Joint Mode Selection and Power Control Scheme for Interference Alleviation in Device-to-Device Communications

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ABSTRACT

Device-to-Device (D2D) communication fulfils the requirements of 5th generation (5G) communication networks such as: low end-to-end latency, higher spectral efficiency, higher data rate and large number of connected devices. But enabling D2D communication in the present cellular network (CN) induces cross-tier interference for cellular user equipment (CUE). This paper proposes a scheme of joint mode selection and power control of D2D user equipment (DUE) to mitigate the cross-tier interference under the assumption that the instantaneous channel gains of user equipments (UEs) and receiver sensitivity of D2D receivers are known to the enhanced-Node B (eNB). Furthermore, it is also assumed that, UEs are in slow fading environment and moving slowly. Mode selection is done on the basis of the instantaneous channel gains, that is, whether UE operates in cellular mode or D2D mode (reuse mode or dedicated mode). Power control of D2D transmitter is done on the basis of D2D receiver sensitivity. The proposed scheme enables more reliable D2D communication with the limited interference to the CN. The proposed scheme uses METIS-2020 channel model for performance evaluation. Simulation results show that the cell sum-rate is significantly increased compared to the conventional CN infrastructure without any major reduction in signal-to-noise-plus-interference ratio (SINR) performance of the cellular users.

Keywords: METIS-2020, D2D, eNB, 5G, CU, CSI.

I. INTRODUCTION

The mobile and wireless communication enablers for twenty-twenty information society (METIS) project predicted that mobile traffic will drastically increase in the years to come [1]. It is expected that IP traffic will reach 194.4 exa-byte (EB) per month which is almost triple than the IP traffic in 2015 [2]. Interestingly the number of user equipments (UEs) and connections also increases faster than the population and internet users. Device-to-Device (D2D) communication enables direct communication between nearby portable wireless equipments, without routing the data paths through a cellular network (CN) infrastructure. This technique will add an exciting and innovative feature to the 5th generation (5G) CNs. D2D communication is a very promising technology of 5G communication networks which fulfils the essential requirements like: high data rate, low end-to-end delay, high spectrum efficiency, low energy consumption and large capacity of the cell [3], [4]. Relaying among the devices makes it possible for the devices to function as transmission relays for each other, resulting in massive ad-hoc mesh network. The enhanced-Node B (eNB) is a dedicated base station capable of handling wireless communication, with several devices in the cell and managing radio resources and handover decisions.

D2D communication is classified in two categories depending upon how the spectrum is used by D2D user (DU) and cellular user (CU): In-band D2D communication, in which the DU operates in the licensed spectrum and the CUs share their spectrum with DUs for the communication between them; and out-band D2D communication, where the DU operates in the unlicensed spectrum [5]. The former suffers from the problem of interference between CUs and DUs whereas the later does not suffer from the cross-tier interference which occurs between CUs and DUs. There is one more type of interference called co-tier interference, which occurs between two or more D2D pairs. Mitigating the interference due to the presence of DUs is a critical research challenge [5], [6]. D2D communication can be network assisted or distributed. In the network assisted D2D communication, the cellular infrastructure controls and assists the efficient operation of D2D links, coexisting with cellular communications within the same shared cellular spectrum. In this approach the potential gains are: capacity gain due to the possibility of sharing spectrum resources between cellular and D2D users, user data rate gain due to the close proximity and potentially favourable propagation conditions high peak rates...
may be achieved; and latency gain when devices communicate over a direct link, the end-to-end latency may be reduced.

