MS. THESIS

Resource Allocation for Device-to-device Communication in Cellular Networks in the Presence of Eavesdropper

도청자가 존재하는 셀룰러 네트워크에서 D2D 통신을 위한 자원 할당 기법

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Abstract

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In this thesis, we propose a resource allocation scheme for device-to-device (D2D) communication in a cellular network in the presence of eavesdropper. In the proposed scheme, transmit power and spectrum are allocated to D2D users such that sum rate of the network is maximized under constraints of data rate and secrecy outage probability for cellular user. Simulation results show that the proposed scheme achieves higher sum rate for the network than the equal power allocation scheme and the proposed scheme guarantees data rate and security of cellular user.

Keywords: Resource allocation, device-to-device communication, eavesdropper.

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Chapter 1

Introduction

In a cellular network, device-to-device (D2D) communication provides high data rate and reduces the traffic load of base station by allowing proximity users to communicate directly with each other [1], [2]. D2D communication is one of the key technologies in future networks such as 3GPP LTE-Advanced. D2D communication is effective to improve spectral utilization and admit more users. D2D communication in cellular networks can share the cellular resources for better spectral utilization [3]. In [4], throughput is maximized for a network with one D2D pair and one cellular user. In [5]-[8], a network with multiple D2D users and multiple cellular users is considered. Since D2D users share spectrum resource with cellular user, D2D communication generates interference to the existing cellular network. Interference coordination is one of the most important issues for D2D communication in cellular network [9], [10].

Because of the broadcast nature of the wireless medium, an unauthorized receiver located within the transmission range is capable of eavesdropping the transmission towards legitimate users. The concept of achieving information-theoretic security by protecting the physical layer of wireless networks has attracted in research area. Wyner [11] proposed the wiretap channel model and showed that a source and a destination can exchange perfectly secure messages. In [13], resource allocation and scheduling is proposed for a cellular network with multiple cellular users and one eavesdropper. In [14], secrecy performance is considered for cellular networks with multiple cellular users and multiple eavesdroppers. There is few work on D2D communication in cellular network considering security of cellular user.In [15], power allocation scheme is proposed such that data rate of D2D user is maximized in a network with one cellular user, multiple D2D users, and one eavesdropper. Since interference caused by D2D communication affects cellular user and eavesdropper, power allocation and spectrum allocation to D2D users can improve sum rate of a cellular network. The problem of resource allocation has not been investigated for a cellular network with multiple D2D users, multiple cellular users, and one eavesdropper.

In this thesis, we consider an uplink cellular network for D2D communication in the presence of eavesdropper. A resource allocation problem is formulated to maximize the sum rate of the cellular network under the constraints of data rate and secrecy outage probability for cellular user. A resource allocation scheme is proposed to solve the formulated problem.

The rest of this thesis is organized as follows. We describe the system model in chapter 2, formulate the resource allocation problem, and propose the resource allocation scheme in chapter 3. We present computer simulation results in chapter 4 and draw conclusion in chapter 5.

Chapter 2

System Model

2.1 System Architecture

Consider a cellular network which consists of a base station, BS, M cellular users, CU_m, $m = 1, 2, \cdots M$, N device-to-device (D2D) pairs, D_n, $n = 1, 2, \cdots N$, and an eavesdropper, E. Assume that two D2D users are paired to communicate directly. In particular, a D2D pair D_n consists of a D2D transmitter DT_n and its receiver DR_n. Assume that cellular users and D2D users are uniformly distributed in the cell. Assume that the cellular users and the D2D users share uplink spectrum which is divided into M channels. There are several reasons for favoring the sharing of uplink spectrum. Firstly, uplink spectrum is under-utilized comparing to downlink spectrum in frequency division duplex (FDD) based cellular networks [6]-[8]. Moreover, uplink spectrum sharing in D2D communications causes interference to base station, which has stronger abilities to manage interference than cellular users [7], [8]. Assume that M cellular users communicate with the base station on M orthogonal channels. Since a fully loaded cellular network as in [6], [7] is assumed, D2D users reuse the cellular user's spectrum.

2.2 Channel Model and Achievable Rate

Let $h_{A,B}$ denote the coefficient of channel from node A to node B and where $A = \{CU_m, DT_n\}$ and $B = \{BS, DR_n, E\}$. All channels are assumed to be independent and complex Gaussian distributed with zero mean and variance $\Omega_{A,B}$. The additive white Gaussian noise (AWGN) at each node has zero mean and variance N_0.

Assume that resource allocation is performed by the base station and perfect channel state information (CSI) of all cellular users and D2D pairs is available at the base station. In practice, it is difficult for the base station to obtain instantaneous CSI of the eavesdropper, since the eavesdropper is generally passive and silent. Assume that the base station knows the statistical distribution of the eavesdropper's channel.

The base station allows a D2D pair to access uplink spectrum when the rate of cellular user is larger than a target rate R_{th}. Also, the D2D pair is possible to access uplink spectrum when the secrecy outage probability of cellular user is smaller than a target secrecy outage ε.

Assume that each D2D pair reuses at most one cellular user's spectrum. Assume that one cellular user's spectrum can be reused by at most one D2D pair. These assumptions are used for reducing the complicated interference scenario caused by D2D communications [6], [7].

Let x_{CU_m} and x_{DT_n} denote the transmit symbols with unit power, and P_m^c and P_n^d denote the transmit power of the cellular user CU_m and the D2D transmitter DT_n. When the D2D pair D_n reuses the cellular user CU_m's spectrum, the received signals at the base station BS and the D2D receiver DR_n are given by

$$y_{m,BS} = \sqrt{P_m^c} h_{CU_m,BS} x_{CU_m} + \sqrt{P_n^d} h_{DT_n,BS} x_{DT_n} + n_{m,BS} \tag{2.1}$$

and

$$y_{DR_n} = \sqrt{P_n^d} h_{DT_n,DR_n} x_{DT_n} + \sqrt{P_m^c} h_{CU_m,DR_n} x_{CU_m} + n_{DR_n}, \tag{2.2}$$

respectively, where $n_{m,BS}$ and n_{DR_n} are the AWGN at BS and DR_n, respectively.

The received signal-to-interference-plus-noise-ratios (SINRs) at BS and DR_n are given by

$$\gamma_{m,BS} = \frac{P_m^c |h_{CU_m,BS}|^2}{P_n^d |h_{DT_n,BS}|^2 + N_0} \tag{2.3}$$

and

$$\gamma_{DR_n} = \frac{P_n^d |h_{DT_n,DR_n}|^2}{P_m^c |h_{CU_m,DR_n}|^2 + N_0}, \tag{2.4}$$

respectively.

The achievable sum rate of CU_m and D_n is given by

$$R_{m,n}^{\text{sum}} = R_{m,n}^c + R_{m,n}^d \tag{2.5}$$

where $R_{m,n}^c = \log_2(1 + \gamma_{m,BS})$ and $R_{m,n}^d = \log_2(1 + \gamma_{DR_n})$.

