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Radio Resource Allocation Scheme for Device-to-Device Communication in Cellular Networks Using Fractional Frequency Reuse

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***Abstract*—Device-to-Device (D2D) communication is the technology enabling user equipments (UEs) to directly communicate with each other without help of evolved nodeB (eNB). Due to this characteristic, D2D communication can reduce end-to-end delay and traffic load offered to eNB. However, by applying D2D communication into cellular systems, interference between D2D and eNB relaying UEs can occur if D2D UEs reuse frequency band for eNB relaying UEs. In cellular systems, fractional frequency reuse (FFR) is used to reduce inter-cell interference of cell outer UEs. In this paper, we propose a radio resource allocation scheme for D2D communication underlaying cellular networks using FFR. In the proposed scheme, D2D and cellular UEs use the different frequency bands chosen as users' locations. The proposed radio resource allocation scheme can alleviate interference between D2D and cellular UEs if D2D device is located in cell inner region. If D2D UEs is located in cell outer region, D2D and cellular UEs experience tolerable interference. By simulations, we show that the proposed scheme improves the performance of D2D and cellular UEs by reducing interference between them.**

I. Introduction

In recent, amount of traffic to be treated by cellular network increases as mobile multimedia services become popular. Especially, evolved nodeB (eNB) handles traffic more than in past years because of fast-growing needs of high data rate services. In order to accommodate huge multimedia traffic, capacity of cellular networks should be enhanced by extending available frequency band or deploying new eNBs. However, radio resource in cellular networks is limited and the installation cost of eNB is high. Therefore, research on improving the capacity of cellular networks is required while maintaining pre-existing infrastructure such as 3rd generation partnership project (3GPP) long term evolution (LTE) and mobile WiMAX [1], [2]. However, these systems cannot sufficiently support data rate to UEs in crowded area, such as concert hall and major supermarket. It may cause congested communication environment. In pre-existing cellular networks, eNB should relay UEs' data even though users located in same cell coverage communicate with each other. Pre-existing communication increases communication delay and offered load to eNB because of densely crowded users. Local ad-hoc networking services can solve this problem by enabling direct communication between two cellular UEs. For cellular networks, device-to-device (D2D) communication has been introduced as one of new local ad-hoc networking technologies reusing the frequency band used in pre-existing cellular network.[3].

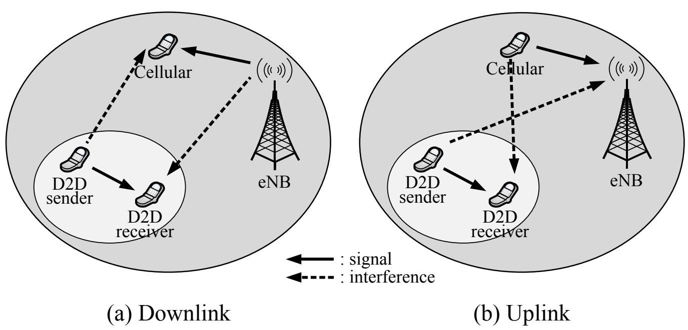

Fig. 1. Interference scenarios in cellular network-based D2D communication when cellular network is in downlink and uplink transmissions.

Introducing D2D communication can offload the traffic handled by eNB and reduce end-to-end transmission delay since end users are able to directly exchange data without intervention of eNB. D2D communication is economical due to use of pre-existing cellular infrastructure. Moreover, reusing radio resource between D2D link and eNB relaying link can significantly improve spectrum efficiency. However, D2D UEs may generate high interference to eNB relaying UEs located in their communication areas if they use the same spectrum with the eNB relaying UEs for data transmission [4].

Fig. 1 shows two interference scenarios in cellular networks supporting D2D communications in case that D2D UEs fully reuse wireless resource with eNB relaying UEs. In Fig. 1(a), signals transmitted by eNB to cellular UEs may cause interference to D2D receiver. Also, channel quality of eNB relaying UEs on downlink can be degraded due to signal transmitted from D2D sender. Fig. 1(b) shows the interference scenario for uplink transmission in cellular network. In this case, eNB and D2D receiver may be interfered by signal transmitted from D2D sender and eNB relaying UE, respectively.

