Efficient Resource Allocation for Device-to-Device Communication Underlaying LTE Network

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***Abstract*—Device-to-device (D2D) communication as an underlaying cellular network empowers user-driven rich multimedia applications and also has proven to be network efficient offloading eNodeB traffic. However, D2D transmitters may cause significant amount of interference to the primary cellular network when radio resources are shared between them. During the downlink (DL) phase, primary cell UE (user equipment) may suffer from interference by the D2D transmitter. On the other hand, the immobile eNodeB is the victim of interference by the D2D transmitter during the uplink (UL) phase when radio resources are allocated randomly. Such interference can be avoided otherwise diminish if radio resource allocated intelligently with the coordination from the eNodeB. In this paper, we formulate the problem of radio resource allocation to the D2D communications as a mixed integer nonlinear programming (MINLP). Such an optimization problem is notoriously hard to solve within fast scheduling period of the Long Term Evolution (LTE) network. We therefore propose an alternative greedy heuristic algorithm that can lessen interference to the primary cellular network utilizing channel gain information. We also perform extensive simulation to prove the efficacy of the proposed algorithm.**

I. Introduction

Due to the emergence of fourth-generation (4G) mobile technology, Cisco estimates 131 percent compound annual growth rate of the mobile traffic between 2008 and 2013 [1]. Third Generation Partnership Project (3GPP) is working on a new air interface known as Long Term Evolution (LTE). With more compelling user-driven applications, LTE is expected to achieve high data rates, low latency and packet optimized radio access technology (RAT). Recently, device-to-device (D2D) communication as an underlay to cellular networks has been introduced as a technology component to the LTE-Advanced [2], [3]. User equipments (UEs) in close proximity, with higher Signal to Interference and Noise Ratio (SINR) between them, may communicate directly instead of through the eNodeB (the LTE base station). UEs communicating directly, by employing D2D connectivity, can achieve better performance than that offered via eNodeB (two-hops) by offloading eNodeB resources. Some appealing applications of D2D communications are video streaming, online gaming, media downloading, peer-to-peer (P2P) file sharing etc. It would be highly advantageous, if some UEs download contents through eNodeB while other UEs retrieve it through D2D communication and thereby avoid congestion at the eNodeB.

If the D2D users are assigned dedicated LTE resource blocks (RBs), there is no interference between cellular users and D2D users. This is only possible when sufficient amount of resources are available. However when D2D communication shares the same resources with cellular communication; the interference of D2D communications to the cellular network needs to be restricted to maintain a target performance level of the cellular network. The eNodeB controls the transmit power of D2D connections in order to restrict the interference of D2D transmitters to the cellular network.

There are manifold benefits of enabling D2D communication in a cellular network under the control of LTE system. With control over D2D connectivity, the operators can incorporate the D2D service exploiting existing cellular architecture, offer new services with new revenue opportunities. The eNodeB can employ power control mechanism for D2D connections and guarantee limited interference to the cellular network. Moreover, with planned resource allocation, eNodeB can decide whether to allocate dedicated resources for D2D services when ample amount of resources available. In LTE system, resource management is fast and operates in high time-frequency resolution; eNodeB controlled D2D services is thus rationalized.

A. Relevant Works and Motivations

There has been considerable research on spectrum sharing between cellular network and infrastructure-less wireless networks [4], [5], [6]. Due to heavier download traffic, uplink (UL) spectrum is under-utilized in frequency division duplex (FDD) based cellular system with equal bandwidths allocated for UL and downlink (DL) transmission. [5] suggested that network capacity can be improved significantly when ad hoc users make use of unoccupied UL sub-channels. The authors in [6] also proposed a spectrum reuse protocol where D2D users are only allowed to communicate with each other during the UL frame of the network. This is due to the fact that during UL only the base station (BS) is exposed to interference by the D2D users. In this scheme, the D2D user measures its pathloss from the known BS power and the received power during DL control frame. The D2D user then calculates its transmit power such that SINR ratio of the BS does not fall below threshold level.

In [3], the authors investigated another D2D communication that is based on the statistics of the SINR of all users. In this

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scheme, SINR behavior is formulated based on the position of the D2D pair. Then power control method is applied to the D2D communication such that SINR degradation of the cellular link does not fall behind a certain level. The results showed that the SINR distribution of the D2D users (with distance constraint) is comparable to that of the cellular user in most of the cell area. The authors also observed that the UL resource sharing is more beneficial for the system when the D2D pair is farther away from the BS. When the D2D pair is closer to the BS, the DL resources sharing performs better. In [7], the authors studied D2D communication using Wi-Fi ad-hoc mode in the license exempt bands. The authors concluded that mobile devices (in close proximity) when communicate directly instead of infrastructure modes, can reduce contentions/collisions and also avoid bottleneck on an access point. However, the cellular operators are more likely to nourish D2D communication on a licensed band as a controlled underlay to a cellular network. With controlled D2D communication, they can design the network with guaranteed lower level of interference as well as make additional profit out of it.

