Partial Co-channel based Overlap Resource Power Control for Interference Mitigation in an LTE-Advanced Network with Device-to-Device Communication

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Abstract—**In Long Term Evolution-Advanced (LTE-A), many techniques for improving the throughput of the system have been suggested. One among these techniques is the deployment of device-to-device (D2D) communication as an underlay to the International Mobile Telecommunications-Advanced (IMT-A) cellular network. However, deploying D2D technology in overlay macro cellular network may generate high interference to macro users (mUEs) as the D2D devices shares the same spectrum resource with mUEs. In this paper, we propose a partial co-channel based overlap resource power control (PC.OVER) scheme by mitigation of co-channel interference between mUE and D2D receiver (D2DR). In the proposed scheme, when more than one D2DR competes for the same resource with mUE, the power for those D2DRs which compete for the resource with mUE is reduced to low power. The simulation results show that the proposed scheme outperforms D2D with partial co-channel scheme in terms of the system throughput and outage probability for mUEs and D2DRs.**

Keywords-LTE-Advanced; Device-to-Device Communication; Interference avoidance; Resource allocation.

I. INTRODUCTION

Recently, there has been an enormous increase in the amount of data traffics treated by cellular networks, due to the increase in mobile multimedia services. The cellular network needs to adopt these fast growing changes which bring about high demands of data rate services. To achieve this purpose, major efforts have been spent on the development of Third Generation Partnership Project (3GPP) LTE for high data rate and system capacity. Different studies showed that the macro base station (mBS) handles more traffics than in the past years. Installing new base station(s) is expensive and the radio resources in cellular networks are limited. In [1], it has been proposed to handle the local peer-to-peer traffic in a reliable, scalable, and cost-efficient manner by enabling direct Device-to-Device (D2D) communication as an underlay to the International Mobile Telecommunications-Advanced (IMT-A) cellular network.

In D2D communication, users communicate directly with each other or via multi-hop without the intervention of the mBS. The spectrum utilization is improved in D2D communication as the D2DRs share the same resource with macro UEs (mUEs). However, when sharing spectrum with mUEs for data transmission, D2D links may generate high interference to mUEs located in their communication areas [2][3].

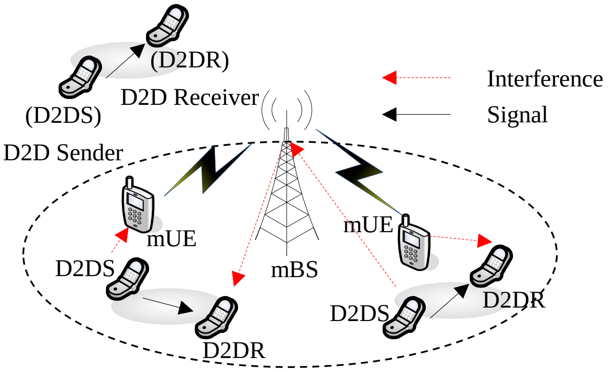


Figure 1. Conceptual diagram of D2D Communication

Interference management in LTE-Advance network with D2D communication is a critical issue. This kind of interference may become even more complex when having great number of D2D pairs across different cells networks [4]. Fig. 1 provides an example of such an interference scenario. For example, there exists an interference from the D2D sender (D2DS) to the mUE (known as inter-tier interference) as indicated by the dashed red arrow.

In this paper, we propose a partial co-channel based overlap resource power control (PC.OVER) scheme aiming to mitigate the co-channel interference between mUEs and D2DR. In low D2DR density, the mUE use any of the available resource block (RB) while the D2DR is restricted to use a portion of the available resources depending on resource allocation ratio (RAR) and use high power for its transmission. In high D2DR density, where more than one D2DRs compete for the same resource with mUE, the power for those D2DRs which compete for the RB with mUE is reduced to low power, P_L. We also consider the spectrum sharing strategies. The simulation results show that there is a significant increase in overall system throughput and the system outage was reduced.

The remainder of this paper is organized as follows: Section II describes the system model. Section III studies the interference scenarios and proposed scheme. In Section IV, three performance measurement indicators have been evaluated as the measurement for our system performance.

