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Cooperative Game Based Resource Allocation in Hybrid D2D Cellular Network

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Abstract

D2D communication refers to a technology that two relatively close terminals communicate with each other without forwarding data through base stations. With continuous evolution of the digital communication, users'requirements on the QoS of data transmission is rising while with the assistance of D2D communication technology in traditional cellular system, the resource utilization rate and the cell throughput can be greatly improved. In the process of non-cooperative games, D2D link takes maximizing its profit as the goal of game. However, this approach will not necessarily obtain the maximum of the system total throughout eventually. To tackle the problem above, in this paper, we propose a model of cooperative games. Specifically, in each resource scheduling cycle, we use Lagrange multiplier method according to the CSI to resolve the maximum channel capacity and its corresponding optimal power solution for each cellular channel. We take the channel capacity as the auction price and the original channel capacity as the cost price. The difference between these two is the corresponding channel revenue. Under the management of the cellular base station, the objective of the game is to maximize each channel revenue. In addition, this paper takes the resource acquisition constraints into consideration to solve the unfair phenomenon appeared in the resource competition and avoid the over-provisioning or under-provisioning for channel capacities due to the different channel conditions.

***Keywords**: D2D communication; resource allocation; cooperative game; incentive constraint; Fund Project: TD-LTE private network broadband multimedia cluster system equipment development and scale networking application verification (Major national science and technology projects 2015ZX03004004*

1. Introduction

With the production of more and more mobile multimedia services, the demand for high speed and low latency mobile communication networks is increasing. $D2D$ (Device-to-Device) is a kind of communication means of equipment to equipment, and the data do not need to be relayed through the base station but allowing the establishment of two adjacent mobile devices between each other to establish a direct local link in the base station. This flexible communication method can relieve the problem of the base station to deal with the bottleneck and the blind spot, besides it can be widely used in traffic systems and other intensive user communication scenarios. Choosing both the $D2D$ users and the cellular subscribers to reuse the same spectrum resources can not only save the valuable wireless resources of cellular network but also obtain a high spectrum utilization rate and improve the performance of cellular network.

The main problem is same frequency interference facing the joining of $D2D$ communication in a cellular network. If the system spectrum resources are enough to maintain the independent channels of cellular users and $D2D$ users, there is no interference in the same frequency. But with the continuous development of digital

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communications, the users' demand for the spectrum resources will exceeds the supply. In this paper we communicate by underlay $D2D$ mode and multiplexing cellular resources.

In the process of $D2D$ communication, the channel capacity of the link is mainly determined by three points: the channel gain, the transmission power of the transmitter and the interference noise. In order to obtain better channel capacity, a $D2D$ link can select small resource blocks that have little interference to docking receiver, or increase the transmission power of the transmitter [1]. However, the growth of a single terminal power can bring the interference noise to other users and reduce the capacity of the whole channel.

In the research process of $D2D$ resource allocation, the literature [2] used the method of competitive game to indirectly increase the system capacity and increase the utilization rate of the system by reducing the total interference noise of the system. A shared resource optimization algorithm based on linear programming and two point graph matching model was proposed in the paper[3]. Firstly, the resource optimization problem is decomposed into two sub optimization problems which are $DU-CU$ matching optimization and time resource allocation optimization, and then use the method of linear programming to obtain the optimum solution of the sub problems of time resource allocation optimization. Finally, solving the $DU-CU$ matching optimization problem by building two graphs model according to the solution of time resource allocation optimization problem.

All of the above literatures were focused on the optimal performance of the system, and the research process was always giving the priority to cellular users QoS [4]. The optimal performance of the system does not mean that the cost and benefit of each user are optimal, which will produce unfair phenomenon to network users. In this paper, we set up the same threshold power and the minimum threshold value for each radio link, and we set up the decision factor K of the cellular channel of $D2D$ link. Due to the different geographical position, the interference is not entirely dependent on the transmission power of the same frequency users. Therefore, this method allows a cellular channel to be multiplexed by multiple links.

This paper proposes a bargaining game model [5], the $D2D$ user access network is regarded as being the channel multiplexing cellular access terminal by sharing auction of spectrum resources, the capacity difference before and after $D2D$ user access as income, each $D2D$ for free bid, bid competitors will replace the last round of the winners, until the end of the resources the scheduling cycle, the last winner right competitive resource block reuse.