Several authors studied D2D communication over cellular architecture in the context of P2P file sharing [8], [9], [10]. In [9], the authors suggested that an extended peer (non cellular user) from P2P network can communicate with cellular users as a client/server based communication between them. In this way cellular users can participate indirectly in the P2P network, using the extended peers as proxies and also avoid the costly competition for resources. [10] proposed a P2P file sharing application for cellular users using session initialization protocol (SIP) as control protocol and then elaborated the modifications that should be made to SIP in order to meet the requirements of that application.

Cognitive radio (CR) technology, a very active research area for the past two decades, also reuses the under-utilized spectrum in an opportunistic manner [11], [12], [13]. CRs sense the radio frequency environment to detect temporal and spatial "holes" in the spectrum and thereby avoid the interference with the primary users. However, the sensing ability of secondary users demands high level of complexity to detect weak primary signals. Even CR system requires some degree of coordination among the secondary users to ensure fairness of spectrum usages [12].

Several authors emphasized the advantages of cellular/WLAN interworking systems as a two-tier overlaying structure [14], [15]. In this structure, disjoint WLANs provide local coverage in hotspot areas, while cellular networks provide wide area coverage. Mutual interference and vertical handoff (switching between two access networks) are inevitable problems of this type of coexisting network.

B. Contributions

In this paper, we address the spectrum sharing problem between 3GPP-LTE cellular network and underlaying D2D communication network. We identify and analyze the interference problem of the primary cellular network caused by the D2D transmitter during the UL and DL phases separately. To the best of our knowledge, we first formulate the problem of D2D shared radio resource allocation problem as a MINLP problem where eNodeB controls D2D connections. We also propose an alternative greedy heuristic algorithm which can diminish interference to the primary cellular network utilizing channel gain information. The proposed greedy heuristic D2D radio resource allocation algorithm does not require any modification to the scheduling of the primary cellular network; rather it utilizes information provided by the primary scheduler. We also perform extensive simulation to prove the efficacy of the proposed algorithm over the random selection of radio resources.

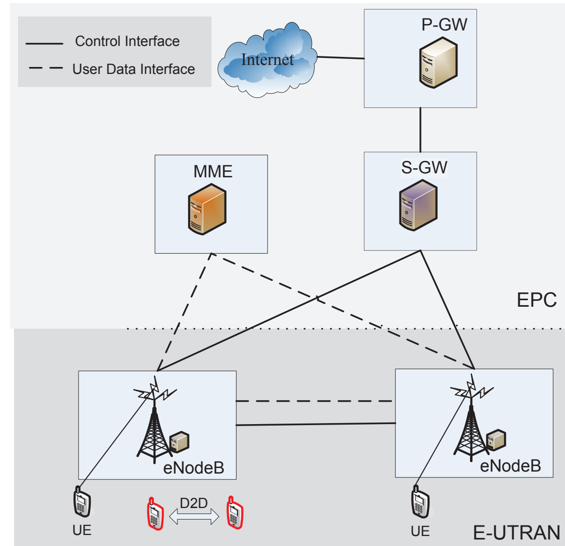


Fig. 1. System level overview of LTE architecture.

II. Network and Channel Modeling

A. Network Model

The entire LTE architecture is termed as EPS (Evolved Packet System) which comprises of Evolved Packet Core (E-PC) and the core network named as evolved UMTS Terrestrial Radio Access Network (E-UTRAN). The E-PC consists of Mobility Management Entity (MME), Serving Gateway (S-GW), and packet data network (PDN) Gateway (P-GW). The E-UTRAN only comprises the evolved base stations (also known as eNodeBs). User equipments (UEs) communicate through eNodeB, whereas the eNodeBs are interconnected and also connected to MME, and S-GW. Fig. 1 depicts the high-level system overview of the LTE system architecture. In this architecture, UEs may communicate directly over the D2D links. However, eNodeB needs to establish the D2D connection and also remains in control of resource allocation to limit the interference experienced by the cellular receivers. In [2], the authors illustrated two options for D2D session setup and management along with interference coordination to protect the primary LTE cellular network. In 3GPP-LTE IP-based systems, P-GW performs the routing from/to the Internet

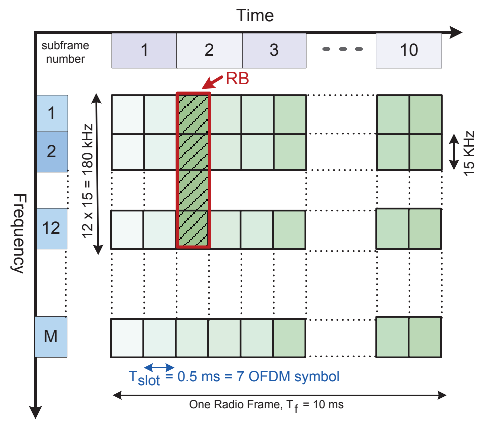


Fig. 2. The LTE downlink physical resource.

and also is aware of which eNodeB the UE is served. Therefore, P-GW is able to detect potential D2D from the source and destination of IP addresses of the UEs. Alternatively, the authors also proposed a new type of dedicated radio bearer that enables D2D communications and stays in control of the session setup and the radio resources. We consider cellular network as the primary network and D2D communication only use shared channel to improve the overall performance.