Let $\rho_{m,n}$ denote the reuse indicator for cellular user CU_m and D2D pair D_n. If the D2D pair D_n reuses the spectrum of cellular user CU_m, $\rho_{m,n} = 1$, otherwise, $\rho_{m,n} = 0$. With the reuse indicator $\rho_{m,n}$, the achievable sum rate of CU_m and D_n is given by

$$R_{m,n}^{\text{sum}} = R_{m,n}^c + \rho_{m,n} R_{m,n}^d \tag{2.6}$$

where $R_{m,n}^c = \log_2\left(1 + \frac{P_m^c \left|h_{CU_m,BS}\right|^2}{\rho_{m,n} P_n^d \left|h_{DT_n,BS}\right|^2 + N_0}\right)$ and $R_{m,n}^d = \log_2(1 + \gamma_{DR_n})$.

The secrecy rate of cellular user CU_m is given by [12]

$$R_m^{\text{sec}} = \left[\log_2\left(1 + \frac{P_m^c |h_{CU_m,BS}|^2}{N_0}\right) - \log_2\left(1 + \frac{P_m^c |h_{CU_m,E}|^2}{N_0}\right)\right]^+ \tag{2.7}$$

where $[x]^+ = \max\{x, 0\}$. In (2.7), the first and the second term are the achievable data rates of CU_m and E, respectively. When the D2D pair D_n reuses the cellular user CU_m's spectrum, the secrecy rate of CU_m is given by

$$\begin{aligned} R_{m,n}^{\text{sec}} = \Bigg[&\log_2\left(1 + \frac{P_m^c |h_{CU_m,BS}|^2}{P_n^d |h_{DT_n,BS}|^2 + N_0}\right) \\ &- \log_2\left(1 + \frac{P_m^c |h_{CU_m,E}|^2}{P_n^d |h_{DT_n,E}|^2 + N_0}\right)\Bigg]^+. \end{aligned} \tag{2.8}$$

With the reuse indicator $\rho_{m,n}$, the secrecy rate of CU_m is given by

$$R_{m,n}^{\text{sec}} = \Bigg[\log_2\left(1 + \frac{P_m^c|h_{CU_m,BS}|^2}{\rho_{m,n}P_n^d|h_{DT_n,BS}|^2 + N_0}\right) \\ -\log_2\left(1 + \frac{P_m^c|h_{CU_m,E}|^2}{\rho_{m,n}P_n^d|h_{DT_n,E}|^2 + N_0}\right)\Bigg]^+. \tag{2.9}$$

Since the base station knows the statistical CSI of eavesdropper, the secrecy outage probability is considered to guarantee security of cellular communication. Secrecy outage occurs when the secrecy rate is below a target secrecy rate $R_{\text{th}}^{\text{sec}}$. The secrecy outage probability of CU_m is defined as [12]

$$P_{\text{out}}(R_{\text{th}}^{\text{sec}}) = \Pr\left\{R_{m,n}^{\text{sec}} < R_{\text{th}}^{\text{sec}}\right\}. \tag{2.10}$$

Using known instantaneous channel information, the secrecy outage probability of CU_m conditioned on channel information of $h_{CU_m,BS}$, $h_{DT_n,BS}$ is given by [12]

$$\Pr\left\{R_{m,n}^{\text{sec}} < R_{\text{th}}^{\text{sec}} \,\middle|\, h_{CU_m,BS}, h_{DT_n,BS}\right\}. \tag{2.11}$$

With channel knowledge at the base station, (2.11) is used for resource allocation problem.

Chapter 3

Resource Allocation Problem

In this chapter, we formulate the resource allocation problem for D2D communication in cellular network. Due to the presence of eavesdropper, it is important for the D2D pair to guarantee not only rate requirement of cellular user but also secrecy requirement of cellular user. The secrecy requirement of cellular user is expressed in a probability-constrained manner because of the statistical channel knowledge related to the eavesdropper [16]-[19]. To maximize the sum rate of the network, the resource allocation problem is formulated as

$$\max_{\boldsymbol{\rho},\mathbf{P}} \left\{ \sum_{m=1}^{M} \sum_{n=1}^{N} R_{m,n}^{\text{sum}} \right\} \tag{3.1}$$

$$\text{subject to:} \quad R_{m,n}^{c} \geq R_{\text{th}}, \forall m \tag{3.2}$$

$$\Pr\left\{ R_{m,n}^{\text{sec}} < R_{\text{th}}^{\text{sec}} \middle| h_{CU_m,BS}, h_{DT_n,BS} \right\} \leq \varepsilon, \forall m \tag{3.3}$$

$$\sum_{m} \rho_{m,n} \leq 1, \forall m \tag{3.4}$$

$$\sum_{n} \rho_{m,n} \leq 1, \forall n \tag{3.5}$$

$$0 \leq P_n^d \leq P_n^{d,\max}, \forall n \tag{3.6}$$

where $\boldsymbol{\rho} = \{\rho_{m,n}, \forall m, n\}$, $\mathbf{P} = \{P_n^d, \forall n\}$, $R_{m,n}^c$ is the achievable rate of CU_m which is given in (2.6), and $P_n^{d,\max}$ is the maximum transmit power of DT_n. In the objective function, $R_{m,n}^{\text{sum}}$ is the achievable sum rate of CU_m and D_n which is given in (2.6). The constraint (3.2) indicates that the rate of CU_m is larger than the target rate R_{th}. The constraint (3.3) indicates that the secrecy outage probability of CU_m conditioned on channel information of

$h_{CU_m,BS}$, $h_{DT_n,BS}$ is smaller than the target secrecy outage ε. In (3.3), $R^{\text{sec}}_{m,n}$ is the secrecy rate of CU_m which is given in (2.9). The constraint (3.4) indicates that each D2D pair can reuse at most one cellular user's spectrum. The constraint (3.5) indicates that the cellular user's spectrum cannot be reused by more than one D2D pair. The constraint (3.6) indicates that the transmit power of DT_n is within the maximum transmit power $P_n^{d,\max}$.

The resource allocation problem in (3.1) jointly considers power allocation and spectrum allocation. High computational complexity is required to find the joint optimal resource allocation to users by an exhaustive search over all possible uplink spectrum assignments to D2D pairs. Note that the problem in (3.1) is not a convex optimization problem because of the objective function of the problem. The objective function is sum rate of users in the network with the reuse indicator, so the objective function is not concave in transmit power P_n^d. The resource allocation problem does not using a convex optimization technique. The resource allocation problem is divided into two separate problems: first, the power allocation and second, the reusing spectrum allocation.