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It is important to efficiently allocate frequency resources to D2D UEs in order to reduce interference between D2D and eNB relaying communications when D2D and eNB relaying communications utilized the same frequency band. To solve this problem, research on reducing interference between D2D UEs and eNB relaying UEs in cellular network supporting D2D communication was conducted. Pre-existing studies consider the case that D2D UEs use exclusive radio resource from eNB relaying UEs [6] and the same resource of eNB relaying UEs [7]. In case that D2D UEs use the exclusive radio resource, interference between D2D and eNB relaying UEs does not occur, but throughput of UEs can be decreased because UEs can use a part of resource. On the other hand, D2D communications can spatial spectral efficiency by reusing limited radio resources. Therefore, many studies considered that D2D UEs reuse radio resource with eNB relaying system and tried to solve the interference problem caused by D2D communication. For example, Janis $et\ al.$ proposed a scheme to find suitable channel reflecting characteristic of each channel. The resource management scheme allocates the radio resource to the D2D links, and then adjusts their transmission powers. The transmission power of D2D UE is determined as satisfaction that the additional interference to the eNB relaying link is kept at an acceptable level while maximizing signal to interference-plus-noise ratio (SINR) of the D2D link. [8].

Current cellular systems aimed at using frequency reuse factor (FRF) of one to improve spatial spectral efficiency of the network. However, using FRF of one degrades performance of cell outer UEs due to co-channel interference from neighboring cell. Fractional frequency reuse (FFR) can become a solution to improve channel quality of cell outer UEs by using different radio resource with adjacent cell while minimizing performance degradation of cellular system. We propose a resource allocation scheme to reduce the interference between the eNB relaying and D2D UEs underlaying cellular network using FFR.

The remainder of this paper is organized as follows. In Section II, we present preliminaries of FFR, and Section III proposes a resource allocation scheme for D2D communication underlaying cellular network using FFR. In Section IV, we describe the simulation scenario and present the numerical results of the proposed resource allocation scheme. Finally, conclusion is given in Section V.

II. Preliminaries

The FRF is the rate at which the same frequency can be used in the cellular system. On other words, if FRF is N, N cells cannot simultaneously use the same frequency band in the cellular network. Performance of the cellular network, such as channel quality of UEs in cell outer region, is primarily affected by inter-cell interference (ICI). In FRF of one, since every cell uses same frequency band for data transmission, serious interference to UEs in cell outer region can be generated from neighboring cell [9] , [10]. The simplest way to alleviate ICI is to use FRF greater than one. In this case, ICI can be reduced because adjacent cell use different frequency band, thus interference from neighboring cells is not generated. However, using FRF greater than one may decrease spatial spectrum efficiency of the cellular network. Inter-cell interference coordination (ICIC) is introduced in order to reduce interference between adjacent cells maintaining the spatial spectrum efficiency of the cellular network.

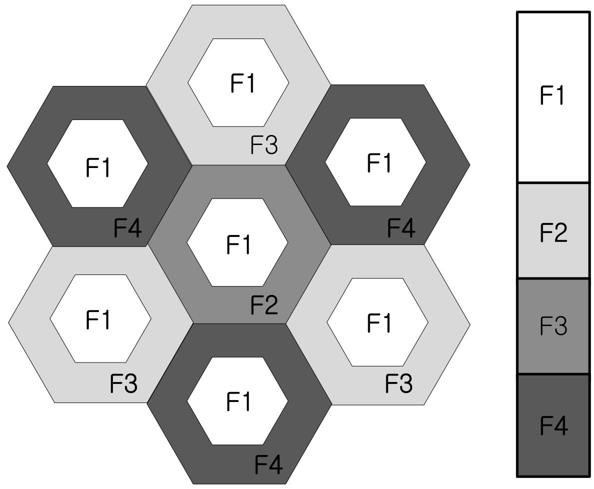


Fig. 2. An example of FFR scheme in 7-cell network.

