Master's Thesis
석사 학위논문

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Advisor : Professor Ji-Woong Choi

Co-advisor : Professor Hongsoo Choi

By

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Department of Information and Communication Engineering
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A thesis submitted to the faculty of DGIST in partial fulfillment of the requirements for the degree of Master of Science in the Department of Information and Communication Engineering. The study was conducted in accordance with Code of Research Ethics[1]

Dec. 04. 2013

Approved by

Professor Ji-Woong Choi ______(Signature)
(Advisor)

Professor Hongsoo Choi ______(Signature)
(Co-Advisor)

[1] Declaration of Ethical Conduct in Research: we, as a graduate student of DGIST, hereby declare that we have not committed any acts that may damage the credibility of my research. These include, but are not limited to: falsification, thesis written by someone else, distortion of research findings or plagiarism. We affirm that my thesis contains honest conclusions based on my own careful research under the guidance of my thesis advisor.

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Jaesub Shin

Accepted in partial fulfillment of the requirements for the degree of Master of Science

Dec. 04. 2013

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201222006 신 재 섭. Jaesub Shin. An autonomous interference avoidance scheme for D2D communications through frequency overhearing in OFDM system. 2013. 35p. Advisors Prof. Ji-woong Choi, Prof. Co-Advisors Hongsoo Choi.

ABSTRACT

Device to device (D2D) communication user equipment (UE) transmits data signals to each other over a direct link instead of through the BS, which differs from femto cell where users communicate with the help of small low power cellular base stations. Since D2D has many advantages such as improvement of data rate, spectral efficiency, usability in disaster situations, and overload mitigation of base stations D2D has been spotlighted for the next generation communication technology, especially in the 5G technology. However, disadvantages remain such as interference with cellular in case of spectrum sharing mode where cellular and D2D communicate using the same resource. In the worst case, the cellular system experiences outage if the interference from the D2D pair is too much which is a main concern in this paper. The processes of D2D can be divided into three: peer discovery, link establishment, and data transmission. In this paper, we deal with the link establishment and data transmission procedures. Assuming that D2D pair is already discovered each other. When frequency resources are persistently allocated in orthogonal frequency division multiplexing (OFDM) time division duplexing (TDD) system, we propose an autonomous interference avoiding scheme for D2D communication where resources are opportunistically shared with uplink cellular users. It does not allocate subchannels that nearby cellular users currently use via overhearing the signal power of uplink cellular users and calculating the interference in the frequency domain without the use of explicit control channels. With the proper decision of parameters such as the threshold, the proposed scheme can increase the total system throughput at the cost of small cellular throughput. The performance of the proposed scheme is shown through computer simulation, where a tradeoff between total system throughput and cellular only throughput are observed, and an appropriate threshold accepting new link needs to be optimized. In addition, success probability of the overhearing operation is analyzed and compared to simulation results.

Keywords: Device to device communication, interference avoidance, D2D modes, orthogonal frequency division multiplexing (OFDM)

Contents

Ⅰ. INTRODUCTION

Device to device communication (D2D) is considered as one of future communication services to overcome current problems such as overload of base station (BS). The definition of D2D is that it is direct communication between devices without any infrastructure such as an access point (AP). D2D has many advantages compared with traditional cellular networks. D2D can decrease the overload of cellular networks through direct communication between devices. Furthermore, spatial reuse can be applied. It means that the same wireless frequency resource can be used in the cell simultaneously. Hence, this can improve the spectral efficiency. D2D can decrease the power and delay of devices since the D2D does not communicate via BS. Cell coverage can be extended through relay communication of D2D. In addition, D2D can be used in disaster situations. D2D communication does not only improve the performance of networks, but it can also be applied to various communication services such as social networks, personal mobile advertisements, and short distance file transfer.

There are three types of D2D communication modes: orthogonal sharing mode, non-orthogonal sharing mode, and cellular mode [1]. Non-orthogonal sharing mode is that both cellular traffic and D2D traffic use the same resources. Orthogonal sharing mode is that D2D communication uses dedicated resource. Cellular mode is that the D2D traffic is relayed through the BS. In this paper, we consider non-orthogonal sharing mode to avoid interference between D2D and cellular users.

There have been studies on interference analysis and avoidance in this non-orthogonal sharing mode [2, 3]. [2] considers near-far-risk from cellular users to D2D pair in the 3GPP long term evolution (LTE) frequency division duplexing (FDD) system. By monitoring the common control channel (CCCH), base station identifies near-far-risk cellular users and broadcasts the information to D2D to use a resource that has the least interference to cellular. [3] assumes that base station acquires all the channel gain between cellular and D2D terminals, and it is able to take this information into account when allocating D2D radio resources. The proposed method in [3] is allocating resources to D2D and cellular that generate the lowest interference each other.

In this paper, we propose an autonomous interference avoidance D2D scheme when it shares resources with cellular system employing OFDM time division duplexing (TDD) system when uplink (UL) resources are allocated in a static manner. By overhearing the cellular UL signal power, candidate frequency subchannels for D2D are determined such that it avoids the use of subchannels employed by nearby cellular users without any help of control channels, e.g. CCCH as [2]. Hence, it is conceptually different with [3] since the base station allocates resource to cellular and D2D that has the lowest interference

The rest of paper is described as follows. In section II, we will explain the basics of D2D. In section III, system model is explained. In section IV, we describe the proposed scheme. In section V, the simulation results will be shown. Finally, we will make a conclusion in section VI.

II. BASICS OF D2D COMMUNICATION

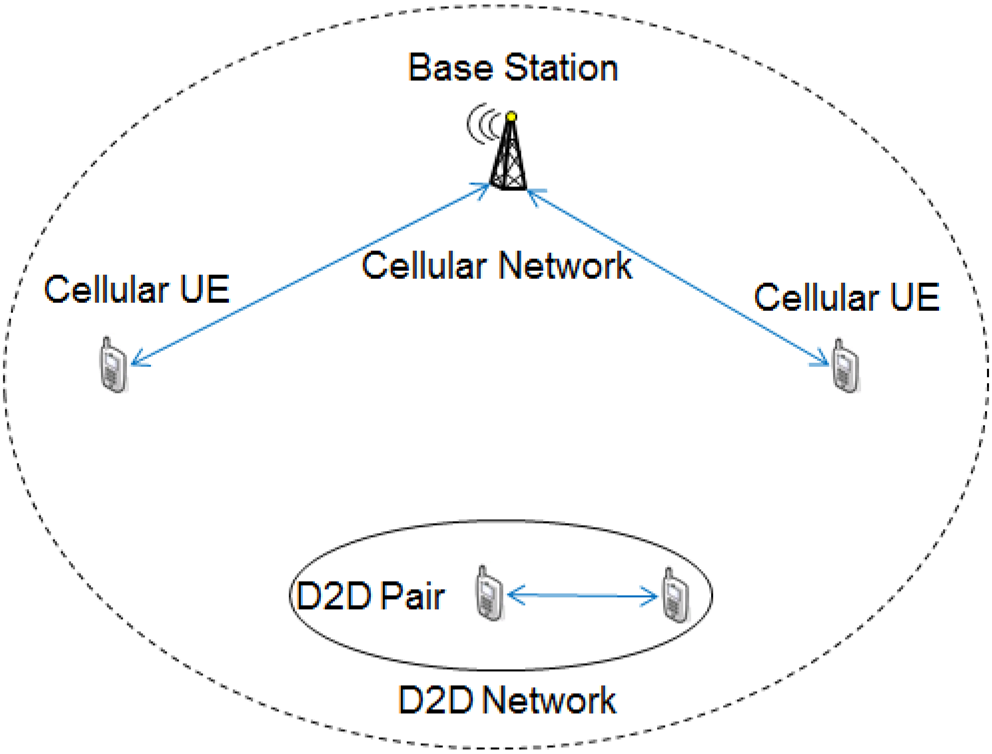

Fig.1. D2D communication

2.1 System overview

D2D is a future communication technology. D2D communication allows a device to communicate directly with each other over D2D links, but without infrastructure as shown in Fig.1 [4]. D2D can use license bands or unlicensed bands where emerging license band-based D2D devices are expected to share the same resources with cellular systems.

This D2D has various advantages. First of all, D2D can reduce device transmission power. D2D reduces communication delay because a device can communicate directly with neighboring device. The other advantage of D2D is cellular traffic offload, so that it can enhance cellular capacity. D2D increases spectral efficiency due to spatial reuse through many D2D links. Furthermore, D2D can extend cell coverage area and can support location-based services.