3.1 Power Allocation

To solve the resource allocation problem, we first determine the transmit power of DT_n. The transmit power of DT_n is determined from the constraints (3.2), (3.3), and (3.6). To derive the expressions for the transmit power from those constraints, it is assumed that the D2D pair D_n reuses the cellular user CU_m's spectrum. With this assumption, the rate and the secrecy rate of CU_m are given by

$$R_{m,n}^{c} = \log_2 \left(1 + \frac{P_m^c |h_{CU_m,BS}|^2}{P_n^d |h_{DT_n,BS}|^2 + N_0} \right) \tag{3.7}$$

and

$$R_{m,n}^{\text{sec}} = \log_2 \left(1 + \frac{P_m^c |h_{CU_m,BS}|^2}{P_n^d |h_{DT_n,BS}|^2 + N_0} \right) - \log_2 \left(1 + \frac{P_m^c |h_{CU_m,E}|^2}{P_n^d |h_{DT_n,E}|^2 + N_0} \right), \tag{3.8}$$

respectively. From (3.2) and (3.7), the transmit power constraint of DT_n is given by

$$P_n^d \leq \frac{1}{|h_{DT_n,BS}|^2}\left(\frac{P_m^c|h_{CU_m,BS}|^2}{2^{R_{\text{th}}}-1} - N_0\right). \tag{3.9}$$

From (3.3) and (3.8), the secrecy outage probability of CU_m conditioned on the channel information of $h_{CU_m,BS}$, $h_{DT_n,BS}$ is given by

$$\begin{aligned}
&\Pr\left\{ R_{m,n}^{\text{sec}} < R_{\text{th}}^{\text{sec}} \middle| h_{CU_m,BS}, h_{DT_n,BS}\right\} \\
&= 1 - \Pr\left\{ R_{m,n}^{\text{sec}} \geq R_{\text{th}}^{\text{sec}} \middle| h_{CU_m,BS}, h_{DT_n,BS}\right\} \\
&= 1 - \Pr\ \left\{P_m^c|h_{CU_m,E}|^2 \leq \left(P_n^d|h_{DT_n,E}|^2 + N_0\right) A_{m,n} \middle| h_{CU_m,BS}, h_{DT_n,BS}\right\}
\end{aligned} \tag{3.10}$$

where $A_{m,n} = 2^{-R_{\text{th}}^{\text{sec}}}\left(1 + \frac{P_m^c|h_{CU_m,BS}|^2}{P_n^d|h_{DT_n,BS}|^2+N_0}\right) - 1$. For simplicity of derivation, let $X = P_m^c|h_{CU_m,E}|^2$ and $Y = P_n^d|h_{DT_n,E}|^2 + N_0$. The secrecy outage probability of (3.10) is given by

$$1 - \Pr\ \{X \leq YA_{m,n} \,|\, h_{CU_m,BS}, h_{DT_n,BS}\}$$

$$= 1 - \int_{N_0}^{\infty} \Pr \left\{ X \leq y A_{m,n} \,|\, h_{CU_m,BS}, h_{DT_n,BS}, Y = y \right\} f_Y(y) dy$$
$$= 1 - \int_{N_0}^{\infty} \int_{0}^{y A_{m,n}} \frac{1}{P_m^c \Omega_{CU_m,E}} \exp\left(-\frac{x}{P_m^c \Omega_{CU_m,E}}\right) dx f_Y(y) dy$$
$$= 1 - \int_{N_0}^{\infty} \left(1 - \exp\left(-\frac{y A_{m,n}}{P_m^c \Omega_{CU_m,E}}\right)\right) \frac{1}{P_n^d \Omega_{DT_n,E}} \exp\left(-\frac{y - N_0}{P_n^d \Omega_{DT_n,E}}\right) dy$$
$$= \int_{N_0}^{\infty} \exp\left(-\frac{y A_{m,n}}{P_m^c \Omega_{CU_m,E}}\right) \frac{1}{P_n^d \Omega_{DT_n,E}} \exp\left(-\frac{y - N_0}{P_n^d \Omega_{DT_n,E}}\right) dy$$
$$= \frac{P_m^c \Omega_{CU_m,E}}{A_{m,n} P_n^d \Omega_{DT_n,E} + P_m^c \Omega_{CU_m,E}} \exp\left(-\frac{A_{m,n} N_0}{P_m^c \Omega_{CU_m,E}}\right) \tag{3.11}$$

where $f_Y(y)$ is the probability density function of Y. Substituting (3.11) into (3.3), the secrecy outage constraint is given by

$$\frac{P_m^c \Omega_{CU_m,E}}{A_{m,n} P_n^d \Omega_{DT_n,E} + P_m^c \Omega_{CU_m,E}} \exp\left(-\frac{A_{m,n} N_0}{P_m^c \Omega_{CU_m,E}}\right) \leq \varepsilon. \tag{3.12}$$

Since it is difficult to obtain the analytical expression with respect to P_n^d from (3.12), the numerical value of P_n^d can be obtained when all other parameters are known. In particular, numerical analysis method such as Newton's method [20] is used for find the numerical value of P_n^d. The Newton's method is described as follows. Given a function f defined over real number x and its derivative f', we begin with a initial value x_0 for a root of the function f. The process is repeated as $x_{k+1} = x_k - \frac{f(x_k)}{f'(x_k)}$ until a sufficiently accurate value is reached where k represents the k-th iteration step. In this subsection, the function f is given by

$$f(P_n^d) = \frac{P_m^c \Omega_{CU_m,E}}{A_{m,n} P_n^d \Omega_{DT_n,E} + P_m^c \Omega_{CU_m,E}} \exp\left(-\frac{A_{m,n} N_0}{P_m^c \Omega_{CU_m,E}}\right) - \varepsilon. \quad (3.13)$$

Since the analytical expression for the derivative of $f(P_n^d)$ is not easily obtained, the derivative is approximated by using the slope of a line through two nearby points on the function. By using numerical analysis, more than one value of P_n^d that satisfies (3.12) can be obtained. From more than one value of P_n^d obtained by numerically, find the range which satisfies (3.12).

To determine the value of transmit power P_n^d, find the range which satisfies each of constraints (3.6), (3.9), and (3.12). Let $\mathcal{B}_n^{d,1}$, $\mathcal{B}_n^{d,2}$, and $\mathcal{B}_n^{d,3}$ denote the ranges of P_n^d which satisfy (3.9), (3.12), and (3.6), respectively. If $\mathcal{B}_n^{d,1} \cap \mathcal{B}_n^{d,2} \cap \mathcal{B}_n^{d,3} = \phi$, the transmit power is not allocated to DT_n. Otherwise, the largest element in $\mathcal{B}_n^{d,1} \cap \mathcal{B}_n^{d,2} \cap \mathcal{B}_n^{d,3}$, $P_n^{d,\mathrm{sel}}$, becomes the transmit power of DT_n. For all possible combinations of cellular user CU_m and D2D pair D_n, the transmit power is allocated to D2D transmitter DT_n. Let $\mathcal{S}_m$ denote the set of D2D pairs that allocated transmit power is larger than zero for cellular user CU_m's spectrum. The element of the set $\mathcal{S}_m$ is determined after power allocation.