Depending on the period of interference coordination, ICIC can be classified into dynamic ICIC scheme and static ICIC scheme. Dynamic ICIC scheme coordinates interference between adjacent cells by dynamically allocating radio resource and adjusting transmission power of eNB. Therefore, it requires exchange of additional signaling information between neighboring eNBs to effectively coordinate interference between them. The static ICIC schemes such as fractional frequency reuse (FFR) statically determines the radio resources used for cell inner and cell outer regions to avoid interference between neighboring cells. The FFR is effective in terms of network signaling overhead because it does not require exchange of extra signaling between eNBs for interference coordination.

In FFR, each cell is partitioned into two regions, cell inner and cell outer regions, and different FRFs are assigned to cell inner and cell outer regions. eNB allocates radio resources to UEs located in cell inner region using FRF of 1 and to UEs in cell outer region using FRF of 3. Fig. 2 shows an example of FFR where frequency band is exclusively divided into F1, F2, F3, and F4. Since UEs in cell inner region are closely located to eNB and receive high strength signal from eNB, they are immune to co-channel interference from neighboring cells. Therefore, in each cell, UEs located in cell inner region receive resources in F1 reused by every cell, because the performance degradation caused by frequency reusing is small to UEs in cell inter region. UEs in cell outer region can be seriously interfered by neighboring cell if adjacent cells utilize the same frequency band. Interference from neighboring cell

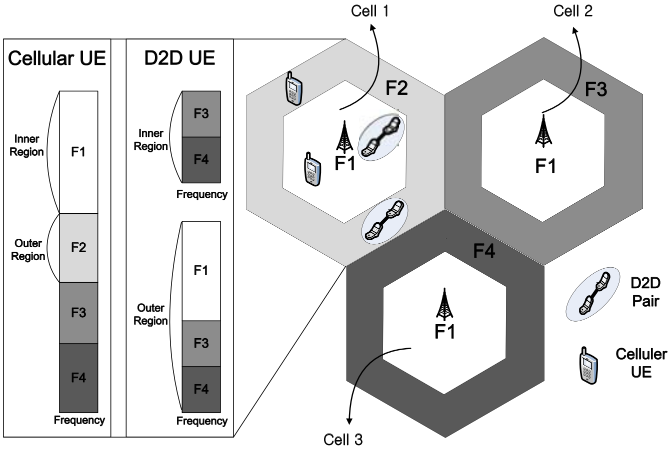


Fig. 3. Proposed resource allocation scheme for D2D communication underlaying cellular network using FFR

can be alleviated in case that UEs in cell outer region use exclusive frequency band from neighboring cells. Thus, FFR allocates exclusive radio resources in F2, F3, and F4 to UEs located in outer region of three adjacent cells. For the reasons, FFR can maximize spatial spectral efficiency for UEs in cell inner region and improve both signal strength and throughput of UEs in cell outer region.

III. PROPOSED SCHEME

In this section, we propose a radio resource allocation scheme for D2D communication underlaying cellular networks using FFR. We consider a cellular network as shown in Fig. 2 and assume that D2D UEs communicate each other in downlink period of cellular networks. In each cell, eNB relaying UEs in cell inner region reuse a part of whole frequency band, and UEs located in outer region utilize a third of the remainder.

In the proposed scheme, different resources are allocated to D2D UEs according to their locations. Fig. 3 shows an example of available resources for D2D and eNB relaying UEs in the proposed scheme. If D2D UEs are located in cell inner region, D2D UEs can use the frequency band that eNB relaying UEs do not use. In other words, for cell 1, D2D UEs in cell inner region use F3 and F4 which are not used by eNB relaying UEs. D2D and eNB relaying UEs located in the same cell do not cause interference to each other because radio resources with different frequency band are orthogonally allocated to D2D and eNB relaying UEs. In case that D2D UEs are in cell outer region, they can use the radio resources except for the resources used by eNB relaying UEs in identical cell outer region. For example, if eNB relaying UEs in cell outer region use resources in F2, D2D UEs in cell outer region can use resource in F1, F3, and F4. D2D can cause interference to eNB relaying UEs located in cell inner region if D2D UEs use the radio resource in F1. However, received signal of eNB relaying UEs is high because eNB relaying UEs in cell inner region are close to eNB.

