# Resource Allocation in D2D Communication – A Game Theoretic Approach

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*Abstract*—**D2D communication has been proposed as a transmission approach to improve the resource efficiency and lighten the heavy load of the base station(BS) in LTE-Advanced system. In D2D communication, resource efficiency is seriously influenced by the resource allocation scheme. Additionally, the selfish behaviors of user equipment(UE), such as Unknown Channel Quality(UCQ) Problem potentially harm the system efficiency. For instance, we observed that UEs may report their experienced D2D quality untruthfully in order to gain unfair advantages in resource allocation. The so-called UCQ issue imposes a negative impact on the resource utilization efficiency. In this paper, we propose to use Game Theory to analyze this issue. First, we studied the resource allocating scheme concerning the benefit of the BS, and then analyze the system efficiency and the equilibrium. Second, we discussed the UCQ problem in D2D communication. We proposed a contract-based mechanism to resolve the UCQ problem by eliminating the incentive of UEs to report untruthfully with designed service contracts. The simulation results represents the feasibility and the effectiveness of our approach.**

*Index Terms*—**D2D, Resource Allocation, Game Theory, LTE-Advanced**

## I. Introduction

LTE-Advanced is one of the most promising commercialized wide-area wireless network standard for achieving 4G requirements. Owing to the explosive growth of communications in cellular system, lots of researchers endeavor to lighten the load of network traffic. One of the approaches schemed by the researchers for LTE-Advanced Release 12 standard is the concept of Device-to-Device(D2D) communications.

D2D communication enables direct links between devices in proximity using the cellular spectrum without passing through the base station(BS). There are two main advantages. First, the devices can transmit data with a higher throughput in a low power due to the shorter distance. Second, the BS can lighten its own load and serve more users if low transmission power between devices can make spectrum reusing possible. With these advantages, D2D is a rising star in LTE-Advanced systems. Nevertheless, various challenges, such as Unknown Channel Quality(UCQ) problem, still exist in implementing D2D communications in LTE-Advanced systems.

In D2D communication, UCQ problem is an important issue. In traditional cellular networks, the BS knows the channel quality which is experienced by users since all data transmissions are conducted through the BS. For the case of D2D communications, in contrast, the data is transmitted between UEs without passing through the BS, so the BS doesnt have any knowledge about channel quality.

Nevertheless, channel quality is important in D2D communication because the BS relies on it to determine whether to allocate resource to the UE and the resource quantities to allocate. Traditionally, the BS may obtain the information by sending a channel quality indicator (CQI) request to UEs and reading information from the corresponding reply. However, a traditional approach as such implies an assumption that all UEs will faithfully report their private information. Yet in case that UEs behave rationally, they may report fake channel quality as long as such unfaithful actions will benefit UEs themselves. Such selfish behavior may mislead the decision made by the BS and eventually make the system inefficient and unfair. In order to establish an efficient system in which both D2D and cellular mode are involved, we need to find a solution to solve UCQ problem by addressing the selfish behaviors of UEs.

Game theory is a study of strategic decision making. This theory takes into consideration the expectations of rational individuals and studies the optimum strategies for themselves. We will model and analyze the D2D communication with game theory and Nash Equilibrium(NE) to study how selfish UEs affect the system.

The main contribution of this paper is to design mechanisms with game theoretical approach to allocate channel resource efficiently under realistic scenarios. The proposed game model can allocate channel resource efficiently in systems without UCQ problems. When the UCQ problem exists, we propose a contract mechanism to allocate resource almost as efficient as an omniscient model in the system. With our contract mechanism, the UCQ problem is no longer as a cataclysm of the system in D2D communications.

| | |
|---|---|
| $\beta$ | Satisfactory weighting factor |
| $B$ | Resource quantity |
| $Q$ | Channel quality |
| $P$ | Price of resource per quantity |
| $C(B)$ | Cost function |
| $U(B,Q)$ | Utility function of UEs |
| $R(B,Q)$ | Profit function of BS |
| $X_{cell}$ | Cellular mode of X |
| $X_{D2D}$ | D2D mode of X |

TABLE I: Notation Table

## II. Related Works

D2D communication has been proposed in the literature and has been proved feasible and efficient as an underlay of a cellular system in [1] by Fodor *et al.* In [2], Doppler *et al.*

introduced two different ways to establish D2D connections. Then in [3], the uplink interference of D2D was analyzed in a Rayleigh fading channel by Kang and Shin, and they also derived the maximal transmission range of a D2D link. In [4], Pantisano *et al.* proposed a relay scheme between macrocell and femtocell to alleviate the uplink interference in D2D communication.