2. Scene Layout

As shown in Figure 1, it is assumed that there are M cellular users in a cell and N $D2D$ link pair, R wireless resource block (R>M). $D2D$ users communicate through the reuse of the cellular users' resource block. We usually select $D2D$ multiplexing cellular uplink resource block because the anti-interference ability of the base station is stronger than the terminal. If the specified location of the base station, the cellular user and the $D2D$ user are known, the channel gain between the cellular user to the base station and the $D2D$ link pair can be calculated.

The anti-interference ability of base station is better than the terminal station, and we set the $D2D$ users reuse the uplink channel, so all of the $D2D$ transmitter can only cause the same frequency interference to the base station. Set a restricted area that they seem the base station as center point and the R as radiu, prohibit the occurrence of $D2D$ communication in this range. When the $D2D$ users in the cell are more than cellular users and one cellular channel is reused by more $D2D$ link, the transmitter of each $D2D$ link relative to the other $D2D$ channel receiver is a source of interference. The noise power on the cellular channel is different while the channel gain of the $D2D$ link is different. Therefore, how to ensure that each $D2D$ link has fair SINR has become an urgent problem.

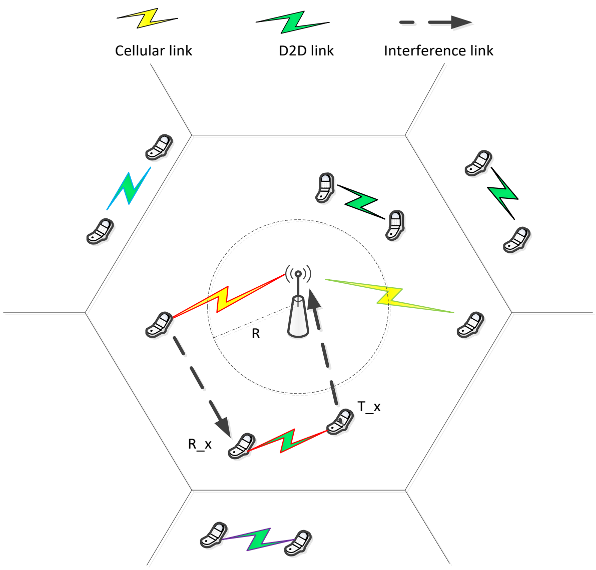

Figure 1. Hybrid D2D Cellular System

3. Resource Allocation

3.1. Algorithm Content

Assuming that in a single cell, there are a total of Q users which includes M cellular users and N $D2D$ users. Cellular users have been accessed the network completely before $D2D$ users, and $D2D$ users access the network through multiplexing cellular user resources. For $D2D$ users which reused the cellular channels RB_i, to increase the transmit power can increase the transmission rate of its own, but it can lead to same frequency interference for other D2D users in the RB_i channel multiplexing and cellular user C_i. Such problems can be solved by getting the power solution of maximum transmission rate in the channel through the Lagrange multiplier method of nonlinear programming. Presuming that cellular communication environment is very stable, the mobile channel gain between terminals is invariant in a certain period of time [6]. Under the management of the channel's cellular users, All cellular channels select the most suitable $D2D$ link access according to time slot.

The maximum transmission rate of the cellular channel RB_i before $D2D_k$ access is C_{iold}. The maximum transmission rate is C_{inew} after $D2D_k$ accessed in cellular channel RB_i. This process that $D2D_k$ accessing to the cellular network can be seen as a cooperative game model, whose goal is to maximize the total throughput of RB_i on cellular channels. C_{inew} is the cost and C_{iold} is the auction price. In the process of the game, with the maximum benefit as the final judgment of the access conditions, and all the $D2D$ links which access to the RB_i is U_i.

In the competitive game proposed [7][8], because of the different channel conditions of the $D2D$, and the purpose of the game process is always to maximize throughput or minimize its interference. Thus the algorithm is only applicable to cellular resources, and each cellular channels only access a $D2D$. There is a problem that the utilization of resources is not high and distribution of resources is unfair. Thus a kind of incentive constraint condition is proposed in this paper to reduce the unfairness of the system.

