

$$\daleth = I_{D2D} + I_c, \quad I_c = \sum_c x_c^m P_B G_{c,m} r_{c,m}^{-\alpha}, \tag{6}$$

This is equivalent to consider:

$$\begin{aligned}P_{out_{l(n,m)}}^{D2D} &= Pr\left(\frac{G_{n,m} P_n r_{n,m}^{-\alpha}}{N_0 + \daleth} \leq \gamma_{th}^{D2D},\ r_{n,m} \geq r_{max}\right),\\ &= Pr\left(r_{n,m}^{-\alpha} \leq \frac{N_0 + \daleth}{G_{n,m} P_n}\gamma_{th}^{D2D},\ r_{n,m} \geq r_{max}\right) + Pr\left(r_{n,m}^{-\alpha} \leq \frac{N_0 + \daleth}{G_{n,m} P_n}\gamma_{th}^{D2D},\ r_{n,m}^{-\alpha} \leq r_{max}^{-\alpha}\right),\\ &= Pr\left(r_{n,m}^{-\alpha} \leq \inf\left(\frac{N_0 + \daleth}{G_{n,m} P_n}\gamma_{th}^{D2D},\ r_{max}^{-\alpha}\right)\right)\end{aligned} \tag{7}$$

Let us define

$$\Lambda = \inf\left(\frac{N_0 + \daleth}{G_{n,m}P_n}\gamma_{th}^{D2D},\ r_{max}^{-\alpha}\right) \tag{8}$$

Then we have

$$P_{out_{l(n,m)}}^{D2D} = Pr\left(r_{n,m}^{-\alpha} \le \Lambda\right) \Rightarrow Pr\left(r_{n,m} \ge \Lambda^{-\frac{1}{\alpha}}\right) \Rightarrow 1 - Pr\left(r_{n,m} < \Lambda^{-\frac{1}{\alpha}}\right) \tag{9}$$

4.3. Multi-hop D2D outage probability

In the D2D communication system assisted by intermediate nodes, information exchange takes place between the D2D source device and D2D destination device through the intermediate node. For successful transmission, each node should receive the information correctly. Using the single-hop outage probability given in (7) we set the outage probability for multi-hop D2D denoted as $P_{out_{l(n,m)}}^{D2D}$. This last probability can be obtained as a function of the success probability for each D2D link $l \in \{1, 2, \ldots L\}$ as follows [11]:

$$P_{out}^{D2D} = 1 - \left(1 - P_{out_{1)}}^{D2D}\right)\left(1 - P_{out_2}^{D2D}\right)\ldots\left(1 - P_{out_L}^{D2D}\right) \tag{10}$$

Therefore, aiming to minimize the outage probability of the D2D multi-hop route the problem is formulated as below:

$$\text{Minimize } P_{out}^{D2D} = 1 - \prod_{l=1}^{L}\left(1 - P_{out_{l(n,m)}}^{D2D}\right) \tag{11}$$

We assume that the links are $i.\,i.\,d.$, for each multi-hop D2D route, then $P_{out_{l(n,m)}}^{D2D} \cong p_{out}^{D2D}$ corresponding to a distance r. Then the end-to-end outage probability in (9) can be written as:

$$\mathbf{P}_{out}^{D2D} = 1 - \left(1 - p_{out}^{D2D}\right)^{L} = 1 - \left(1 - Pr\left(r \ge \Lambda^{-\frac{1}{\alpha}}\right)\right)^{L} = 1 - \left(Pr\left(r \le \Lambda^{-\frac{1}{\alpha}}\right)\right)^{L} \tag{12}$$

Let us define the best single-hop D2D link denoted by l^* is chosen referring to the smallest $P_{out_{l(n,m)}}^{D2D}$ i.e.

$$l^* = \underset{1 \le l(n,m) \le L}{\text{argmin}}\left(P_{out_{l(n,m)}}^{D2D}\right) \tag{13}$$