The standardization of D2D communication is mainly dividing into licensed band and unlicensed band as follows.

2.1.1 Licensed band

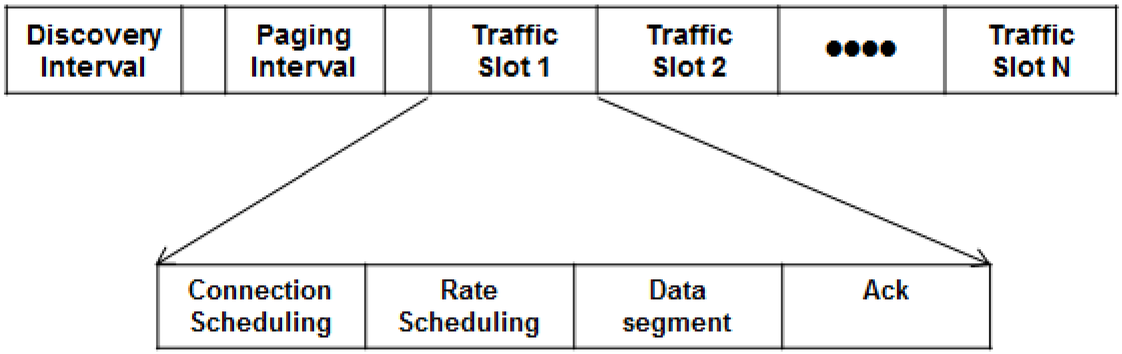

Fig. 2. Timing structure of FlashLinQ

In the licensed band mode, D2D communicates each other in dedicated bands. For licensed bands, D2D communication technology is representatively LTE direct that is based on the FlashLinQ and ProSe that is based on LTE. FlashLinQ operates in the dedicated frequency and is based on the OFDMA in the licensed band. Qualcomm has made an effort to standardize LTE Direct and so the name has been changed from FlashLinQ. The procedures of FlashLinQ are separated into peer discovery, paging, and data communication, and it assumes all the devices are synchronized [5]. The first step is peer discovery. FlashLinQ allocates 20ms time slots for the power efficiency of paging. The UE information is transmitting PDRID (Peer Discovery Resource ID) in the form of single tone OFDM symbol. In this procedure, all the UEs search nearby UEs when UE's periodic time slot is in peer discovery. The resources are allocated into several PDRID to discover all the UEs, and then each UE chooses the PDRID that will be used. Greedy algorithm is applied such that the lowest power of PDRID out of all the received PDRIDs is regarded as its own PDRID. The FlashLinQ is half duplexing that UEs do not listen other signals that are in another frequency while UEs are transmitting signals in its allocated PDRID. To solve half duplexing, it uses Latin square hopping. The second step is paging. If proximity is verified in the first step, D2D transmitter (Tx) requests D2D receiver (Rx) to establish a link and then verifies the D2D link establishment after receiving the acknowledgement (ACK) from D2D Rx. Finally, the results of the earlier procedure are transmitted to the base station to confirm the link, and then the base station allocates a CID (Connection ID) to D2D. The third step is data communication. This step transmits and receives data between D2D Tx and Rx using the established link. To do this, it needs a procedure to schedule the decision of what resource will be used. FlashLinQ proposes the scheduling method for the efficient spatial reuse. The beginning of resource scheduling is to select priority using CID that is already allocated to each link. The base station decides priority pseudo randomly in every slot time to guarantee fairness.

ProSe is a proximity service that is dealt with in 3GPP standard release 12 (LTE-Advanced). ProSe considers direct communication between UEs, unlike existing communication methods that communicate via a network. Additionally, the communication is through LTE or wireless LAN after the UE discovery procedure.

2.1.2 Unlicensed band

For unlicensed bands, Wi-Fi Direct is one of the most well known D2D communication systems. Wi-Fi Direct is authorized by the Wi-Fi Alliance and communicates each other without using an access point (AP) or router. Instead, a group owner (GO) acts as the AP. Wi-Fi Direct networks are composed of more than one GO and client. Wi-Fi Direct follows three procedures: peer discovery, GO establishment, and communication. In addition, the power saving is applied to save the power of mobile GO using opportunistic power saving mode and notice of absence power saving mode [6].

2.2 Usage cases

D2D includes local voice and local data service [4]. In case of local voice service, D2D communications can be used to offload local voice traffic when two geographically proximate users want to talk on the phone, e.g., people in the same large meeting room want to discuss privately, or companions get lost in a supermarket. However, this rarely occurs according to the operators' current market statics. In case of local data service, D2D communications can also be used to provide local data service when two geographically proximate users or devices want to exchange data. One scenario of local data service is content sharing where friends exchange photos or videos through their smart phones, or people attending a conference download materials from a local server. When it is locally multicasting, the shops advertise the sale promotion information to the customers. This context-aware application is a driving factor for the D2D technologies and is based on the people's desire to discover their surroundings and communicate with nearby devices.

2.2 Procedures

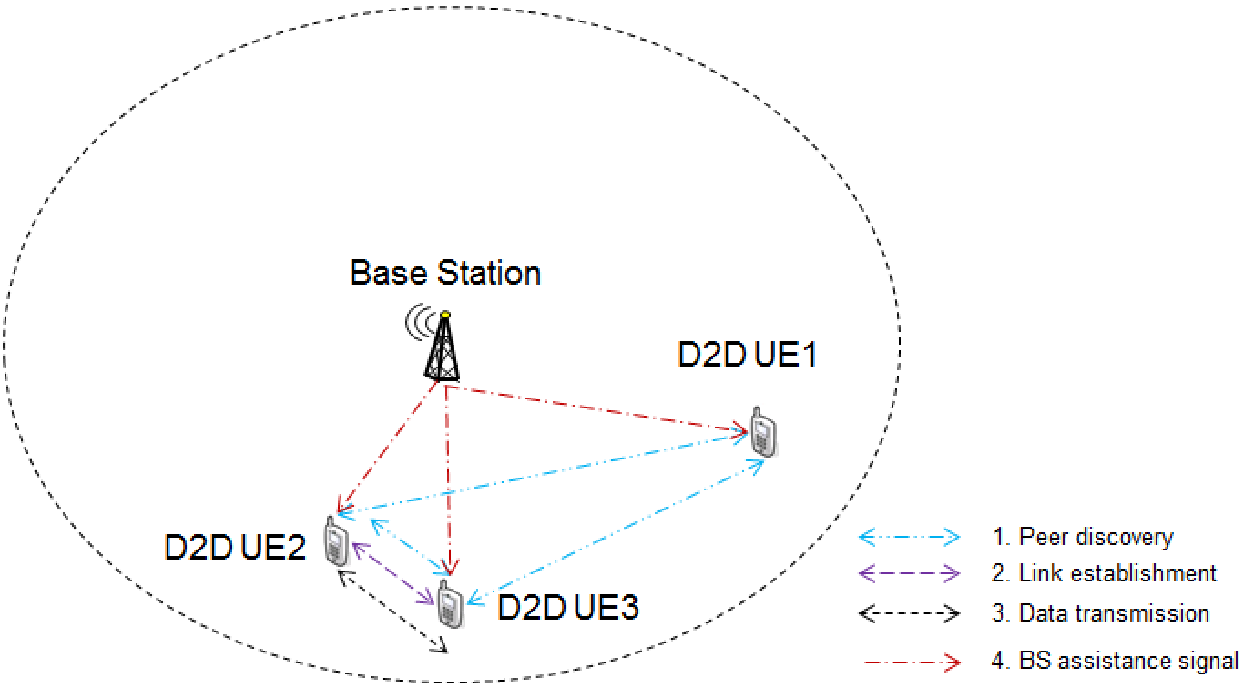

Fig. 3. D2D communication procedure

The procedure of D2D communication is shown in Fig. 3, where all the procedure is generally divided into peer discovery, link establishment, and data transmission [7]. In the procedure of peer discovery, the D2D UE finds nearby D2D UEs to communicate with each other. Before the D2Ds communicate with each other, each D2D should know the nearby D2D UEs, and then the D2D UE makes a decision to establish a link each other. In this procedure, each D2D UE transmits and receives a signal to discover the available D2D UEs. In the procedure of link establishment, links need to be established with the discovered D2D UEs to transmit data. In general, one UE transmits the signal for the link establishment request to the discovered UE , and then that UE receives a request signal and returns a response signal [7]. In the procedure of data transmission after the peer discovery and link establishment procedures, two D2D UEs transmit and receive data each other.