The interference noise power which for the $D2D_k$ on the resource block RB_i is assumed as I_d,so:

$$I_d = \sum_{j \neq d}^{N} x_{ij} P_j^i G_{j\_tx}^{k\_rx} \quad (1)$$

Where

$$x_{ij} = \begin{cases} 0 & If \ \ U_j \ \ doesn't \ \ reuse \ \ RB_i \\ 1 & If \ \ U_j \ \ reuse \ \ RB_i \end{cases} \quad (2)$$

P_j^i is the same frequency transmitting power of $D2D$ users. $G_{j\_tx}^{k\_rx}$ is the channel gain between $D2D_k$ and other $D2D$ users which could use the same frequency with $D2D_k$. I_d is the interference of all devices share in this band to $D2D_k$ receiving in all neighboring regions, including cellular users and other users of $D2D$. The maximum interference value of each terminal is $I_{\max}^d$, adding a limit condition K to the traditional $D2D$.the K can be composed as

$$K_{id} = \frac{I_{\max}^d - \sum_{j \neq d}^{N} x_{ij} P_j^i G_{j\_tx}^{d\_rx}}{G_{dd}} \quad (3)$$

Because the $D2D$ transmit channel conditions between the end and the receiving end is better, the channel gain is greater. The quality of power frequency is better, and the noise in the frequency band is smaller; It is only when both is large or small, the value of K will not exceed the specified range. Both are big means that the good communications of $D2D$ link allows a better quality of band resources to poor communications of the $D2D$ links ; Both are small means that the poor communications of $D2D$ link could select good communication quality frequency band quality to meet the user's reach within the specified power range of QoS requirements. Using this constraint forcefully to reduce the unfairness of the traditional competition game, K is called as the "resource acquisition coefficient". Based on the size of this coefficient, the $D2D$ users or base stations can determine whether a resource block is suitable for the use of $D2D$ link.

The necessary conditions for the $D2D_k$ to reuse RB_i is:

$$\begin{aligned} & C1: K_{ki} > K_{\min} > 0 \\ & C2: I_{i\_all} = \sum_{j=1}^{N} x_{ij} P_j^i G_{jb} < I_{th}^c \\ & C3: I_d^i = \sum_{j \neq d}^{N} x_{ij} P_j^i G_{j\_tx}^{d\_rx} + P_i G_i^{d\_rx} < I_{th}^d (\forall d2d_d \in U_i) \end{aligned} \quad (4)$$

The $C1$ guarantees the QoS of the $D2D$ link which waiting for accessed and suppresses $D2D$ link with better communication conditions to compete for high-quality resources. The $C2$ ensures the QoS of the cellular users. The $C3$ ensures the QoS of other $D2D$ links which has been accessed to the channel.

The constraint conditions to meet the QoS requirements of the cellular users communication is

$$\sin r_c = \frac{P_c G_{cb}}{\sum_{k=1}^{N} P_k G_{kb} x_{ij} + N_0} \geq \sin r_{\min}^{c} \tag{5}$$

The constraints to meet the requirements of $D2D$ users communication QoS is:

$$\sin r_d = \frac{P_d G_{dd}}{\sum_{k=1}^{N/\{j\}} P_k G_{kj} x_{ij} + P_c G_{cj} + N_0} \geq \sin r_{\min}^{d} \tag{6}$$

From the above, the total throughput of the channel RB_i that multiplexed by $D2D_k$ is written as

$$\begin{aligned} &Maxmize \quad C_{Ri} = R_{C_i} + \sum R_{D_j} = \log_2(1 + \frac{P_i G_{ib}}{\sum_{k \in N} x_{id} P_d G_{db} + \sigma^2}) \\ &+ \sum_{j=1}^{N} x_{ij} \log_2(1 + \frac{P_j^i G_{jj}}{\sum_{k \in N, k \neq j} x_{ik} P_k^i G_{kj} + P_i G_{ij} + \sigma^2}) \\ &subject \ \ to: \quad P_i < P_{\max}^{c} \quad P_j^i < P_{\max}^{d} (\forall d2d_j \in U_i) \\ &\sin r_i \geq \sin r_{\min}^{c} \quad \sin r_j \geq \sin r_{\min}^{d} (\forall d2d_j \in U_i) \qquad \sum_{i=1}^{M} x_{id} = 1 \end{aligned} \tag{7}$$

