

Resource Allocation and Power Control Scheme for Interference Avoidance in an LTE-Advanced Cellular Networks with Device-to-Device Communication

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Abstract

In this paper, we propose a resource allocation and Tx power control scheme, called resource allocation and power control (RAPC) in an LTE-Advanced device-to-device (D2D) network. In the proposed scheme, the macro base station (mBS) and D2D senders (D2DSs) service macro user equipment (mUEs) and D2D receivers (D2DRs) use the different frequency bands and Tx power chosen as D2D links' locations in inner and outer zones to reduce interference substantially. We analyze and compare the proposed scheme and random resource allocation (RRA) scheme with fractional frequency reuse (FFR) systems in terms of the system throughput for DL and outage probability according to the number of D2D user's (D2DR) traffic density. Simulation results show that the RAPC scheme has better performance than the random resource allocation (RRA) scheme performance in terms of the system throughput and outage probability for mUEs and D2DRs.

Keywords: LTE-Advanced, Device-to-Device Communication, Interference Avoidance, Resource Allocation, Power control

1. Introduction

In recent years, with the development of different kinds of multimedia services, there is an ever increasing demand for higher data rate transmission and higher spectral efficiency. For this reason, Device-to-Device (D2D) communication, which allows devices to communicate directly by sharing the resources with the cellular network, has received increasing attention as a promising technology to improve spectral efficiency. It provides several advantages, such as improved spectral efficiency, reduced power consumption, increased system throughput, and decreased mBS load [1–3]. However, when the co-channel operation is used with existing cellular networks, some severe interference between cellular links and D2D links occur. Hence, the interference cancellation or management schemes are imperative between cellular links and D2D links in order to avoid the decrease of total cell throughput.

To solve this problem, research on reducing interference between D2DRs and mUEs in cellular networks supporting D2D communication was conducted. When earlier studies are examined, in [1], they suggested the technique of using D2D links' channels first if frequency bands were not already being utilized in the mBS, and observing the D2D links' channel status if all frequency bands are used and getting assigned the best channel from mBS. Also, in [4], the technique of measuring one's own channel gain and the channel gain till mUE that uses an applicable channel, and assigns the lowest gaining channel to the D2D terminal, was

suggested, but such studies focus on the cell center interference control and do not improve the performance of mUEs for the cell edge. Also, they are not designed to respond to strong signals that are received from the cell center for D2DRs. Lastly, in [5], resource allocation that considers the interference and power optimization technique was studied. However, in this case, there was a high possibility of heavy collisions occurring between the two links due to random allocation of frequency resources regardless of the cellular link and D2D link. Therefore, we can consider the resource allocation and power control methods that reduce the interference of the cellular link and D2D link by using the frequency reuse scheme, so that the performance at the cell-edge of cellular links can be improved and the D2D link can respond to a strong signal at the cell center.

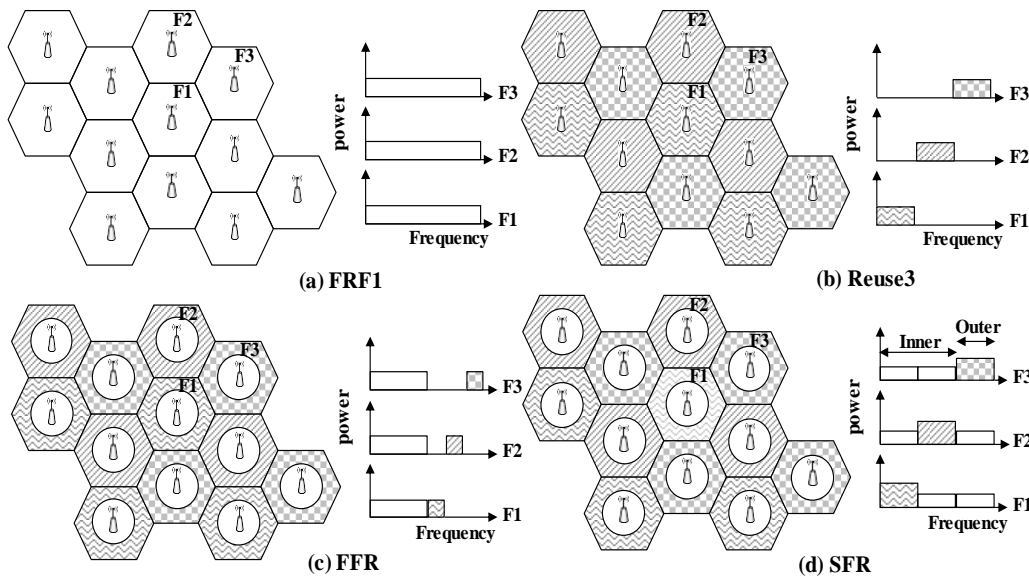


Figure 1. Reuse 1 and Other Static Partition based Schemes (Omni-antenna)