2.3 Operation modes

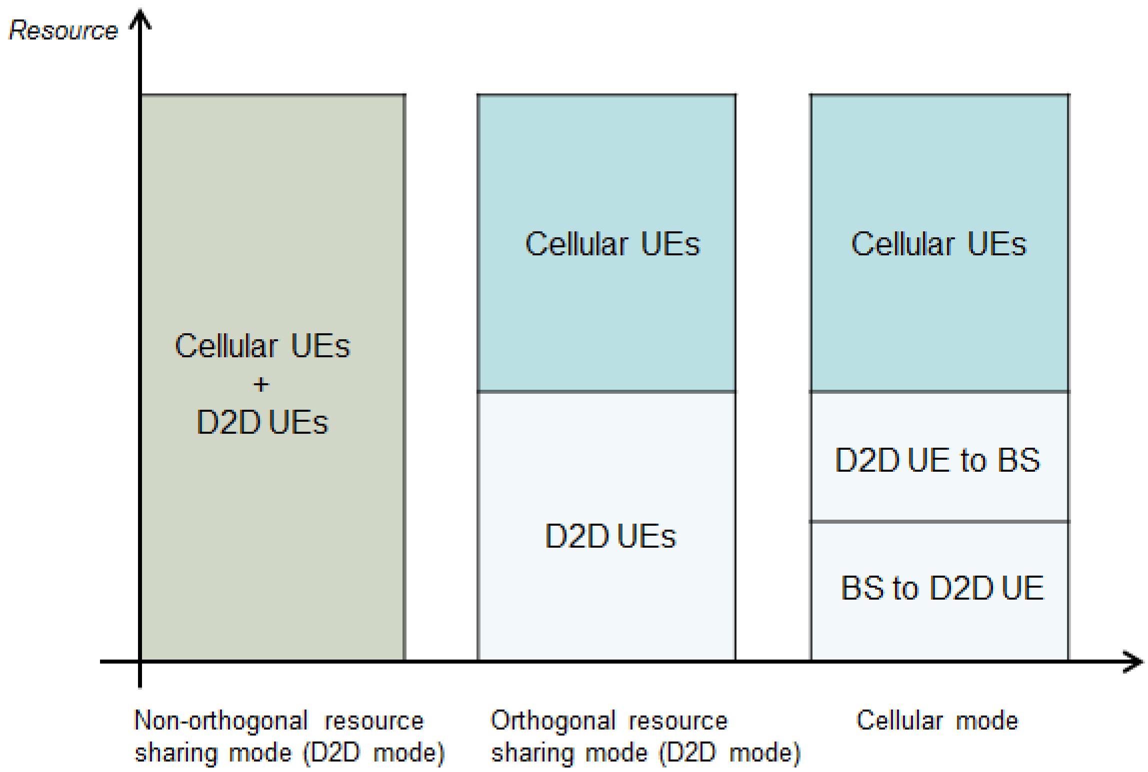

Fig. 4. D2D modes

The D2D pair can communicate in three modes as shown in Fig. 4 [8]. In D2D mode, The two UEs of the D2D pair communicate via a direct link. In this mode, the D2D link uses the same OFDM resource blocks as the cellular UE uses to communicate with its serving AP or BS. D2D mode can be divided into two modes: Non-orthogonal resource sharing mode, orthogonal resource sharing mode. If D2D users occupy resources that are orthogonal to those occupied by the cellular user, they cause no interference to each other and the analysis is simpler. On the other hand, the resource usage efficiency can be higher in non-orthogonal resource sharing where cellular and D2D UEs use the same resource.

The two UEs of the D2D pair communicate via the serving AP in cellular mode. In this case the UE1 and UE2 use orthogonal uplink resources either in the time or in the frequency domain. For example, assuming a time domain separation, during the first period only UE1 transmits to AP1 followed by a period when only UE2 transmits to AP1. The resources are split equally between UE1 and UE2. In non-orthogonal resource sharing mode, D2D users use the same resources as the cellular user, causing interference to each other. The proper power control is needed to mitigate interference between cellular and D2D. In orthogonal

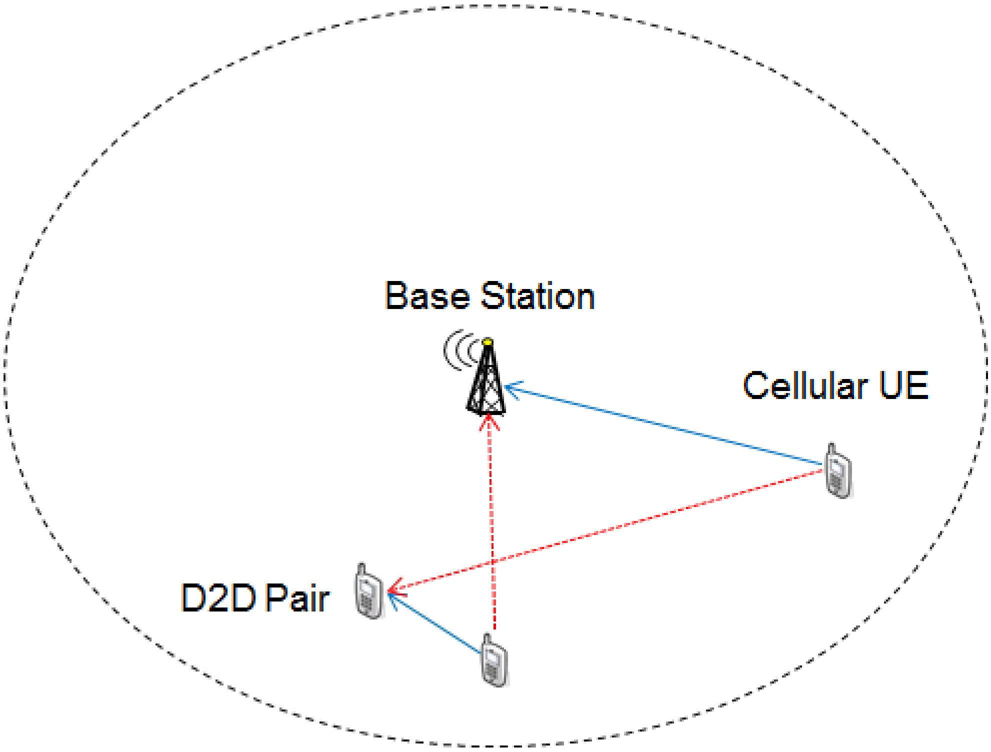

Fig. 5. Interference scenario in uplink resource sharing

resource sharing mode, D2D communication takes half of the exclusive resources from the cellular user and leaves the other half to the cellular user. There is no interference between cellular and D2D communication. The use of the maximum transmit power achieves the maximum sum rate in this case. In cellular mode, the D2D users communicate with each other through the BS that acts like a relay node. They take half of the exclusive resources from the cellular user. All nodes use orthogonal resources and the maximum transmit power. Note that this mode is conceptually the same as a traditional cellular system. The resource sharing takes place in both UL and DL resources of the cellular user. Note that non-orthogonal sharing mode, the source and the receiver of the interference may be different when sharing UL and DL resources.

In non-orthogonal resource sharing mode, interference may occur between cellular UE and D2D UE.