Then, an end-to-end lower bound outage probability $P_{out_{th}}^{D2D} \le P_{out}^{D2D}$ can be derived from (9):

$$P_{out_{th}}^{D2D} = 1 - \left(1 - P_{out_{l^*}}^{D2D}\right)^{L} \tag{14}$$

The probability density function (PDF) of the distance r between two D2D nodes in a circular cell can be derived using the disk line picking described in [[20], Ch. 6] as:

$$\mathbf{f}(r) = \frac{4r}{\pi R^2}\cos^{-1}\left(\frac{r}{2R^2}\right) - \frac{2r^2}{\pi R^3}\sqrt{1 - \frac{r^2}{4R^2}}, \tag{15}$$

with $0 < r_{n,m} \le \Lambda^{-\frac{1}{\alpha}}$. we can obtain the term of D2D outage probability depicted in (13) on top of the next page. After the manipulations of (12), the integral in (15) is calculated numerically in the range $[0, \Lambda^{-\frac{1}{\alpha}}]$. We can obtain the term in (16) on top of the page by integrating both sides:

5. Simulation results and analysis

In this part, the D2D communication underlying cellular networks performance is evaluated. The achievable transmission capacity, the total SINR and the total power transmission of the D2D system are analyzed. Next the proposed multi- hop D2D outage probability approach is investigated and the proposed D2D outage probability is compared under classical approach in order to make the results more insightful. We investigated the DL performance of proposed frequency planning and the interference management scheme for SH-MH D2D communication underlying cellular network using a monte carlo simulation. We performed independent simulations and evaluated system performance. To be more realistic, we set a peak instantaneous transmission power for the eNB as 43 dBm. Table 2 gives the key parameters [1,16,18,21].

Table 2
Simulation parameters.

Symbol	Definition	Value
V	Resource Block number	50
B	System bandwidth	10 MHz
$\gamma_{th}{}^{c}$	Cellular SINR threshold	4, 8 dB
γ_{th}^{D2D}	D2D SINR threshold	2 dB
P_n	D2D Transmit power	200 mW
N_0	Noise power	−107 dBm/Hz

$$P_{out}^{D2D} = 1 - \left(\frac{4}{\pi R^2}\int r\arccos\left(\frac{r}{2R^2}\right)\mathrm{dr} - \frac{2}{\pi R^3}\int (r)^2\sqrt{1 - \frac{(r)^2}{4R^2}}\,\mathrm{dr}\right)^{L}$$

$$= 1 - \left(\frac{-\Lambda^{-\frac{1}{\alpha}}\sqrt{1 - \frac{\left(\Lambda^{-\frac{1}{\alpha}}\right)^2}{R^4}} + 2\left(\Lambda^{-\frac{1}{\alpha}}\right)^2\cos^{-1}\left(\frac{\Lambda^{-\frac{1}{\alpha}}}{R^2}\right)R^4\sin^{-1}\left(\frac{\Lambda^{-\frac{1}{\alpha}}}{R^2}\right)}{\Pi R^2} - \frac{\Lambda^{-\frac{1}{\alpha}}\sqrt{4 - \frac{\left(\Lambda^{-\frac{1}{\alpha}}\right)^2}{R^2}}\left(\left(\Lambda^{-\frac{1}{\alpha}}\right)^2 - 2R^2\right) + 8R^3\sin^{-1}\left(\frac{\Lambda^{-\frac{1}{\alpha}}}{2R}\right)}{4\Pi R^3}\right)^{L}$$

$$= 1 - \left(\frac{-4R^3\Lambda^{-\frac{1}{\alpha}}\sqrt{1 - \frac{\Lambda^{-\frac{2}{\alpha}}}{R^4}} + \Lambda^{-\frac{1}{\alpha}}\left(-\Lambda^{-\frac{2}{\alpha}} + 2R^2\right)\sqrt{4 - \frac{\Lambda^{-\frac{2}{\alpha}}}{R^2}} + \frac{8R}{\Lambda^{\frac{2}{\alpha}}}\cos^{-1}\left(\frac{\Lambda^{-\frac{1}{\alpha}}}{R^2}\right) - 8R^3\cos^{-1}\left(\frac{2R}{\Lambda^{-\frac{1}{\alpha}}}\right) + 4R^5\sin^{-1}\left(\frac{\Lambda^{-\frac{1}{\alpha}}}{R^2}\right)}{4\Pi R^3}\right)^{L} \tag{16}$$

