Optimal Resource Allocation Scheme for Satisfying the Data Rate Requirement in Hybrid Network of D2D-Cellular

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***Abstract*—In this paper, an optimal wireless resources allocation scheme is put forward to improve the performance for both cellular and Device-to-Device (D2D) users in a hybrid network. The resource unit and power allocation can be modeled into a sum-rate optimization problem with the constraint of power limitation and rate ratio. The rate ratio is used to measure the data rate requirements from both cellular and D2D users. By using the Lagrange Multiplier Method, we derived out the optimal formula about allocating the power and resource unit for both cellular and D2D users. According to the optimal formula, the relationship between the transmission power and resource unit allocation is mutually conditional. Then the resource allocation scheme algorithm was given. And the power allocation can be resolved by the water-filling algorithm. Simulation results show that the proposed scheme improves the sum-throughput significantly as well as the fairness.**

***Index Terms*—hybrid network, Device-to-Device (D2D) communication, resource allocation, power control, fairness**

I. Introduction

In a traditional cellular network, the communication is always forwarded by the central node (e.g. Base Station, BS). The communication under the centralized control has benefit in resource allocation and interference management, but it would lead to low wireless resource utilization. In order to resolve this problem, a new hybrid wireless network is proposed. This hybrid network is built up by placing a certain number of D2D (Device-to-Device) terminal users in the traditional wireless communication network (e.g. LTE/LTE-A cellular wireless network). The internal communication between D2D terminal users can be implemented by using the cognitive radio technology. There are two communication models for the UE (User Equipment) in the hybrid network: (1) the cellular mode, in which UE is connected to another UE via the BS; (2) the D2D model, in which source UE can communicate with the destination UE directly. Studies have proved that: by putting the D2D communication model into the traditional cellular network, the data rate and capacity of the network can be increased, while the transmit power is reduced, and then it is easier to balance the load and coverage of the network [1-3].

At present, the mobile operators and equipment manufacturers are trying to explore a way to introduce the D2D function in cellular networks, especially the LTE-A system. In the 3GPP RAN#52 meeting and SA1#55 meeting which are held in 2011 June and August, Qualcomm Corp has already put forward proposals about doing some D2D researches in the LTE-A system. The literature [4] presented the conception of integrating the D2D communication in the LTE-A system. The literature [5] introduces a FlashLinQ technology, which can make a device to detect other devices nearby and then communicates with them directly via the air interface. Different from the normal D2D technology, FlashLinQ can be used in the authorized frequency, which is more efficient. Introducing the D2D function in cellular networks can bring two main benefits. First, the D2D approach can improve the spectral efficiency of wireless transmission. When the two terminals are close, the channel quality of the direct link is always better than when the two terminals connect to base station respectively. And the direct communication only takes up one slot of radio resources, otherwise two slots are required to transmit data indirectly through the base station. Second, by using the D2D function, it would be much more convenient for a mobile device to find out other devices around it. In the traditional cellular network, if a mobile device wants to do this job, it should locate the other device through the network operator, search the information in the operator's database, and then get the result sent back from the operator. In this way, it does not only have a slow speed, but also has a poor scalability, which cannot support a large number of requests like this. If the D2D function is implemented, the mobile device can detect each other directly by transmitting and monitoring the broadcast packet, which makes it much more fast and flexible.

Resource scheduling is a key problem in the MAC layer of wireless network. It directly affects the performance of the whole wireless network system. The resource allocation depends on many factors: network

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architecture, power consumption, the allocation of spectrum resource blocks and radio interference, which are all mutually dependent and interacting.

Recent studies have shown that there are two important aspects in allocating the network resources: spectrum resources scheduling and power control. For spectrum resource scheduling, there are two theoretical models: (1) packet-based model [6,7], the scheduling granularity is based on the executing frequency of scheduling algorithm; (2) flow-based model [8-10], the scheduling granularity is based on the frequency of service data arrival and processing. For the power control, it has two algorithms: (1) the centralized control algorithm in [11-13] have shown that it can get a global optimal solution, but it requires the global information and longer processing time, which means it can't satisfy the real wireless environment; (2) the distributed algorithm has shown in [14,15] that it can be fast convergence to a optimal solution based on the local partial information, which is suitable for the real environment.