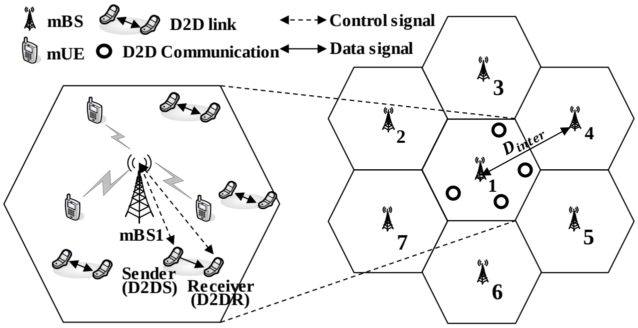


Figure 2. System topology

Section V presents the performance evaluation and Section VI concludes the paper.

II. SYSTEM MODEL

A. System Topology

As shown in Fig. 2, we consider a system topology with 7 hexagonal macrocells where the inter-site distance is D_{inter} designated in meters (m). We assume that each mBS is located at the center of each macrocell and has cell *identification* (ID). mBS denotes an mBS with cell ID = i is described as mBS_i . mUEs and D2DSs are randomly deployed in the macrocell coverage and are stationary. Then, D2DRs are separated from their corresponding D2DSs with distance q, where q is uniform random variable in [1, 20] m. The target cell is the center macrocell, mBS_1 , and interfering neighbor mBSs to mUEs and D2DSs in each cell site of mBS_1.

The physical frame structures in our D2D network is the OFDMA frequency division duplex (FDD). The length of each frame is 10ms and a frame consists of 10 sub-frames. Also, each sub-frame has two slots (a slot is 0.5ms) and each sub channel per slot is the unit of RB [5]. However, in this paper we named it as a sub-channel per symbol RB. The numbers of sub-channels and symbols are S and Z, respectively.

We define RAR, α, between the mBS and D2DSs as

$$\alpha = \frac{D2D\ bandwidth}{Total\ system\ bandwidth}, \tag{1}$$

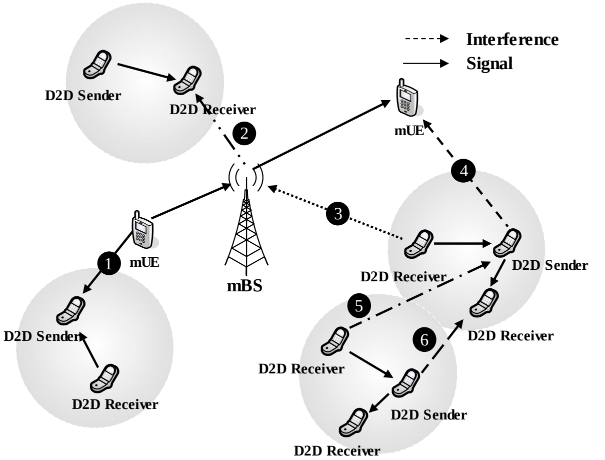
Full frequency bandwidth of the total system bandwidth is allocated to mUE, while D2DS bandwidth depends on the RAR (RAR=0.2).

B. Signal power model

The signal power received, P_r, at mUE and D2DR from mBS and D2DS can be expressed as

$$P_r = P_t * 10 \wedge -(PL/10) * L, \tag{2}$$

where P_t is the transmit power of mBS and D2DS, PL is path loss, L is the shadowing effect, with log-normal distribution with zero-mean and a standard deviation of σ.



Index	Interference Scenario	Interference type	Transmission mode of Macro	Symbol
1	mUE→D2D Sender	Inter-tier	Up link	——→
2	mBS→D2D Receiver	Inter-tier	Down link	·—··→
3	D2D Receiver→mBS	Inter-tier	Up link	··········→
4	D2D Sender→mUE	Inter-tier	Down link	- - - →
5	D2D Receiver→D2D Sender	Intra-tier	Up link	·—·→
6	D2D Sender→D2D Receiver	Intra-tier	Down link	— — →

Figure 3. Interference scenarios for D2D networks

We consider a path loss model in the link between mUE and D2DR [4], where $\mathrm{PL}_{\mathrm{mUE}_{\mathrm{i,m}}}$ is the link between the $\mathrm{mBS_i}$ and the m-th mUE, $\mathrm{mUE_{i,m}}$, in the coverage of $\mathrm{mBS_i}$ and $\mathrm{PL}_{\mathrm{D2DR}_{\mathrm{i,j,h}}}$ is the link between the j-th D2DS and the h-th D2DR, $\mathrm{D2DR_{i,j,h}}$, in the j-th D2DS coverage of $\mathrm{mBS_i}$, as shown in (3) and (4).