In non-orthogonal resource sharing mode, which is main concern of this thesis, D2D users can reuse both the uplink and downlink resources of the cellular network. However, they have different system performance. If D2D users reuse the uplink resources, the cellular user will interfere with the D2D receiver and the base station will be affected by D2D users at the

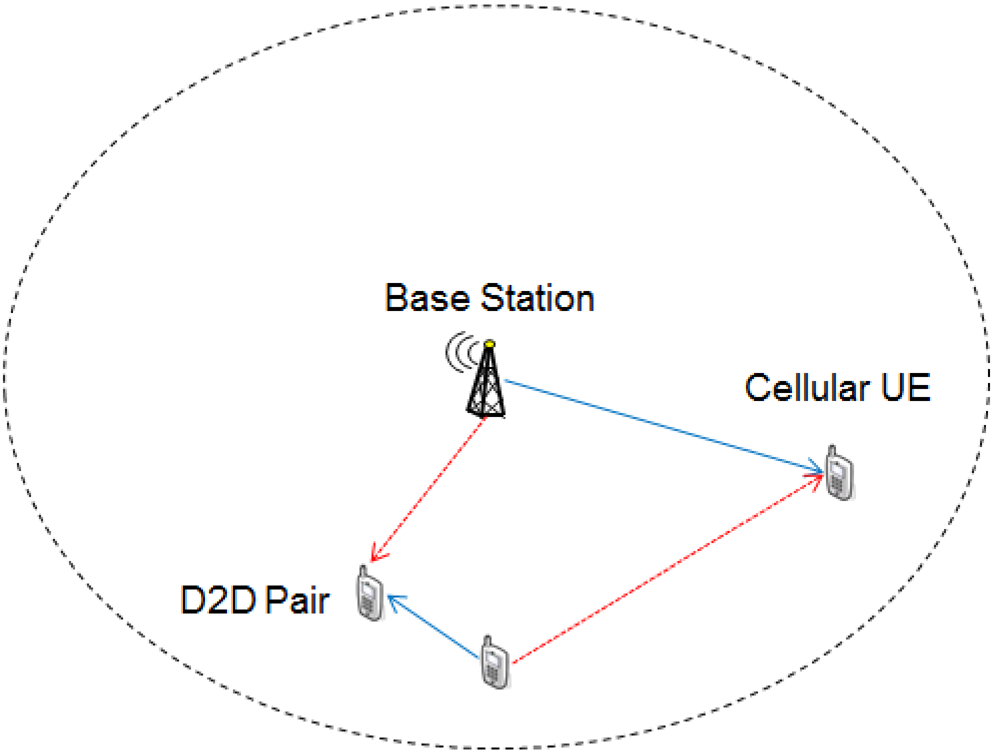

Fig. 6. Interference scenario in downlink resource sharing

same time as shown in Fig. 5. On the contrary, if D2D users reuse the downlink resources, the D2D user will affect the receiving signal of the cellular user and the base station will also interfere with the D2D receiver as shown in Fig. 6 [9].

From the above explanation, we know that reusing the uplink resources outperforms the later for the following reasons. If we reuse the uplink resource, the interference to D2D users comes from the cellular user. However, the interference mainly comes from the base station if we reuse the downlink resource. We also know that the base station always has a larger transmit power than the mobile user, thus it will cause more interference to D2D users. Furthermore, reusing UL resources alleviates the impact on BS-UE links. UL resource has more UE dedicated property while DL resource has more cell common property. Hence, it can easily use power control in UL. Additionally, it has less interference impact on UL receiver. The receiver in the UL resource is usually far from the D2D UE location. Hence, we consider reusing the uplink resource in this paper.

2.4 Power Control

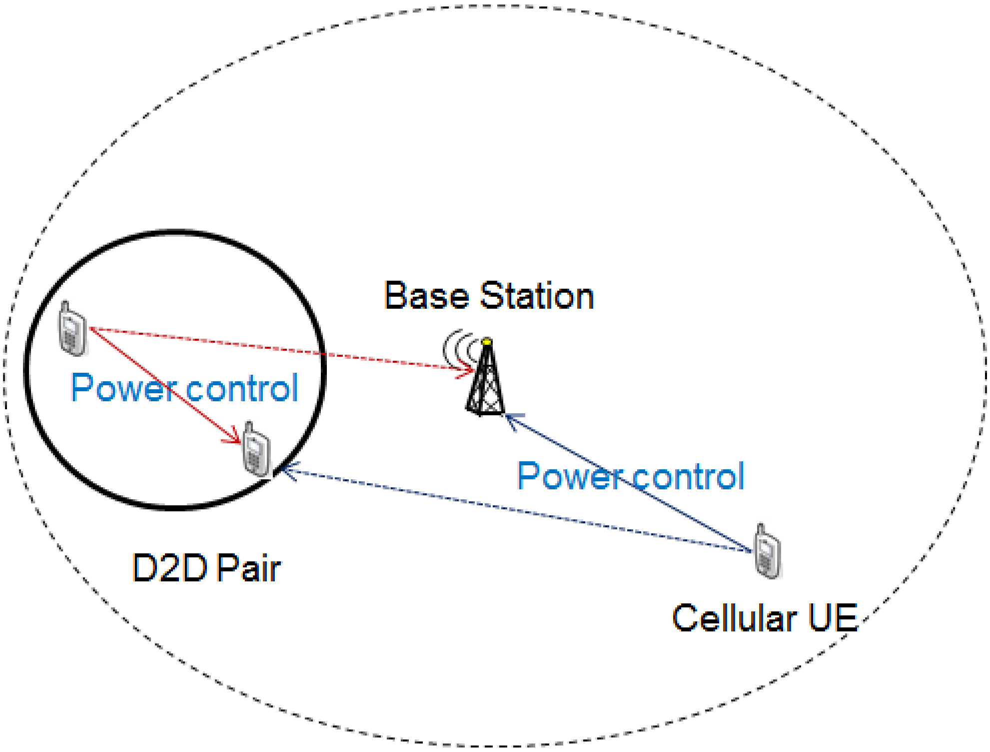

Fig. 7. Power control of D2D and cellular transmit signal

The signal from cellular UE can interfere with D2D Rx and D2D Tx can interfere with BS as shown in Fig. 7. The increase of the transmission power can increase capacity and lower error probability of the corresponding D2D link. It may cause larger interference if there are D2D and cellular users that use the same resources. Therefore, high transmission power does not necessarily mean high performance in terms of total system performance. Hence, the scale of transmission power should be considered with various factors to improve system performance, implying D2D power control should be optimized based on the cellular network.

III. SYSTEM MODEL

We assume there are a D2D Tx, D2D Rx, cellular UE and BS as shown in Fig. 8. In addition, there are M cellular UEs and L subchannels, and we assume that timing synchronization and peer discovery is already done. In this model, all the cellular UEs are in UL period, and the signal from a cellular UE may reach to D2D Rx. Furthermore, we assume that D2D Tx is not signaling to D2D Rx before link establishment, and D2D Tx or Rx are overhearing signals of the cellular UE to measure how much power is received from the cellular UE in each subchannel.

$x(n)$ represents transmit signal of cellular UE in time domain. $X[n, k]$ is transmit signal in frequency domain at the n-th symbol time on the k-th subchannel where $k \in \{0, 1, \cdots, K\text{-}1\}$. The received time domain signal y(n) is sampled and converted into a frequency domain symbol using discrete Fourier transform (DFT) [10]. Then, the received signal at the D2D Tx (or Rx) of the D2D pair d, $d \in \{1, 2, \cdots, D\}$, can be written in the frequency domain as

$$Y_d[n, k] = H_{dc}[n, k]X[n, k] + Z[n, k] = S[n,k] + Z[n,k] \tag{1}$$

where $H_{dc}[n, k]$ is the frequency response of the channel from cellular UE to D2D, and $Z[n, k]$ is the background noise, which is approximated as zero-mean additive white Gaussian noise (AWGN) with variance σ^2.

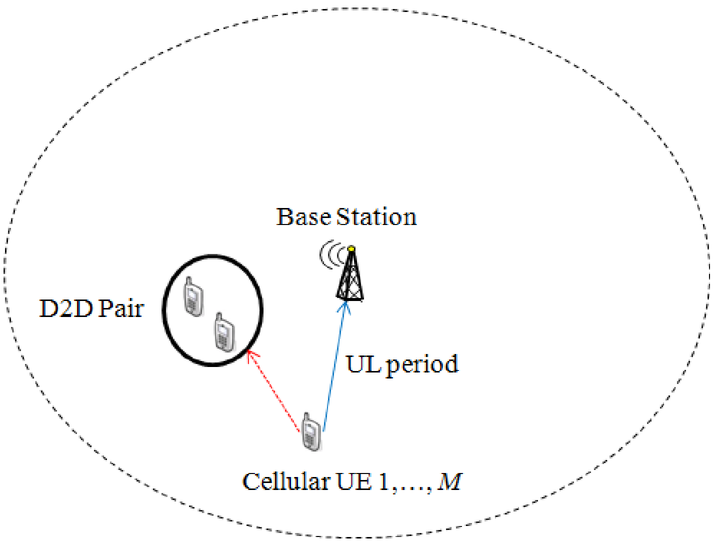

Fig. 8. System model

IV. PROPOSED SCHEME

We propose a scheme to avoid the interference scenario with the flow chart as shown in Fig. 9. The main purpose of this scheme is to prevent significant interference from D2D to cellular link in UL period. The main differences of the proposed scheme with others are that our proposed scheme does not need any other resource such as control channel, e.g. CCCH. Additionally, the help of BS is not necessary at all, hence interference can be reduced in autonomous and distributed manner. We will describe the details of the proposed scheme in the following subsection.