In this paper, we assume the independent communication between the D2D users is implemented by using the uplink resource in the cellular wireless network which is controlled by the base station. For the uplink resource allocation, there are some issues in the hybrid wireless network:

a)In cellular model, such as the traditional cellular network of OFDM (Orthogonal Frequency Division Multiplexing), the UEs use the orthogonal uplink spectrum resources to transfer data, so there is no interference between them when using the uplink spectrum resource.
In hybrid network, the D2D UEs can reuse the uplink spectrum resource to communicate. It would have interference when the D2D UEs are trying to communicate with cellular UEs by using the same spectrum resource, so it is under an interference-limited constraint.

b)In hybrid network, the mutual interference between UEs would lead to a complex wireless link environment. Once a wireless resource is allocated to a new UE, the status of wireless channel would be changed. So the channel gain would be a time-varying parameter, which is different from the traditional cellular model.

c)In traditional cellular model, in order to satisfy the data rate requirement, the pre-set rate ratio of each UE is used to satisfy the proportional fairness criterion.
In hybrid network, the D2D UEs is the secondary users comparing with cellular UEs according to the theory of traditional cognitive radio technology. Indeed, the D2D UEs still have to pay for reusing the cellular resource, why they can't deserve the corresponding service? So the weight value of data rate of D2D UEs is taken into account in this paper.

d)In traditional cellular model, the control central (BS) knows the information of uplink resource scheduling in advance.
In hybrid network, the uplink resource scheduling information of cellular network should be used in the communication of D2D users, which is also controlled by the cellular BS in order to avoid the interference from the cellular UE.

According to the above analysis, the cellular and D2D transmission can be formed as a sum-rate optimization problem. The target is to schedule the frequency resources allocation and transmission power for cellular and D2D users, and then gain the maximum data sum-rate. We first prove that the optimization problem is convex and then solve it by constructing Lagrange function and KKT conditions. Finally we can get the conclusion that: (1) the relationship between the transmission power and resource unit allocation is mutually conditional; (2) the power allocation can be resolved by the water-filling algorithm. Based on the former conclusion, we propose a hybrid scheduling algorithm for the dynamic cellular and D2D accessing process and do some comprehensive analyzes on it. The system simulation results can prove the above conclusions in hybrid network. The contribution of this paper is as follows: (1) the scheduling algorithm of spectrum resource allocation and power control can be used for both cellular and D2D users; (2) transferring the interference-limited system into the noise-limited system can make the sum-rate optimization problem to be solved, it also conforms the idea of making the maximum use of the noise tolerance of cellular users; (3) the weight value of D2D user data rate is set up to ensure fairness in the D2D users.

The rest of this paper is organized as follows. Section II describes the scenario description and system model. In section III, the optimal uplink resource allocation for the D2D and cellular users are derived and proved in details, and then uplink resource scheduling algorithm is provided based on the former conclusion. The system simulation results of the proposed scheme in section III are analyzed in section IV. Finally the conclusions are summarized in section V.

II. Scenario Description and System Model

In this section, we present the scenario description of the hybrid wireless network, which defines the model of hybrid network and optimization constraints.

A. Scenario Description

The basic scenario is a hybrid network system, which contains a cellular system and D2D pairs. As shown in Fig. 1, there are some users need to be served in the hybrid network, and they are all able to transmit data in both cellular mode and D2D mode. We make the following definition and assumption:

a)BS could receive the CSI (Channel Signal Information) immediately from the mobile terminals which include cellular and D2D terminal users;

b)By sensing on the spectrum, the D2D terminal could detect several resource blocks (RBs) which are idle to be used, and then report the number of RBs to the BS;

c)The spectrum resource allocation and transmission power of D2D user is also controlled by BS as the cellular users;

d)D2D user can reuse the uplink resource of cellular network, and we assume that only one D2D pair is allowed to reuse the spectrum resource of one cellular user to communicate in the same time slot.

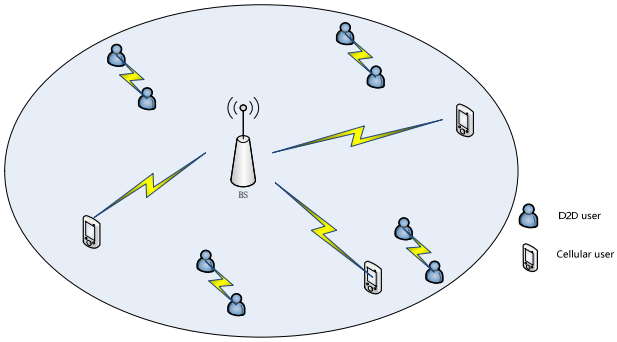

Figure1. Hybrid network

B. System Model

We assume that: in one cell, there are M activation cellular users, N activation D2D pairs, K RBs can be used to communication. The channel gain and transmission power of m-th cellular user and n-th D2D pair on the k-th RB is denoted as $h_{mk}, p_{mk}, h_{nk}, p_{nk}$, and the density of noise power is N_0, the spectrum bandwidth of each RB is ω. The sum of available rate that of the m-th cellular user is $R_{cm} = \sum_{k=1,2,\ldots,K} \rho_{mk}\gamma_{mk}$, while the sum of data rate of the n-th D2D pair is $R_{dn} = \sum_{k=1,2,\ldots,K} \rho_{nk}\gamma_{nk}$, where ρ_{mk} and ρ_{nk} is the indicating factor of the m-th cellular user and the n-th D2D pair use the k-th RB to communicate respectively, the value of ρ_{mk} and ρ_{nk} is 0 or 1, γ_{mk} and γ_{nk} is the data rate of the m-th cellular user and n-th D2D pair use the k-th RB to communicate respectively as follows:

$$\gamma_{mk} = \omega \log_2 (1 + \frac{p_{mk} |h_{mk}|^2}{N_0\omega + \sum_{n=1}^{N} \rho_{nk} p_{nk} |h_{nk}|^2}) \quad (1)$$

$$\gamma_{nk} = \omega \log_2 (1 + \frac{p_{nk} |h_{nk}|^2}{N_0\omega + \sum_{m=1}^{M} \rho_{mk} p_{mk} |h_{mk}|^2}) \quad (2)$$

Let $I_1 = N_0\omega + \sum_{n=1}^{N} \rho_{nk} p_{nk} |h_{nk}|^2$ denote the sum of background noise and the interference from D2D user n to cellular user m which are using the same RB k to communication at the same time, and let $I_2 = N_0\omega + \sum_{m=1}^{M} \rho_{mk} p_{mk} |h_{mk}|^2$ denote the sum of background noise and the interference from cellular user m to D2D user n which are using the same RB k to communication at the same time. So the SNR of the cellular user m which uses RB k to communication is $SINR_{mk} = \frac{p_{mk} |h_{mk}|^2}{I_1}$, and the SNR of the D2D user n which uses RB k to communication is $SINR_{nk} = \frac{p_{nk} |h_{nk}|^2}{I_2}$. The maximum cellular transmission power is set as $p_{\max 1}$, and the D2D transmission power is set as $p_{\max 2}$.

Base on the above analysis, the maximum total rate of hybrid network and the optimization constraints are modeled as follows:

$$\begin{aligned}
&\max_{p_{mk},\rho_{mk},p_{nk},\rho_{nk}} (\sum_{m=1}^{M} R_{cm} + \sum_{n=1}^{N} R_{dn}) \\
&= \max_{p_{mk},\rho_{mk},p_{nk},\rho_{nk}} [\sum_{m=1}^{M}\sum_{k=1}^{K} \rho_{mk}\omega \log_2 (1 + \frac{p_{mk}|h_{mk}|^2}{N_0\omega + \sum_{n=1}^{N} \rho_{nk} p_{nk} |h_{nk}|^2}) + \sum_{n=1}^{N}\sum_{k=1}^{K} \rho_{nk}\omega \log_2 (1 + \frac{p_{nk}|h_{nk}|^2}{N_0\omega + \sum_{m=1}^{M} \rho_{mk} p_{mk} |h_{mk}|^2})] \\
&= \max_{p_{mk},\rho_{mk},p_{nk},\rho_{nk}} [\sum_{m=1}^{M}\sum_{k=1}^{K} \rho_{mk}\omega \log_2 (1 + \frac{p_{mk}|h_{mk}|^2}{I_1}) + \sum_{n=1}^{N}\sum_{k=1}^{K} \rho_{nk}\omega \log_2 (1 + \frac{p_{nk}|h_{nk}|^2}{I_2})] \\
&s.t. \begin{cases}
\sum_{k=1}^{K} p_{mk} \le p_{\max 1}, \\
\sum_{k=1}^{K} p_{nk} \le p_{\max 2}, \\
\sum_{m=1}^{M} \rho_{mk} = 1, \\
\sum_{n=1}^{N} \rho_{nk} = 1, \\
p_{mk}, \rho_{mk}, p_{nk}, \rho_{nk} \ge 0, \\
\{R_{c1}:R_{c2}:,\ldots,:R_{cM}:R_{d1}:R_{d2}:,\ldots,:R_{dN}\} = C\{\theta_{c1}:\theta_{c2}:,\ldots,:\theta_{cM}:\theta_{d1}:\theta_{d2},\ldots,:\theta_{dN}\} = C\{\theta_i\}.
\end{cases}
\end{aligned} \quad (3)$$

In this formulation, the first and second constraints denote the maximum power of cellular UEs and D2D UEs should be less than $p_{\max 1}$ and $p_{\max 2}$. The third and fourth constrains denote the cellular UEs use the resources orthogonally, and the D2D UEs reuse the resources orthogonally with each other. The fifth condition is obvious.

The last expression stands for the proportional fairness criterion, where $\{\theta_i\} = \{\theta_{c1}, \theta_{c2}, \ldots, \theta_{cM}, \theta_{d1}\theta_{d2}, \ldots, \theta_{dN}\}$, $i = c1, c2, \ldots, cM, d1, d2, \ldots, dM$ is the predefined proportional fairness factor which reflects the weight value of the cellular and D2D users to guarantee the fairness of hybrid network and QoS of the D2D users.