The path-loss is modeled according to the micro-urban models ITU-R report [6]. We apply different path-loss models to D2DRs and mUEs as given in (3) and (4) [7]. The path-losses of the micro-urban models for D2DRs ($PL_{D2DR_{i,j,h}}$) and mUEs ($PL_{mUE_{i,m}}$) are expressed as

$$PL_{D2DR_{i,j,h}} = 40\log_{10} d[km] + 30\log_{10} f_c[MHz] + 49, \tag{3}$$

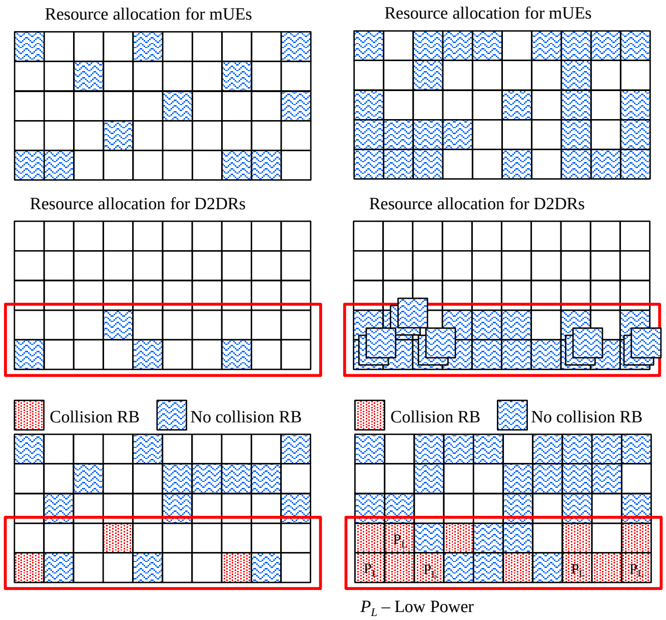
$$PL_{mUE_{i,m}} = 36.7\log_{10} d[m] + 40.9 + 26\log_{10}(f_c[GHz]/5), \tag{4}$$

where d represents distance between a sender and a receiver, and f_c means carrier frequency of the system.

III. INTERFERENCE SCENARIOS AND PROPOSED SCHEME

A. Interference Scenarios for D2D Networks

As shown in Fig. 3, we consider two types of interference that occur in a two-tier (Inter-tier and Intra-tier) D2D network architecture. Inter-tier type of interference occurs among network elements that belong to the same tier in the network. In the case of a D2D network, Inter-tier interference occurs between neighboring D2D links. Intra-



a. Sparse Distribution b. Dense Distribution

Figure 4. Proposed Resource Allocation Schemes (RAR=0.2)

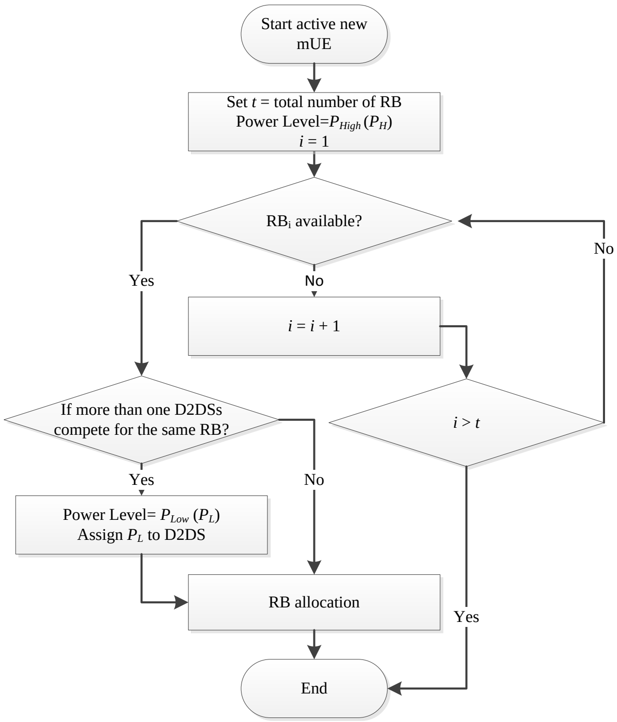


Figure 5. Resource allocation procedure for D2DS

tier type of interference occurs among network elements that belong to the different tiers of the network, i.e., interference between D2D links and macrocells.

