A Novel Resource Allocation in Imperfect D2D Cooperation in LTE-Advanced Pro Systems

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***Abstract*—The increasing demand on higher transmission speed and lower latency has become popular in 5G related researches. Cooperation is one possible solution to enhance system performance. In this work, we focus on the problem of enhancing the performance of cooperative among mobile terminals under the constraint of cooperative link capacity. Different from traditional researches, we consider the scenario that multiple mobile terminals are working in cooperative mode and the capacity of the link to perform cooperation is limited, which will limit the performance of cooperation. First of all, we establish the scenario and mathematical modeling of the imperfect cooperation among terminals, then we propose a novel sub-optimal centralized method to tackle the problem. A system level simulation result has been given at the end of our manuscript. The result indicates that, the capacity constraint cooperative link will greatly limit the performance of cooperation, by adopting our proposed method, about 7% performance gain could be obtained on average.**

***Keywords*- D2D; resource allocation; capacity constraint; LTE-Advanced Pro**

I. Introduction

The development of wireless personal communication techniques provide opportunities and challenges to researchers and network providers. Recently, performance of mobile terminals are developing in an incredible speed, which could possibly turn terminal cooperation into reality. For 5G and related systems, terminal cooperation has become one key technique in the development procedure, both ITU-R [1]and 3GPP LTE-Advanced Pro[2] have established related workgroups to tackle the key problems.

In fact, many academic and industry researchers have focused on this issue since 2011, the Device to Device communication (D2D) is firstly developed to solve the cell edge performance and terminals are working as relay node but the ability is limited due to the process ability of mobile terminals. To achieve higher transmission speed, the terminals could now work in cooperative mode as is listed in [3], [4]. When cooperation is proposed within mobile terminals, every terminal could work as a service node, traditional Joint Processing (JP) or Coordinated Scheduling/Beamforming (CB/CS)[5]. In fact, the deployment of base stations or related service nodes such as eNodeBs is limited because of the city layout and planning, so the transmission of the last 10 meters may not be solved by deploying more and more base stations/ small cells.

Cooperation of terminals is one possible solution to improve cell-edge performance and peak data rate. In [6] and [7], performance metric and analysis of D2D CoMP have been studied, but further discussion about implementation and algorithms are not mentioned. In [8], [9], the authors studied the scenario that the cooperative device are working as relay node for signal extension, gain from receiving diversity has been obtained from original service base station and cooperative relay device. To further improve the system performance, in [10], [11], [12], transmission delay has been taken into account and novel collaborative strategy / offloading scheme has been proposed. In [13]-[20], resource allocation schemes are discussed to perform device cooperation, in these references, authors are making full use of the spectrum resources through optimal power allocation using convex optimization in different scenarios, but the assumption of ideal cooperative link capacity limit the utilization of methods in real scenario. In this work, we are discussing the D2D CoMP in capacity constraint cooperative link capacity, where there is still little researchers focus. The problem reflect the fact that there exists upper limit of cooperation within terminals when considering the imperfect condition, such non-ideal factors must be considered in real transmission system.

The rest of the paper is organized as follows. In part II, we give the scenario and system model of capacity constraint D2D cooperation in LTE-Advanced Pro systems. In part III, we present the modeling and our proposed novel resource allocation scheme in capacity limit cooperative link. In part IV, both theoretical and field trial results have been given with discussion about our method. Conclusions are given in the last part.

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II. System Model of D2D Cooperative Communication

In Fig.1, we illustrate the network model of the LTE-Advanced Pro system. Many types of service nodes such as 5G cellular, WiFi, ZigBee consist a hybrid network topology. To improve system performance of the last 10 meters, terminal cooperation is introduced. Traditional base station cooperation require the link between base stations such as X2 or S1 interface, the transmission media is usually optical fiber or Gbit Ethernet, providing sufficient transmission bandwidth for cooperation. But in D2D cooperation, the link to adopt transmission has been changed to wireless link, so the bandwidth and power are all limited. Such limitation also lead to the bottleneck of the cooperation if no resource allocation or scheduling method is adopted in cooperative link.