B. Radio Resource and Access Technology

In LTE system bandwidth is divided into equal size physical RBs. Each RB physically occupies (0.5ms) 1 slot in the time domain and 180 kHz in the frequency domain with subcarrier spacing of 15 kHz. Fig. 2 illustrates the LTE DL physical resource. LTE has adopted Orthogonal Frequency Division Multiplex (OFDM) based radio interface due to its higher spectral efficiency and resilience against multi-path delay spread. There is, however, one important difference between the feasible assignments on the UL and DL shared channels. In LTE, the multiple access scheme for DL (from eNodeB to UEs) is OFDM access (OFDMA). The radio access technology in UL is single carrier frequency division multiple access (SC-FDMA) due to its characteristics of low peak-to-average power ratio (PAPR) that enables higher transmit power efficiency for the UEs. The physical properties of SC-FDMA require that RBs allocated to a single user to be contiguous in frequency. The minimum scheduling period in the frequency domain is one physical RB; therefore the smallest unit of resource that can be assigned is two RBs.

C. Channel Model

In order to measure two important parameters SINR and channel gain, we consider both distant dependent macroscopic pathloss and shadow fading pathloss. For urban and suburban areas, the macroscopic pathloss between an eNodeB and an UE at a distance d meter is:

$$\begin{aligned} L_{dB}(d) = &\ 40(1 - 4 \times 10^{-3} h_b)\log_{10}(d/1000) \\ &-18\log_{10}(h_b) + 21\log_{10}(f_c) + 80 \end{aligned} \quad (1)$$

here, f_c is the carrier frequency in MHz, and h_b is the base station antenna height (in meter). For different scenarios and details, the readers are encouraged to read [16].

The slow fading or shadowing on a wireless channel is caused by obstacles in the propagation path of the radio waves and obviously is location-dependent [17]. When shadowing is modeled only by log-normally distributed random variables, the variables do not meet the spatial correlation properties. Finding an accurate fading model is a myth. However, we generate realistic looking patterns as described in [18]. Gaussian random fields are generated first and then convoluted two-dimensionally along with the following exponential correlation function.

$$R(\Delta d) = e^{-\frac{|\Delta d|}{d_{corr}}\ln 2} \quad (2)$$

where d_{corr} is the decorrelation distance. We assume that the impact of fast fading is averaged out over a certain time period.

Each eNodeB consists of three sectoral antenna with the following radiation pattern as described in [19]:

$$A_{db}(\theta) = -\min\left[(\theta/\theta_{3dB})^2, A_m\right]; \quad -180^0 \leq \theta \leq 180^0$$

θ_{3dB} is the 3 dB beam width, and A_m maximum attenuation. The total pathloss, which includes the antenna gain, between eNodeB B and the user u, is:

$$PL_{dB,B,u}(.) = L_{dB}(d) + \log_{10}(X_u) - A_{dB}(\theta) \quad (3)$$

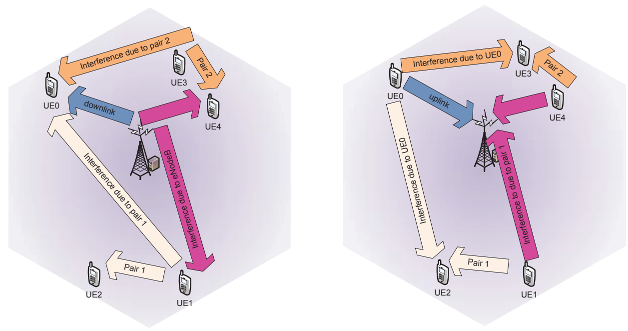
where X_u lognormal shadow fading pathloss of user u. The linear gain between the eNodeB and a user u is

$$G_{Bu} = 10^{-PL_{dB,B,u}/10} \quad (4)$$

For D2D communication, the gain between two UEs u and v is $G_{uv} = K_{uv} d_{uv}^{-\alpha}$ [20]. Here, d_{uv} is the distance between transmitter u and receiver v, α is a constant path loss exponent and K_{uv} is a normalization constant. The normalization constant depends on the radio propagation properties of the environment, and also accounts for the effects of coding gain, spreading gain, beamforming, etc.

III. Problem Definition

D2D commutation takes place underlaying the primary cellular network. We acknowledge the radio resources to be valuable and D2D communication shares the same resources with cellular communication; rather than using dedicated resources. Hence, the interference of D2D communications to the cellular network needs to be restricted to maintain a target performance level of the cellular network. If the distance between D2D is too long, the D2D will require high power. In that case, the primary cellular network would suffer from interference. Fig. 3 illustrates the interference problem when primary cellular network shares channel with the D2D network. During the download period of cellular network (see Fig. 3(a)), cellular UE_0 is exposed to interference when any D2D transmitter (UE_1, or UE_3) transmits using the same allocated subband. Also, D2D receiver (UE_2, or UE_4) will suffer from interference from the UE_0, whichever shares the



(a) Download period (b) Uplink period

Fig. 3. Interference problem when primary cellular network shares channel with the D2D network.

same subband with the cellular UE_0. One can easily speculate that the amount of interference will depend not only on D2D transmit power but also spatial distance between D2D transmitter and the cellular users. On the other hand, during the UL period of the cellular network (see Fig. 3(b)), the D2D transmitter (UE_1 or UE_4) causes interference only to the immobile eNodeB. D2D receiver (UE_2 or UE_3) also suffers from interference from the UE_0. Anyone can whisper that the amount of interference depends on the transmitter power and the spatial distance as well. Hence, intelligent selection of the shared RB would result in better performance in terms of network throughput. According to the suggestion [2], we deny D2D connections if the the maximum distance between D2D is higher than $d_{max} = 25$ m. Since, eNodeB coordinates the D2D session setup, we assume that both UEs need to be in the same cell for possible D2D connection.