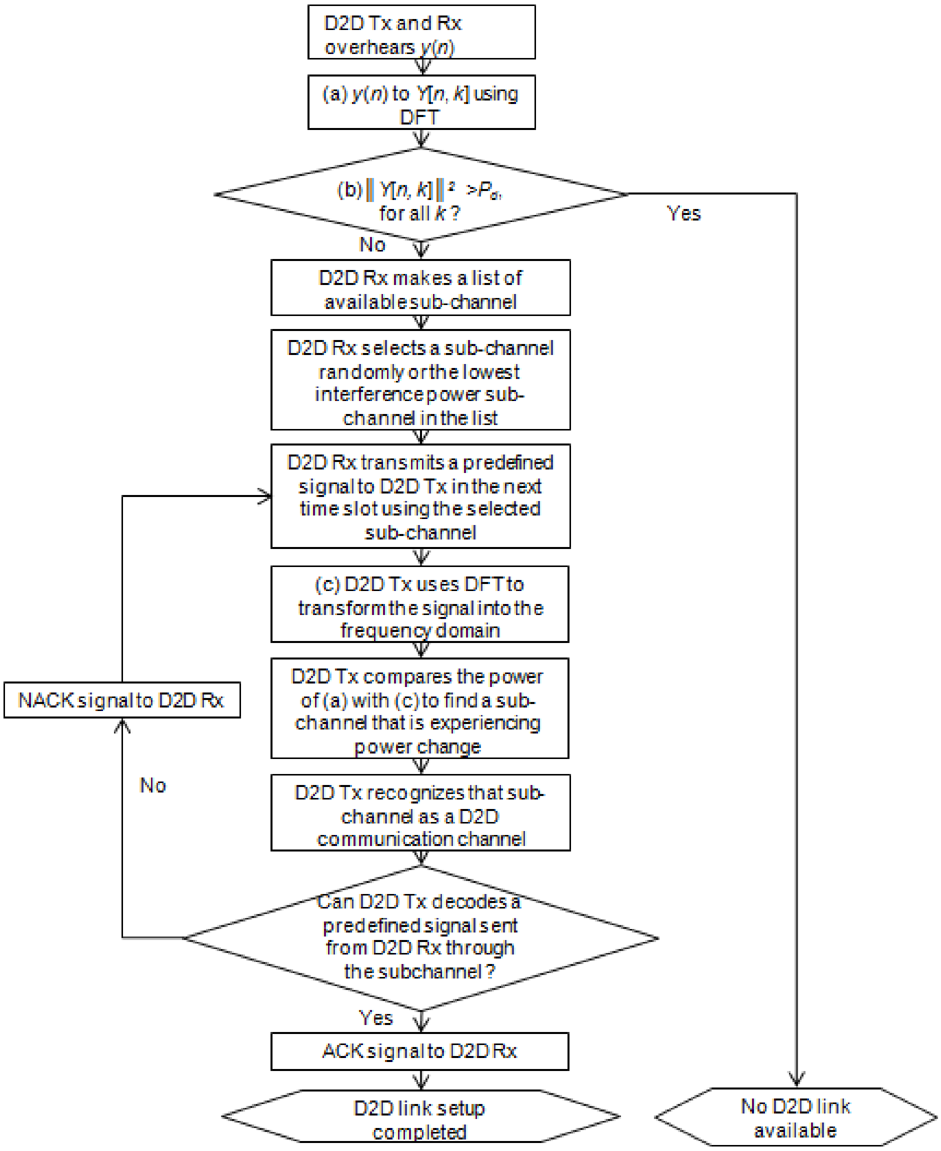

Fig. 9. Flow chart of proposed scheme

4.1 Procedures

In Step 1, when a cellular UE that is close to D2D pair is signaling to the D2D UEs in UL period, D2D Tx and Rx overhear the power of signal from the cellular UE. For each k, the power of $Y_d[n, k]$ is compared with a given threshold subchannel power (P_d), which is the highest received power of cellular signal that D2D pair can endure. The decision of D2D communication can be divided into 3 ways. The first way is that power of cellular in at least one k is less than the P_d, it goes to second step where D2D Tx makes a list on the available subchannels that are not occupied by nearby cellular UE. Note that, although we assume there is one cellular UE, the same procedure can be applied when two or more UEs are close to D2D pair. On the other hand, the second way is that all the power from cellular are less than P_d, and thus D2D pair can use any subchannel where all the subchannels are available. Finally, the last way is that all the power from cellular are larger than P_d where D2D does not communicate each other.

In Step 2, D2D Rx selects a preferred subchannel randomly or the lowest interference power subchannel among the subchannels in the list. D2D Rx transmits a predefined constant signal to D2D Tx at the selected subchannel k and its power must be larger than interference power of cellular in that subchannel. The predefined signal can be pilot signal or data signal ($\Delta(k)$) depending on the way to use. The reason why D2D Rx transmits predefined signal is that the power from cellular UE to D2D Tx can be different with Rx due to channel loss in this scheme. Therefore, D2D Rx must be signaling to D2D Tx to indicate what subchannel D2D Rx wants to use. D2D Tx uses DFT to transform signal from D2D Rx into frequency domain. At this point, D2D Tx can hear both signal of cellular UE and D2D Rx. Then, D2D Tx compares the power of received signal at time n and (n+1), and chooses a subchannel having the largest change of power.

$$\hat{k}_d = \arg\max_k \left| \left|S[n,k]+Z[n,k]\right|^2 - \left|S[n+1,k]+Z[n+1,k]\right|^2 \right| \quad , \quad k \neq k_d \tag{2}$$

$$\hat{k}_d = \arg\max_k \left| \left|S[n,k]+Z[n,k]\right|^2 - \left|S[n+1,k]+Z[n+1,k]+\Delta\right|^2 \right| \quad , \quad k = k_d \tag{3}$$

where k is subchannel index and $\hat{k}_d$ is the estimated subchannel. $P_n(k)$ and $P_{n+1}(k)$ is received signal from cellular in the channel k at the first symbol time (n_1) and second symbol time (n_2). For this reason, D2D is not available if D2D Tx cannot recognize any difference between the power of channel k at time n and n+1, i.e., $k \neq k_d$. In this case, D2D Tx may transmit the signal through the subchannel k that was not the same subchannel k_d decided by D2D Rx. Hence, D2D Tx causes interference to BS in the subchannel k_d, whereas D2D Rx cannot receive any data from D2D Tx. If D2D Tx recognizes the power change of subchannel, D2D Tx transmits its information to D2D Rx. Finally, D2D Rx transmits the ACK or NACK signal to D2D Tx whose signal power is predetermined (P_{DRT}). Furthermore, D2D Tx does not choose the any subchannel if power difference between (a) and (b) is less than $3N_0$ to reduce estimation error probability of decided subchannel.

Finally, D2D Tx can make a decision the subchannel for D2D communication. As a result of these procedures, D2D can communicate each other on the subchannel selected by D2D Rx.

For communication between D2D Tx and D2D Rx, it needs power control to mitigate interference to BS. We employ a power control method to satisfy the SNR of the D2D link [11]. D2D power control should also satisfy the SNR of D2D (λ_D) when the D2D UE shares the uplink resource with a cellular. To satisfy λ_D, D2D Rx transmits the predefined signal with the power of P_{DRT}.

The reason why power is $P_{D2D\,Tx}$ is that the signal from the D2D Rx can experience channel between D2D Rx and Tx, so that there will be path loss from the channel. Hence, D2D Tx knows the power loss of that channel, and then D2D Tx decides its own power following λ_D.

$$P_{D2D\,Tx} = 10 * \log_{10}\left(N * 10^{\frac{SNR_{D2D}}{10}} \right) + L \tag{4}$$

In the proposed scheme, D2D has to incur low interference to cellular as much as possible, so D2D needs to have very low power. This means that D2D Tx and Rx communicate with each other with just the minimum required power, so that the power of D2D Tx ($P_{D2D\,Tx}$) is set. However, there is one more condition when determining power of D2D Tx.

$$P_{DTx} = min\ (P_{max}, P_{D2D\,Tx}) \tag{5}$$

This means that the power of D2D Tx has to be less than $P_{\max}$ since it can cause severe interference to cellular link if D2D Tx is close to a base station, requiring higher power than $P_{\max}$. When it is following the second way in the flow chart, D2D Rx selects subchannel randomly or the lowest interference power subchannel. When it is following the last way, D2D does not communicate each other.

$$P_c(k) + PL(k) + S > P_d \text{, for all } k \tag{6}$$

$P_c(k)$ is the power of cellular from subchannel k.