3.2 Spectrum Allocation

The spectrum allocation problem for given transmit power $P_n^{d,\text{sel}}$ is formulated as

$$\max_{\boldsymbol{\rho}} \left\{ \sum_{m=1}^{M} \sum_{n \in \mathcal{S}_m} \log_2 \left(1 + \frac{P_m^c |h_{CU_m,BS}|^2}{\rho_{m,n} P_n^{d,\text{sel}} |h_{DT_n,BS}|^2 + N_0} \right) \right.$$
$$\left. + \rho_{m,n} \log_2 \left(1 + \frac{P_n^{d,\text{sel}} |h_{DT_n,DR_n}|^2}{P_m^c |h_{CU_m,DR_n}|^2 + N_0} \right) \right\} \tag{3.14}$$

$$\text{subject to:} \quad \sum_m \rho_{m,n} \leq 1, \forall m \tag{3.15}$$

$$\sum_n \rho_{m,n} \leq 1, \forall n \in \mathcal{S}_m \tag{3.16}$$

where $\mathcal{S}_m$ is the set of D2D pairs that allocated transmit power is larger than zero for cellular user CU_m's spectrum. The problem described above is solved by an allocation method. Several algorithms are available for solving this spectrum allocation problem. The method called the Hungarian algorithm [21] is used for optimal spectrum allocation in this subsection. In Hungarian algorithm, the base station finds an optimal combination of cellular user and D2D pair for spectrum allocation in order that the sum rate of the network is maximized. The Hungarian algorithm is described as follows. Construct an $M \times N$ matrix called the cost matrix in which each element $\text{Cost}_{m,n} = -R^{\text{sum}}_{m,n}$ represents the cost. The minus sign is added in $R^{\text{sum}}_{m,n}$ since the Hungarian algorithm is based on the minimization of total cost. The cost $\text{Cost}_{m,n}$ represents the cost of allocation D2D pair D_n to cellular user CU_m's spectrum. We wish to find an spectrum allocation $\rho_{m,n}$ in the cost matrix which maximizes (3.14). Let c_m and d_n denote the minimum elements in the m-th row and n-th column of the cost matrix, respectively. Subtract c_m from each element of the m-th row for all m. Subtract d_n from each element of the n-th column for all n obtaining the resulting matrix. This procedure produces at least one zero in each row and column. The problem can be solved by finding an independent set of zeros in the resulting matrix. Note that by finding an independent set of zeros we are obtaining an allocation which has the minimum cost associated with it.

The proposed algorithm for the resource allocation problem is shown in

Algorithm 1. The proposed algorithm consists of three steps. In the first step, transmit power is allocated to D2D transmitter. In particular, find ranges of transmit power under the constraints (3.2), (3.3), and (3.6) and determine transmit power from the intersection of those ranges. In the second step, find an element of the set $\mathcal{S}_m$ by computing constraints (3.2) and (3.3). Since transmit power is allocated in previous step, substitute $P_n^{d,\mathrm{sel}}$ into constraints (3.2) and (3.3). In the third step, compute sum rate of cellular user and D2D pair for all D2D pairs in the set $\mathcal{S}_m$ and obtain reuse indicator $\rho_{m,n}$ by using Hungarian algorithm.

Algorithm 1 Proposed algorithm

Initialize $\rho_{m,\,n} = 0$, $\mathcal{S}_m = \phi$, $\forall m,\ n$.

Step 1:

for $m = 1 : M$ **do**

  for $n = 1 : N$ **do**

    Find $\mathcal{B}_n^{d,1}$, $\mathcal{B}_n^{d,2}$, and $\mathcal{B}_n^{d,3}$.

    Determine $P_n^{d,\text{sel}}$ from $\mathcal{B}_n^{d,1} \cap \mathcal{B}_n^{d,2} \cap \mathcal{B}_n^{d,3}$.

Step 2:

for $m = 1 : M$ **do**

  for $n = 1 : N$ **do**

    Compute $R_{m,n}^{c}$ and $\Pr\left\{ R_{m,n}^{\text{sec}} < R_{\text{th}}^{\text{sec}} \middle| h_{CU_m,BS}, h_{DT_n,BS} \right\}$.

    if $R_{m,n}^{c} \geq R_{\text{th}}$ and $\Pr\left\{ R_{m,n}^{\text{sec}} < R_{\text{th}}^{\text{sec}} \middle| h_{CU_m,BS}, h_{DT_n,BS} \right\} \leq \varepsilon$ **then**

      $\mathcal{S}_m = \mathcal{S}_m + \{n\}$.

Step 3:

for $m = 1 : M$ **do**

  for $n \in \mathcal{S}_m$ **do**

    Compute $R_{m,n}^{\text{sum}}$.

Get $\rho_{m,n}$ from (3.14) by using Hungarian algorithm.

Chapter 4

Simulation Results

Consider a cell with a 500 meter radius and the base station at its center. The eavesdropper is located on the 35 meter radius circle centered at the base station. The cellular users and D2D users are uniformly distributed between circles of radii 35 and 500 meter in the cell. Suppose that the target rate R_{th} is 1 bits/s/Hz, the target secrecy rate $R_{\mathrm{th}}^{\mathrm{sec}}$ is 0.5 bits/s/Hz, the target secrecy outage ε is 0.1, and the transmit power P_m^c is 23 dBm.

The simulation parameters of the 3GPP urban macro model in LTE are adopted [22]. Suppose that shadow fading is modelled using a log-normal distribution. For D2D link, the path-loss model and shadow fading model in [23], [24] are adopted. The simulation parameters are shown in Table 4.1.

The performance of the proposed scheme is compared with those of the proposed power allocation (PA) with greedy, equal PA, and equal PA with greedy schemes. In the proposed PA with greedy scheme, a D2D pair is allocated to the cellular user's spectrum based on greedy algorithm [25]. In greedy algorithm, the base station randomly selects a cellular user and then matches the cellular user with a D2D pair in order that the sum rate for the cellular user and D2D pair is maximized. This process continues until there are no cellular users to be matched. In the equal PA scheme, each D2D pair transmits with the same power and a D2D pair is allocated to the cellular user's spectrum based on Hungarian algorithm [21]. In the equal PA with greedy scheme, the equal PA scheme is adopted and a D2D pair is allocated to the cellular user's spectrum based on greedy algorithm.

Table 4.1. Simulation parameters

Parameter	Value
System bandwidth	10 MHz
Path-loss model	$128.1 + 37.6\log_{10}(d)$ for cellular link $148.0 + 40.0\log_{10}(d)$ for D2D link (d in kilometers)
Shadow fading standard deviation	10 dB for cellular link 12 dB for D2D link
Antenna gain	15 dB at BS 0 dB at user
Penetration loss	10 dB
Noise power spectral density	-174 dBm/Hz
Noise figure	5 dB at BS 9 dB at user
Maximum user transmit power	23 dBm

Figure 4.1 and Figure 4.2 show sum rate of users versus user ratio N/M for $M = 20$ and $M = 40$, respectively. It is shown that, for a given value of M, as the number of D2D pairs N increases, sum rate of users increases. It is shown that sum rate of users under the proposed scheme is higher than those under the proposed PA with greedy, equal PA, and equal PA with greedy schemes. It means that the proposed PA achieves higher sum rate of users compared with equal PA. It is shown that, for any user ratio N/M, sum rate of users increases as the number of cellular users M increases. This is due to the increase of the potential multiuser diversity gain.

Figure 4.3 and Figure 4.4 show sum rate of users versus maximum D2D distance r for $M = 20$ and $M = 40$, respectively. In the figures, for a D2D pair, the maximum distance between D2D transmitter and D2D receiver is r. It is shown that as the maximum D2D distance r increases, sum rate of users decreases. The reason is as follows. Since the channel gain of D2D link decreases as the maximum D2D distance r increases, the achievable rate of D2D pair decreases and it is possible for cellular user and D2D pair to cause more interference to each other.