IV. Problem Formulation

The eNodeB schedules the primary cellular network in standard way, and our solution does not require any modification for D2D resource allocation. However, we want to allocate the same assigned RB(s) of any cellular UE c to one of D2D connections for which total network throughput is increased. We formulate the problem of assigning appropriate RBs for underlaying D2D communication as an optimization problem that achieves higher throughput without impairing the existing cellular network. Consider a time division duplex (TDD) cellular network with identical splitting of UL and DL resources. The total number of available RBs during the DL and UL is equal to M and N. This is due to the fact that because of TDD, there is only a single-carrier frequency and the UL and DL transmissions are separated in time, and also on cell site basis; however this does not affect our proposed scheme. We assume infinitely backlogged model where data is always available from each UE. We also assume that more advanced intercell interference mitigation scheme works on top of our scheme. The eNodeB serves a set $\mathcal{C} = \{1, \ldots, C\}$ of cellular users and also coordinates a set $\mathcal{D} = \{1, \ldots, D\}$ D2D pairs. According to our assumptions, $C >> D$.

A. Downlink Phase Interference Coordination

During the download phase of cellular network, any UE is exposed to interference when any D2D user is allowed to transmit using the same allocated subband. And the amount of interference will depend not only on D2D transmit power but also the channel gain between D2D transmitter and the cellular users. G_{cd} denotes the channel gain between UEs c and d. G_{Bc} denotes the channel gain between the eNodeB and UE c. When D2D devices utilizes DL RBs, any D2D transmitter d causes interference to cellular user c while using RB(s) assigned to it. The DL SINR of user c is

$$\gamma_c^{DL} = \frac{P_B G_{Bc}}{N_0 + I + \sum_d x_c^d P_d G_{cd}} \quad (5)$$

The SINR of the D2D pair d is

$$\gamma_d^{DL} = \frac{\sum_c x_c^d P_d G_{dd}}{N_0 + I + \sum_c x_c^d P_B G_{dB}} \quad (6)$$

Here, x_c^d represents a binary variable which satisfies $x_c^d = 1$ if D2D pair d uses RB(s) assigned to cellular user c. N_0 accounts for receiver's noise figure and thermal noise density; I accounts for intercell interference. Let us define the rates r_c^{DL} and r_d^{DL} corresponding to the SINR γ_c^{DL} and γ_d^{DL} as determined by the Shannon capacity model. We want to maximize the sum rate of the primary cellular UEs and secondary D2D UEs. The problem is formulated as a MINLP problem as below:

$$Maximize \quad \sum_c^C m_c r_c^{DL} + \sum_d^D \sum_c^C x_c^d m_c r_d^{DL} \quad (7)$$

$$P_B G_{Bc} \geq \gamma_{c,tgt}^{DL} \left(N_0 + I + \sum_d x_c^d P_d G_{cd} \right); \ \forall c \in \mathcal{C} \quad (8)$$

$$\sum_c x_c^d P_d G_{dd} \geq \gamma_{d,tgt}^{DL} \left(N_0 + I + \sum_c x_c^d P_B G_{dB} \right); \ \forall d \in \mathcal{D} \quad (9)$$

$$\sum_c x_c^d \leq 1; \ \forall d \in \mathcal{D} \quad (10)$$

$$\sum_d x_c^d \leq 1; \ \forall c \in \mathcal{C} \quad (11)$$

Here, m_c denotes the number of RBs allocated to the cellular user c at each time slot during the DL period. Constraints in (8), and (9) guaranty the target SINR of the cellular UE and D2D communication, respectively. Constraints in (10) ensure that each device shares at most one user's RB(s). Whereas constraints in (11) ensure that at most one D2D pair shares any user's RB(s).

B. Uplink Phase Interference Coordination

During the UL phase of the cellular network, the D2D transmitter causes interference only to the immobile eNodeB. Any D2D receiver is also exposed to interference from the

UE whose subband is being shared. The SINR of the D2D receiver d during the UL phase is γ_d^{UL} and calculated as:

$$\gamma_d^{UL} = \frac{\sum_c y_c^d P_d G_{dd}}{N_0 + I + \sum_c y_c^d P_c G_{cd}} \quad (12)$$

$$\gamma_{eNB}^c = \frac{P_c G_{cB}}{N_0 + I + \sum_d y_c^d P_d G_{dB}} \quad (13)$$