User equipments (UEs) can operate in cellular mode, D2D reuse mode or D2D dedicated mode. In D2D reuse mode (underlay mode), there is direct communication between the devices. CUEs share their spectrum with the DUEs without degrading their signal-to-noise-plus-interference ratio (SINR) performance below a certain level. Cross-tier and co-tier interference are prominent in this mode. In D2D dedicated mode (overlay mode), there is a direct communication between the devices. Dedicated spectrum is assigned to the DUEs by the eNB which is orthogonal to the CUEs. As the spectrums are orthogonal, there is no cross-tier interference, but co-tier interference exists. In cellular mode communication data is relayed through the base station. This is the normal mode of communication popularly used today. Transmission power control is an important concern in wireless communication. In multi-D2D user environment, quality-of-service (QoS) requirements of cellular user equipment (CUE) have the top most priority. Various power management schemes control the power of DUs, in such a way that they cause less interference to the CUEs. A random network model for a D2D underlay cellular system using stochastic geometry, with an optimal ON-OFF power control strategy, which maximizes the sum rate of the D2D links has been proposed for distributed control [7]. Receiver sensitivity based power allocation is described [8] and performance is evaluated in various environments. Multi-antenna based beamforming mechanism with power control, maximizing the transmit power towards the intended D2D receiver node only, has been proposed to minimize the interference in the network [9]. An efficient iterative resource allocation and power control scheme for energy-efficient D2D communications underlaying cellular networks has been proposed [10]. A novel idea is to simply decrease the power of D2D transmitter, to limit the SINR declination of CU, under the assumptions that DUs and CUs are distributed uniformly in a single cell. This scheme results in achieving higher SINR than CUs [11]. The reuse of the uplink channel for D2D communication has been proposed considering a scenario in which one CU co-exists with the multiple DUs. It is assumed that the CUs and DUs are uniformly distributed in a cell radius of around 200 m. Turning OFF the D2D transmitter which has lowest SINR results in improvement of cell sum-rate over conventional CN [12]. These schemes use an ITU-R channel model [13] for their system design and analysis. A detailed analysis for D2D enabled uplink cellular networks with flexible mode selection along with truncated channel inversion power control has been presented. The same has been used to investigate the performance gains and provide guidelines for selecting the network parameters [14]. A novel optimal energy-aware scheme has been proposed for the joint optimization of power and mode selection (JPAMS) under imperfect channel state information (CSI) [15]. To improves the overall packet rates for D2D communications systems in the bursty traffic model three types of D2D modes, i.e., dedicated mode, cellular mode, and reuse mode have been proposed. In the full-buffer traffic model, if all the uplink (UL) channels are occupied by cellular users, the dedicated and cellular modes are not available for the DUEs to choose. A mode selection scheme, which considers the traffic load for the bursty traffic model has been proposed [16]. A resource allocation problem which aims at maximizing the system sum rate of all D2D and cellular links while guaranteeing the required minimum rates of cellular and D2D links has been proposed and shown to outperform conventional schemes [17]. The proposed method which invokes outer approximation approach (OAA)-based linearization technique gives guaranteed optimal solution with reasonable computational complexity. Simulation results have been used to verify the effectiveness of the proposed method.

The rest part of this paper is organized in the following manner: Section II describes system model under consideration. Section III explains the channel model used in simulation. Section IV builds the background for defining the selected problem. Numerical results are shown in section V and the improvement in the performance has been justified. Finally section VI concludes the paper.

II. SYSTEM MODEL

The system model is depicted in Figure 1. DUEs uses uplink channel resources because it makes task a little simpler, as one can get average or instantaneous CSI of all user equipments (UEs) at the eNB also known as BS. Traffic on the uplink channel is low compared to the downlink channel. In this paper, multiple UEs with one CUE in single cell are considered. UE’s mode is selected on the basis of the channel gain threshold; i.e. UEs switch to D2D mode from normal mode. This switching is done only when channel gain between the user equipments is greater than particular threshold ($H_b$). Due to the existence of multiple DUEs, cross-tier
interference will exist at the eNB. It is highly desirable to reduce this interference without degrading the performance of CUE. So a simple power control algorithm has been proposed, in which the DUE with received power less than receiver-sensitivity is turned OFF. One or more DUE which transmit at the same time on the same uplink channel resource, have been considered. The transmit power of CUE is fixed, but transmit power of the DUE is not fixed and it depends upon CSI of CUE. Decision for DUE is taken, whether it will remain ON or enter into the OFF state, based on the receiver-sensitivity, after assigning power to each DUE. The proposed work assumes that instantaneous CSI is available at the eNB. The state of the DUE is represented by binary random variable $x_q = \{0, 1]\$, for $q = \{1, ..., M + 1\}$, where $M$ = number of DUs and $x_1 = 1$ for CUE always. “0” to represents DUE in OFF state and “1” represent DUE in ON state. Let $H_{ij}$ denotes the instantaneous channel gain, where $i$ denotes $i^{th}$ transmitter and $j$ denotes $j^{th}$ receiver, such that $i, j \in \{1, 2, ..., M + 1\}$. $i, j = 1$ represents CUE and eNB and $i, j \neq 1$ represents DUE. Instantaneous Channel gain $H_{ij}$ consists of path loss $PL_{ij}$, and Rayleigh fading coefficients $|G_{ij}|^2$, with expectation $E[|G_{ij}|^2] = 2\sigma^2 = 1$. Therefore,

$$H_{ij} = PL_{ij} \times |G_{ij}|^2.$$  

(1)

To calculate the path loss we use METIS-2020 channel model. Channel model and various parameters of the channel model are described in the next section.