In order to realize D2D communication under the existing cellular system, spectrum leasing mechanism is an important issue. Game theory has become a new and effective approach for this problem. Wang *et al.* in [5] introduced Stackelberg game to deal with the resource sharing problem in cognitive radio networks. In [6], Pei and Liang proposed a resource allocation protocol overlaying two-way cellular networks with the concept of Pareto Boundary. Auction is another popular approach to solve the resource allocation problem. In [7], [8], Wang *et al.* designed the auction rules to make the system power efficient while maintaining good channel quality. In [9], Xu *et al.* proposed a reversed iterative-combinatorial auctions (I-CAs) algorithm for spectrum allocation and reduced the interference between D2D and cellular users.

Resource allocation in D2D communication with game-theoretic approaches has been proposed. In [10], [11], Yin *et al.* and Wang *et al.* both formulated a two-stage Stackelburg game and made the system power efficient while guaranteeing the fairness between cellular and D2D users. On the other hand, in [12], Zhang *et al.* modeled the system in which both D2D pairs and cellular users reach for a set of resource blocks. They made the users cooperate with one another in a coalition-game-approach. In [13], Akkarajitsakul *et al.* allocated diagonal channels to cellular users and modeled the cooperative behaviors of D2D pairs in transmission mode selection by an distributed coalition formation algorithm. In [14], Yu *et al.* proposed three different spectrum sharing modes in the system which contains a D2D pair and a cellular user in single cell.

Though there are already many works discussing about the resource allocation problem in D2D communication overlaying cellular system in the game-theory approach, most of them made efforts on maximizing spectrum efficiency or power efficiency in systems which D2D users shared the spectrum with cellular users. All previous works assume that the quality is known by the BS and therefore they can do efficient allocation. This assumption may not be true in the real system. If the assumption fails, all previous works fail, and therefore we propose the contract design to deal with this problem.

## III. SYSTEM MODEL

In this section, we first introduce the D2D communication scenario we consider, and then formulate a mathematical model about the LTE-Advanced system with resource allocation problem.

The basic scenario we consider is an LTE-Advanced system which provides a typical cellular communication service. In each cell there is one BS, which acts as a spectrum license holder. So every UE who wants to transmit has to request a permission from the BS. The system provides D2D service

as an alternative choice in addition to cellular service. When UEs utilize D2D service among themselves, they still require permissions from the BS. Additionally, the resource is allocated to the UE with a specific payment, which may differ in service type and the characteristics of UEs as well.



① Request for communication
② Ack with call for channel quality
③ Estimation of channel quality
④ Report channel quality
⑤ Service parameters
⑥ Reply service mode $(P_{cell}, B_{cell})$, $(P_{D2D}, B_{D2D})$
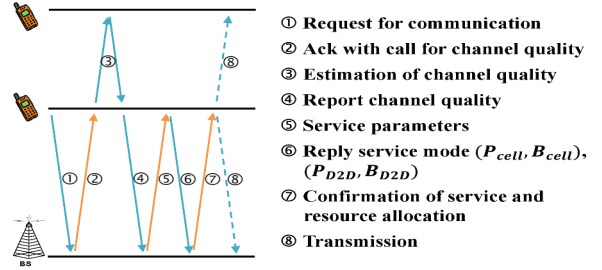⑦ Confirmation of service and resource allocation
⑧ Transmission

Fig. 1: System Scheme of BS-centric Model

The D2D communication set-up mechanism works as follows. Every communication incident is first launched by a request from an the UE, who sends the request to the BS with receiving destination and other related information. Then the BS will determine its service reply, in which contains the price-service offer of both cellular service and D2D service, based on the information it receives from the UE. At the end is the confirmation from the UE, which presents whether the UE wants to choose D2D service or cellular service.

Formally speaking, the BS provides two services, which are cellular service $(B_{cell}, P_{cell})$ and D2D service $(B_{D2D}, P_{D2D})$. In cellular service, the BS allocates an amount of resource $B_{cell}$ and determine the price $P_{cell}$ for taking the service. Then the UE transmits its packets to the BS in traditional cellular communication. In D2D service, the BS also allocates resource $B_{D2D}$ and sets a per unit price $P_{D2D}$ to the UE, legalizing the transmission between UEs. But after that, the UE can transmit its packets to the destined receiver directly.