Here, y_c^d represents a binary variable which satisfies $y_c^d = 1$ if D2D pair d uses RB(s) assigned to cellular user c. Let us define the rates r_d^{UL} and r_{eNB}^c corresponding to the SINR γ_d^{UL} and γ_{eNB}^c as determined by the Shannon capacity model. We want to maximize the sum rate of the primary cellular UEs and secondary D2D UEs. The problem is formulated as a MINLP problem as below:

$$Maximize \quad \sum_c^C n_c r_{eNB}^c + \sum_d^D \sum_c^C y_c^d n_c r_d^{UL} \quad (14)$$

$$P_c G_{Bc} \geq \gamma_{eNB}^{c,tgt} \left(N_0 + I + \sum_d y_c^d P_d G_{dB} \right); \; \forall c \in \mathcal{C} \quad (15)$$

$$\sum_c y_c^d P_d G_{dd} \geq \gamma_{d,tgt}^{UL} \left(N_0 + I + \sum_c y_c^d P_c G_{cd} \right); \; \forall d \in \mathcal{D} \quad (16)$$

$$\sum_c y_c^d \leq 1; \; \forall d \in \mathcal{D} \quad (17)$$

$$\sum_d y_c^d \leq 1; \; \forall c \in \mathcal{C} \quad (18)$$

Here, n_c denotes the number of RBs allocated to the cellular user c at each time slot during the UL period. Constraints in (15), and (16) guaranty the target SINR of the cellular UE and D2D communication, respectively. Constraints in (17) ensure that each device shares at most one user's RB(s). Whereas constraints in (18) ensure that at most one D2D pair shares of any user's RB(s).

V. Greedy Heuristic RB Selection Algorithm

The aforementioned MINLP problem is notoriously hard to solve otherwise impossible within such a short scheduling period (1 millisecond). Therefore, we propose an alternative greedy heuristic RBs selection algorithm. During the DL phase, higher values of γ_c^{DL} and γ_d^{DL} would aid in increased cell and D2D throughput, respectively. Through careful observation of Eq. (5), it is obvious that lower channel gain (G_{cd}) between UE c, and D2D transmitter d will result in higher γ_c^{DL}; i.e. will cause less interference to UE c. Therefore, any UE with higher channel quality indicator (CQI) can share RBs assigned to them with the D2D transmitter with lower channel gain between them. Here, we assume that the eNodeB receives channel gain (between UE and D2D user) information through control; as it remains in control of D2D connections.

For the UL phase, by observing Eq. (12), and Eq. (13); we intuitively decide that lower G_{cd} or increase spatial distance

Algorithm 1: Downlink D2D RB allocation scheme

$\mathcal{C}$: Sorted list of CQIs for all downlink UEs in decreasing order
G_{cd} : Channel gain matrix
$\mathcal{D}$: List of D2D connections yet to be assigned RBs
m_c : Number of RBs assigned to cellular UE c
begin
  $c \leftarrow 1$;
  while $\mathcal{D} \neq \phi$ *or* $c == C$ **do**
    Pick RBs with c^{th} largest value;
    Find the D2D transmitter d for which channel gain is minimum;
    $\gamma_c^{DL} \leftarrow \frac{P_B G_{Bc}}{N_0 + I + P_d G_{cd}}$;
    $\gamma_d^{DL} \leftarrow \frac{P_d G_{dd}}{N_0 + I + P_B G_{dB}}$;
    if $\gamma_c^{DL} \geq \gamma_{c,tgt}^{DL}$ *and* $\gamma_d^{DL} \geq \gamma_{d,tgt}^{DL}$ **then**
      Share all RBs of the UE c with D2D connection d;
      $\mathcal{D} = \mathcal{D} - \{d\}$;
      $c \leftarrow c + 1$
    else
      Do not assign RBs to D2D connection d
    end
  end
end

Algorithm 2: Uplink D2D RB allocation scheme

$\mathcal{C}$: Sorted list of CQIs for all uplink UEs in decreasing order
G_{cd} : Channel gain matrix
$\mathcal{D}$: List of D2D connections yet to be assigned RBs
m_c : Number of RBs assigned to cellular UE c
begin
  $c \leftarrow 1$;
  while $\mathcal{D} \neq \phi$ *or* $c == C$ **do**
    Pick RBs with c^{th} largest value;
    Find the D2D transmitter d for which channel gain is minimum;
    $\gamma_d^{UL} \leftarrow \frac{P_d G_{dd}}{N_0 + I + P_c G_{cd}}$;
    $\gamma_{eNB}^{c} \leftarrow \frac{P_c G_{Bc}}{N_0 + I + P_d G_{dB}}$;
    if $\gamma_d^{UL} \geq \gamma_{d,tgt}^{DL}$ *and* $\gamma_{eNB}^{c} \geq \gamma_{eNB}^{c,tgt}$ **then**
      Share all RBs of the UE c with D2D connection d;
      $\mathcal{D} = \mathcal{D} - \{d\}$;
      $c \leftarrow c + 1$
    else
      Do not assign RBs to D2D connection d
    end
  end
end

between cellular UE and D2D receiver d would result in higher D2D throughput. Howsoever, the paramount importance is to limit the interference at the eNodeB caused by the D2D connections. Both algorithms are summarized in Fig. 1, and 2.