Performing these procedures without CCCH or any other channel information transfer between cellular UE and D2D UE, interference between D2D and cellular UE can be mitigated by choosing the proper subchannel.

4.2 Analysis of overhearing success probability

In this section, we analyze overhearing success probability in a mathematical manner. We assume that the power of cellular and D2D Rx is zero when the subchannels are distributed from 1 to L. The desired subchannel is k among the subchannels L.

$$(n_k(t+1)+\Delta)^2 - (n_k(t))^2 \text{, for subchannel } k \tag{7}$$

$$n_{k+1}(t+1)^2 - n_{k+1}(t)^2 \text{, for other subchannels} \tag{8}$$

$$(n_k(t+1)+\Delta)^2 - (n_k(t))^2 > n_{k+1}(t+1)^2 - n_{k+1}(t)^2 \tag{9}$$

The equation of desired subchannel is (7), but (8) is not. When we compare (7) and (8), (7) must be larger than (8) because D2D Tx experiences power change in that subchannel as the decided subchannel by D2D Rx.

$$(n_k(t+1)+\Delta)^2 + (n_{k+1}{}^2(t) - (n_k{}^2(t)) + n_{k+1}{}^2(t+1)) > 0 \tag{10}$$

The equation (9) can be shown like (10) and all the values are independent. The left term in the equation (10) is $(n_k(t+1)+\Delta)^2$ and it can be solved by non-central chi square distribution. The pdf of $(n_k(t+1)+\Delta)^2$ is given

$$
\begin{aligned}
f(x;k,\lambda) &= \frac{1}{2}e^{-\frac{x+\lambda}{2}}\left(\frac{x}{\lambda}\right)^{-\frac{1}{4}}\left(\frac{\sqrt{\lambda x}}{2}\right)^{-\frac{1}{2}}\lim_{n->\infty}\sum_{j=0}^{n}\frac{(\frac{\lambda x}{4})^j}{j!\Gamma(-\frac{1}{2}+j+1)} \\
&= \frac{1}{2}\left(\frac{\sqrt[4]{\lambda}}{\sqrt[4]{x}}\right)\left(\frac{\sqrt{2}}{\sqrt[4]{\lambda x}}\right)e^{-\frac{x+\lambda}{2}}\lim_{n->\infty}\sum_{j=0}^{n}\frac{(\frac{\lambda x}{4})^j}{j!\Gamma(-\frac{1}{2}+j+1)} \qquad (11) \\
&= \left(\frac{1}{\sqrt{2x}}\right)e^{-\frac{x+\lambda}{2}}\lim_{n->\infty}\sum_{j=0}^{n}\frac{(\frac{\lambda x}{4})^j}{j!\Gamma(-\frac{1}{2}+j+1)}
\end{aligned}
$$

The mean of this is Δ and variable is σ^2, and non-centrality parameter is $\lambda = \frac{\Delta}{\sigma}$.

The right term of (10) is $(n_{k+1}(t)^2 - (n_k(t)^2 + n_{k+1}(t+1)^2))$, and it is solved by central chi square distribution. This term can be divided into 2 parts, $n_{k+1}(t)^2$ and $n_k(t)^2 + n_{k+1}(t+1)^2$, to solve this easily. The value of k is 1 for $n_{k+1}(t)^2$, and the value of k is 2 for $n_k(t)^2 + n_{k+1}(t+1)^2$.

$$f(x_1,x_2;k_1,k_2) = \frac{1}{\sqrt{2\pi}}x_1^{-\frac{1}{2}}e^{-\frac{1}{2}} - \frac{1}{2}e^{-1} \qquad (12)$$

The pdf of $(n_{k+1}(t)^2 - (n_k(t)^2 + n_{k+1}(t+1)^2))$ is expressed as (12). By combining (11) and (12), we can express (10) in a new form.

$$f = \left(\frac{1}{\sqrt{2x}}\right)e^{-\frac{x+\lambda}{2}}\lim_{n->\infty}\sum_{j=0}^{n}\frac{(\frac{\lambda x}{4})^j}{j!\Gamma(-\frac{1}{2}+j+1)} + \frac{1}{\sqrt{2\pi}}x_1^{-\frac{1}{2}}e^{-\frac{1}{2}} - \frac{1}{2}e^{-1} > 0 \qquad (11)$$

$$p = \int_0^{\infty}\left(\frac{1}{\sqrt{2x}}\right)e^{-\frac{x+\lambda}{2}}\lim_{n->\infty}\sum_{j=0}^{n}\frac{(\frac{\lambda x}{4})^j}{j!\Gamma(-\frac{1}{2}+j+1)} + \frac{1}{\sqrt{2\pi}}x_1^{-\frac{1}{2}}e^{-\frac{1}{2}} - \frac{1}{2}e^{-1}dx \qquad (12)$$

So far the equations have expressed comparison between subchannel k and subchannel $k+1$. However, we need to compare subchannel k and the strongest power difference subchannel except subchannel k. To do this, we need to adopt selection combining method. The following equation represents the pdf of the strongest power difference subchnnel.

$$S_N(p) = [G(p)]^N = (1-e^{-p})^N \tag{13}$$

S and G indicate that the pdf of strongest power difference subchannel and distribution in individual channel power ratios, respectively. Finally, we can get the overhearing success possibility as

$$p_{success \quad possibility} = \int_0^{\infty} (1-e^{-p})^N \left(\left(\frac{1}{\sqrt{2x}} \right) e^{-\frac{x+\lambda}{2}} \lim_{n->\infty} \sum_{j=0}^{n} \frac{(\frac{\lambda x}{4})^j}{j!\Gamma(-\frac{1}{2}+j+1)} + \frac{1}{\sqrt{2\pi}} x_1^{-\frac{1}{2}} e^{-\frac{1}{2}} - \frac{1}{2} e^{-1} \right) dx \tag{14}$$

V. SIMULATION RESULTS

In this section, we evaluate the performance of the proposed scheme by simulation in terms of total data rate. The D2D UEs and cellular UEs are randomly distributed in a 500 m by 500 m cell. Spectral efficiency (bits/sec/Hz) of each user is computed using Shannon capacity formula. Distance between D2D UEs is uniformly determined from 1 to 10, 100, and 150 meter. The bandwidth is 1.25 MHz and carrier frequency is 2000 MHz that is commonly adopted in LTE [12]. Additionally, λ_D is set to 0 dB and λ_C is set to 10 dB. The number of subchannel is 20 in this simulation. For random channel conditions, we use the COST231 HATA model for path loss and lognormal distribution for shadowing [13]. The number of simulations is 500000 times. Table 1 lists simulation parameters.

TABLE 1. Simulation Parameters

Center frequency (MHz)		2000
Bandwidth (MHz)		1.25
Number of D2D UEs		20
Number of cellular UEs		20
Path loss model		COST231 HATA
Shadowing		Lognormal distribution, N~(0,5)

5.1 Success probability of overhearing

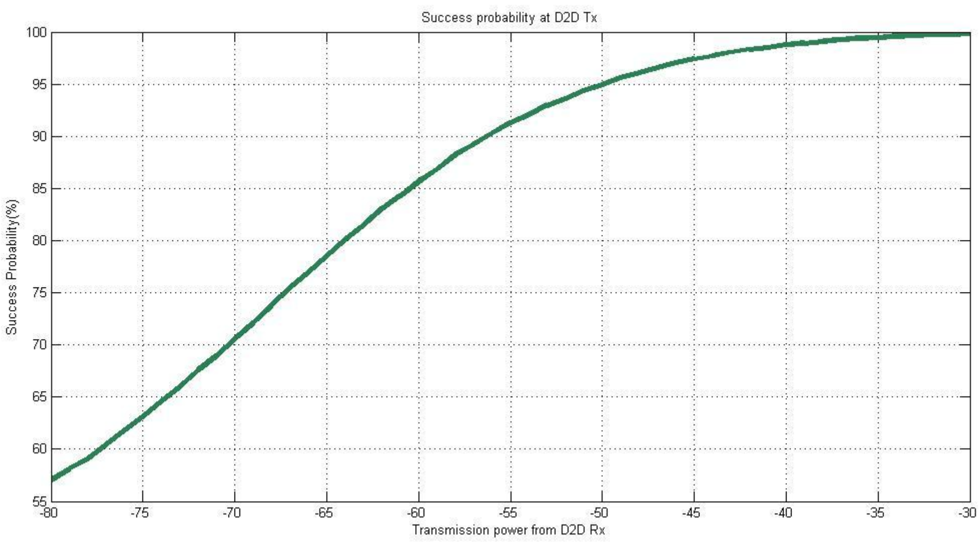

Fig. 10. The success probability following the power from D2D Rx

The figure 10 shows the success probability of recognition of the subchannel at D2D Tx. D2D Rx transmits predefined signal to D2D Tx and its power of predefined signal will be Δ at D2D Tx. The success probability is 57 percent when the transmission power from D2D Rx. However, the success probability increases as the power from D2D Rx. When it is -30 dBm, the success probability is almost perfect as shown in Fig. 10.