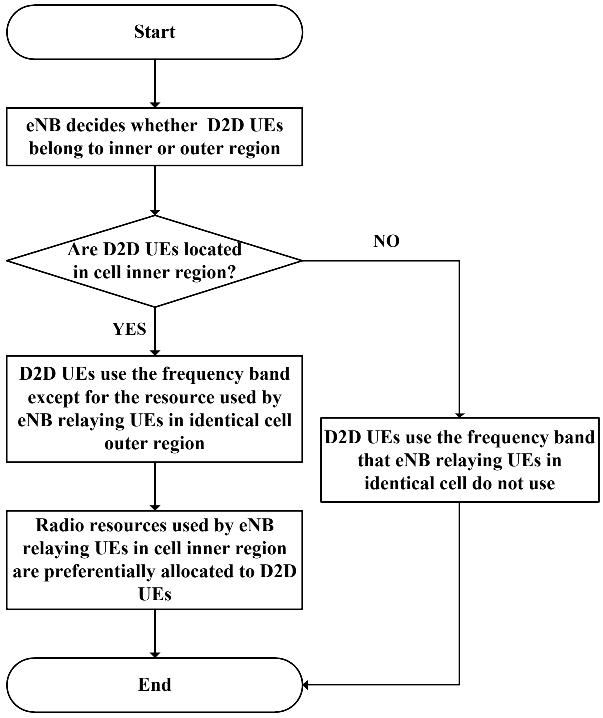


Fig. 4. Resource allocation procedure for D2D UEs

Therefore, interference from D2D UEs in cell outer region to eNB relaying UEs located in cell inner region is tolerant level. If D2D UEs use the radio resource in F3 and F4, D2D UEs interfere with eNB relaying UEs in outer region of adjacent cells. However, since distance between the eNB relaying UEs in outer region of adjacent cells and the D2D UEs is long, interference to the eNB relaying UEs caused by D2D UEs is insignificant. D2D UEs reuse the frequency band which is used by eNB relaying UEs as stated above, but D2D UEs in cell inner region and in cell outer region do not reuse the same radio resource.

In order to guarantee that radio resources are sufficiently allocated to D2D UEs in cell inner region, D2D UEs located in cell outer region are preferentially use the radio resource which cannot be used by D2D UEs located in cell inner region. Fig. 4 shows the procedure how eNBs allocate the radio resources to D2D UEs in the proposed scheme.

IV. PERFORMANCE EVALUATION

In order to evaluate the performance of proposed resource allocation scheme for D2D communications in cellular networks using FFR, we consider a cellular network with 7 hexagonal cells. An eNB is located in the center of hexagonal cell. The number of eNB relaying UEs per cell is 70 and they are uniformly distributed. In each cell, 93 D2D senders are distributed in grid pattern with distance of 100 m in each cell, and D2D receivers are apart from their corresponding D2D senders with distance x, where x is uniform random variable

TABLE I
SIMULATION PARAMETERS

Parameters	Value
eNB tansmission power	43 dBm
D2D UE transmission power	8 dBm
Antenna type	Omni-directional
Noise power density	-174 dBm/Hz
Noise figure	5 dB
Inter-eNB distance	1000 m
Inter-D2D pair distance	100 m
D2D pair distance	20-55 m
The number of eNB relaying UEs per cell	70
Number of cells	7
Carrier frequency	2.0 GHz
System bandwidth	10 MHz
Bandwidth of a subchannel	180 KHz
Number of subchannels	50

in [20, 50] m. Detailed simulation parameters are given in Table I.

The criterion of decision that eNB relaying UEs and D2D UEs are located in cell inner or outer region is distance between eNB and UEs in this simulation scenario. In addition, decision on whether UEs belong to inner or outer region can be made using SINR. The users with their average SINR greater than the given threshold are grouped into cell inner user while those with the average SINR less than threshold are grouped into cell outer user.