Figure 4.5 shows sum rate of users versus user ratio N/M for different target rate R_{th}. It is shown that as the target rate of cellular user R_{th} increases, sum rate of users under the proposed scheme decreases. It means that the increase of the target rate causes less D2D pairs to satisfy the constraint (3.2) and thus reduces the probability of access.

Figure 4.6 shows sum rate of users versus user ratio N/M for different target secrecy rate $R_{\mathrm{th}}^{\mathrm{sec}}$. It is shown that as the target rate of cellular user $R_{\mathrm{th}}^{\mathrm{sec}}$ decreases, sum rate of users under the proposed scheme increases. It means that the decrease of the target secrecy rate causes more D2D pairs to satisfy the constraint (3.3) and thus increases the probability of access.

Figure 4.7 shows sum rate of users versus user ratio N/M for different target secrecy outage ε. It is shown that as the target secrecy outage of cellular user ε decreases, sum rate of users under the proposed scheme decreases. It means that the decrease of the target secrecy outage causes less D2D pairs to satisfy the constraint (3.3) and thus decreases the probability of access.

Figure 4.8 shows average secrecy rate of cellular user versus user ratio N/M for $M = 20$ and $M = 40$, respectively. It is shown that average secrecy rate of cellular user with D2D user is higher than that without D2D user. It means that interference caused by D2D communication affects not only the cellular user but also the eavesdropper. It is shown that average secrecy rate of cellular user increases slightly by D2D communication. This is due to the objective of resource allocation problem is to maximize sum rate of users. It means that secrecy rate of cellular user is guaranteed when D2D pairs reuse the cellular user's spectrum.

Figure 4.9 and Figure 4.10 show sum rate of users versus number of D2D pairs N for $M = 20$ and $M = 40$, respectively. Although the number of D2D pairs N becomes larger than that of cellular users M, the results are similar to Figure 4.1 and Figure 4.2. Since the fully loaded cellular network is assumed, there is limitation in using resource that is available for D2D pairs. It means that there are at most M D2D pairs that can transmit by reusing cellular user's spectrum to maximize sum rate of users.

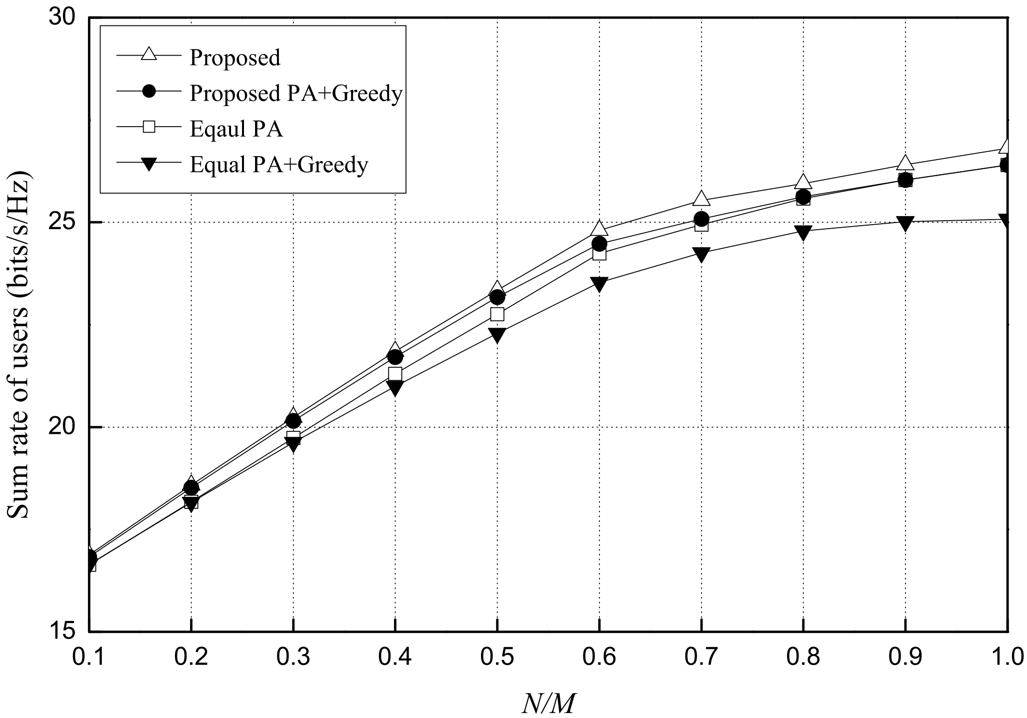

Figure 4.1. Sum rate of users versus user ratio N/M. $M = 20$.

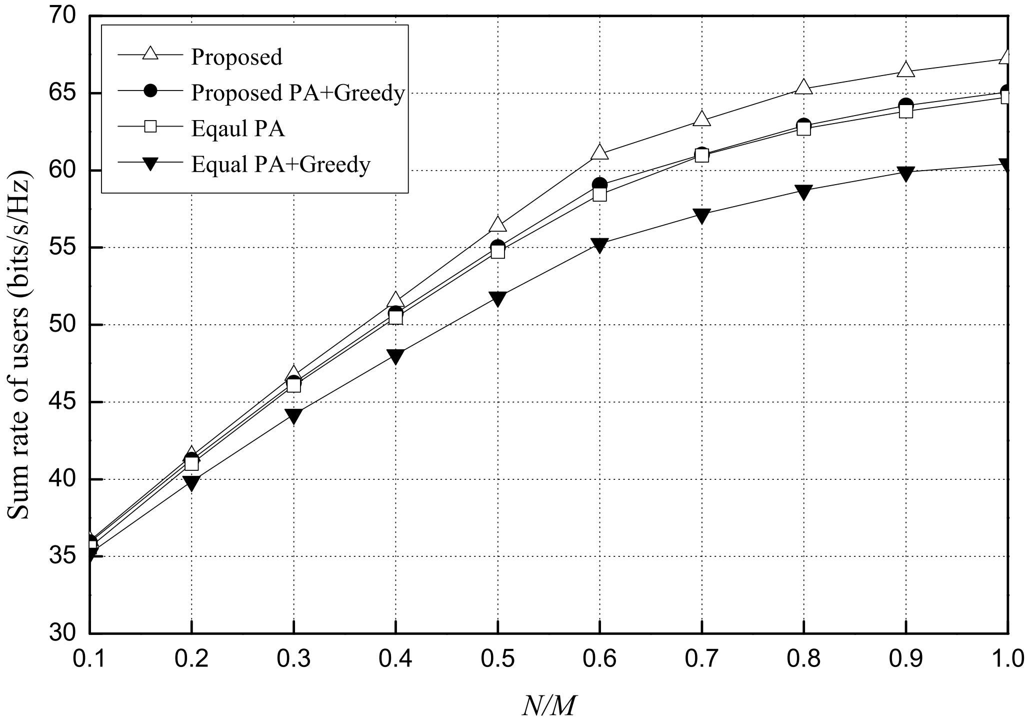

Figure 4.2. Sum rate of users versus user ratio N/M. $M = 40$.