### III. CHANNEL MODEL

Future mobile communication system scenario will be completely different from the present one, due to the increasing demands of data rate, bandwidth, etc. To meet these requirements, the telecommunication industry is about to set new standard i.e. 5G standard, which defines the data rate of 10 Gbps, cell edge data rate of around 100 Mbps, and latency of around 1 msec. To develop the 5G systems, which will operate over the bands of frequency range up to 100 GHz, there will be need of some standard channel model, different from the current ones [18]. Conventional channel model such as stochastic channel model (SCM), WINNER and international mobile telecommunications (IMT)-advanced were developed for frequencies up to 6 GHz only. METIS-2020 channel model covers the full bandwidth of cellular communication below 6 GHz up to 86 GHz. The model also provides realistic path loss model for D2D communication [1]. Table I lists out the mathematical models for path loss which are used in urban micro environment. Table II contains probability of line of sight (LOS) for link between eNB and base station and also for connection link between D2D users. Some parameters have been taken from WINNER-II [19] model and some modifications have been incorporated from [18]. The modified parameters are also shown in the Tables I and II. Average path loss due to LOS and Non-LOS (NLOS) component is given by,

$$PL = \alpha \times PL_{LOS} + (1 - \alpha) \times PL_{NLOS},$$  

(2)

where $\alpha$ is the probability of LOS, $PL_{LOS}$ is the path loss of LOS component, $PL_{NLOS}$ is the path loss of NLOS component.
Table I: Path loss model for urban micro environment.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>-</th>
<th>Path loss</th>
<th>Shadow fading std. [dB]</th>
<th>Application range</th>
</tr>
</thead>
<tbody>
<tr>
<td>eNB-Device</td>
<td>LOS</td>
<td>$PL=22.7 \times \log_{10}(d_1) + 41.0 + 20 \times \log_{10}(f/5)$</td>
<td>$\sigma = 3$</td>
<td>$10m &lt; d_1 &lt; d'_{bp}^*$</td>
</tr>
<tr>
<td></td>
<td>NLOS</td>
<td>$PL = 40.0 \times \log_{10}(d_1) + 9.45 - 17.3 \times \log_{10}(h'<em>{\text{BS}}) - 17.3 \times \log</em>{10}(h'<em>{\text{MS}}) + 2.7 \times \log</em>{10}(f/5)$</td>
<td>$\sigma = 3$</td>
<td>$10m &lt; d_1 &lt; 5km$</td>
</tr>
<tr>
<td></td>
<td>D2D</td>
<td>$PL = (18.7 \times \log_{10}(d_1) + 46.8 + 20 \times \log_{10}(f/5)$</td>
<td>$\sigma = 3$</td>
<td>$3m &lt; d &lt; 100m$</td>
</tr>
<tr>
<td></td>
<td>NLOS</td>
<td>$PL = (36.8 \times \log_{10}(d_1) + 43.8 + 20 \times \log_{10}(f/5)$</td>
<td>$\sigma = 4$</td>
<td>$3m &lt; d &lt; 100m$</td>
</tr>
</tbody>
</table>

$$d'_{bp}^* = 4 h'_{\text{BS}} h'_{\text{MS}} f c / c,$$

where, $f_c$ is the center frequency in Hz, $c = 3.0e8$ m/s is the velocity of light in free space, $h'_{\text{BS}}, h'_{\text{MS}}$ are the effective antenna heights at the BS and the MS, respectively,

$$h'_{\text{BS}} = h_{\text{BS}} - 1.0 \text{ m}, \quad h'_{\text{MS}} = h_{\text{MS}} - 1.0 \text{ m},$$

$h_{\text{BS}}, h_{\text{MS}}$ - the actual antenna heights.

Table II: Probability of loss

<table>
<thead>
<tr>
<th>Scenario</th>
<th>LOS probability ($\alpha$) as a function of distance $d$[m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Micro</td>
<td>P_{LOS} = \min(18/d_1 \times (1-\exp(-d/36)) + \exp(-d/36)</td>
</tr>
</tbody>
</table>
| D2D | \begin{cases} 
\alpha = 1 & \text{for } d \leq 2.6 \\
1 - 0.9 \times (1 - (1.16 - 0.4 \times \log_{10} d)^3)^{1/3} & \text{for } d > 2.6 
\end{cases} |

IV. PROBLEM DEFINITION

When multiple UEs adopts D2D mode and reuses the uplink channel resource of a CUE then it causes interference to the CUE. D2D communication is allowed in CN without affecting SINR of the CU, under the assumptions that instantaneous channel gains between DUEs, and also between eNB and all user equipments are available at the eNB and that the DUEs are stationary. Power of DUEs (after D2D mode selection) is controlled in such a way that it causes interference to a CUE within permissible limits, so that the performance of CUEs which are primary users will not be severely affected.