A significant difference between each service is the channel quality $Q$ experienced by UEs. Here we represent the service quality in each service by means of the throughput, which can be derived by channel quality and resource amount. Then we consider the Shannon Capacity as the expected throughput.

$$C = B \times log_2(1 + SINR)$$

where $C$ is the expected throughput, $B$ is the used bandwidth and $SINR$ is the Signal Interference plus Noise Ratio. To simplify the expression, in this article we define channel quality as $Q = log_2(1 + SINR)$ and define resource quantity as $B$. Thus, we can simply express the expected throughput $C = B \times Q$.

Payment of resource allocation is the main issue in our work. Since BS is the one who holds the spectrum license, allocation should be carefully determined in order to maintain spectrum efficiency while maximizing total profit of the BS. On the BSs aspect, it not only determines the price/resource parameter to optimize efficiency and its profit, but has to guarantee that UEs will be willing to accept the service.

$$\arg \max_{P_{D2D}} R_{BS}(P_{D2D}, B_{cell}, P_{cell}, B_{D2D})$$
$$where \ U_{D2D} \geq U_{cell} \tag{1}$$

The BS's decision is based on the channel qualities of both service modes reported by UEs. Ensuring the faithful report of UEs is a key factor of forming an efficient system.

## IV. GAME MODEL

Game theory is suitable for our problem. Under our system model, the BS should analyze the final outcome under every specific service price it offers and then determine an optimal service. On the other hand, UEs choose the service offer that maximizes their own utility. The final outcome is determined by the interactions between the BS and UEs. Game theory is applicable to analyze this problem since the system we consider involves interactions and selfish behaviors. A basic game model consists of the following elements: players, actions and utility functions.

In our system the BS affirmed the right of UEs to use the resource before the devices can start to transmit its packages. We construct a game approach as the backbone of our model.

*1) Players and Actions:* This game has 2 players: the BS and the UE. The BS determines offers of D2D/cellular services and the UE can choose one of them.

*2) Utility function of UEs:* In general, we assume the utility function of UEs has the following characteristics: (i) Utility increases concavely in quantity. (ii) Cost for spectrum resource increases in quantity. In our work, we propose the utility function with parameters mentioned in *Table I* as follows.

$$U(B, P) = \beta \ln(1 + B \times Q) - P \times B, \qquad (2)$$

*3) Profit function of the BS:* The profit of the BS will be the revenue it receives minus the cost of offering the service. In this work we assume that the cost for leasing the spectrum increases convexly in quantity, thus the revenue function is concave in quantity. The profit of the BS is:

$$R_{BS}(B, P) = P \times B - C(B) \qquad (3)$$

where we set the cost function $C(B) = c \times B^2$ in our work.

In the following sections, we design two mechanisms for analyzing resource allocation problem under different assumptions of the channel quality reported by UEs.

1) Perfect Information, BS-centric (PIBS)
2) Unknown quality, BS-centric (UQBS)

In the PIBS game, BS knows the exact channel quality experienced by UEs. In the UQBS game, UEs may lie to the BS with fake channel qualities. With these models, we can study how the UCQ problem affects the performance in D2D system.

## V. PERFECT INFORMATION, BS-CENTRIC ALLOCATION

In this section, we introduce a game that the BS has perfect information about the channel quality. We are curious about how the system performance will become in equilibrium.

The game mechanism is the same as described in *Section III*. The strategy set of the BS is choosing cellular/D2D service $[(P_{cell}, B_{cell}), (P_{D2D}, B_{D2D})]$. And, the strategies of UEs is transmitting in either cellular mode $B = B_{cell}$ or D2D mode $B = B_{D2D}$. In the PIBS game, the UE will reply its experienced channel quality to the BS in step 4 in *Fig. 1*. Then the BS will determine its strategy based on the reported channel quality.

### A. Strategy Analysis

The PIBS game can be classified as a Stackelburg game and solved with the leader-follower backward induction approach. We can analyze the strategy of the follower, which are UEs. Given the expected strategies of UEs, we then analyze how the BS determines its optimal strategy accordingly.

*1) the UE's strategy:* In PIBS game, the device can only choose to utilize D2D service or cellular service based on different (price, quantity) pairs given by the BS. We would like to know which D2D mode offer will be accepted given the quantity and price pair for cellular mode. As mentioned above, UEs will reject the D2D offer if it violates the willingness constraint (1). The UE will accept all the D2D offers except those mentioned above in D2D mode.