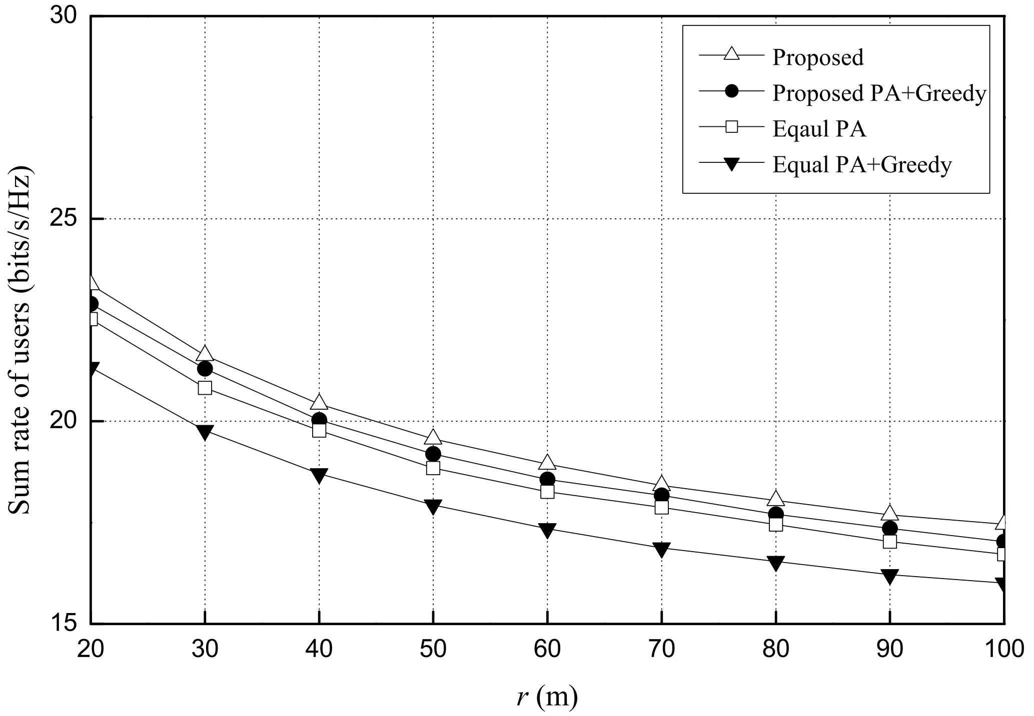

Figure 4.3. Sum rate of users versus maximum D2D distance r. $M = 20$ and $N = 10$.

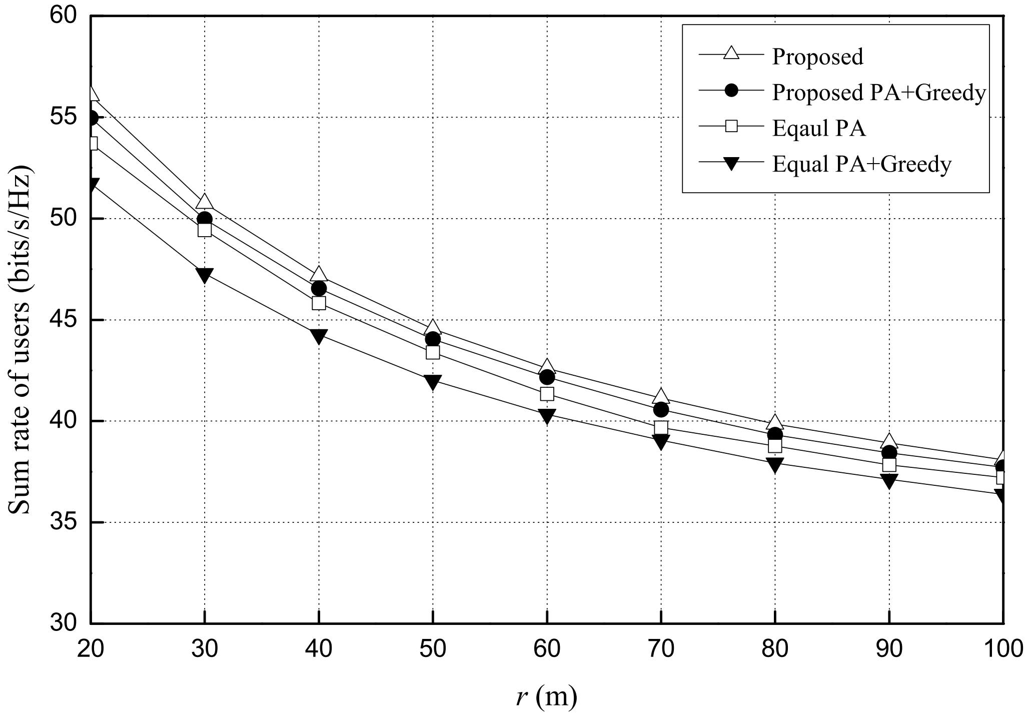

Figure 4.4. Sum rate of users versus maximum D2D distance r. $M = 40$ and $N = 20$.

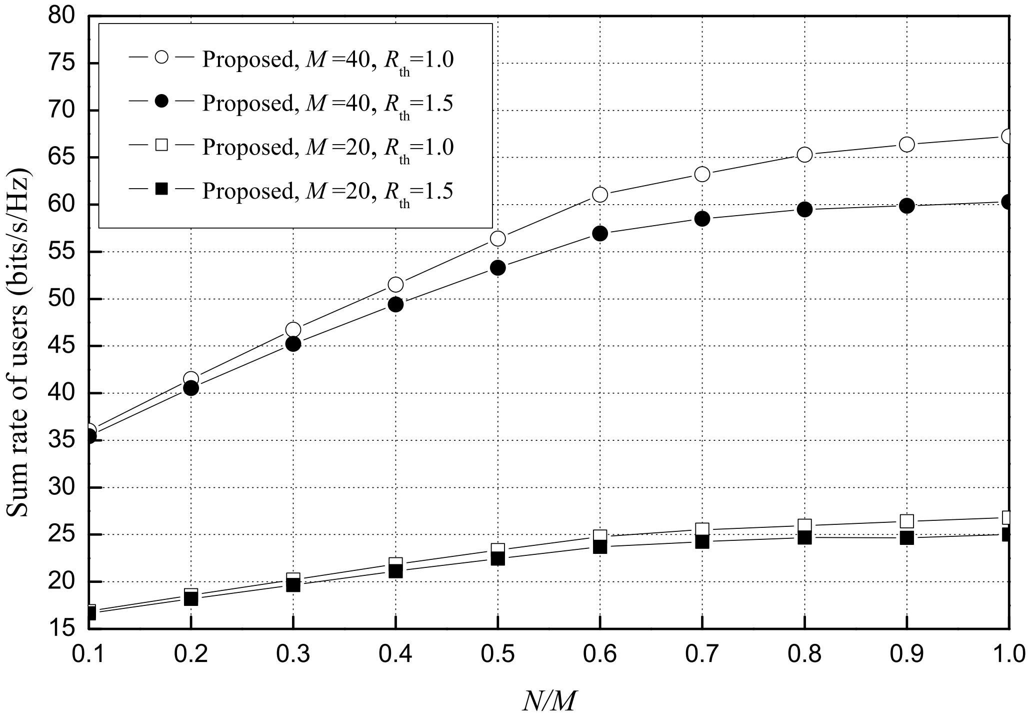

Figure 4.5. Sum rate of users versus user ratio N/M for various $R_{\rm th}$.