VI. Simulation Methodology

We perform extensive simulations to evaluate the efficacy of the proposed RBs sharing methods. We developed a simulator using $C++$ programming language that realistically modeled the LTE system. Table I summarizes a list of simulation parameters and their default values. We generated distant dependent macroscopic pathloss including antenna gain with 7-cell, 3 sectors hexagonal layout. Fig. 4 shows the aforementioned pathloss map. Shadow fading, when approximated only by a log-normal distribution, cannot accurately model the location-dependent characteristics. Hence, we generated realistic space-correlated shadow fading pathloss applying 2D convoluted

TABLE I
SIMULATION PARAMETERS AND VALUES

Parameter	Values
Spectrum allocation(UL/DL)	20 MHz
Carrier frequency	2 GHz
Number of subcarriers per RB	12
Neighboring subcarrier spacing	15KHz
RB bandwidth	180 kHz
Number of available RBs	100
Max eNodeB Tx power	20 W
Max antenna gain	15 dBi
Max UE Tx Power	250mW [24dBm]
Modulation and coding scheme (MCS)	QPSK: 1/6, 1/3, 1/2, 2/3 16QAM: 1/2 , 2/3, 3/4 64QAM: 1/2 , 2/3, 3/4, 4/5
Slot duration	0.5ms
Number of symbols per slot	7(1 Pilot+6 Data)
3dB beam width, θ_{3dB}	65^0
Maximum attenuation, A_m	20 dB
Cell-level user distribution	Uniform
Number of active users per cell	10, 20, 30, 40, 50
User speed	5 km/h
Log-normal shadowing Standard deviation	8 dB
Shadowing decorrelation distance	d_{corr} =20 m
Distance attenuation	$L = 35.3 + 37.6 \times \log(d)$
Log-normal shadow fading	8 dB standard deviation
Cell layout	Hexagonal grid, 3-sector sites, 21 sectors in total
Cell radius	167m (500m inter-site distance)
UE noise figure	9 dB
UE thermal noise density	-174 dBm/Hz

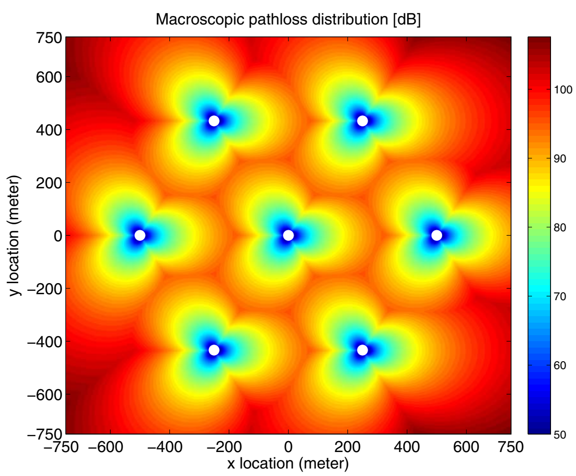


Fig. 4. Distance dependent macroscale pathloss map (in dB, including antenna gain) with 7 eNodeBs (in white circle).

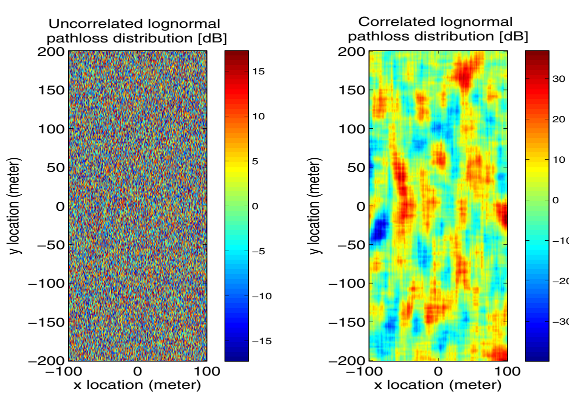


Fig. 5. Uncorrelated and space-correlated lognormal shadow fading pathloss map (in dB).

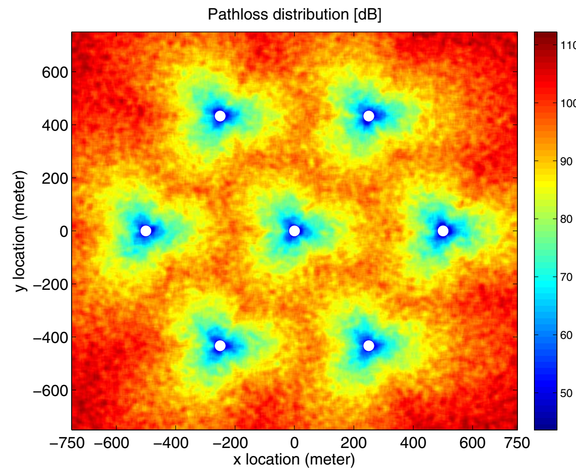


Fig. 6. Simulation region (of size 1500×1500 m^2) showing pathloss (dB) that includes antenna gain, distant dependent macroscale pathloss, and lognormal shadow fading pathloss.