*2) BS's strategy:* In order to maximize the profit, the BS tries to determine the most profitable quantity and price pair under the constraint of the UE's willingness to accept the offer.

**Lemma 1.** $U^* = U_{cell}$ holds when BS maximizes its profit.

*Proof.* Refer to (3), we can see that the BS can always improve its profit by increasing the price $P$ under every fixed quantity $B$. A rational UE will choose the D2D service only if $U_{D2D} \geq U_{cell}$. Consider any feasible $(P_{D2D}, B_{D2D})$: If $U(P_{D2D}, B_{D2D}) > U_{cell}$, let $P'_{D2D}$ be the solution solved from $U(P'_{D2D}, B_{D2D}) = U_{cell}$. Since the utility function $U(P, B)$ strictly decreases in $P$ and $U(P_{D2D}, B_{D2D}) > U(P'_{D2D}, B_{D2D})$, we derive that $P'_{D2D} > P_{D2D}$, implying $R_{BS}(P'_{D2D}, B_{D2D}) > R_{BS}(P_{D2D}, B_{D2D})$ because the profit of the BS increases in $P$. The result contradicts the assumption that the BS has already maximized its profit. $\square$

With *Lemma 1*, we can present the price $P$ as a function of resource quantity, $P(B)$, by solving the equation as boundary condition. By replacing $P$ with $B$ in the profit function $R_{BS}$, we can derive the resource quantity which maximizes the profit: $B^* = \arg\max_B R_{BS}(B)$. Since $R_{BS}(B)$ is a concave function, letting $\dfrac{\partial R_{BS}}{\partial B} = 0$ can maximize the BS's profit. So the best strategy of the BS is

$$B = \frac{-1 + \sqrt{1 + \dfrac{2C}{\beta} \ln Q^2}}{2 \ln Q} \qquad (4)$$

$$P = \frac{\beta \ln(1 + SQ) - U_{cell}}{B} \qquad (5)$$

*3) System Performance:* According to *Lemma 1*, the BS can always extract the UE's utility by increasing the price, as long as it satisfies the willingness constraint (1). Furthermore, the BS can achieve a NE in D2D system by slightly decreasing the price from its best strategy in a discrete pricing scheme.

Observing the results in (4) and (5), we find out that as the channel quality increases, the price the BS offers will increase, as expected. However, the resource quantity that the BS allocates will stay approximately unaffected when the channel quality changes. When the channel quality is good enough, that is, $BQ >> 1$, the utility function can be simplified as $U(B) = \ln(BQ) - PB$, and the resource quantity that the BS allocate becomes independent of channel quality.

## VI. UNKNOWN QUALITY, BS-CENTRIC ALLOCATION

In this section, we will discuss the challenge when the UCQ problem exists in the system. We adopt the BS-centric system introduced in *Section V* and design a new mechanism to resolve the UCQ issue.

The game mechanism is the same as the PIBS game except that, in the UQBS game, we allow UEs to lie about their channel qualities. Under this scenario, we assume that there are N different types of channel quality: $Q_1, Q_2, \cdots, Q_N$. All devices share the similar utility functions that are only different in their channel qualities. In the system, the BS knows the distribution of UEs' channel qualities, but it doesn't know the exact channel quality of any UE.

**Definition 1.** *The total profit function of the BS is the sum of profit from all types of UEs it serves. $R_{total} = a_1 R_1 + a_2 R_2, \cdots, a_N R_N$, with $R_k = P_k \times B_k - c \times B_k^2$ ($a_k$: number of devices of type k)*

It is hard to analyze the best response of all types of UEs and the BS in general mode directly. Instead, we start from $N = 2$ first and then expand our result to general case.