III. Optimal Resource Selection and Power Allocation

In this section, we derive the relationship of the transmission power and spectrum resource allocation of the hybrid network. In particular, we turn the interference-limited system into the noise-limited system to solve the optimization problem, which based on the several researches [16-18] on the D2D communication reuse the resource of cellular network. We can conclude that the results for RB allocation per time slot and transmission power of D2D users and cellular users are mutual restraint. After this, we give the specific scheduling algorithm.

A. Problem Formulation

From [17,18], the outstanding advantage of hybrid network is to improve overall network performance. Even though it scarifies the performance of cellular network, it greatly increases the wireless resource utilization. To maximize the hybrid network load and resource utilization, we suppose that the SNR of all the communication links can just meet to the customer satisfaction, which means we suppose the system model is based on the maximum noise. So we turn the interference-limited system into the noise-limited system, and the formula (3) turns to:

$$\max_{p_{mk},\rho_{mk},p_{nk},\rho_{nk}} (\sum_{m=1}^{M} R_{cm}+\sum_{n=1}^{N} R_{dn})$$
$$= \max_{p_{mk},\rho_{mk},p_{nk},\rho_{nk}} [\sum_{m=1}^{M}\sum_{k=1}^{K}\rho_{mk}\omega\log_2(1+\frac{p_{mk}|h_{mk}|^2}{I_{1\max}})+\sum_{n=1}^{N}\sum_{k=1}^{K}\rho_{nk}\omega\log_2(1+\frac{p_{nk}|h_{nk}|^2}{I_{2\max}})] \quad (4)$$

where the $I_{1\max}$ and $I_{2\max}$ is the maximum noise withstand the limiting conditions, which are defined as constant.

Obviously, it is neither a linear nor a standard convex problem. By [19], we can transform the problem to a convex problem and it can be expressed as

$$\min_{p_{mk},\rho_{mk},p_{nk},\rho_{nk}} -\left[\sum_{m=1}^{M}\sum_{k=1}^{K}\rho_{mk}\omega\log_2(1+\frac{p_{mk}|h_{mk}|^2}{I_{1\max}})+\sum_{n=1}^{N}\sum_{k=1}^{K}\rho_{nk}\omega\log_2(1+\frac{p_{nk}|h_{nk}|^2}{I_{2\max}})\right] \quad (5)$$

According to the Lagrangian Arithmetic, the objective function (5) and the constrictions in function (3) can be transformed into a Lagrange function as

$$L=\left[\sum_{k=1}^{K}\sum_{m=1}^{M}-\rho_{mk}\omega\log_2(1+\frac{p_{mk}|h_{mk}|^2}{I_{1\max}})-\sum_{k=1}^{K}\sum_{n=1}^{N}\rho_{nk}\omega\log_2(1+\frac{p_{nk}|h_{nk}|^2}{I_{2\max}})\right]+\sum_{m=1}^{M}\lambda_m(\sum_{k=1}^{K}p_{mk}-p_{\max 1})$$
$$+\sum_{n=1}^{N}\mu_n(\sum_{k=1}^{K}p_{nk}-p_{\max 2})+\sum_{k=1}^{K}\eta_k(\sum_{m=1}^{M}\rho_{mk}-1)+\sum_{k=1}^{K}\vartheta_k(\sum_{n=1}^{N}\rho_{nk}-1)+\sum_{m=1}^{M}\sum_{k=1}^{K}\phi_{mk}(-p_{mk})+\sum_{n=1}^{N}\sum_{k=1}^{K}\gamma_{nk}(-p_{nk})$$
$$+\sum_{m=1}^{M}\sum_{k=1}^{K}\xi_{mk}(-\rho_{mk})+\sum_{n=1}^{N}\sum_{k=1}^{K}\delta_{nk}(-\rho_{nk})+\sum_{i=1}^{M+N}D_i(\frac{R_i}{\theta_i}-C) \quad (6)$$

Where λ_m, μ_n, η_k, ϑ_k, ϕ_{mk}, γ_{nk}, ξ_{mk}, δ_{nk} and D_i is the Lagrange multiplier factor , C is a constant and defined as $C=\frac{R_i}{\theta_i}=\frac{R_{c1}}{\theta_{c1}}=\frac{R_{c2}}{\theta_{c2}}=\ldots=\frac{R_{cM}}{\theta_{cM}}=\frac{R_{d1}}{\theta_{d1}}=\frac{R_{d2}}{\theta_{d2}}\ldots=\frac{R_{dN}}{\theta_{dN}}$.