Assuming that the number of $D2D$ link which reuse the resource block RB_i is k, the Lagrange equation can be expressed as

$$\begin{aligned} &L(P_c, P_1 .. P_K, \beta_1 .. \beta_K, \alpha_1 .. \alpha_K) = C_{Ri} + \sum C_{Rd} - \beta_{K+1}(P_c - P_{\max}) \\ &+ \sum_{i=1}^{K} \beta_i (P_i - P_{\max}) - \alpha_{K-1}(\sin r_{\min} - \frac{P_c G_{cb}}{\sum_{j \neq i}^{K} P_j G_{jb} - \sigma^2}) \\ &- \sum_{i=1}^{K} \alpha_i (\sin r_{\min} - \frac{P_i G_{ii}}{\sum_{j \neq i}^{K} P_j G_{ij} - P_c G_{ci} - \sigma^2}) \\ &\frac{\partial L}{\partial P_c} = 0, \frac{\partial L}{\partial P_1} = 0 ..... \frac{\partial L}{\partial P_K} = 0 \\ &\frac{\partial L}{\partial \alpha_1} = 0 .. \frac{\partial L}{\partial \alpha_{K+1}} = 0, \frac{\partial L}{\partial \beta_1} = 0 .. \frac{\partial L}{\partial \beta_{K+1}} = 0 \end{aligned} \tag{8}$$

According to the Lagrange multiplier method [9] ,the system can find out the solution of every terminal power which maximize C_{Ri} and largest value of C_{Ri}.

For a single $D2D$ user k, the system gains of reusing cellular channel RB_i are denote as

$$\begin{aligned} &U(k,-k) = C_{inew} + \sum C_{D2Dnew} - C_{iold} - \sum C_{D2Dold} \\ &= \log_2(1 + \frac{P_i G_{ib}}{\sum_{j=1}^{N} x_{ij} P_j G_{jt,b} + N_0}) + \sum_{k=1}^{N} \log_2(1 + \frac{P_k G_{kk} x_{ik}}{\sum_{j \neq k}^{N} x_{ij} P_j G_{jt,kr} + P_i G_{ik} + N_0}) \\ &-[\log_2(1 + \frac{P_i G_{ib}}{\sum_{j \neq k}^{N} x_{ij} P_j G_{jt,kr} + P_i G_{ik} + N_0}) + \sum_{h \neq k}^{N} \log_2(1 + \frac{P_h G_{hh} x_{ih}}{\sum_{j \neq k, j \neq h}^{N} x_{ij} P_j G_{jt,hr} + P_i G_{i,hr} + N_0})] \end{aligned} \tag{9}$$

where, x_{ij}、x_{ik}、x_{ih} are binary number with x_{ij} as an example. Only when the $D2D_j$ multiplex cellular channel R_i ,so $x_{ij}=1$, otherwise, $x_{ij}=0$.

Assuming the $U_{\min}$ as the value of minimum income, to determine whether the bargaining game can be expressed as

$$\begin{cases} U(k,-k) \geq U_{\min} & \text{User D2D}_\text{k} \text{ can participate in the competition} \\ U(k,-k) \leq U_{\min} & \text{User D2D}_\text{k} \text{ can't participate in the competition} \end{cases} \tag{10}$$

Each $D2D$ user is free to bid to compete for cellular channels, resulting in a competitive cycle for a higher gain of the $D2D$ link to gain access to this cellular channel.

In the initial state, the channel of cellular users will not be reused by any $D2D$ users [10], there will be no noise of the same frequency interference on cellular channel while there is only the Gauss noise. Obviously, the capacity of the channel will be the biggest if the cellular user transmit at the maximum power. So, it requires that the cost of each cellular subscriber in the first bargaining process is $C_{i\max}$. The ultimate gain of the cellular channel RB_i for the entire system is written as

$$\begin{aligned} U_{D2D} &= C_{Inew} + \sum C_{D2D} - C_{i\max} \\ &= \log_2\left(1+\frac{P_i G_{ib}}{\sum_{j=1}^{N} x_{ij} P_j G_{jt,b} + N_0}\right) + \\ &\sum_{k=1}^{N} \log_2\left(1+\frac{P_k G_{kk} x_{ik}}{\sum_{j\neq k}^{N} x_{ij} P_j G_{jt,kr} + P_i G_{ik} + N_0}\right) - \log_2\left(1+\frac{P_{c\max} G_{ib}}{N_0}\right) \end{aligned} \tag{11}$$

According to the literature [11], the formula of evaluating a wireless communication system's fairness is

$$F_\varphi(\Delta t) = \frac{\left[\sum_{l=1}^{L} \varphi_d(\Delta t)\right]^2}{N_d \sum_{l=1}^{L} [\varphi_d(\Delta t)]^2} \tag{12}$$

Where the N_d represent the number of users in the system. The $\varphi_d(\Delta t)$ represent the actual throughput in the time interval Δt of all users. The data transmission rate got by users will be more average and the fairness of the whole system will be better when the fairness factor is higher.