**Lemma 2.** *If there are only two types of UEs, the equilibrium $(P_1, P_2)$ are as follows:*

$$P_1 = \frac{\beta \ln(1 + B_1 Q_1) - U_{cell}}{B_1} \quad (6)$$

$$P_2 = \frac{\beta}{B_2} \ln(\frac{(1 + B_2 Q_2)(1 + B_1 Q_1)}{1 + B_1 Q_2}) - \frac{U_{cell}}{B_2} \quad (7)$$

*Proof.* There are 2 types of UEs, sharing similar utility functions which differ only in channel quality $Q_1$, $Q_2$. Assume channel quality of type 2 is better than type 1: $Q_2 > Q_1$ (without loss of generality). For Type 1, we can maximize the profit of the BS by satisfying $U_{D2D}^{Q_1} = \beta \ln(1 + B_1 Q_1) - P_1 B_1 = U_{cell}$. The reason is similar to PIBS game. Now we can solve the relationship between $P_1$ and $B_1$.

$$P_1 = \frac{\beta \ln(1 + B_1 Q_1) - U_{cell}}{B_1}$$

Now, we need to introduce contract theorem for determining $P_2, B_2$. If any type 2 device lies their channel quality to get $P_1, B_1$ offer, it will get a positive utility. The contract must take this situation into consideration to obviate lying of type 2 devices. So the contract must satisfy the following inequality:

$$U_{D2D}^{Q_2} \geq \beta \ln(1 + B_1 Q_2) - P_1 B_1 = U_{cell} + \beta \ln(\frac{1 + B_1 Q_2}{1 + B_1 Q_1})$$

To maximize the profit of the BS, the equal sign of above equation must holds. The reason is similar to the proof in *Lemma 1*. Then we can solve the $P_2$ in equilibrium.

$$P_2 = \frac{\beta \ln(1 + B_2 Q_2) - U_{cell} - \beta \ln(\frac{1 + B_1 Q_2}{1 + B_1 Q_1})}{B_2}$$

The above equation can be rearranged to (7). □

With *Lemma 2*, we can get the profit function of the BS in $B_1$, $B_2$ by solving the equations of $P_1$ and $P_2$. Then we can use the total profit function of the BS, solving partial differential equations to get the exact value of $B_1$, $B_2$.

From the above analysis, we discovered that when $BQ \gg 1$, the solution induced under original utility function will approximate to the solution derived from $\beta \ln(BQ) - PB$.
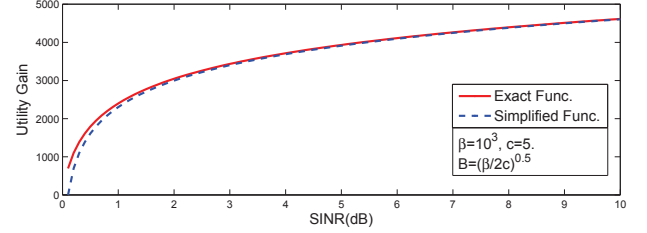


Fig. 2: Comparing Estimated Solution with Exact Solution

As *Fig. 2* portrays, the difference between two solutions is smaller than 1% when SINR≥3. It suggests that when the channel quality is good enough($BQ \gg 1$), the original exact utility function can be replaced by a simplified one, $\beta \ln(BQ) - PB$. With this simplified one, we can start to analyze the general system with N different types of devices.

**Lemma 3.** *With the simplified function $\beta \ln(B_k Q_k) - P_k B_k$, all types of UEs which the BS serve will be allocated the same resource $B_k = \sqrt{\frac{\beta}{2C}} \quad \forall k \in [1, N]$ in equilibrium.*

*Proof.* The same method can be used to solve N types of devices. The following equations must hold when the profit of the BS is maximized.

$$U_{D2D}^{Q_1} = \beta \ln(B_1 Q_1) - P_1 B_1 = U_{cell} \quad (8)$$

$$U_{D2D}^{Q_2} = \beta \ln(B_2 Q_2) - P_2 B_2 = U_{cell} + \beta \ln(\frac{Q_2}{Q_1}) \quad (9)$$

$$\vdots$$

$$U_{D2D}^{Q_N} = \beta \ln(B_N Q_N) - P_N B_N = U_{cell} + \beta \ln(\frac{Q_N}{Q_1}) \quad (10)$$

From the above equations, the constant term will disappear in the process of differentiation, so the optimum $(B_k, Q_k)$ pair of the BS remains unaffected by other types of devices. We can solve each $B_k \forall k \in [1, N]$ as follows:

$$B_k = \sqrt{\frac{\beta}{2C}} \quad \forall k \in [1, N]$$

All devices will be allocated the same resource quantity. □

With the same resource quantity, they must have the same resource price, which means the BS gives different types of devices the same contract when $BQ \gg 1$.