5.1. Simulation analysis of multi hop D2D transmission capacity

We analyze and compare the proposed scheme and many other schemes in terms of the system throughput, SINR and power consumption for DL scenario. We first consider a purely cellular system, in the second scenario we consider a heterogenous system, where cellular users and D2D users are allocated a dedicated resources independently. In the third scenario, cellular users and Intra-Cell-D2D users are present, single hop D2D communication allows devices to communicate directly by sharing the resource with the cellular network and is controlled by eNB. The fourth scenario is one where both Intra-Cell-D2D and Inter-Cell-D2D are present in the underlying cellular network by sharing the resource with them. The last scenario, we consider a multi hop D2D communication underlying cellular network by sharing the resource with them.

We plot in Fig. 4 the CDF curve of total user throughput where the maximum distance between D2D pairs is 50 (m). We clearly obtain a performance improvement for the MH-D2D in terms of total user throughput. Throughput of D2D user is higher than eNB relaying UE because the distance between D2D pairs is much shorter than distance between eNB relaying UEs. So throughput of cellular network support-

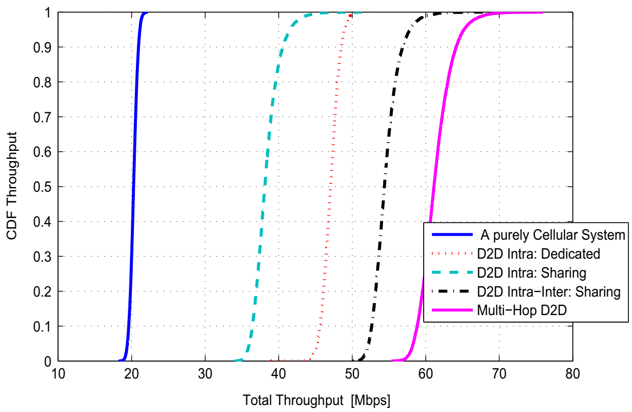

Fig. 4. CDF of System Throughput.

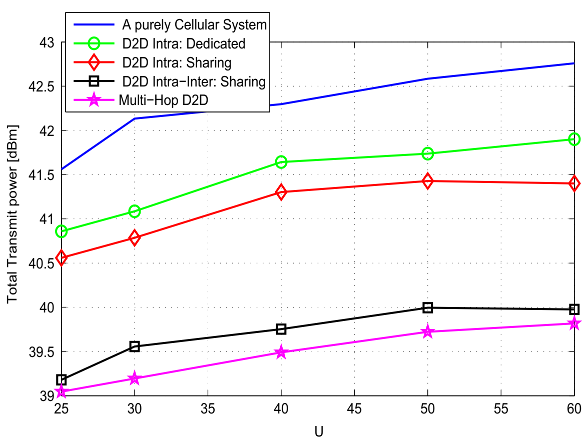

Fig. 5. Total Transmit Power per Cell.

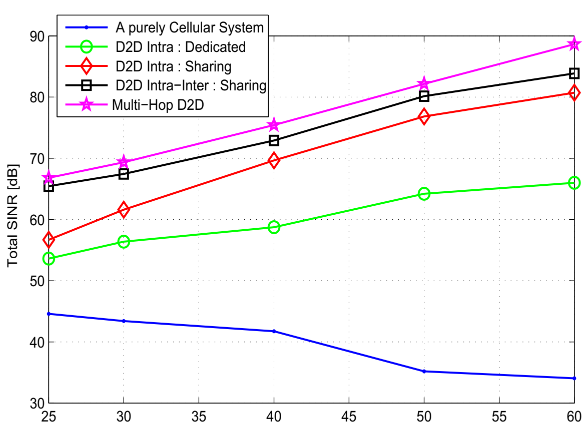

Fig. 6. Total System SINR.