As shown in Figure 1, several schemes of inter-cell interference mitigation are being considered in OFDMA networks, such as fractional frequency reuse (FFR) [6] and soft frequency reuse (SFR) [7]. Partial reuse adopts different reuse factors for the cell center and cell edge. Thus, partial reuse schemes can achieve a much higher network capacity compared to traditional frequency reuse schemes and can simultaneously reduce inter-cell interference compared to a frequency reuse factor (FRF) of 1. However, since the cell edges use a higher reuse factor, the cell edge spectral efficiency may be significantly degraded compared to the cell center.

In this paper, we propose a resource allocation and Tx power control scheme, called resource allocation and power control (RAPC) in an LTE-Advanced device-to-device (D2D) network. We analyze and compare the proposed scheme and random resource allocation (RRA) scheme with fractional frequency reuse (FFR) [6] systems in terms of the system throughput for DL and outage probability according to the number of D2D user's (D2DR) traffic density. Simulation results show that the RAPC scheme has better performance than the random resource allocation (RRA) scheme performance in terms of the system throughput and outage probability for mUEs and D2DRs.

2. System Model

2.1. System Topology and Path Loss Model [8, 9]

As shown in Figure 2, we consider a system topology with 7 hexagonal macrocells where the inter-site distance is D_{inter} designated in meters (m) to analyze the performance. We assume that each mBS is located at the center of each macrocell and has a cell identification (ID). For example, an mBS with cell ID = i is described as mBS_i . mUEs and D2DSs are randomly deployed in the macrocell coverage and are stationary. In each cell, D2DSs are distributed in a grid pattern with a distance of 50m in each cell, and D2DRs are separated from their corresponding D2DSs with distance q , where q is a uniform random variable in [1 20] m. The target cell is the center macrocell, mBS_1 .

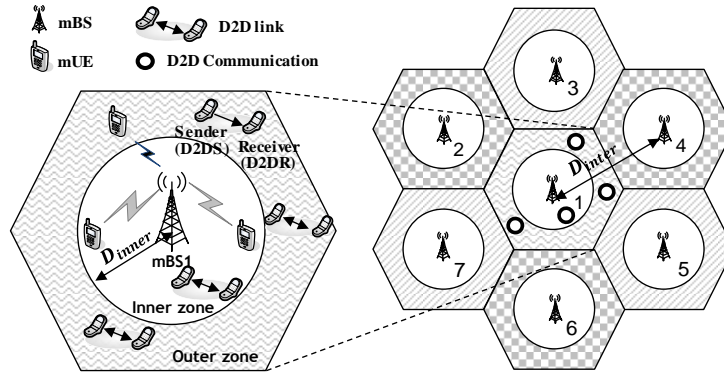


Figure 2. System Topology

We consider a path loss model for mUE and D2DR [8], where $PL_{mUE_{i,m}}$ is the link between the mBS_i and the m -th mUE, $mUE_{i,m}$, in the coverage of mBS_i and $PL_{D2DR_{i,j,h}}$ is the link between the j -th D2DS and the h -th D2DR, $D2DR_{i,j,h}$, in the j -th D2DS coverage of mBS_i , as shown in (1) and (2). The path-loss is modeled according to the micro-urban models ITU-R report [10]. We apply different path-loss models to D2DRs and mUEs as given in Eqs. (1) and (2) [8]. The path-losses of the micro-urban models for D2DRs ($PL_{D2DR_{i,j,h}}$) and mUEs ($PL_{mUE_{i,m}}$) are expressed as

$$PL_{D2DR_{i,j,h}} = 40 \log_{10} d[km] + 30 \log_{10} f_c [MHz] + 49 \quad (1)$$

$$PL_{mUE_{i,m}} = 36.7 \log_{10} d[m] + 40.9 + 26 \log_{10} (f_c [GHz] / 5) \quad (2)$$

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

2.2. Physical Frame Structure and Signal to Interference and Noise Ratio (SINR) Model

The physical frame structure in our D2D network is orthogonal frequency division multiple access (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 resource block (RB) [11] but we name a sub-channel per

symbols RB is this paper. The numbers of sub-channels and symbols are S and Z, respectively.