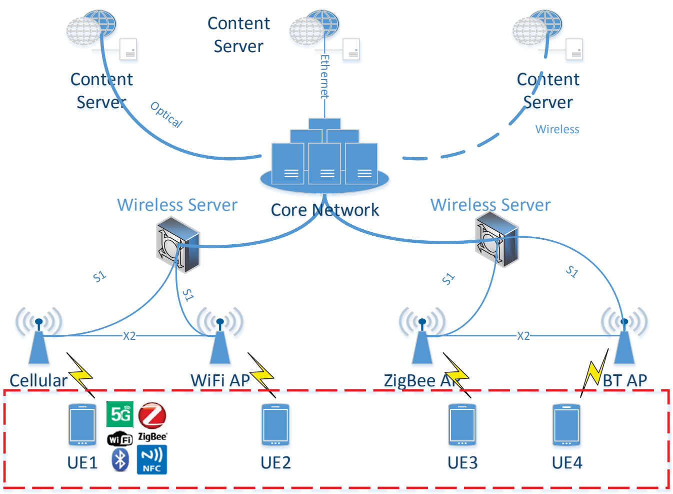

Figure 1. Network Model of LTE-Advanced Pro Cooperative D2D Communication. UE with different transmission ability such as WiFi, 5G, Zigbee, etc. could perform cooperation within terminals.

So in the following part, we will model the capacity limit D2D cooperation scenario and propose our novel resource allocation method in cooperation link to improve the transmission speed.

III. Novel Resource Allocation Method in Imperfect Condition

For D2D cooperative communication, users around target user are working like small base stations to provide relay or cooperation. In D2D cooperation, target users are mainly located at the edge of the base station, who could only receive poor performance. To enhance the performance of target user, adjacent users will help transmit useful information to target UE. When the capacity of cooperative link is unlimited, this problem is just like the base station cooperation, but when the link capacity is limited, this problem becomes far more complex.

A. D2D Cooperation Scenario and System Model

In fig.2, the scenario of D2D cooperative communication has been given. A base station could afford a particular range by providing satisfied signal to noise ratio (SNR). In this figure, we consider target user located at the edge of the base station and UE 1, UE 2 and UE 3 consist a cooperative group. Sorted by distance, UE 4 are not capable to provide service to target UE, UE 1 and UE 2 are working as relay nodes to extend signals from base station to the direction of target UE, UE 3 located between UE 1, 2 and target UE, so target UE will receive signal from UE 1 and UE 2 directly, also will get processed signal from UE 3. Because the cooperative links among all these terminals are capacity constraint, so some resource allocation schemes must be adopted to improve the spectrum efficiency.

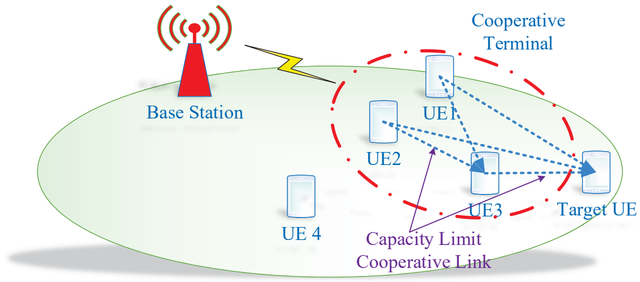

Figure 2. D2D Cooperation Scenario. Target UE is located at the edge of the service area and adjacent users are working as cooperative nodes.

Define the received signal of target UE using the following equation, $y_{UE}(i)$ is the received signal of target UE from user i:

$$y_{UE}(i) = H_{UE_i} s + n_{UE_i} \tag{1}$$

Define K the number of subcarriers in OFDM related systems and $k \in K$ is the index of subcarriers, $s \in C^{2k \times 1}$ is the signal vector to be transmitted on subcarrier k. $H_{UE_i} = diag(h_{UE_i,k}) \in C^{K \times 2K}$describes channel matrix from UE i to target UE, where the diagonal element $h_{UE_i,k}$ is the channel response from user i that mapped on subcarrier k to target UE. The noise vector n_{UE_i} is a zero-mean circularly symmetric complex Gaussian random process with $n_{UE_i} \sim \mathcal{NC}(0, \sigma^2 I_K)$, and σ^2 is the noise variance.