The path-loss is modeled according to micro-urban models ITU-R report [11]. We apply different path-loss models to D2D UEs and eNB relaying UEs as given in Eqs. (1) and (2) [12]. The path-losses of the micro-urban models for D2D UEs (PL_{D2D}) and eNB relaying UEs (PL_{eNB}) are expressed as

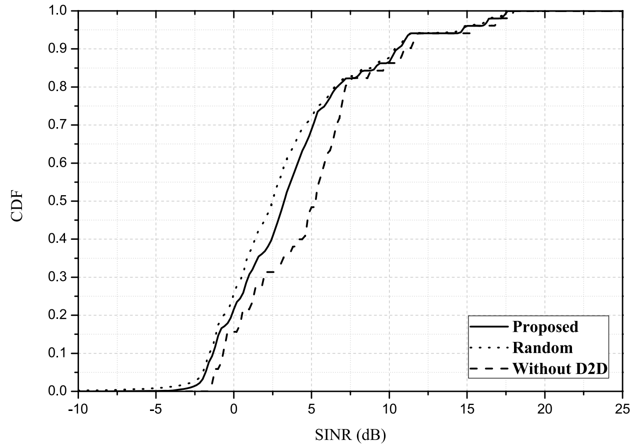
$$PL_{D2D} = 40\log_{10} d + 30\log_{10} f_c + 79, \quad (1)$$

$$PL_{eNB} = 36.7\log_{10} d + 40.9 + 26\log_{10}(f_c/5.0), \quad (2)$$

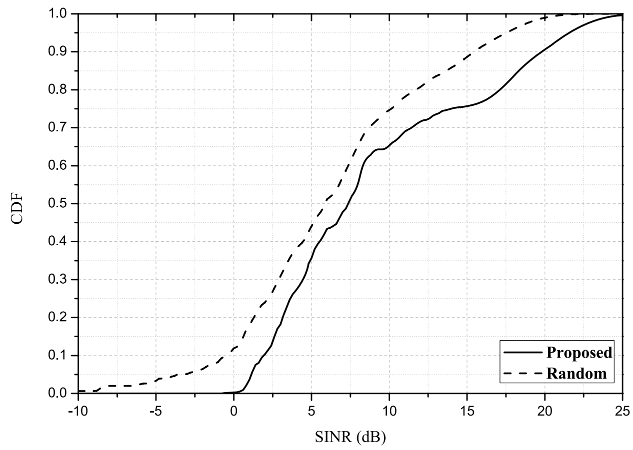
where d represents distance between a sender and a receiver in meter, and f_c means carrier frequency of the system in GHz.

Simulation results are obtained from 10,000 realizations. In each realization, the eNB relaying UEs are independently distributed over entire area and send data through allocated radio resource according to FFR. We compare the performance of proposed scheme to the network without D2D UEs and a scheme which allocates radio resource randomly selected from entire frequency band to D2D UEs.

Fig. 5 illustrates SINR CDF of eNB relaying UEs and D2D UEs when cell inner UEs use 20 radio resources and cell outer UEs use 10 radio resources in each subband. As shown in Fig. 5(a), the SINR of eNB relaying UEs in the network without D2D communication is higher than the others because the eNB relaying UEs are not interfered by D2D UEs. In the network supporting D2D communication, SINR of eNB relaying UEs is degraded due to interference from D2D communication. The eNB relaying UEs in the proposed scheme achieve higher SINR than those in random allocation scheme. Fig. 5(b) shows the SINR CDF of the D2D UEs. SINR of D2D UEs in the proposed scheme is higher than the other scheme. This is because D2D UEs in cell inner use different radio resources with their serving eNB and interference from eNB to D2D UE in cell outer region is weak due to the long distance between eNB and D2D UEs.