D2D links are deployed over the existing macrocell network and share the same frequency spectrum with macrocells. Due to spectral scarcity, the D2D links and macrocells have to reuse the total allocated frequency band partially or totally, which leads to inter-tier or co-channel interference. At the same time, in order to guarantee the required QoS to the mUEs, D2DRs should occupy as little bandwidth as possible that leads to intra-tier interference. As a result, the throughput of the network would decrease substantially due to such inter-tier and intra-tier interference.

Fig. 3 illustrates all possible interference scenarios in an orthogonal frequency division multiple access (OFDMA) based D2D network. If an effective interference management scheme can be adopted, then the inter-tier interference can be mitigated and the intra-tier interference can be reduced which would enhance the throughput of the overall network.

B. *Proposed Resource Allocation Schemes*

The primary goal of this paper is to enhance throughput for both mUE and D2DRs. One way to achieve this is to mitigate interference. In partial co-channel scheme called PC scheme, the mUE transmits in any of the available RB from any of the 50 RBs as showed in Fig. 4(a). The D2DR is restricted to transmit data in the RB depending on the RAR[8].

The PC scheme can be applied to the mitigation of co-channel interference when D2DRs are deployed in a systematic way with low density. However, when multiple mUEs and D2DRs are densely deployed, i.e., having more than one user need to access of the same RB, PC scheme will create serious co-channel interference. To solve this problem PC.OVER scheme is proposed to mitigate the interference. In this scheme, the mUE transmits in any of the available RB from those 50 RBs as in PC scheme. The difference is only for the D2D case when we have more than one D2DRs compete for the same RB with the mUE as shown in Fig. 4 (b). The co-channel interference in such kind of situation is severe. Allowing D2DRs to transmit data with their high power will even worsen the interference. To avoid this and further mitigate the interference, for those RBs where more than one D2DRs compete for the same resource with mUE, the power for the competing D2DRs is reduced to low power (P_L) (Fig. 4 (b)). Note that where there is no D2DR competition, we have normal collision as indicated in the red colored RBs. Fig. 5 shows the procedure of how mBSs allocate the RB to D2DRs in the proposed scheme.

IV. PERFORMANCE MEASUREMENT

In this section, the system performance is measured. The detailed explanations of the performance measures used to evaluate the system are described as follows:

A. *SINR Model*

The SINR model is defined as the ratio of a signal power to the interference power for the b-th RB in the a-th sub-channel, $RB_{a,b}$. We assume that X mBSs are placed in a given area and Y D2DSs are deployed in each macrocell's coverage. Also, L mUEs are serviced by each mBS and F D2DRs are serviced by each D2DS.

Under these assumptions, let $R_{mBS_{i,m}}^{RB_{a,b}}$ and $R_{D2DS_{i,j,h}}^{RB_{a,b}}$ be the power of a received signal for the b-th RB $(1 \leq b \leq Z)$ in the $a\text{-}th$ sub-channel $(1 \leq a \leq S)$ from the $i\text{-}th$ mBS $(1 \leq i \leq X)$ to the $m\text{-}th$ mUE $(1 \leq \mathrm{m} \leq \mathrm{L})$ in the $i\text{-}th$ macrocell coverage and from the $j\text{-}th$ D2DS $(1 \leq j \leq Y)$ to the $h\text{-}th$ D2DR $(1 \leq h \leq F)$ in the j-th D2DS coverage in the $i\text{-}th$ macrocell coverage, respectively.