function with decorrelated distance $d_{corr} = 20$ m [18]. Fig. 5 shows the shadow fading map with random (uncorrelated) shadow fading variables (left) and with convolutional correlated shadow fading variables (right). The mean and standard deviation of the shadow fading variables are 0 dB and 10 dB. Fig. 6 shows the pathloss map (dB) that includes antenna gain, distant dependent macroscale pathloss, and lognormal shadow fading loss. Users are distributed uniformly inside the scenario. The SINR is calculated from the received signal power and interference power level. The CQI are calculated from the SINRs at the UEs and then fed back to eNodeB. Link adaptation is performed based on the CQI at the eNodeB. Various modulation and coding schemes (MCS) (QPSK, 16QAM, 64QAM) are considered with varying coding rates ranging from 1/8 to 4/5 (see [19], [21] for details). The rate corresponds to a certain block error rate (BLER, %10) are also estimated from the Ack/Nack of the past transmissions. The number of RBs is 100 for 20MHz bandwidth. UL and DL bandwidth is divided equally into m RBs. The UL/DL bandwidth ratio does not effect the proposed scheme. Three different scheduling algorithms are employed for the primary cellular network: Round Robin (RR), Maximum Carrier to Interference ratio (Max C/I) and Proportional Fair (PF) with CQI feedback [22]. The throughput is calculated by mapping the SINR to the ideal link-adaptation based LTE link-level capacity as follows:

$$\eta = \begin{cases} 0, & \text{if } \gamma < \gamma_{min} \\ W_{eff} \times \log_2(1+\gamma), & \text{if } \gamma_{min} \le \gamma < \gamma_{max} \\ 4.7, & \text{if } \gamma \ge \gamma_{max}; \end{cases}$$

where η is the estimated spectral efficiency in bps/Hz, γ is the SINR and W_{eff} (0.57) is the attenuation factor applied to the Shannon bound. W_{eff} accounts for link level implementation overhead and also for overhead due to pilot, and control channel signal. We apply hard spectral efficiency, which gives $\eta_{max} = 4.7$ bps/Hz at $\gamma_{max} = 25$ dB or higher. Also, $\eta = 0$

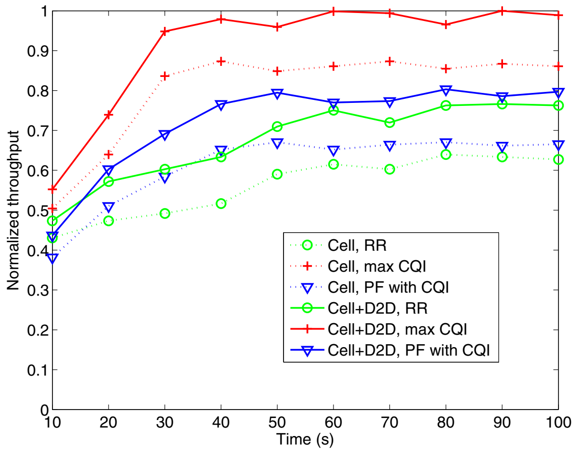


Fig. 7. Normalized network throughput for different scheduling algorithms with the proposed greedy heuristic RB assignment algorithm [scenario 1: the number of D2D connection is 10% (of total UEs)].

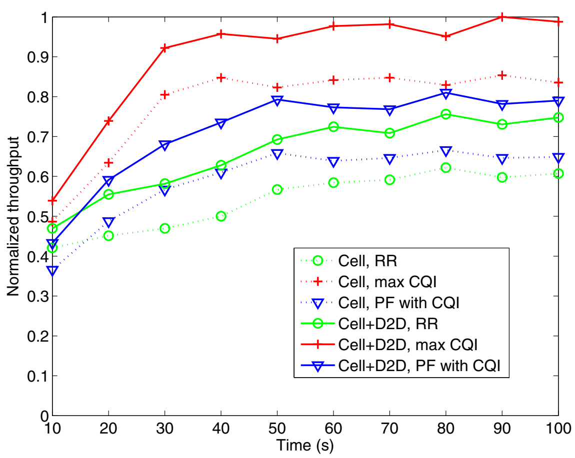


Fig. 8. Normalized network throughput for different scheduling algorithms with the proposed greedy heuristic RB assignment algorithm [scenario 2: the number of D2D connection is 20% (of total UEs)].

at $\gamma_{min} = -10$ dB or lower..

VII. Results

In this section, we analyze and discuss the simulation results.

A. Performance of heuristic D2D RB assignment algorithm for different scheduling algorithms

D2D commutation takes place underlaying the primary cellular network. We limit the number of possible D2D connections as a percentage of total UEs in the network. We perform the simulations for a period of 500 seconds on two scenarios where the number of D2D connections are restricted to 10% and 20% of the total UEs in the work. As the patterns remain the same, we present the results for the first 100 seconds to show the initial variations. To show how the proposed D2D RB assignment algorithm performs, we plot sum rate of cell and D2D throughput. We also plot cell throughput to investigate whether primary cellular network does not degrade due to interference from the D2D connections. Fig. 7 and Fig. 8 shows normalized throughput variation with time for RR, Max C/I, PF with CQI scheduling algorithms in the case of scenario 1 and 2, respectively. For both scenarios, RR performs poorly in terms of cell and sum of cell and D2D throughput than that of other two scheduling algorithms. This is due to that RR does not consider current channel condition and allocates equal resources to all users. Max C/I performs the best in terms of cell and sum of cell and D2D throughput by exploiting channel condition. Moreover, for all algorithms network throughput is higher when D2D communication integrated underlaying the cellular network.