5.2 System throughput

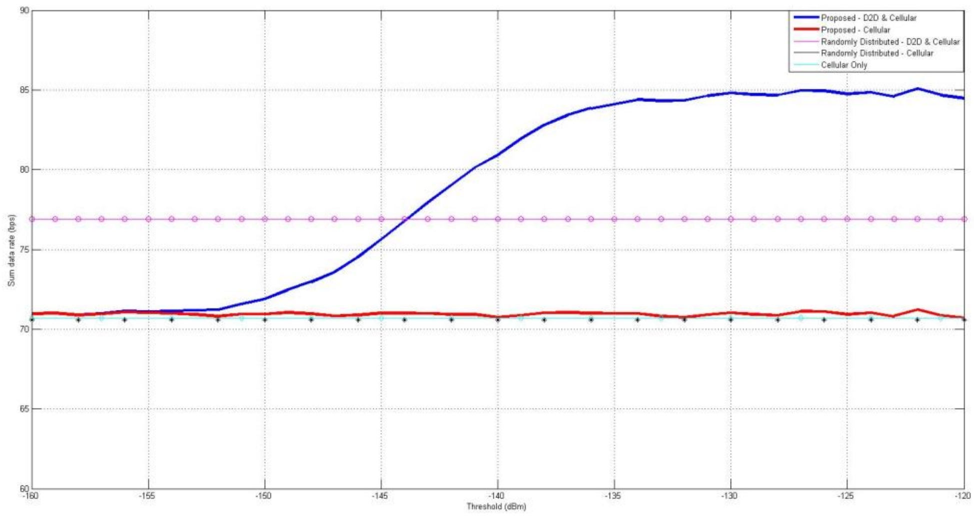

Fig. 11. Sum data rate when distance between D2D is from 1 to 10 meter

In Fig. 11, it shows the sum data rates of the proposed scheme, randomly distributed, and cellular-only scheme assuming frequency overhearing is perfect. In randomly distributed scheme, 20 cellular and 20 D2D links interfere each other randomly. There is not any D2D UE in cellular only manner. The sum data rate, i.e., total data rate of cellular and D2D communication of proposed scheme increases with P_d while cellular data rate itself decreases due to higher D2D interference. It has higher data rate than that of randomly distributed D2D and cellular scenario when the threshold is larger than -143 dBm. In this figure, the data rate of cellular only case is very similar to randomly distributed manner. The power of D2D Tx is very low since D2D distance is very short. Hence, it can scarcely affect to the cellular as in

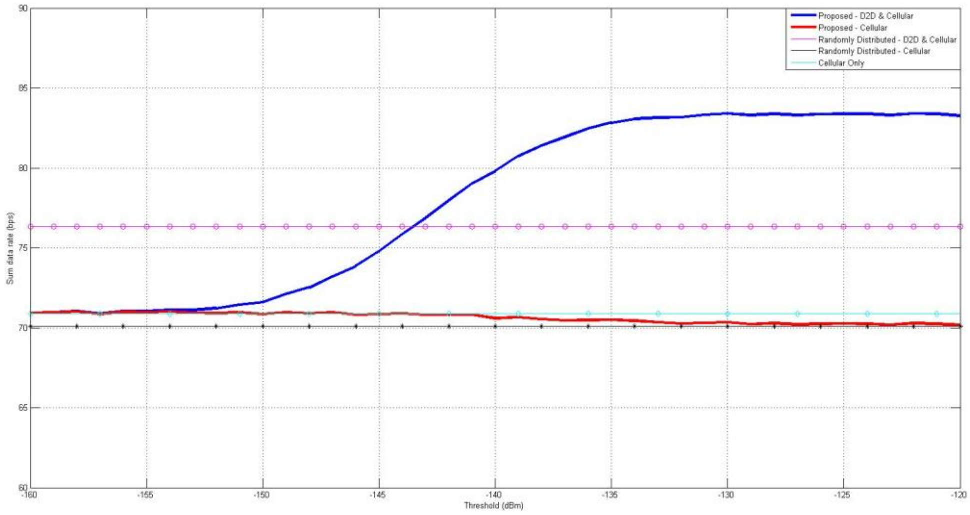

Fig. 12. Sum data rate when distance between D2D is from 1 to 100 meter

terference, and maximizing the benefit of D2D proximate communication.

Fig. 12 shows also higher data rate than that of randomly distributed D2D and cellular only scheme. In this figure, the distance between D2D is randomly distributed from 1 to 100 meter that is wider than Fig. 11. Therefore, D2D Tx transmits with higher power in average when employing power control method. Thus, D2D Tx usually interferes to BS with higher power.

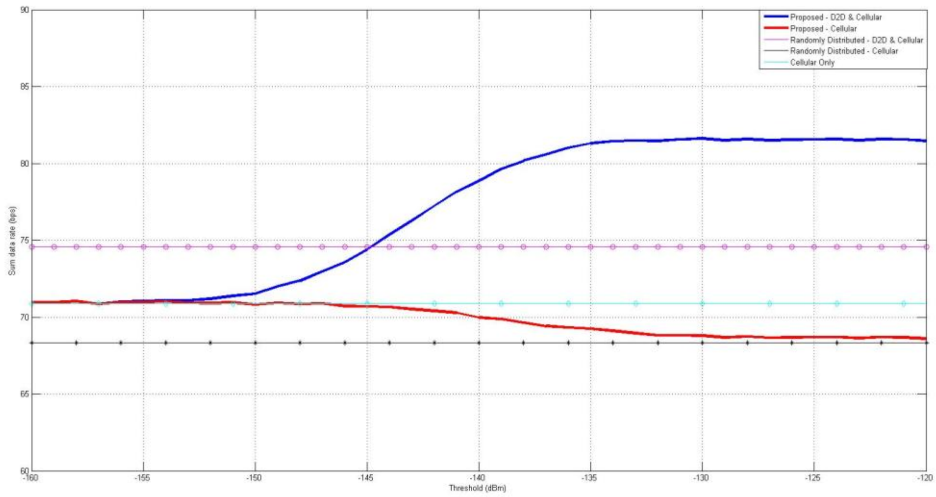

Fig. 13. Sum data rate when distance between D2D is from 1 to 150 meter

In Fig. 13, it can be seen that the interference from D2D Tx has been increased because transmit power increases following the wider range between D2D Tx and Rx. Thus, the cellular data rate of the proposed scheme becomes lower as P_d increases, i.e., more D2D links become available. In this figure, the proposed scheme still shows the higher performance than randomly distributed scenario from P_d = -144 dBm while keeping higher cellular data rate. The proposed scheme provides higher cellular data rate, i.e., less affecting quality of service (QoS) of cellular links, than that of randomly distributed scenario.

When the additional transmission power from D2D Rx to Tx for frequency overheaing is -80 dBm, most of all the transmission power from D2D Rx can be measured. The result of data rates in Fig. 14 is similar to the result of data rates in Fig. 13 where the overhearing success probability is perfect.

The sum data rate of proposed scheme in Fig. 15 is lowered when it is compared with the data rate of proposed scheme in Fig. 14 since the power of D2D Rx is not enough to reach to D2D Tx due to the power loss through channel and the noise power makes D2D Tx to differentiate it from the other channels. It still means that D2D Tx does not interfere with BS when its data rate is 0. However, the sum data rate of proposed scheme of cellular is enhanced because of lowered interference from D2D.