The SINR model is defined as the ratio of a signal's 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 strengths of a received signal for the b-th RB ($1 \leq b \leq Z$) in the a-th sub-channel ($1 \leq a \leq S$) from the i-th mBS ($1 \leq i \leq X$) to the m-th mUE ($1 \leq m \leq L$) in the i-th macrocell coverage and from the j-th D2DR ($1 \leq j \leq Y$) to the h-th D2DR ($1 \leq h \leq F$) in the j-th D2DS coverage in the i-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

(3). 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 strengths of the interfering signal from the x-th mBS and from the y-th D2DS in the x-th macrocell coverage to the mUE_{i,m} for the $RB_{a,b}$. $\omega_{x,m}$ and $\psi_{a,b}$ for which 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 (4).

$$\gamma_{mUE_{i,m}}^{RB_{a,b}} = \frac{R_{mBS_{i,m}}^{RB_{a,b}}}{N_0 + \sum_{x=1, x \neq i}^X I_{mBS_{x,m}}^{RB_{a,b}} \cdot \omega_{x,m} \cdot \psi_{a,b} + \sum_{x=1}^X \sum_{y=1}^Y I_{D2DS_{x,y,m}}^{RB_{a,b}} \cdot \psi_{a,b}} \quad (3)$$

$$\gamma_{D2DR_{i,j,h}}^{RB_{a,b}} = \frac{R_{D2DS_{i,j,h}}^{RB_{a,b}}}{N_0 + \sum_{x=1}^X I_{mBS_{x,h}}^{RB_{a,b}} \cdot \psi_{a,b} + \sum_{x=1}^X \sum_{\substack{y=1 \\ x=i|y \neq j}}^Y I_{D2DS_{x,y,h}}^{RB_{a,b}} \cdot \psi_{a,b}} \quad (4)$$

2.3. Proposed Resource Allocation Scheme

As shown in Figure 3, D2DSs allocate random RBs in the DL subframe (RB_{inner} and RB_{outer}) for D2DRs in conventional D2DS networks with an FFR scheme. Thus, D2DSs cause substantial interference for mUEs in the outer zone while D2DRs in the inner zone are affected by substantial interference from the mBS.

In the proposed scheme, mBSs and D2DSs service mUEs and D2DRs using different RBs in RB_{outer} to reduce strong interference of the outer zone, as shown in Figure 4. The mBS services mUEs in the inner zone by using RBs in RB_{inner} whereas mUEs in the outer zone use RBs in RB_{outer} . However, D2DSs in the inner zone service their D2DRs by using RBs in RB_{outer} , except for the same sub-channel group for mUEs in the same site, because D2DRs in the inner zone are affected by substantial interference from the mBS. Also, D2DSs in the outer zone service their D2DRs using RBs in RB_{inner} and RB_{outer} , because D2DRs are affected by slight interference from the mBS. In addition, mBSs and D2DSs's powers are controlled. We increase the power of mBSs for mUEs in the outer zone, and increase the D2DS's power for the D2D resource used in the outer zone.