The SINR of the $mUE_{i,m}$ for the $RB_{a,b}$, $\gamma_{mUE_{i,m}}^{RB_{a,b}}$, can be expressed as (5). N_0 is the white noise power. $I_{mBS_{x,m}}^{RB_{a,b}}$ and $I_{D2DS_{x,y,m}}^{RB_{a,b}}$ are the power of the interfering signal from the x-th mBS and from the $y\text{-}th$ D2DS in the $x\text{-}th$ macrocell coverage to the $mUE_{i,m}$for the $RB_{a,b}$. $\omega_{x,m}$ and $\psi_{a,b}$ which are binary values are 1 or 0 if mBS_x is in the group of interfering neighbor mBSs for the *m-th* mUE and the $RB_{a,b}$ is used by the neighbor mBSs or D2DSs, respectively.

The SINR of the $D2DR_{i,j,h}$ for the $RB_{a,b}$, $\gamma_{D2DR_{i,j,h}}^{RB_{a,b}}$, can be expressed as (5).

$$\gamma_{mUE_{i,m}}^{RB_{a,b}} = \frac{R_{mBS_{i,m}}^{RB_{a,b}}}{N_0 + \sum_{x=1,x\neq i}^{X} I_{mBS_{x,m}}^{RB_{a,b}} \cdot \omega_{x,m} \cdot \psi_{a,b} + \sum_{x=1}^{X}\sum_{y=1}^{Y} I_{D2DS_{x,y,m}}^{RB_{a,b}} \cdot \psi_{a,b}},$$

$$\gamma_{D2DR_{i,j,h}}^{RB_{a,b}} = \frac{R_{D2DS_{i,j,h}}^{RB_{a,b}}}{N_0 + \sum_{x=1}^{X} I_{mBS_{x,h}}^{RB_{a,b}} \cdot \psi_{a,b} + \sum_{x=1}^{X} \sum_{\substack{y=1 \\ (x=1, y\neq j)}}^{Y} I_{D2DS_{x,y,h}}^{RB_{a,b}} \cdot \psi_{a,b}}. \quad (5)$$

B. System Throughput

We analyze the throughputs for $mUE_{i,m}$ and $D2DR_{i,j,h}$, $T_{mUE_{i,m}}$ and $T_{D2DR_{i,j,h}}$, using the Shannon theorem as expressed in (6).

$$T_{mUE_{i,m}} = \sum_{s=1}^{S}\sum_{z=1}^{Z}(RB_{s,z} \cdot \xi_{s,z}) \cdot \log_2(1+\gamma_{mUE_{i,m}}^{RB_{s,z}}),$$

$$T_{D2DR_{i,j,h}} = \sum_{s=1}^{S}\sum_{z=1}^{Z}(RB_{s,z} \cdot \xi_{s,z}) \cdot \log_2(1+\gamma_{D2DR_{i,j,h}}^{RB_{s,z}}), \quad (6)$$

where, $\xi_{s,z}$ is a binary value and $\xi_{s,z} = 1$ else $\xi_{s,z} = 0$ if the $RB_{s,z}$ is used by the $mUE_{i,m}$ and $D2DR_{i,j,h}$.

The system throughputs for mBS and all D2DS, $T_{mBS,i}$ and $T_{D2DS,i}$, in the i-th macrocell are calculated by (7).

$$T_{mBS,i} = \sum_{l=1}^{L} T_{mUE_{i,l}},$$

$$T_{D2DS,i} = \sum_{y=1}^{Y}\sum_{f=1}^{F} T_{D2DR_{i,y,f}}. \quad (7)$$

C. Outage Probability

We also analyze the outage probabilities, $O_{mBS,i}$ and $O_{D2DS,i}$, for mUEs and D2DRs in the i-th macrocell coverage and those are calculated by (8).

$$O_{mBS,i} \approx \frac{N_{mUE,i}^{out}}{L}, O_{D2DS,i} \approx \frac{N_{D2DR,i}^{out}}{Y}, \quad (8)$$

where, $N_{mUE,i}^{out}$ and $N_{D2DR,i}^{out}$ are the numbers of SINR values less than -6dB considering a bit error rate less than 10^{-6} [4] for mUEs and D2DRs, respectively.