From the previous paragraph, we find out that when $BQ \gg 1$, the BS will give different types of device the same $(P, B)$ offer. The quantity is always equal to $\sqrt{\frac{\beta}{2C}}$; and the price is determined by the type with lowest channel quality which the BS would like to provide D2D service. From the perspective of BS, a higher price leads to a higher per-UE profit, but implies fewer UEs will adopt D2D service, and vice versa. In order to maximize the profit, we find an optimal boundary channel quality that the BS is willing to serve to balance between these two effects. We first provide the necessary condition under which the BS will give up a certain type of devices.

**Lemma 4.** *Let $k \in \mathcal{N}$, if k satisfies the inequality*

$$\frac{a_k}{\sum_{i=k+1}^{N} a_i} \leq \frac{\beta \ln(\frac{Q_{k+1}}{Q_k})}{\frac{\beta}{2}(\ln(\frac{\beta Q_k^2}{2C}) - 1) - U_{cell}}$$

*forgoing D2D service profit from type 1 to k will be a possible solution for the BS pursuing the profit maximization.*

*Proof.* At first, we serve all types of devices with channel qualities from $Q_1$ to $Q_N$, the profit of the BS is $a_1 R_1 + a_2 R_2 + \cdots + a_N R_N$, with $R_k = P_k B_k - C B_k^2$. Because all devices get the same contract, we can arbitrary suppose $Q_1 \leq Q_2 \leq \cdots \leq Q_N$ without loss of generality, the function will be simplified as:

$$\sum_{i=1}^{N} a_i (P_1 B_1 - C B_1^2) \tag{11}$$

$$where \quad P_1 B_1 = \frac{\beta}{2} \ln(\frac{\beta Q_1^2}{2C}) - U_{cell} \tag{12}$$

$$C B_1^2 = \frac{\beta}{2} \tag{13}$$

If the BS chooses not to serve devices from type 1 to type k-1, it will lose clients among these types, $\sum_{i=1}^{k-1} a_i$, but still serves type k to n. The lowest channel quality from type k to N is $Q_k$, which means the BS can raise the price to a new $P_k$, treating the type k as previous type 1, to increase its profit. The profit function of the BS is similar to (11)-(13), replacing all parameters of type 1 to type k.

When the BS chooses whether refusing to serve type k devices or not, it checks if the following profit function hold:

$$\sum_{i=k+1}^{N} a_i (P_{k+1} B_{k+1} - C B_{k+1}^2) \geq \sum_{i=k}^{N} a_i (P_k B_k - C B_k^2) \tag{14}$$

Then, we can substitute the result of *Lemma 3* into the above equation and reduce it as follows.

$$\frac{a_k}{\sum_{i=k+1}^{N} a_i} \leq \frac{\beta \ln(\frac{Q_{k+1}}{Q_k})}{\frac{\beta}{2}(\ln(\frac{\beta Q_k^2}{2C}) - 1) - U_{cell}} \tag{15}$$

$\square$

If the inequality of *Lemma 4* is satisfied, refusing to provide service for those UEs from type 1 to type k is a possible way to increase the profit of the BS. However, finding the first k and adopting it do not guarantee a maximal profit of the BS because *Lemma 4* only compares the difference of profit between serving type k or not. When UEs can be categorized to many different types, there may exists a set of k satisfying the inequality. Each k has a potential to be the solution for achieving maximum profit of the BS.

In order to solve the UCQ problem, we introduce the linear search algorithm: *Algorithm 1* to compute the optimal serving type set of the BS. First, we use the inequality in *Lemma 4* to define a Possible Unavailable Set $K$, which the BS may not will to serve in D2D mode. By doing so, we limit the search space to a Possible Unavailable Set to avoid the heavy load of computing all types of devices. Then, we use linear search to compare the BSs profit with each possible k to find the optimal solution.

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**Algorithm 1** A Linear Search Algorithm for UQBS System

**Input:** Number of UEs, Channel Quality, and Price of Channel quality of each type: $a_i, i \in [1, N]$; $Q_i, i \in [1, N]$; $P_i, i \in [1, N]$; c=cost;
**Output:** The most profitable choice $K_{opt}$.
1: Initial $K_{opt}$=1; $profit\_t$=0; $profit^*$=$(P_1 Q_1 - c * Q_1^2) \sum_{l=1}^{N} a_l$.
2: Use the inequality in *Lemma 4* to find all possible $K_i, i \in [1, m]$, then store it.
3: **for** each $j \in [1, m]$ **do**
4:      initial $profit\_t = P_{K_j} Q_{K_j} - c * Q_{K_j}^2) \sum_{l=K_j}^{N} a_l$.
5:      **if** $profit\_t > profit^*$ **then**
6:          $profit^*$= $profit\_t$, $K_{opt} = K_j$.
7:      **end if**
8: **end for**
9: Return $K_{opt}$.