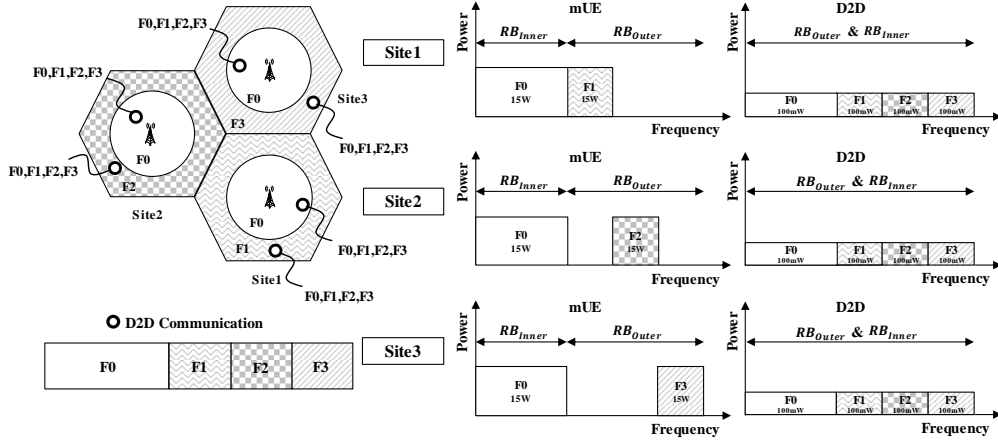


Figure 3. Random Resource Allocation (RRA) Scheme for mUEs and D2DRs

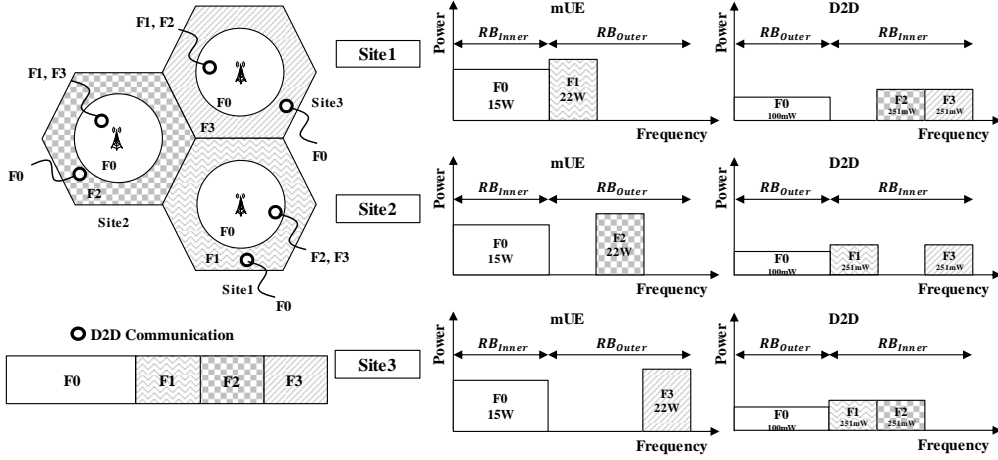


Figure 4. Proposed Resource Allocation and Power Control (RAPC) Scheme for mUEs and D2DRs

We analyze the throughputs for $mUE_{i,m}$ and $D2DR_{i,j,h}$, $T_{mUE_{i,m}}$ and $T_{D2DR_{i,j,h}}$ by using the Shannon theorem as expressed in (5) and (6).

$$T_{mUE_{i,m}} = \sum_{s=1}^S \sum_{z=1}^Z (RB_{s,z} \cdot \xi_{s,z}) \cdot \log_2(1 + \gamma_{mUE_{i,m}}^{RB_{s,z}}) \quad (5)$$

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

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) and (8).

$$T_{mBS,i} = \sum_{l=1}^L T_{mUE_i,l} \quad (7)$$

$$T_{D2DS,i} = \sum_{y=1}^Y \sum_{f=1}^F T_{D2DR_{i,y,f}} \quad (8)$$

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 (9).

$$O_{mBS,i} \approx \frac{N_{mUE,i}^{out}}{L}, O_{D2DS,i} \approx \frac{N_{D2DR,i}^{out}}{Y} \quad (9)$$

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} [12] for mUEs and D2DRs, respectively.

3. Performance Evaluation

We investigated the DL performance of proposed frequency planning and the power management scheme in terms of the system throughput and outage probability of mUEs and D2DRs for D2D networks using a Monte Carlo simulation. We performed 30,000 independent simulations and evaluated system performance according to the number of D2DSs in the analysis. The values of X, S, Z, Y, L, and F are 7, 5, 10, 10~200, 30, and 1, respectively. We assumed that the mBS and D2DSs allocated only one RB for each mUE and D2DR, respectively. The mBS were not allocated the same RBs to mUEs in the same cell, but D2DSs were allocated randomly an RB in given channel groups for each D2DR. Log-normal shadow fading was considered with a 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 multipath fading was not considered. Table 1 gives the key parameters.