We derivative the p_{mk} , p_{nk} , ρ_{mk} and ρ_{nk} separately as

$$\frac{\partial L}{\partial p_{mk}}=-\rho_{mk}\frac{\omega}{\ln 2}\frac{|h_{mk}|^2}{I_{1\max}+p_{mk}|h_{mk}|^2}+\lambda_m-\phi_{mk}+\frac{D_i}{\theta_i}\frac{\omega}{\ln 2}\frac{|h_{mk}|^2}{I_{1\max}+p_{mk}|h_{mk}|^2} \quad (7)$$

$$\frac{\partial L}{\partial p_{nk}}=-\rho_{nk}\frac{\omega}{\ln 2}\frac{|h_{nk}|^2}{I_{2\max}+p_{nk}|h_{nk}|^2}+\mu_n-\gamma_{nk}+\frac{D_i}{\theta_i}\frac{\omega}{\ln 2}\frac{|h_{nk}|^2}{I_{2\max}+p_{nk}|h_{nk}|^2} \quad (8)$$

$$\frac{\partial L}{\partial \rho_{mk}}=-\omega\log_2(1+\frac{p_{mk}|h_{mk}|^2}{I_{1\max}})+\eta_k-\xi_{mk}+\frac{D_i}{\theta_i}\omega\log_2(1+\frac{p_{mk}|h_{mk}|^2}{I_{1\max}}) \quad (9)$$

$$\frac{\partial L}{\partial \rho_{nk}}=-\omega\log_2(1+\frac{p_{nk}|h_{nk}|^2}{I_{2\max}})+\vartheta_k-\delta_{nk}+\frac{D_i}{\theta_i}\omega\log_2(1+\frac{p_{nk}|h_{nk}|^2}{I_{2\max}}) \quad (10)$$

By using KKT constriction, we have λ_m, μ_n, η_k, ϑ_k, ϕ_{mk}, γ_{nk}, ξ_{mk}, δ_{nk}, $D_i \geq 0$, $p_{mk}\cdot\phi_{mk}=0$, $\lambda_m(\sum_{k=1}^{K}p_{mk}-p_{\max 1})=0$, $p_{nk}\cdot\gamma_{nk}=0$, $\mu_n(\sum_{k=1}^{K}p_{nk}-p_{\max 2})=0$, $\rho_{mk}\cdot\xi_{mk}=0$, $\rho_{nk}\cdot\delta_{nk}=0$, $\eta_k(\sum_{m=1}^{M}\rho_{mk}-1)=0$, $\vartheta_k(\sum_{n=1}^{N}\rho_{nk}-1)=0$. And then, we have analysis and discussion as follows:

(1) When $p_{mk}\neq 0$, the equation $\phi_{mk}=0$ holds, $\therefore \frac{\rho_{mk}}{\ln 2}(1-\frac{D_i}{\theta_i})\frac{\omega|h_{mk}|^2}{I_{1\max}+p_{mk}|h_{mk}|^2}\leq\lambda_m$, and then the optimal RB selection k_m^* for cellular UE m is

$$k_m^*=\arg\max_{k=1,2,\ldots,K}\frac{1}{\ln 2}(1-\frac{D_i}{\theta_i})\frac{\omega|h_{mk}|^2}{I_{1\max}+p_{mk}|h_{mk}|^2}\ ; \quad (11)$$

(2) When $p_{nk}\neq 0$, the equation $\gamma_{nk}=0$ holds, $\therefore \frac{\rho_{nk}}{\ln 2}(1-\frac{D_i}{\theta_i})\frac{\omega|h_{nk}|^2}{I_{2\max}+p_{nk}|h_{nk}|^2}\leq\mu_n$, and then the optimal RB selection k_n^* for D2D UE n is

$$k_n^*=\arg\max_{k=1,2,\ldots,K}\frac{1}{\ln 2}(1-\frac{D_i}{\theta_i})\frac{\omega|h_{nk}|^2}{I_{2\max}+p_{nk}|h_{nk}|^2}\ ; \quad (12)$$

(3) When $\rho_{mk}\neq 0$, the equation $\xi_{mk}=0$ holds, $\therefore (1-\frac{D_i}{\theta_i})\omega\log_2(1+\frac{p_{mk}|h_{mk}|^2}{I_{1\max}})\leq\theta_k$, and then the optimal cellular UE allocation m_k^* for using RB k is

$$m_k^*=\arg\max_{m=1,2,\ldots,M}(1-\frac{D_i}{\theta_i})\omega\log_2(1+\frac{p_{mk}|h_{mk}|^2}{I_{1\max}})=\arg\max_{m=1,2,\ldots,M}(1-\frac{D_i}{\theta_i})r_{mk} \quad (13)$$