3.2. Algorithm Flow

Step1: Initialization, Taking the first $D2D$ user who meet the access conditions of formula (4) as the initial participant to access to the cellular channel RB_i, and name it as $D2D_{first}$.

Step2: Through the Lagrange multiplier method, the maximum transmission rate and the corresponding power solutions of each terminal can be obtained while $D2D_{first}$ access to the cellular channel RB_i. The positioning of $D2D_\lambda$ as the quasi access user .

Step3: Determining whether the resource scheduling cycle ends, otherwise updating the remaining time ; Introducing the new participant $D2D_x$ which meets the formula (4). Using the method of step 2 to calculate the benefits of that $D2D_x$ access to the channel. If it is greater than $D2D_\lambda$, $D2D_x$ will be replaced by $D2D_\lambda$; Otherwise, continuing to introduce new participants.

Step4: Repeating step (2)and (3) until the end of the scheduling cycle. The last iterating $D2D_\lambda$ user is the one who requests to access and can bring the maximum benefits in the period of the cycle.

The specific process is shown below:

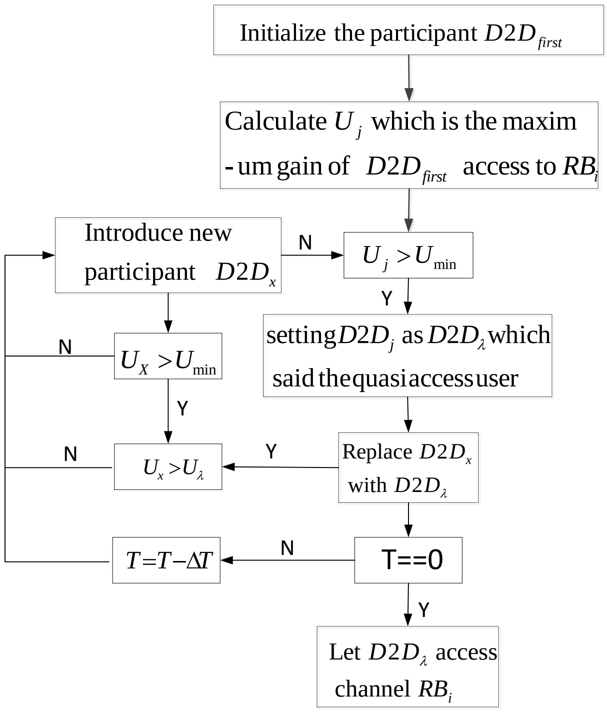

Figure 3.1. Flow Chart of Algorithm

4. Simulation Analysis

In this paper, MATLAB is used to do LTE system level simulation. Because of considering no interference of other cells, the simulation scene is set as a single cell environment.

The simulation parameters are set as follows:

Parameter	Value
Cellular radius	200 meters
Attenuation model	Cellular mode :128.1+36.71gd D2D mode :148+40 lgd
Shadow fading standard deviation	Cellular mode: 10dB D2D mode : 12dB
D2D maximum communication distance	60 meters
Maximum transmit power for D2D users	14dBm
System bandwidth	10MHz
Simulation times	200
Duration of simulation	0.5h or more

In this paper, the simulation is compared with the random resource allocation in literature [12] and the competitive game resource allocation in literature [13]. We select eleven $D2D$ links to be the simulation object, and the distance are set as follows: 10 meters, 15 meters, 20 meters, 25 meters, 30 meters, 35 meters, 40 meters, 45 meters, 50 meters, 55 meters and 60 meters. If not considering the multipath effect and shadow fading, the channel gain corresponding decrease in turn. According to Figure 4.1, the competition game in literature , the $D2D$ link of better Channel conditions get higher transfer rate in the course of the game, and it is lower for poor channel conditions link. The cooperation game model and the incentive mechanism in this paper reasonably assure that the transmission rate of the link of different channel conditions changes smoothly. in From the Figure 4.2, we can see that the cooperative game algorithm considered the overall throughput of the system, while the competition game algorithm just took the each link throughput as the distribution condition. So the spectral efficiency of this algorithm compared to the competition game with stochastic resource allocation has a certain promotion. And in fairness comparison of Figure 4.3, the selfish characteristics of the competition game algorithm make the system resource allocation unfair. The proposed cooperative game in this paper which put forward the corresponding constraints according to data rate requirements of each link has better behaviors to maintain the fairness of the system.