Table 1. System Parameters

Parameter	Value
Carrier Frequency	2GHz
Bandwidth for DL	10MHz
D_{inter}	866m / 500m(radius)
D_{inner}	300m
mBS Tx power (P_{mBS})	Inner zone 41.76dBm(15W)
	Outer zone 43.42dBm(22W)
D2DS Tx power (P_{D2DS})	High Power 24dBm(251mW)
	Low Power 20dBm(100mW)
Noise power density (N_0)	-174dBm/Hz

We compared the performance of the proposed scheme to the network without D2D links and a scheme which allocates radio resources randomly selected from the entire frequency band to D2D links with the FFR [6] systems.

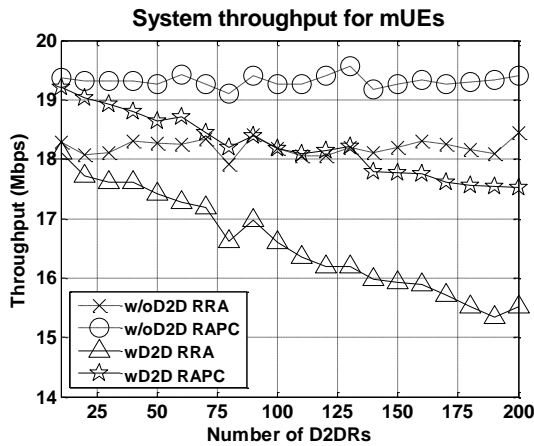


Figure 5. System Throughput for mUEs

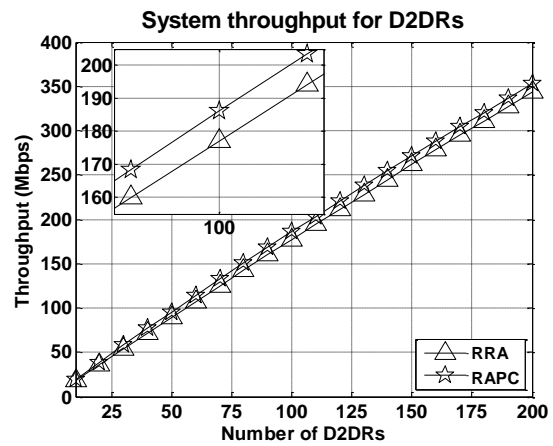


Figure 6. System Throughput for D2DRs

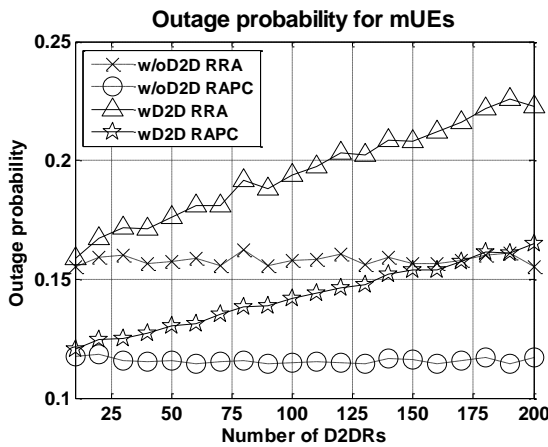


Figure 7. Outage Probability for mUEs

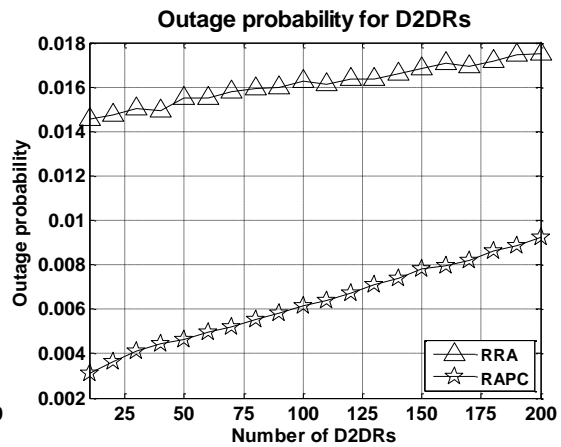


Figure 8. Outage Probability for D2DRs

Figure 5 describes the results of $T_{mBS,i}$, as the number of D2DRs increases. The traditional cellular system that was without D2DSs (Figure 5 broken line) always had the same performance. However, the results of the D2D networks (Figure 5 unbroken line) decreased with the number of D2DSs. The proposed scheme had better performance of $T_{mBS,i}$ than those of the RRA scheme. The results of the proposed scheme with 200 D2DSs were approximately increased by 13% compared to those of the RRA scheme.