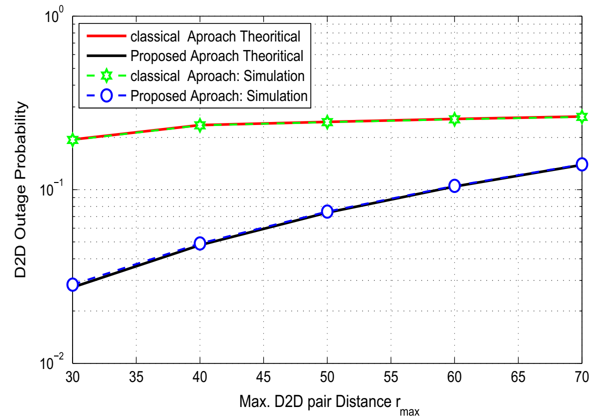

Fig. 7. D2D Outage Probability, L=5 and $\alpha = 4$.

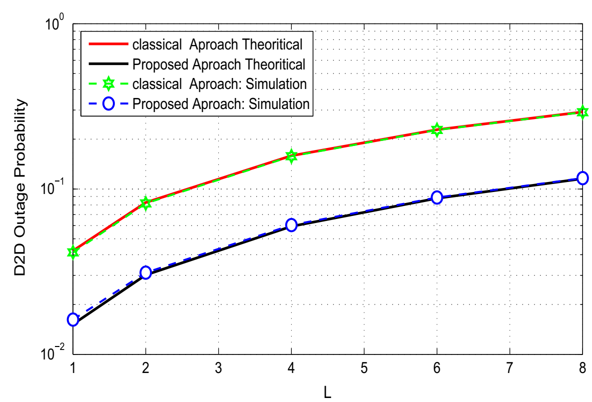

Fig. 8. D2D Outage Probability $r_{max} = 50$ m and $\alpha = 4$.

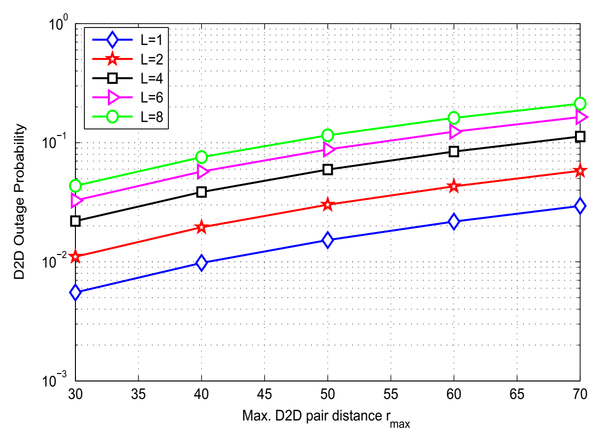

Fig. 9. D2D Outage Probability, $\alpha = 4$.

ing D2D communication is higher than the network without D2D communication. By integrating D2D communications into the cellular system an obvious throughput gain can be achieved because of the short range of the D2D link, multiple D2D users can communicate for higher network throughput. This enables high bit rates, low delays, and low power consumption. Moreover, reusing radio resource between D2D link and eNB relaying link can significantly improve throughput and spectrum efficiency. Fig. 5 shows the total DL transmission power versus different user number. In the case of a purely cellular user, the quantity of power increases with the increase of users' number. However, with the integration of D2D communication, we notice a decrease in the global consumption. This happens because of the weak rate of the communication's consumption which leads to a profit in the power. Network-assisted MH-D2D communication can increase the system performance in terms of power consumption by taking advantage of the proximity, reuse, and hop gains when radio resources are properly managed between the cellular and D2D layers. Fig. 6 shows the total SINR versus users number. When allocating resource, the eNB assigns either dedicated or reused resource to cellular users and D2D users. There is not mutual intra-cell interference between D2D users and cellular users if both of them use dedicated resources. On the other hand, the spectrum efficiency can be higher in reused resource sharing. The multi-hop D2D communication scheme offers the best performance in terms of SINR. Thus, the power control generates efficient frequency reuse patterns for CEUs, which improves their SINR performance so lower power consumption and lower interference.