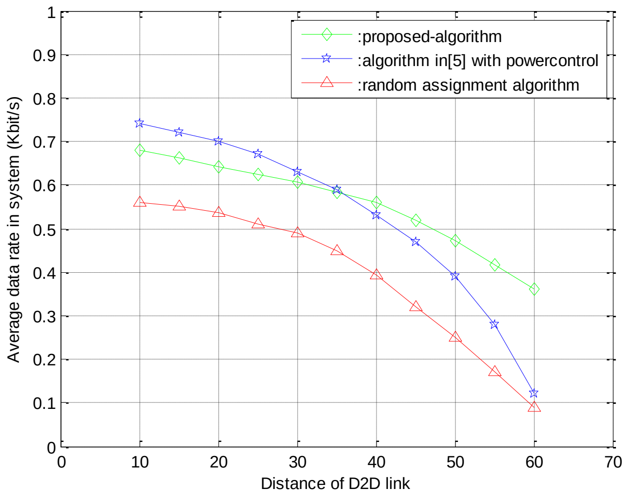

Figure 4.1. Relationship between Channel Capacity and Distance in D2D

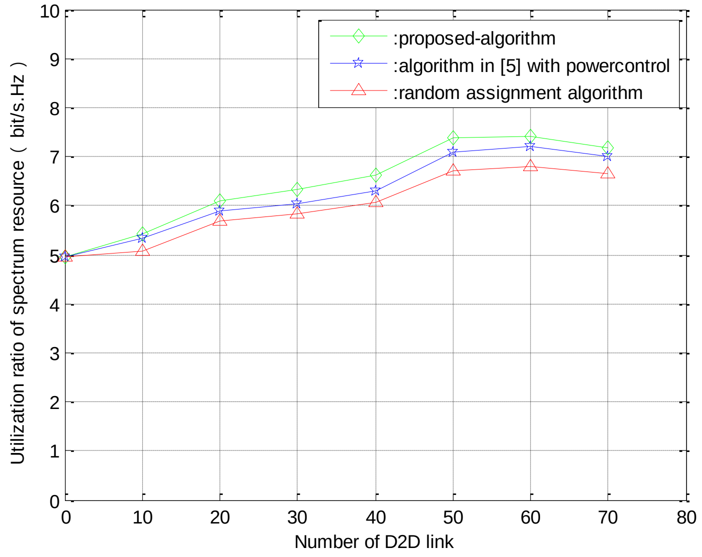

Figure 4.2. Average Spectral Efficiency

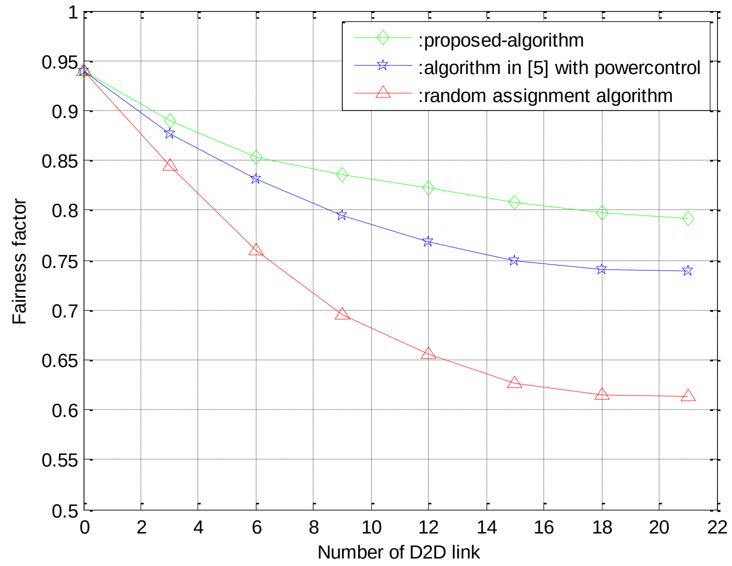

Figure 4.3. Comparison of Fairness Factors

5. Conclusion

D2D communication is a kind of communication mode that can be added to the cellular network and improve the system throughput and resource utilization. A *D2D* resource allocation method and a new resource competition constraint is proposed based on bargaining game in this paper .Simulation results show that the proposed algorithm has distinct advance than the previous algorithms in terms of throughput and fairness.

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