Figure 6 describes the results of $T_{D2DS,i}$ that increased linearly, as the number of D2Ds increased. All $T_{D2DS,i}$ for the proposed scheme were higher than those of the RRA scheme. Figure 7 and Figure 8 describes the results of outage probability $O_{mBS,i}$ and $O_{D2DS,i}$ as the number of D2DSs increased. The results increased as the number of D2DSs increased, as did the increasing interference from the D2DSs. Also, the results of the proposed scheme were lower than those in the RRA scheme.

Figure 9~Figure 12 describes the cell center and edge results given 200 D2DRs with 30 mUEs. As shown in Figure 9, the system throughput of mUEs in a network without a D2D network is higher than the others because the mUEs are not interfered by D2DSs. In the network supporting D2D communication, system throughput of mUEs is degraded due to interference from D2D communication. Also, when the throughputs of the suggested RAPC scheme and RRA scheme are compared, it can be confirmed that the RAPC scheme generally has better performance than the RRA scheme. Figure 10 shows the system throughputs ($T_{D2DS,i}$) of the D2DRs. System throughput of D2DRs in the proposed schemes are higher than the random resource allocation scheme. Figure 11 and Figure 12 describes the results of $O_{mBS,i}$ and $O_{D2DS,i}$, given 30 mUEs with 200 D2DRs. The results of the proposed RAPC scheme are lower than those of the RRA scheme.

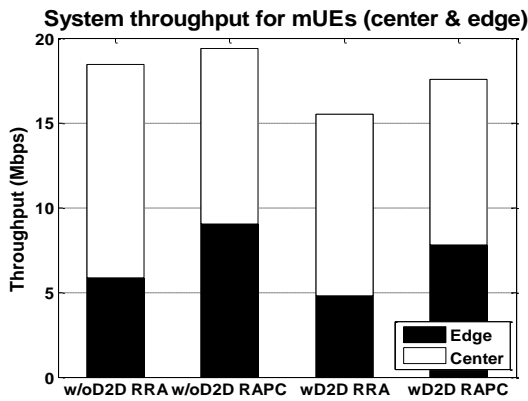


Figure 9. System throughput for mUEs (center & edge)

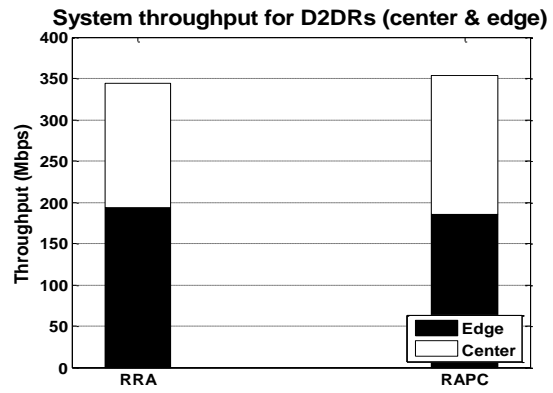


Figure 10. System throughput for D2DRs (center & edge)

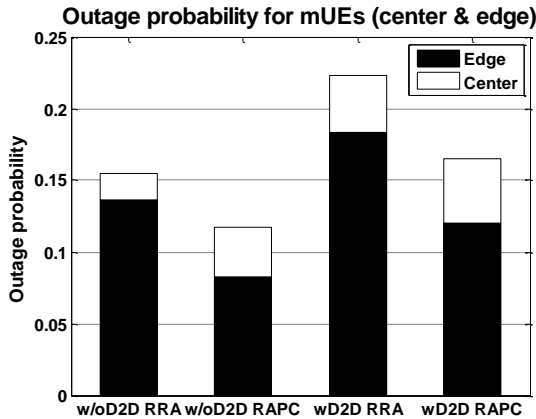


Figure 11. Outage probability for mUEs (center & edge)