To decode the received information at the target UE under the capacity constraint wireless cooerative link, traditional unlimited joint processing method is limited, so cooperation based on compression and forward is proposed [21]. Define $q \in C^{K \times 1}$ the compression noise vector and $\Phi \in C^{K \times K}$ is covariance variance matrix of compression noise. The compression process is given in equation 3:

$$y_{\hat{UE_i}} = y_{UE_i} + q, q \sim \mathcal{NC}(0, \Phi) \tag{2}$$

To evaluate the system performace, the sum rate metric needs to be introduced. According to Shannon formula, the achievable sum rate R of the cooperative D2D communication link must satisfy the constraint given in equation 3:

$$R \leq I(s; y_{UE_i} \widehat{y_{UE_i}}) = \sum_{k=1}^{K} I(s_k; y_{UE_i,k} \widehat{y_{UE_i,k}}) \tag{3}$$

In equation 3, $y_{UE_i,k}$ is the received signal on subcarrier k from UE_i and $y_{\widehat{UE_i},k}$ is the reconstructed signal decompressed by target UE. To calculate the overhead of the cooperative link, define $\mathcal{R}=\{r|r \in R_+^K, 1^T r \leq C_{bound}\}$ the set of all achievable rate vector and C_{bound} is the capacity constraint of the D2D cooperative link. Then the overhead could be defined using equation 4.

$$R = I(y_{\widehat{UE_i}}; y_{UE_i}) = \sum_{k=1}^{K} I(y_{\widehat{UE_i},k}; y_{UE_i,k}) \leq C_{bound} \quad (4)$$

B. Our Proposed Method

In this scenario, due to the limitation of cooperative capacity, we must make full use of the limited resources to maximize the system achievable rate. In fig. 2, we can see that UE 1 and UE 2 are working as a group to relay information received from base station, so we call this a UE group. UE 3 and target UE will all receive relay information from UE group and UE 3 will transmit compressed and decoded information through capacity limit wireless link to target UE. So the optimization problem of the above observation could be summarized as follows:

$$\max_{\theta,R,\Phi} \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{K} \theta_{i,j,k} R_{i,j,k} \quad (5)$$

$$s.t. \sum_{j=1}^{N}\sum_{k=1}^{K} \theta_{i,j,k} = 1, \forall i \quad (6)$$

$$\sum_{i=1}^{N}\sum_{k=1}^{K} \theta_{i,j,k} = 1, \forall j \quad (7)$$

$$\sum_{i=1}^{N}\sum_{i=1}^{N} \theta_{i,j,k} \leq 1, \forall k \quad (8)$$

$$R^T 1 \leq C_{bound} \quad (9)$$

In the optimization problem, $R_{i,j,k}$ is the achievable sum rate for cooperative UE group (i,j) carried by the arranged subcarrier k in cooperative link, $\theta_{i,j,k} \in \{0,1\}$ is an integer indicator to decide if the UE group (i,j) is served by subcarrier k , that means if this mapping is true, then $\theta_{i,j,k} = 1$, elsewise $\theta_{i,j,k} = 0$.

Analyzing the fact that $\theta_{i,j,k}$ is an integer, so the optimization problem introduced in equation 5~9 is an integer programming problem, which is hard to find out the optimal solution. To tackle this optimization problem, we propose a novel step wise method to divide the complex integer programming problem into three sub-optimal problems, and find out the optimal solution of the new problem.

Step1: Optimization of the Artificial Noise Vector:

Considering the integer variable $\underline{\theta}$ and cooperative link resource allocation vector $\underline{R}$, define $\psi(\underline{\theta}, \underline{R}, \Phi)$ the objective function. So the problem of maximizing the transmission speed under fixed constraint is summarized as follows:

$$\min_{\eta_k} I(s_i s_j; y_{UE_i,k} y_{\widehat{UE_i},k}) \quad (10)$$

$$s.t.\ I(y_{UE_i,k} y_{\widehat{UE_i},k}) \leq R_k \quad (11)$$

The optimal solution for such optimization problem is $\eta_k^* = \frac{e_{i,j,k}}{2^{R_k}-1}$, where the above optimization is a typical convex optimization problem [23].

Step 2: Optimization of the link resource allocation vector R

After the optimization of the artificial noise vector, we are now working on the problem to make a perfect match of the UE group and subcarrier k. Because the subcarrier is the continuous resource in time domain, so given the UE group and mapping $\underline{\theta}$, the objective function$\psi(\underline{x}, \underline{R}, \Phi(R))$ is concave in R, the optimal solution could be calculated using CVX optimization tool. Detailed proof could be found in our previous work [22].