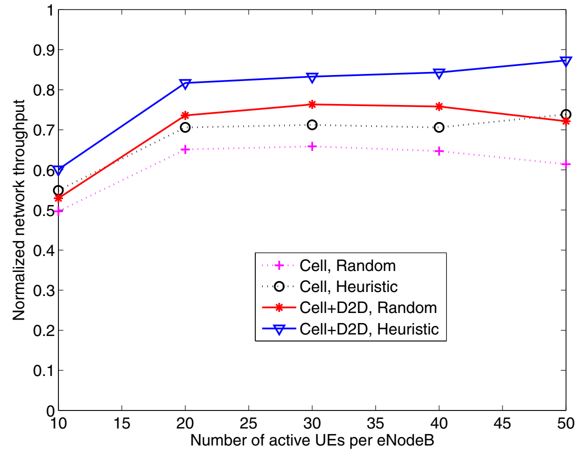


Fig. 9. Comparisons between random and heuristic D2D RB assignment algorithms in terms of normalized aggregate throughput.

B. Comparisons between random and heuristic D2D RB assignment algorithms

To compare the proposed D2D RB assignment algorithm with the random assignment algorithm, we plot the normalized throughput with varying number of active UEs in the cell (see Fig. 9). We kept the number D2D connections constant (20% of the cell UEs). The cell throughput is higher for the proposed heuristic algorithm than the random algorithm for all active number of UEs in the cell. This is due to the fact that random D2D RB assignment causes significant amount of interference on the primary cellular network. For example, with the number of 30 active UEs per site, normalized cell throughput is 7% higher in the case of heuristic algorithm than the random algorithm. As the proposed heuristic algorithm is more efficient to avoid interference to the cell UEs than the random algorithm, the sum of cell and D2D throughput is also higher for the heuristic algorithm than that of the random algorithm. For example, with the number of 30 active UEs per site, normalized cell throughput is 9% higher in the case of heuristic algorithm than the random algorithm.

C. Impact of number of D2D connections on network throughput

Finally we present the impact of number of D2D connections on the network throughput with varying number of active

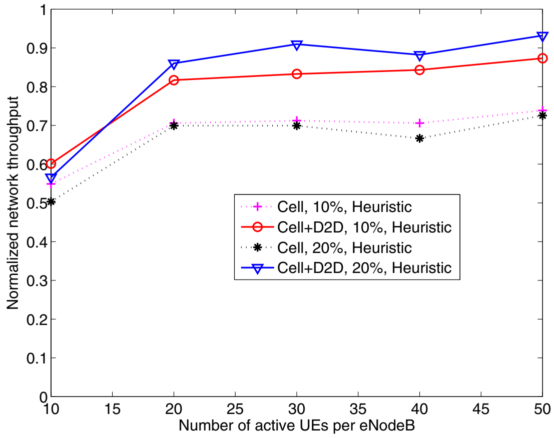


Fig. 10. Impact of the number of D2D connections on normalized aggregate throughput.

UEs for the proposed greedy heuristic algorithm. The number of D2D connections is either 10% or 20% of the number active UEs. For any specific number of active UEs, the cell throughput is lower with 20% D2D connections than that of with 10% D2D connections. For example with 40 active UEs per eNodeB, the cell throughput is 5% lower with 20% D2D connections than that of with 10% D2D connections. With more D2D connections, the interference is higher and the the cell throughput is lower. However, for any specific number of active UEs, the sum throughput of cell and D2D users is higher with 20% D2D connections than that of 10% D2D connections. With higher D2D connections the sum throughput increases from the contribution of D2D communications.

VIII. Conclusion

D2D communication offers an advantageous complement to infrastructure mode. The network performance improves when D2D communications share radio resources with the primary network. However, D2D transmitter causes interference to the UE receiver during the DL period and to the immobile eNodeB during the UL phase. In this paper, we proposed spectrum sharing strategies between 3GPP-LTE cellular network and underlaying D2D communication network that is capable of diminish interference. We performed extensive simulations with realistic scenario and LTE-standard parameters. Simulation results showed that the proposed greedy heuristic algorithm improves network performance in terms sum of cell and D2D throughput without causing significance harm to the primary cellular network for all standard scheduling algorithms of the primary network. The proposed heuristic algorithm selects the appropriate shared radio resource for which channel gain between the UE receiver and D2D transmitter during the DL phase and channel gain between the D2D transmitter and the eNodeB during the UL phase are lower. The results also showed cell and sum of cell and D2D throughput is higher for the proposed heuristic algorithm than the random algorithm. With the increase of D2D connections, although the cell throughput has decreased, the sum of cell and D2D throughput has increased significantly with the proposed algorithm. As the eNodeB remains in control of D2D connections, D2D communication is a promising integration for LTE Advanced network.

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