(a) SINR CDF of eNB relaying UEs



(b) SINR CDF of D2D UEs

Fig. 5. SINR CDF of D2D UEs and eNB relaying UEs

We evaluate the performance of the networks according to the variation in amount of radio resources allocated to UEs in cell outer region. Portion of radio resources for cell outer UEs means that the proportion of the number of radio resources for cell outer UEs to total number of radio resources. Fig. 6 represents total throughput of the network, which is defined as the sum of throughputs of D2D and eNB relaying UEs. Throughput of cellular network supporting D2D communication is higher than the network without D2D communication. Since D2D UEs reuse radio resources of eNB relaying UEs, D2D communication can improve total throughput although D2D UEs can cause interference to eNB relaying UEs. Proposed scheme shows the better performance than random allocation scheme by alleviating interference between D2D and eNB relaying UEs.

In Fig. 7, throughputs of D2D and eNB relaying UEs are

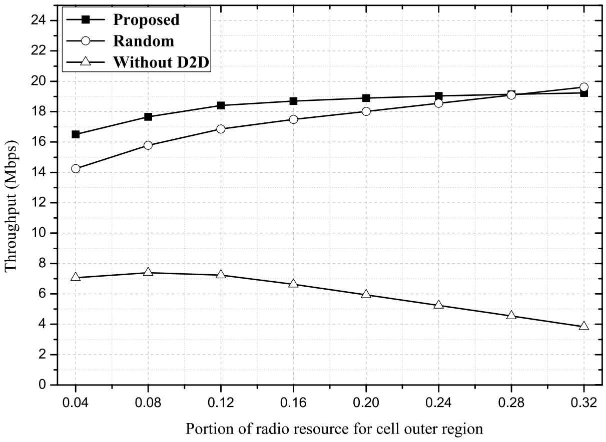


Fig. 6. Total throughput of networks

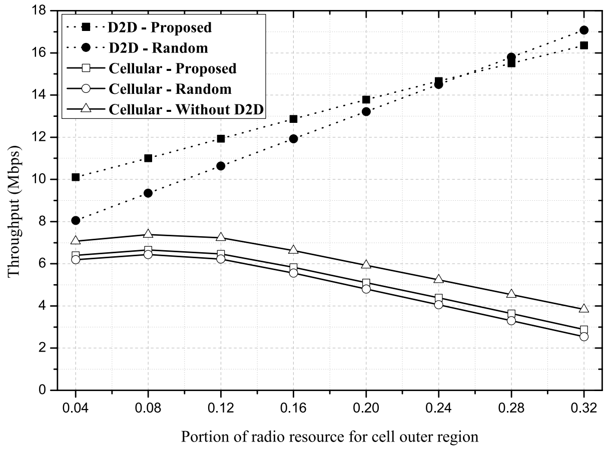


Fig. 7. Throughput of eNB relaying and D2D UEs.

represented. Throughput of D2D UEs is higher than eNB relaying UEs because the distance between D2D pairs is much shorter than distance between eNB relaying UEs and eNB. In the proposed scheme, throughput of D2D UEs is higher than that in random allocation scheme. In addition, the proposed scheme can use less radio resources than the random allocation scheme. When portion of radio resources of cell outer UEs is bigger than 0.28, the absolute number of UEs allocated radio resource is getting smaller and total throughputs show a reducing tendency. Throughputs of eNB relaying UEs are getting smaller as portion of radio resources of cell outer UEs increases. This is why an amount of eNB relaying UEs allocated radio resource in a cell is reduced. When portion of radio resources for cell outer UEs is getting bigger, more D2D UEs are able to be allocated the radio resources. For this reason, throughput of D2D UEs increases.

V. Conclusion

In this paper, we proposed a radio resource allocation scheme for D2D communication in cellular network using FFR. The D2D communication can improve overall system capacity by reusing frequency band of cellular networks. However, it may degrade throughput of eNB relaying UEs due to the interference from D2D UEs utilizing the same radio resource. In order to reduce interference from D2D UEs to eNB relaying UEs, the proposed scheme enables D2D UEs to selectively use radio resource according to their positions. From performance evaluation result of the proposed scheme under various simulation scenarios, we showed that introduction of D2D communication could significantly improve total throughput of the cellular networks. Especially, the proposed scheme improved throughputs of both D2D and eNB relaying UEs compared with the random allocation scheme.

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Prof. M.Y. Chung is the corresponding author.

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