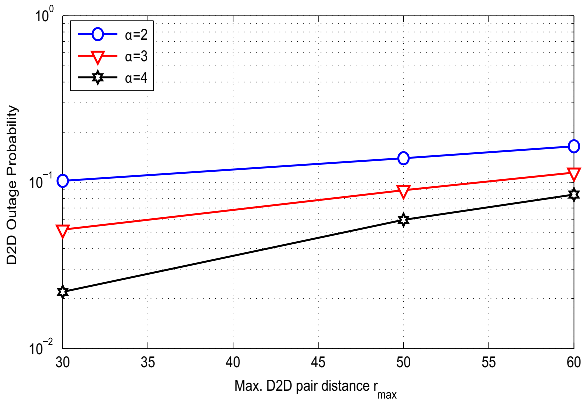

Fig. 10. D2D Outage Probability, r_{max} = 50 m and L=5.

This phenomenon demonstrates that the proposed scheme effectively reduces the ICI.

5.2. Simulation analysis of D2D outage probability

Next the simulation results of outage probability of multi hop D2D communication underlaying cellular networks are discussed. We introduce the scenario of multi-hop communications which is based on D2D technology. We discuss that how to build multi-hop communication, how D2D UEs are distributed, and how to reduce the outage probability in D2D-enabled cellular network. Hence, we propose and analyze a new way to determine the multi-hop D2D outage probability that is able to enhance the system performance.

In Fig. 7, we investigate the behavior of the outage probability of the multi-hop D2D communications when the single D2D source and destination r_{max} varies. It is observed that the new way to determine the outage probability of multi-hop D2D communications is much more efficient than the the classical approach. Equally, it is observed that the outage probability decreases with the decrease of the r_{max}. Moreover, we note that a change in r_{max} in the down level has a greater impact on the outage probability of the multi-hop D2D Communications. For r_{max}=40 m, the probability of outage decrease is approximately 20%.

In the Fig. 8 we evaluate the dependence of the outage probability on the number of intermediate nodes between the D2D source S and the D2D destination S'. We compare the performance of our proposed approach and the classical approach defined in the literature. We can observe that the probability of outage versus L: number of intermediate hops, the outage probability increases with the increase of L. It can be seen as a dependance between the probability of outage and the number of links in the D2D multi-hop route. We can interpret this result as the multi-hop D2D mode is limited by the number of potential relays and by the interference constraints imposed by the cellular network. Fig. 9 shows D2D outage probability versus the upper bound distance between the single D2D source and destination r_{max}. We consider the α value equals to 4. As shown the outage probability increases when L decreases. This is evident because we reduced the diversity order L. This figure shows the effect of the number of hops on the multi-hop D2D communications performance.

The outage probability versus the path loss exponent α is plotted in Fig. 10. A fixed number of link L and an upper bound on the distance between the D2D pair r_{max} is used. As α increases, the outage probability decreases. Relays are willing to forward information for the D2D source can help overcome high attenuation channels due to large distances. Even though each hop in the D2D route sees higher attenuation, interference from cellular users is lower, and D2Ds interfere with the BS less allowing them to transmit at a higher power. Finally, the Fig. 10 shows that using a higher value of α will significantly improve the outage probability of multi-hop D2D communications. So as conclusion When α is larger, D2Ds become more isolated from the base station making shorter distance hops more efficient.

6. Conclusion

In this paper We have analyzed multi hop D2D communications underlying a cellular network. We have shown that given coordination mechanisms and proper power control it is possible to have D2D connections that reuse cellular band and still cause only minimal interference to the cellular communication. We considered several allocation strategies, including traditional cellular communications. The results have shown that significant gains in total throughput can be achieved by enabling single hop D2D or multi- hop D2Dcommunications compared to the conventional cellular system. Further, we have performed analytical studies to analyze how much gain can be expected in terms of outage probability for the multi- hop D2D communication. The simulation results have shown the impact of the r_{max} we note that a change in value in the down level has a greater impact on the outage probability of the system performance. Equally, because D2D mode has been ideal for shorter distances, the normally harmful affects of pathloss actually help manage the interference at the eNB. When pathloss exponent is larger, D2Ds become more isolated from the base station making shorter distance hops more efficient. In addition, we can observe that the probability of outage depends on the number of hops in the D2D multi-hop route.

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