SINR of CUE:

$$g_1 = \frac{p_1 \times H_{11}}{\sum_{q=2}^{M} x_q \times p_q \times H_{q1} + N},$$

where, $x_q$ state (on or off) of qth user, $p_1$ is power of CUE, $H_{11}$ is the channel gain between CUE and eNB, $H_{q1}$ is the channel gain between qth DUE and eNB and N is the power level of noise.
SINR of DUE:

\[
g_q = \frac{x_q \times p_q \times H_{qq}}{\sum_{\substack{q' \neq q \neq q' \neq q}} x_{q'} \times p_{q'} \times H_{qq'} + p_q \times H_{1q} + N}
\]

where, \(H_{qq}\): channel gain between \(q^{th}\) D2D transmitter and \(q^{th}\) D2D receiver.
\(H_{1q}\): channel gain between CUE and \(q^{th}\) D2D receiver.

Cell sum-rate is an important parameter in cellular communication, and it is highly desirable to maximize the total cell sum-rate given as:

\[
\text{Cell sum-rate} = \max_{x_i} \{ R_1 + \sum_{i=2}^{M} x_i \times R_i \},
\]

where,

\[
R_1 = \log_2(1+g_1)
\]

\[
R_i = \log_2(1+g_i)
\]

The proposed scheme tackles the problem of enhancing the cell sum-rate under the constraints on instantaneous SINR of CUE. It is difficult to calculate the instantaneous SINR at the eNB at all instances, this imposes a high signalling overhead on the network.

**Instantaneous SINR constraint:** D2D communication between users are allowed in CN only and it is assumed that UEs are in slow fading environment. When,

\[
g_1 \geq g_{th},
\]

where,

\(g_{th}\): SINR threshold level of CUE
\(g_1\): SINR of CUE

As we know that UE can transmit only ‘\(p_{max}\)’ power.

\[
0 \leq p_q \leq p_{max} \text{ for } q \in \{1, \ldots, M+1\}.
\]

Power calculation procedure and simulation steps are described in [11] for each DUE.

V. SIMULATION RESULTS

Cell sum-rate is an important metrics in D2D communication and Monte Carlo simulation of the proposed scheme has been done in MATLAB to evaluate the performance. A hexagonal cell with radius R is assumed and that the UEs are distributed uniformly over the entire cell. Simulation parameters are mentioned in [12]. Figure 2 depicts the cell sum-rate in various modes, for various SINR threshold of CUE (only in case of reuse mode), and for METIS-2020 channel model. When UE enters into D2D mode it can use either reuse or dedicated mode for their operation. When DUE is in D2D reuse mode, it uses uplink channel resources of a CUE while maintaining its SINR threshold. When DUEs are in D2D dedicated mode, dedicated resources are used by DUE.

Figure 2. CDF of cell sum-rate for channel gain based mode selection and for METIS-2020 channel model
From Figure 2 it is clear that cell sum-rate of UE in cellular mode is less than the cell sum rate of UEs in D2D mode (reuse and dedicated). Performance of D2D reuse mode and D2D dedicated mode is shown, cell sum-rate in reuse mode is less than the dedicated mode. Reuse mode increases the spectral efficiency by reusing the resources of the system, so it is beneficial to use the reuse mode of D2D than dedicated mode.

VI. CONCLUSION

This paper proposes a novel scheme for alleviation of interference by proper mode selection and power control of D2D transmitter, based on the assumptions that instantaneous channel gains are available at the eNB. D2D communication is performed under the supervision of cellular infrastructure, that is, network assisted D2D communication. Mode selection is done on the basis of channel gain threshold, which is set at the eNB. Power allocation is also done on the basis of receiver sensitivity of D2D receiver, which is known to the eNB. Furthermore, the paper discusses about the cell sum-rate in METIS-2020 channel model, which is very realistic for D2D communication, and also in various modes like cellular mode, D2D reuse mode and D2D dedicated mode. From the simulation results it is clear that in dedicated mode the cell sum-rate is always greater than the other two modes. However, assigning dedicated spectrum to the DUEs is not always a good idea, because it results in wastage of cellular spectrum in many situations. Mode selection on the basis of distance between CUE and DU pair will be an interesting extension of the present work.

REFERENCES