Step 3: Optimization of the UE group and subcarrier:

In the previous step, vector R has been optimized, to continue finishing the whole optimization problem, relationship of UE group should be addressed, that means, we should decide how many users are grouped together and working as relay node. If the allocation vector $\underline{\theta}$ and noise $\Phi(R)$ are given, so the complexity of the objective function ψ is reduced:

$$\psi(\underline{\theta}, \underline{R}, \Phi(R)) = \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{K} \theta_{i,j,k} R_{i,j,k}(\theta_{i,j,k}) \quad (12)$$

To summarize the above observations, our proposed new optimization problem that equal to the original one could be expressed below:

$$\min_{\beta,R,\Phi} \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{K} \theta_{i,j,k} R_{i,j,k} \quad (13)$$

$$s.t. \sum_{j=1}^{N}\sum_{k=1}^{K} \theta_{i,j,k} = 1, \forall i \quad (14)$$

$$\sum_{i=1}^{N}\sum_{k=1}^{K} \theta_{i,j,k} = 1, \forall j \quad (15)$$

$$\sum_{i=1}^{N}\sum_{i=1}^{N} \theta_{i,j,k} \leq 1, \forall k \quad (16)$$

$$R^T 1 \leq C_{bound} \quad (17)$$

$$\alpha(i) = k \quad (18)$$

$$\beta(i) = j \quad (19)$$

Through the three step sub-optimal solution, the original integer programming problem has been degenerated. The following algorithm describe the programmable step of our proposed according to the mathematical observations above.

Algorithme 1 Proposed Resource Allocation Scheme in Imperfect Cooperative D2D Communications

Begin:
1. Mapping users in group using K subcarriers to target UE
2. **Initialize** $\beta^{(0)}$ **and** $R^{(0)}$ **randomly, t=0**
3. Repeat:
4. **t=t+1**
5. Get $R^{(t)}$ **using CVX**
6. Compute $\Phi^{(t)} = diag(\eta_1^{(t)}, \eta_2^{(t)}, \cdots, \eta_K^{(t)})$
7. Compute $R_{i,j,k}^{(t)}(\beta^{(t-1)}, R^{(t)})$
8. Get $\beta^{(t)}$ **using linear programming**
9. Compute objective function $R^{(t)}$ using $\beta^{(t)}, \Phi^{(t)}, R^{(t)}$
10. Until $\psi^{(t)}$ converges

IV. Simulation and Analysis

In this part, we give the simulation result related to this work. First of all, we discuss the influence of capacity limit cooperation link between users in D2D communications.

In Fig.3, the influence of cooperative link capacity is given. We consider a link level simulation in LTE-Advanced Pro scenario with 2 eNodeBs and 10 users uniformly located at the range of the eNodeB. The antenna configuration for users are 2, and the speed of users are 1m/s. Other parameters are set to default according to 3GPP TR 36.942 Urban Micro scenario[24]. The x-axis indicates the average target UE throughput in Mbps and the y-axis means the cdf of the figure. From left to right, the cooperative bandwidth of the UE cooperation increased from 10MHz to 50MHz, leading to the difference of the transmission speed. From this figure, we can infer that, the capacity of the cooperation link will limit the performance of the given systems, for example, when the capacity is 50MHz, about 60% target UE could get the average speed of 52Mbps, but when the bandwidth is limited to 10MHz, 60% target UE could only receive the speed of 28Mbps, only a half of the reference.

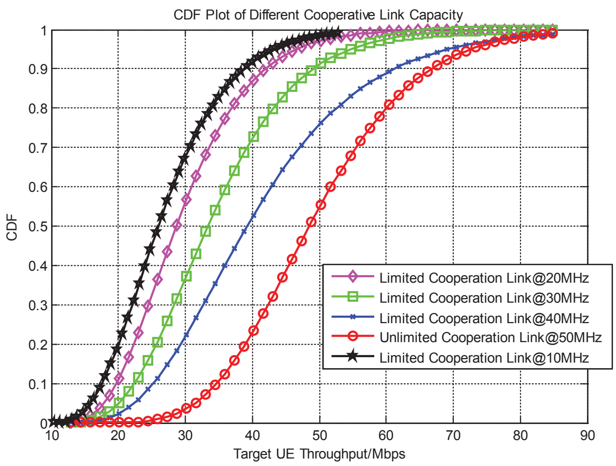

Figure 3. Influence of Cooperative Link. The capacity of the cooperative link greatly limit the performance.