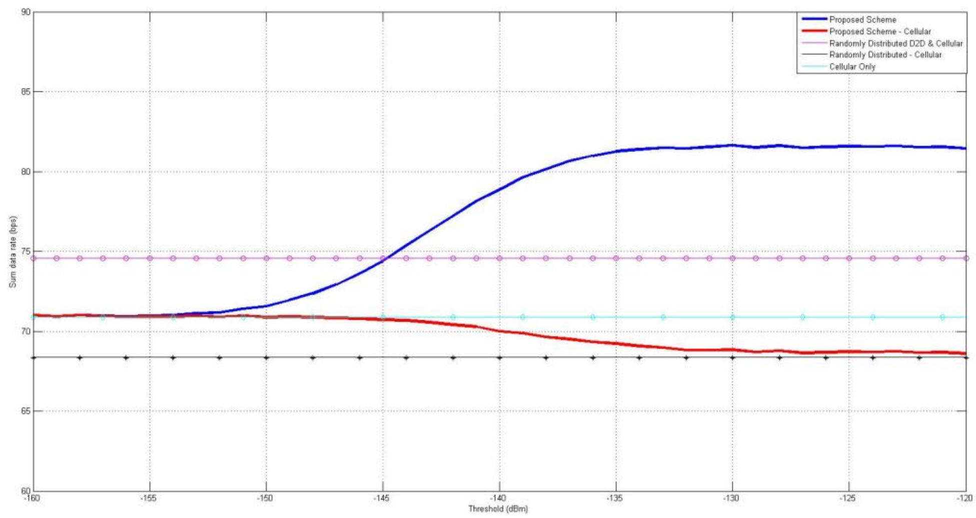

Fig. 14. Sum data rate when distance between D2D is from 1 to 150 meter and $|\Delta|^2$ is -80 dBm

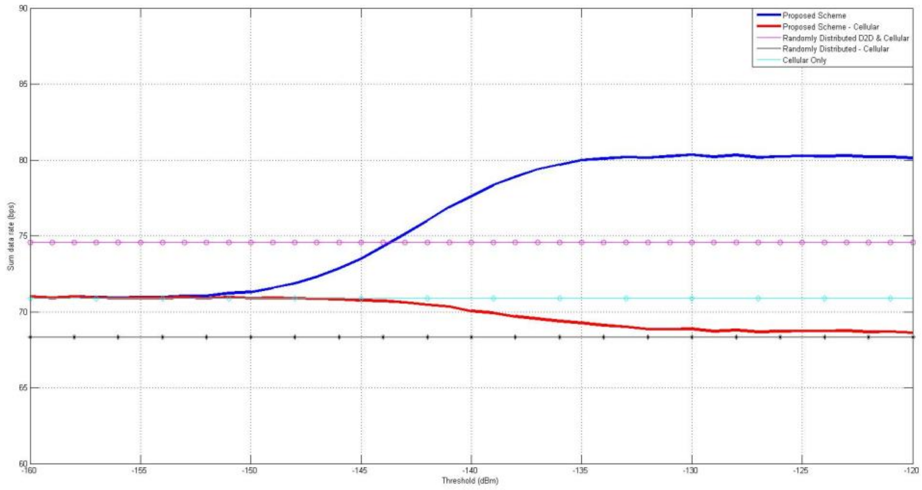

Fig. 15. Sum data rate when distance between D2D is from 1 to 150 meter and $|\Delta^2|$ is -90 dBm

The sum data rate of proposed scheme in Fig. 16 is lowered compared with the data rate of proposed scheme in Fig. 14 and Fig. 15. It is not enough to recognize in D2D Tx when the power of D2D Rx is -100 dBm, so that the performance of proposed scheme is worse. This indicates the power of Δ needs to be properly determined.

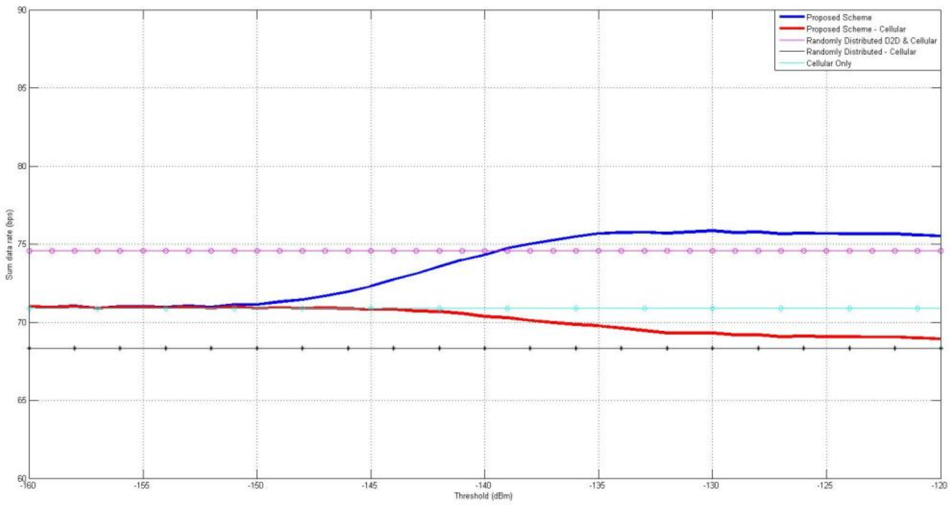

Fig. 16. Sum data rate when distance between D2D is from 1 to 150 meter and $|\Delta|^2$ is – 100 dBm

Note that P_d needs to be determined considering the tradeoff in the data rates of D2D and cellular links. In this simulation, D2D link is not available if power from cellular UE is larger than threshold power. However, D2D link can interfere with cellular link when D2D link is available. Therefore, the data rate of cellular is lowering because of the interference from the D2D.

VI . CONCLUSIONS

In this paper, we propose an interference avoidance scheme for D2D communication by measuring interference level from cellular UEs in the OFDM system. After comparing with a given threshold subchannel by subchannel in the frequency domain, a preferred subchannel for D2D link can be chosen autonomously without any control information exchange between D2D pair and cellular link. The proposed scheme provides better performance than random allocation scheme. As shown in the simulation results, the gain of the proposed scheme increases as the distance between D2D transmitter and receiver decreases. It indicates that the benefit of D2D can be maximized for proximity services where D2D pair are closely located. In addition, the performance of data rate is getting better when overhearing success probability (P_d) is high, where P_d needs to be determined considering the gain of D2D link and the loss of cellular links.

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요 약 문

OFDM 시스템의 D2D 통신에서 주변 주파수 감지를 이용한 자동적인 간섭 회피 방식

D2D 통신은 기지국의 도움 없이 UE 간에 데이터 신호를 서로 주고받을 수 있는 통신 방식이다. D2D 통신은 데이터율과 스펙트럼 효율의 향상 및 재난 상황에도 통신이 가능하며 기지국의 부담을 줄여줄 수 있는 장점을 가지고 있는 차세대 통신 기술이다. 하지만 D2D 와 셀룰러가 같은 자원을 공유할 때 셀룰러와 D2D 간의 간섭을 일으킬 수 있는 문제점이 존재한다. 최악의 경우에는 셀룰러가 아웃티지가 생길 수 있는 확률을 가지게 된다. D2D 가 통신하는 과정은 단말 탐색, 링크 형성, 데이터 전송으로 크게 3 가지로 나눌 수 있다. 본 논문에서는 단말 탐색은 이미 이루어져있다고 간주하고, 그 이후의 과정인 링크 형성과 데이터 전송 과정에서의 간섭 회피 방법을 제시한다. 또한 OFDM 의 TDD 시스템에서 셀룰러의 상향링크 자원을 공유할 때의 D2D 통신에서 자동적인 간섭 회피 방법을 제시한다. 이 방법은 공통 제어 채널과 같은 전용 채널을 사용하지 않고 주변 셀룰러가 사용하는 부채널의 신호 전력을 감지하고 그 부채널들을 피하여 자원을 할당하는 방식을 사용하고 있다. 제시된 방법은 문턱 신호 전력을 조절하여 약간의 셀룰러 수율을 감소시키는 대신에 전체적인 시스템 수율을 향상시킬 수 있다. 또한 전체적인 시스템 수율과 셀룰러 수율간의 관계에 관한 성능을 시뮬레이션을 통하여 보여주었다. 추가적으로 주변 주파수 감지에 대한 성공 확률을 분석하고 이를 시뮬레이션과 비교하였다.

핵심어 : D2D 통신, 간섭 회피, D2D 모드, OFDM