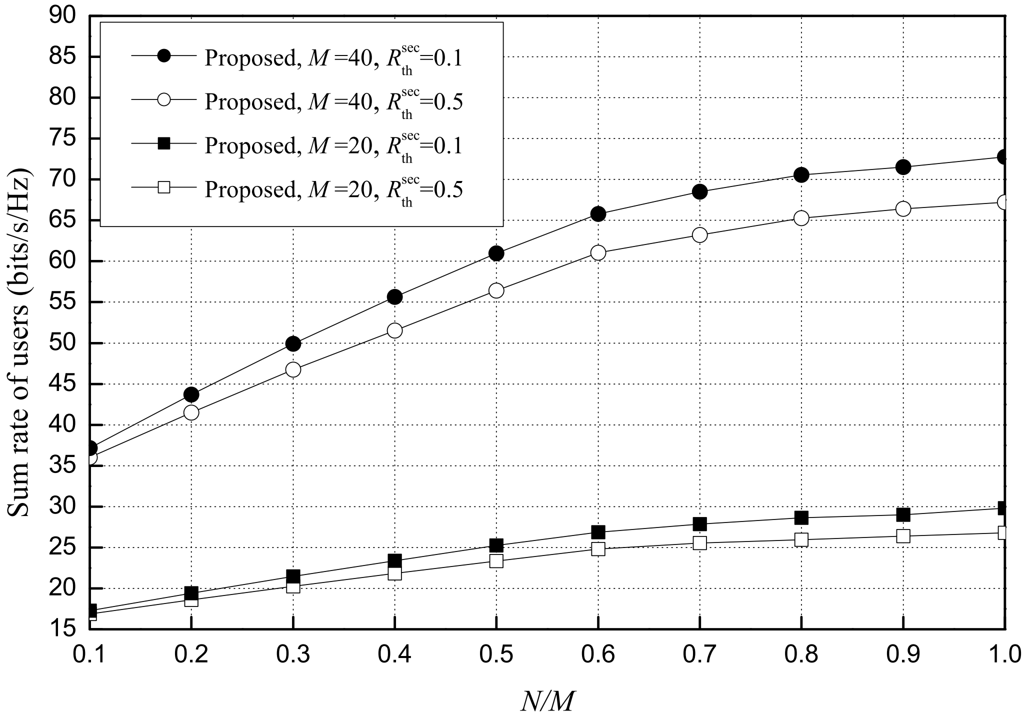

Figure 4.6. Sum rate of users versus user ratio N/M for various $R_{\text{th}}^{\text{sec}}$.

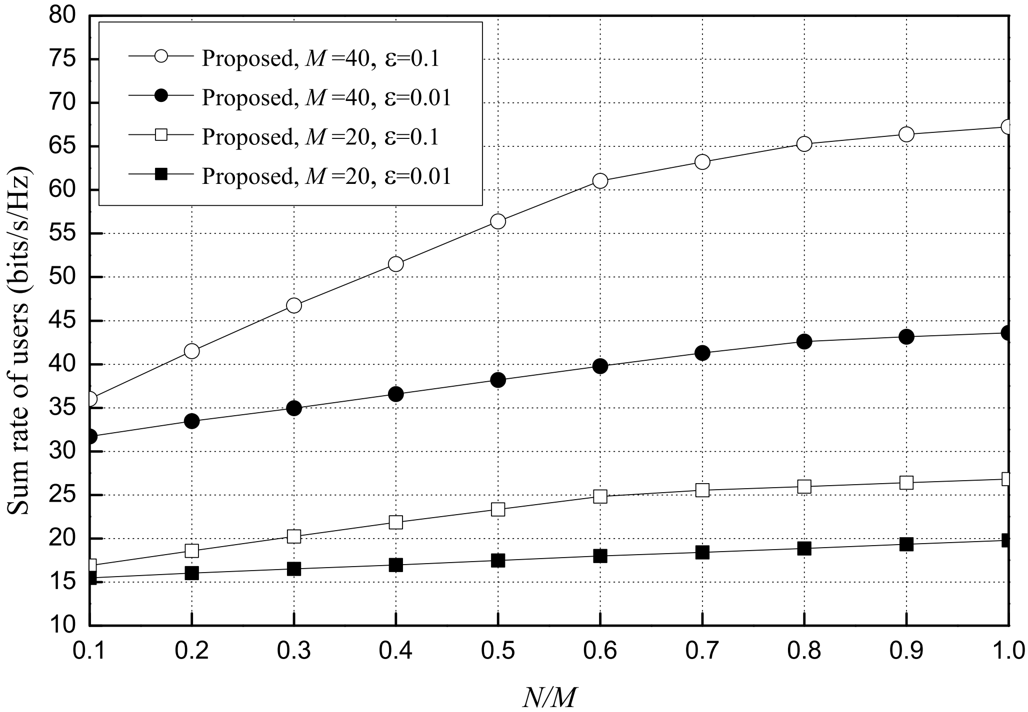

Figure 4.7. Sum rate of users versus user ratio N/M for various ε.

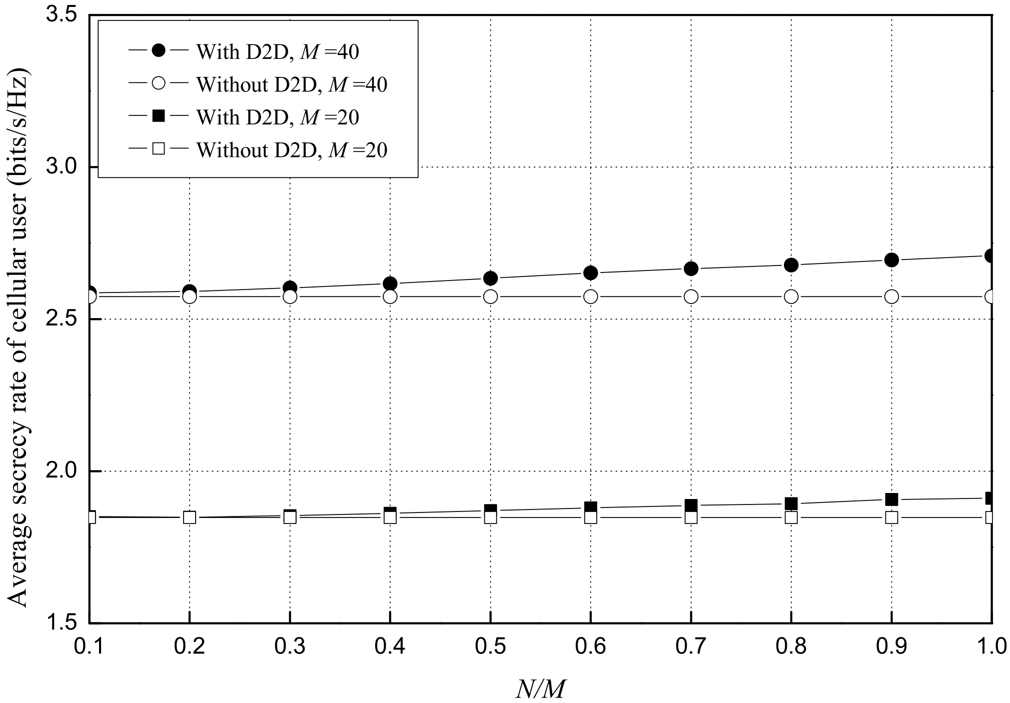

Figure 4.8. Average secrecy rate of cellular user versus user ratio N/M.