From this point of view, it is necessary to perform resource allocation in cooperation links to make full use of the finite bandwidth resource, especially when the need of D2D cooperation increases and the capacity of cooperative link is actually limited in real scenario.

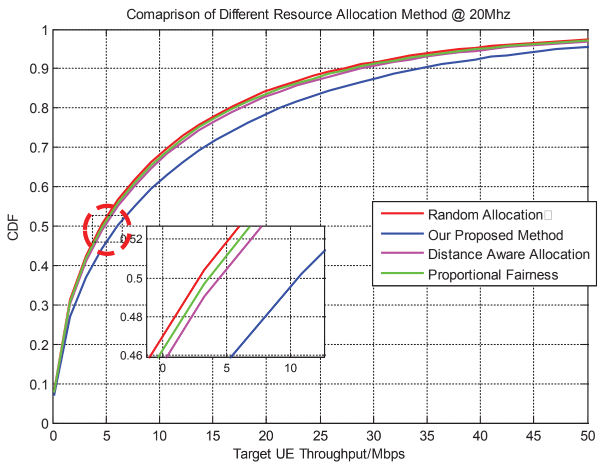

Figure 4. Influence of Cooperative Link. The capacity of the cooperative link greatly limit the performance.

In fig.4, we present the comparison of our proposed method and other commonly used scheduling method in 20MHz cooperative link. The 20MHz cooperative link is defined by Qualcomm in the outdoor experiment, so we consider this value as default in simulation. The definition of x and y axis is the same as the figure above. The blue curve indicates our proposed method, the green one means the proportional fairness scheduling method, the pink one means the distance aware resource allocation scheme and the red one is the random allocation. From this figure, we can infer that, by using our proposed method, about 7% gain could be obtained when the cdf is about 75%, when the cdf is 50%, we amplify the curves and find out that the improvement is about 2% than distance aware allocation method.

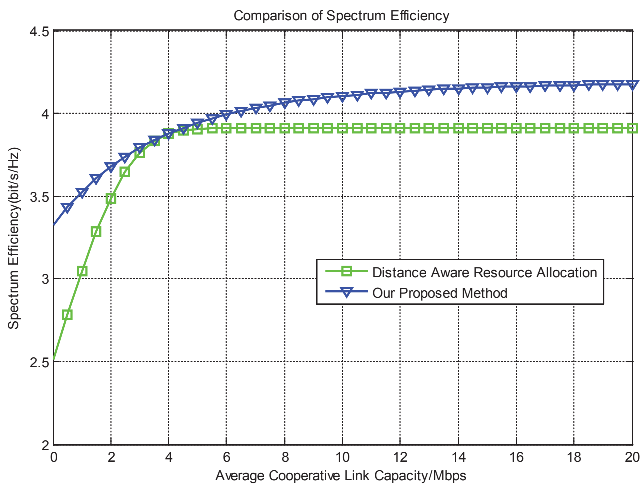

Figure 5. Comparison of Spectrum Efficiency.

From the comparison of target UE throughput, our proposed method has only a little advantage compared to other method, so we present the comparison of spectrum efficiency compared to distance aware resource allocation. In fig. 5, the x-axis is the average cooperative link capacity and the y-axis is the spectrum efficiency in bit/s/Hz. The blue curve is our proposed method and the green one is the reference distance aware method. When the link capacity is below 4Mbps, the spectrum of our proposed method is 1 bit/s/Hz higher than the reference method, which express the advantage of compress and forward method rather than transmit original information to perform cooperation. When the capacity is around 4 Mbps, the two methods have the same performance. When the link capacity increases, the distance aware method meets the bottleneck that the spectrum efficiency would not increase, but our proposed method could gain higher SE because of the compression.

V. Conclusion

In this paper, we propose a novel resource allocation method to make full use of the capacity limited D2D cooperative link, which could significantly increase spectrum efficiency and system throughput at the receiver side. The contributions and advantages of this paper can be summarized as follows:

1)we discuss the capacity constraint D2D cooperation problem in LTE-Advanced Pro related systems and first publish the link level simulation result to evaluate the influence of cooperative capacity in D2D cooperation;

2)we propose the novel method to solve an integer programming problem by using the step wise optimization method, which could make the resource allocation running in an satisfied speed. Simulation result indicates that our proposed method could gain 7% compared to reference method.

However, there are still disadvantages of our work, e.g. the influence of mobility is not considered, channel estimation is ideal, etc.

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