(4) When $\rho_{nk}\neq 0$, the equation $\delta_{nk}=0$ holds, $\therefore (1-\frac{D_i}{\theta_i})\omega\log_2(1+\frac{p_{nk}|h_{nk}|^2}{I_{2\max}})\leq\vartheta_k$, and then the optimal D2D UE allocation n_k^* for using RB k is

$$n_k^*=\arg\max_{n=1,2,\ldots,N}(1-\frac{D_i}{\theta_i})\omega\log_2(1+\frac{p_{nk}|h_{nk}|^2}{I_{2\max}})=\arg\max_{n=1,2,\ldots,N}(1-\frac{D_i}{\theta_i})r_{nk} \quad (14)$$

Based on the above theoretical derivation, we can draw two conclusions as follows:

Theorem 1: The two problems: the allocation of the resource block for each UE (including cellular UE and D2D UE) and the optimal power controlling for UE using

the appropriate resource block to communicate, are mutually restraint.

Proof: From formula (13) and (14), the m_k^* is a function of p_{mk} and the n_k^* is a function of p_{nk}, which means for the k-th resource block, choosing which user (concluding cellular and D2D user) using the k-th resource block to communicate can be determined by the cellular users and the D2D users' power allocation.

From formula (11) and (12), the k_m^* is a function of p_{mk} and the k_n^* is a function of p_{nk}, which means for the m-th cellular UE and n-th D2D UE, choosing which resource block to communicate that can be determined by the power allocation of these UEs.

In particular, from the above formula $\frac{\rho_{mk}}{\ln 2}(1-\frac{D_i}{\theta_i})\frac{\omega|h_{mk}|^2}{I_{1\max}+p_{mk}|h_{mk}|^2}\le\lambda_m$ with equality, the optimal power p_{mk} of m-th cellular UE using the k-th RB to communicate is

$$p_{mk}=\frac{\left(\frac{1}{\ln 2}-\frac{r_{mk}}{\theta_{mk}}\right)\omega}{\lambda_m}-\frac{I_{\max 1}}{|h_{mk}|^2} \tag{15}$$

And also from the above formula $\frac{\rho_{nk}}{\ln 2}(1-\frac{D_i}{\theta_i})\frac{\omega|h_{nk}|^2}{I_{2\max}+p_{nk}|h_{nk}|^2}\le\mu_n$ with equality, we have the optimal power p_{nk} of n-th D2D UE using the k-th RB to communicate is

$$p_{nk}=\frac{\left(\frac{1}{\ln 2}-\frac{r_{nk}}{\theta_{nk}}\right)\omega}{\mu_n}-\frac{I_{\max 2}}{|h_{nk}|^2} \tag{16}$$

Thus we have shown that in order to determine the value of p_{mk} and p_{nk}, the resource allocation is also required as a prerequisite. □

Note that the formula (15) and (16) satisfy the water-filling algorithm form ($p=[\mu-\frac{1}{SNR}]_+$) in [18-20]. So we have the following corollary.

Corollary 1: In the hybrid wireless network, the water-filling power allocation algorithm can be used to realize the power allocation of cellular UEs and D2D UEs.

B. Algorithm of RB Selection and Power Allocation

We assume that the setting of resource blocks for selecting the whole cell is $\Omega=\{1,2,...,K\}$, the resource blocks setting of cellular UEs using is presented as $\Omega_m\subseteq\Omega$, and the resource blocks setting which D2D UEs have sensed for using is $\Omega_n\subseteq\Omega$.

The proposed algorithm is as follows:

Step 1: Initialized the resource blocks allocation for cellular and D2D users.

For cellular user m is assigned with the resource block which has the highest channel gain in the hybrid wireless network by base station; the resource block can be assigned to the user that with highest channel gain when the resource block is chosen by several users at the same time. Then add these block number to Ω_m.

For D2D user n, add the sensed resource blocks could be used to Ω_n.

Step 2: Calculate the rate and priority for each user.

For cellular user m, load the whole transmit power on the RB allocated in Ω_m, then calculate the rate R_{mk} and priority $Y_{mk}=\frac{R_{mk}}{\theta_{mk}}$.

For D2D user n, load the transmit power on the RB sensed in Ω_n, and then calculate the rate R_{nk} and priority $Y_{nk}=\frac{R_{nk}}{\theta_{nk}}$.

Step 3: The iterative process.

According to

$$x^*=\arg\min_{m=1,2,...,M;n=1,2,...,N}\{Y_{mk},Y_{nk}\}=\arg\min_{m=1,2,...,M;N=1,2,...,N}\{\frac{R_{mk}}{\theta_{mk}},\frac{R_{nk}}{\theta_{nk}}\}$$

, find the right terminal which has the highest priority.