V. PERFORMANCE EVALUATION

We investigate the DL performance of the proposed resource allocation scheme using a Monte Carlo simulation. We performed 10,000 independent simulations and evaluated system performance according to the number of mUEs in the analysis. The values of X, S, Z, Y, L, and F are 7, 5, 10, 10~ 200, 30, and 1, respectively. We assume that the mBS and D2DSs allocate only one RB for each mUE and D2DR, respectively. The mBS does not allocate the same RBs to mUEs in the same cell but D2DSs allocate randomly one RB in allocated channel groups for each D2DR. Log-normal shadow fading is considered with zero mean and standard deviations of 8dB for the link between the mBS and mUEs, and 9dB for the link between the D2DS and D2DRs but multi-path fading is not considered. Table 1 gives the key parameters.

TABLE I. SYSTEM PARAMETERS.

Parameter	**Value**
Carrier Frequency	2GHz
Bandwidth for DL	10MHz
Bandwidth of sub-channel	180KHz
mBS/D2D radius	866m / 20m
mBS Tx power (P_{mBS})	41.7 dBm(15W)
D2DS Tx power (P_{D2DS})	P_L = 8dBm(6.3mW) P_H= 24dBm(251mW)
Noise power density (N_0)	-174dBm/Hz

We compare the performance of proposed scheme to the network without D2D links and a scheme which allocates radio resource randomly selected from entire frequency band to D2D links. We show the system performance of proposed scheme. The system was evaluated and compared with the conventional scheme where radio resources are randomly selected. 200 D2D pairs were deployed in the region of 30 mUEs. Four cases are considered: consider having only mUEs (w/oD2D), mUEs and D2DRs are randomly allocate

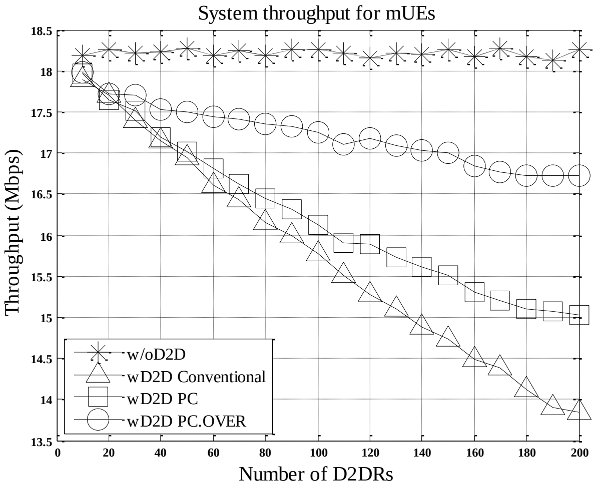


Figure 6. System throughput for mUEs (The number of D2DRs increase)

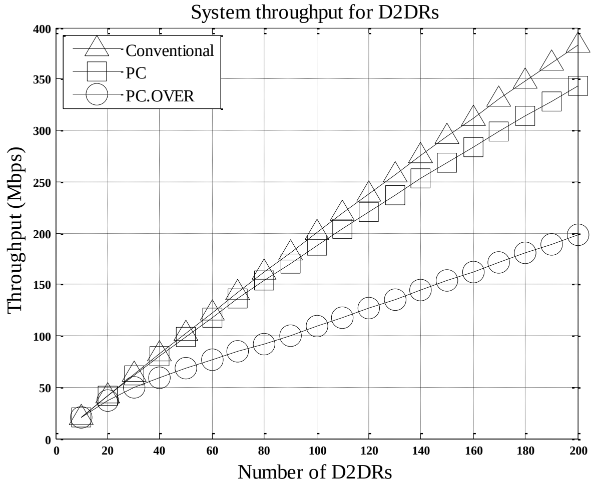


Figure 7. System throughput for D2DRss (The number of D2DRs increase)

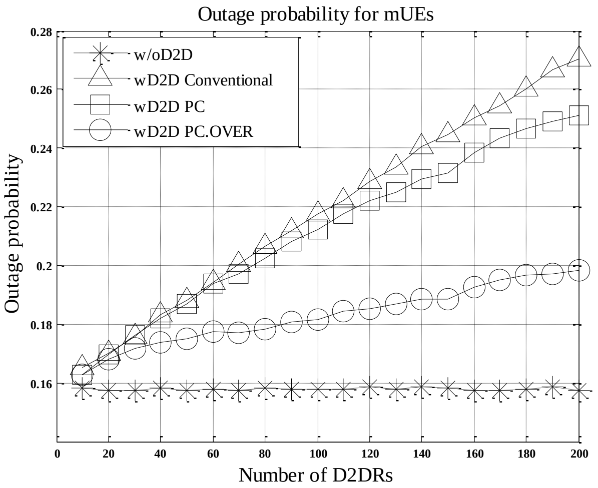


Figure 8. Outage probability for mUEs (The number of D2DRs increase)