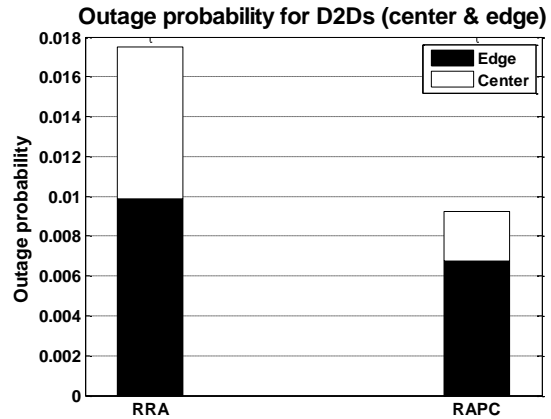


Figure 12. Outage probability for D2DRs (center & edge)

4. Conclusion and Future Work

In this paper, we proposed a novel frequency planning and Tx power-management scheme to enhance the DL system performance for D2D networks. In the proposed scheme, the mBS and D2DSs service mUEs and D2DRs in the inner and outer zones with different frequency bands and Tx power, tended to reduce substantial interference. Simulation results showed the proposed scheme outperforms D2D networks with RRA schemes in terms of system throughput and outage probability for mUEs and D2DRs. Based on this study, we plan to conduct additional future research in the fields of frequency planning schemes and power management technology that have been improved in a sectorized environment which considers a directional antenna.

Acknowledgments

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References

- [1] K. Doppler, M. P. Rinne, C. Wijting, C. B. Ribeiro and K. Hugl, "Device-to-Device Communication as an Underlay to LTE-Advanced Networks", *IEEE Communications Magazine*, vol. 47, no. 12, (2009), pp. 42-49.
- [2] P. Janis, C. -H. Yu, K. Doppler, C. B. Ribeiro, C. Wijting, K. Hugl, O. Tirkkonen and V. Koivunen, "Device-to-Device Communication Underlying Cellular Communications Systems", *International Journal of Communications, Network and System Sciences*, vol. 2, no. 3, (2009) June, pp. 169-178.
- [3] G. Fodor, E. Dahlman, G. Mildh, S. Parkvall, N. Reider, G. Mikl \acute{o} and Z. Tur \acute{a} nyi, "Design Aspects of Network Assisted Device-to-Device Communications," *IEEE Communications Magazine*, vol. 50, no. 3, (2012) March, pp. 170 –177.
- [4] P. Janis, V. Koivunen, C. Ribeiro, J. Korhonen, K. Doppler and K. Hugl, "Interference-Aware Resource Allocation for Device-to-Device Radio Underlying Cellular Networks", in *Proc. IEEE 69th Vehicular Technology Conference*, (2009) April, pp. 1-5.
- [5] C. Yu, O. Tirkkonen, K. Doppler and C. Ribeiro, "Power Optimization of device-to-device communication underlying cellular communication", in *Proc. of IEEE ICC*, (2009).
- [6] WiMAX Forum, "Mobile WiMAX part 1: A technical overview and performance evaluation", (2006) June.
- [7] R1-050841, Huawei, "Further Analysis of Soft Frequency Reuse Scheme", 3GPP TSG RAN WG1#42, (2005) August 29- September 2.
- [8] H. S. Chae, J. Gu, B. G. Choi and M. Y. Chung, "Radio Resource Allocation Scheme for Device-to-Device Communication in Cellular Networks Using Fractional Frequency Reuse", In *17th Asia-Pacific Conference on Communications (APCC)*, (2011) October, pp. 58-62.
- [9] H. Xing and S. Hakola, "The Investigation of Power Control Schemes for a Device-to-Device Communication Integrated into OFDMA Cellular System", in *Proceeding of IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, (2010) September, pp. 1775-1780.
- [10] ITU-R report M.2135, "Guidelines for evaluation of radio interface technologies for IMT-Advanced", (2008).
- [11] 3GPP TS 36.211 v10.0.0, "Evolved universal terrestrial radio access (E-UTRA); Physical channels and modulation", (2011) January.
- [12] D. Yoon, K. Cho and J. Lee, "Bit Error Probability of Mary Quadrature Amplitude Modulation", *IEEE VTC-Fall*, vol. 5, (2000) September, pp. 2422-2427.

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