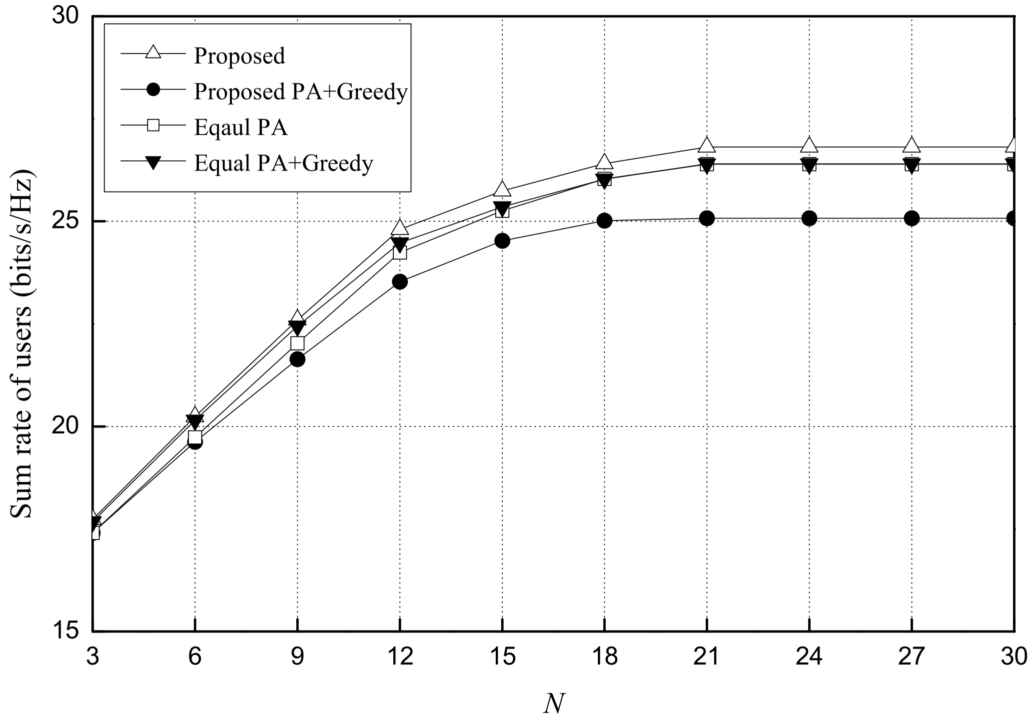

Figure 4.9. Sum rate of users versus number of D2D pairs N. $M = 20$.

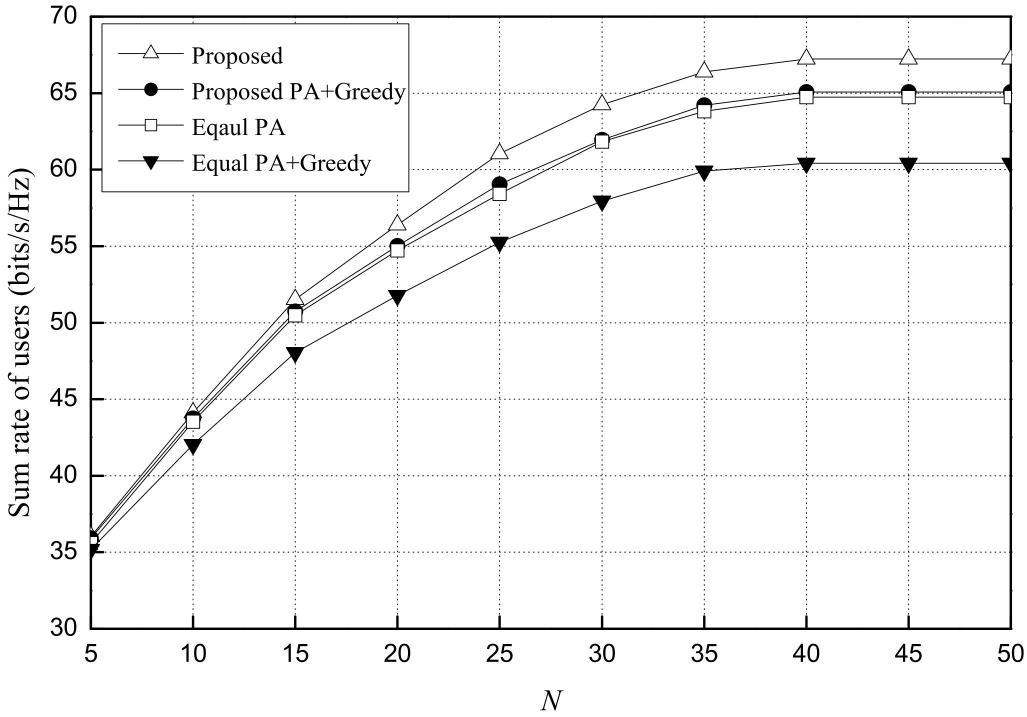

Figure 4.10. Sum rate of users versus number of D2D pairs N. $M = 40$.

Chapter 5

Conclusion

In this thesis, we consider the uplink cellular network for D2D communication in the presence of eavesdropper. We formulate a resource allocation problem to maximize the sum rate of the network. We proposed a resource allocation scheme to solve the formulated problem. The proposed resource allocation scheme is divided into two stages. In the first stage, transmit power is allocated to D2D transmitter according to constraints of data rate and secrecy outage probability for cellular user, and the maximum transmit power of D2D transmitter. In the second stage, for a given transmit power, spectrum is allocated to D2D user such that the sum rate of the cellular network is maximized. Simulation results show that the proposed scheme has higher sum rate of users than the equal power allocation scheme. It is shown that as the number of D2D users increases, sum rate of users increases. It is shown that sum rate of users increases as the target data rate of cellular user decreases or the target secrecy outage of cellular user increases. In addition, it is shown that the proposed scheme guarantees the data rate and the secrecy rate of cellular user.

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한글초록

본 논문에서는 셀룰러 네트워크에서 셀룰러 사용자의 도청자가 존재할 때, D2D 통신을 위한 자원 할당 기법을 제안한다. 제안된 기법에서 셀룰러 네트워크 사용자의 총합 전송률을 최대화시키도록 셀룰러 사용자의 데이터 전송률과 보안 불능 확률을 고려하여 D2D 사용자에게 전력 할당 및 주파수 스펙트럼을 할당한다. 컴퓨터 모의 실험을 통해 제안된 기법이 균등 전력 할당 기법 보다 셀룰러 네트워크 사용자의 총합 전송률을 향상시킴을 확인하였다.

주요어: 자원 할당, D2D 통신, 도청자.

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