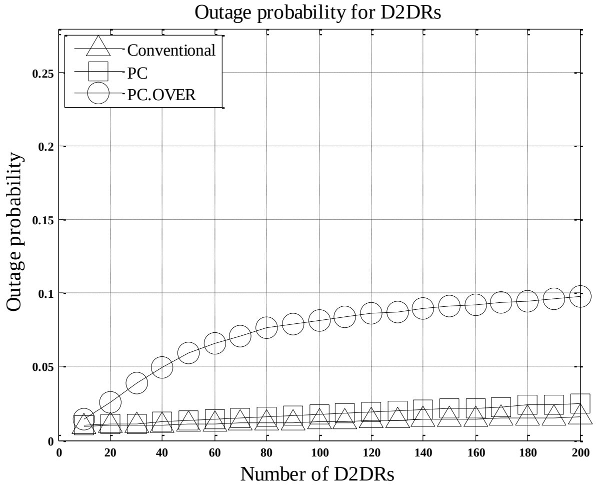


Figure 9. Outage probability for D2DRs (The number of D2DRs increase)

(wD2D conventional), the PC scheme with D2DRs (wD2D PC), and wD2D PC.OVER presenting our proposed scheme.

Fig. 6 shows the system throughput of mUEs for the increasing number of D2DRs per 30 mUEs. Only the DL was simulated. There are several factors that contribute to the throughput variations between the schemes. Since the resources are randomly selected, the throughput for the conventional scheme decreases as the number of D2DR increases. For wD2D PC, there is improvement in system throughput. Though there exist interference between mUE and D2DR for those resources shared by mUE and D2DRs (collision areas), the system throughput is improved because the D2DR transmits only in RBs allocated by RAR. The throughput is further improved in our proposed scheme. This is due to the fact that our scheme avoided further generation of interference by reducing the power of D2DRs competing for the resources with either another D2DR or mUE. Proposed scheme shows better performance than other scheme by mitigating interference between D2DRs and mBS relaying mUE.

Fig. 7 shows the results of D2DRs system throughput that increases linearly, as the number of D2Ds increases. Due to RB exclusion, D2Ds's available RB is less than that of PC scheme and Conventional Scheme; thus, there is a decrease of D2DRs system throughput.

Figs. 8 and 9 show the outage probability for the mUEs and D2DRs respectively. In Fig. 8, comparing with conventional scheme, there is a slight decrease in outage in wD2D PC. Unlike in conventional scheme, the users in wD2D are uniformly distributed which in turn reduces the outage. The outage is further reduced in the wD2D PC. OVER scheme as the users are uniformly distributed and that the D2DRs use low power for data transmission when more than one D2DRs compete for the same RB with mUE. PC. OVER scheme are largely mitigates the interference from D2DRs. The resources also are well utilized in PC.OVER scheme.

In Fig. 9, the outage probability of PC.OVER scheme is generally higher than conventional and PC schemes. The high outage is due to the decrease of the power of the D2DSs which may cause some of the D2DRs to be denied of the services. There is a tradeoff between the system throughput and the outage. Since the system shows significant throughput improvement in mUEs, we still have a strong believe that our proposed scheme performs better than the conventional scheme and PC scheme.

VI. CONCLUSION AND FUTURE WORK

We have studied interference mitigation using partial co-channel based overlap resource power control scheme in LTE-Advance D2D networks. The impact of D2D interference on capacity was investigated. In this paper, we presented a PC.OVER Scheme for D2D outage and throughput. Simulation results showed that the proposed schemes outperform D2D networks in terms of system throughput and outage probability for mUEs and D2DRs. Inter-cell interference is one of the key problems for D2D networks. Thus, in future, we plan to study the improved resource allocation scheme considering Tx power management and the efficiency frequency planning of D2DSs to enhance system performance in future works.

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