If the right terminal x^* is a cellular user, m^*, $m=x$, $\Omega_m\neq\varnothing$:

(1) Choose the right RB k_{m^*} with highest channel gain to the cellular UE m^* according to $k_{m^*}=\arg\max_{k=1,2,...,K}|h_{mk}|$;

(2) Calculate the data rate $R_{m^*}=\sum_{k\in\Omega_m}\log_2(1+\frac{p_{m^*k}|h_{m^*k}|^2}{N_0\omega+\sum_{n=1}^{N}\rho_{nk}p_{nk}|h_{nk}|^2})$, where the p_{m^*k} is the transmit power of the m^*-th cellular user by using the water-filling algorithm;

(3) Update the priority of m^*-th cellular user Y_{m^*}, $Y_{m^*}=\frac{R_{m^*}}{\theta_{m^*}}$;

(4) Update the channel gain of the whole hybrid network, Ω_m, and Ω_n.

TABLE I.
KEY PARAMETERS IN THE SYSTEM SIMULATIONT

Simulation Parameters	Value
Max transmitting power of cellular UE	24dBm
Max transmitting power of D2D UE	15dBm
Spectral density of noise power	173dBm/Hz
Cell Length	500m
Number of D2D UE	30(variable)
Number of cellular UE	30
Pathloss factor	4
Frequency of carrier	2GHz
Radius of D2D pairs	20m(variable)
Threshold of lowest transmitting rate R_{th}	2Mbps(variable)

If the right terminal x^* is a D2D pair n^*, $n=x$, $\Omega_n \neq \varnothing$:

(1) Choose the right RB k_{n^*} with the highest channel gain to the D2D pair n^* according to $k_{n^*} = \arg\max_{k=1,2,\ldots,K} |h_{nk}|$;

(2) Calculate the data rate $R_{n^*} = \sum_{k\in\Omega_n} \log_2(1+\frac{p_{n^*k}|h_{n^*k}|^2}{N_0\omega+\sum_{m=1}^{M}\rho_{mk}p_{mk}|h_{mk}|^2})$, where the p_{n^*k} is the transmit power of the n^*-th D2D pair by using the water-filling algorithm;

(3) Update the priority of n^*-th D2D pair Υ_{n^*}, $\Upsilon_{n^*} = \frac{R_{n^*}}{\theta_{n^*}}$;

(4) Update the channel gain of the whole hybrid network, Ω_m, and Ω_n.

IV. PERFORMANCE ANALYSIS

In this section, we present system simulation results to illustrate the performance of the proposed resource and power allocation scheme. The simulated system network is contained in a 500m×500m area where BS is located in the center. Cellular UEs and D2D UE transmitters are randomly placed in this area according to uniform distribution, and the corresponding D2D receivers are randomly placed around D2D transmitters with the radius of 40m (the factor is variable). We set θ=1,2,3 for the three grades of the priority of data rate in the hybrid network. The channel gain is $h=d^{-\alpha}f$, where α is pathloss factor, d is the distance between the interference source and the terminal received the interference, f is independent unit-mean exponential random variable for modeling the frequency-selective fading channels. Key parameters are shown in TABLE I.

By randomly operate the above scenario simulation for 2000 times, we get the average number of iteration as shown in Figure 2. So the convergence of the proposed algorithm in Section III is guaranteed. And with the higher lowest transmitting rate R_{th}, the convergence of sum throughput is better.

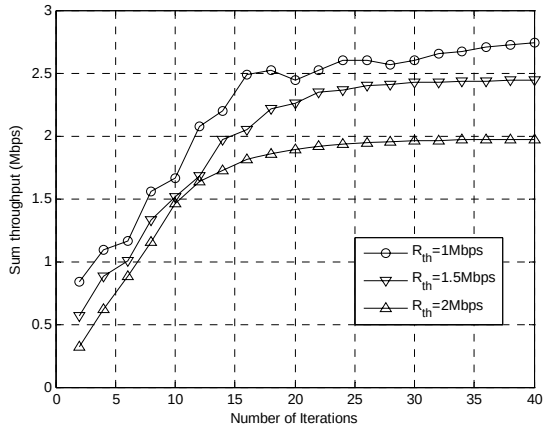

Figure2. Convergence performance

Fig.3 shows the relationship between the sum-throughput and the radius of the D2D pair. We can see that with the increasing of radius between D2D pair, both sum-throughputs of the proposed and traditional algorithm are decreased. It is because that the radius increment requires increasing the D2D transition power, which may bring interference to cellular users. We can still find out that the sum-throughput of proposed algorithm is always higher than the traditional algorithm. Comparing with the traditional algorithm, the decline of proposed algorithm is slower which means the minimum throughput constraint of D2D pairs has effect on the sum-throughput. Because in our scheduling algorithm, some D2D pair with low throughput should be allowed to occupy more spectrum resource blocks in order to maintain the fairness.

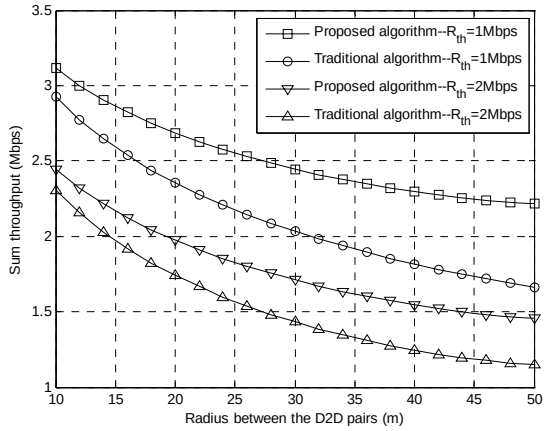

Figure3. Relationship between sum throughput and radius of D2D pairs

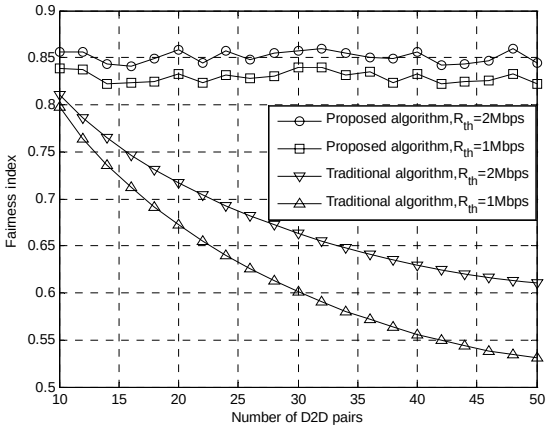

Figure4. Fairness performance

In Fig.4, the fairness of our proposed algorithm is compare with the algorithm presented in [20]. From [20], the Jain's fairness index is defined as: $f(\mathrm{T}_1,\mathrm{T}_2,...,\mathrm{T}_N)=\frac{(\sum_{i=1}^{N}T_i)^2}{N\sum_{i=1}^{N}T_i^{\,2}}$, where T is the throughput of each terminal user, N is the number of terminal user. And the Jain's fairness index is used to evaluate the fairness of the algorithms. From Fig.4, the fairness index of the proposed algorithm is better than the traditional algorithm because it can satisfy the data rate requirement of the D2D pairs. And the fair index of the traditional algorithm decreases with the increasing of the number of D2D pairs increase in the hybrid network. Meanwhile the fairness index of the proposed algorithm maintains a relative stable value.

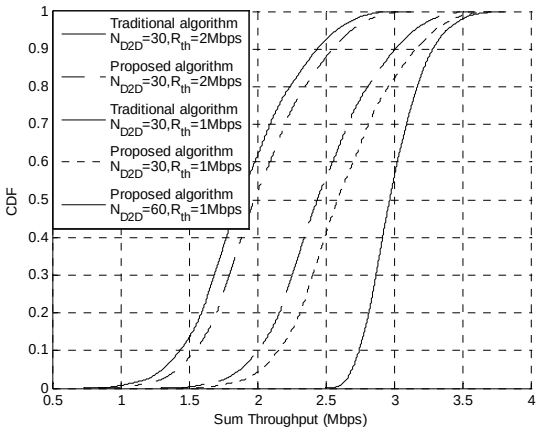

Figure5. CDF of sum-throughput for different number and R_{th} of D2D pairs

Fig.5 illustrates the cumulative Distribution Function (CDF) of sum-throughput for hybrid network. The parameters are shown in TABLE 1, the number of D2D is 30, 60 and the threshold of lowest transmitting rate is 1Mbps and 2Mbps. From fig.5, the leftmost curve is denote the traditional algorithm with the number of D2D pairs is 30, the R_{th} is 2Mbps, the rightmost curve is denote the proposed algorithm with the number of D2D pairs is 60, the R_{th} is 1Mbps, and the sum-throughput of two algorithm scheme increase with the number of D2D pair. We can see the proposed algorithm scheme in this paper is better than the traditional algorithm because of the steep slope. And the more number of D2D pair the superior performance presents.

V. CONCLUSIONS

In this paper, we have given the optimal resources allocation and power control for the hybrid network which is built up by placing a certain number of D2D (Device-to-Device) terminal users in a traditional wireless communication network. The problem is formed as a sum-rate optimization with rate ratio constraint for both cellular and D2D users. First we drive out the optimal wireless resources allocation scheme for achieving the maximum the data rate of hybrid network including the cellular and D2D users. Then we concluded that: the relationship of the transmission power and spectrum resource allocation of the hybrid network is mutually conditional; and the water-filling power allocation algorithm can be used to implement the power allocation of cellular UEs and D2D UEs. And then we proposed the specific scheduling algorithm. The simulation results verify the correctness of our conclusions.

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