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With *Algorithm 1*, we derive what kinds of UEs the BS should serve with D2D service. In the real world, forgoing such kinds of UEs can be achieved by setting a lower bound of D2D mode. For those UEs with poor channel qualities, they can use cellular mode only; conversely, others with channel qualities higher than lower bound have the right to select a transmission service between cellular and D2D mode.

## VII. SIMULATION RESULT

In this section, we would like to evaluate the performance of the proposed D2D-cellular systems and mechanisms. First, we analyze the behavior of the BS and the equilibrium under UQBS game, showing the profit of the BS under different distributions of channel qualities. Then, we verify the efficiency of the system by comparing the performance between optimal situation and the scenario under UQBS game. In general, all the notations in our simulation are mentioned in *Table I*; and we set the same system parameters for the following simulations with satisfactory weighting factor $\beta = 1000$, and cost weighting factor $c = 5$.

### A. Strategy of UQBS varies with distribution

In the UQBS system, we would like to know how the BS's strategies will be affected under different distributions. Here we assume there are 100 different types of UEs with $SINR = 0.4i \ dB, i \in [1, 100]$. We compare four different systems with various distributions, which all have the same mean value, to figure out the importance of distributions in the BS's strategies.

As *Fig. 3* shows, the strategy of the BS in UQBS varies with distribution. Each point on *Fig. 3* shows the BS's profit when the BS sets the lower-bound channel quality there. The highest point with each color marks the highest profit of the BS under such distribution. The channel quality it corresponds to, pointed by the arrow, is the optimal strategy for the BS to set the lower-bound channel quality at that level. This simulation brings out two facts: first, if a system includes relatively more devices with higher channel quality, the BS will set a higher lower-bound, and vice versa. Second, in a more
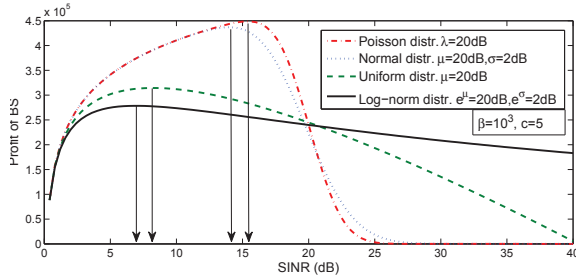
Fig. 3: Serving Different kinds of UEs under each Distribution

concentrated distribution, the BS will set a lower-bound closer to the average SINR than a dispersed one. The phenomenon is reasonable because the less UEs in extremes implies the lower cost in BS's strategies for not serving extreme type users but the greater loss for not serving central type users.

### B. System Efficiency of UQBS under Normal Distribution

After we know the set of UEs which the BS should serve with D2D service in UQBS game, we want to know how much the efficiency is improved in our solution and the difference between our solution to the social optimal system. This subsection will show the efficiency improvement of our solution.
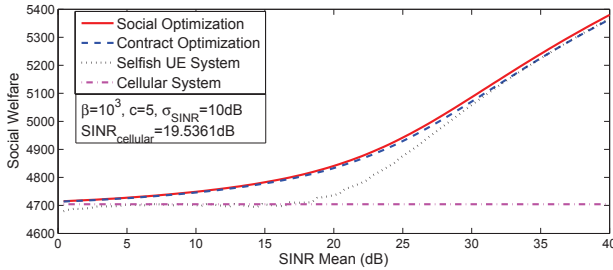


Fig. 4: System efficiency comparison

In *Fig. 4*, we adopt a outdoor D2D scenario in a 19 cell model with 150 UE/75 D2D pairs in central cell to analyze. The interference of D2D communication comes from the BS from neighboring cells. In this system, we set the UE's utility in cellular mode $U_{cell}$ constant and the same as utility at $SINR = 19.5361 \ dB$, which is derived from the SINR average of UEs in 10,000 differnt 19-cell system located randomly. And the distribution of each mean of SINR in D2D mode is portrayed from 750,000 D2D pairs selected randomly. Then, we assume that the BS has the ability to distinguish UEs in 100 different types. The selfish UE mechanism in the figure represents that the BS has no requirements and is free to serve anyone who wants to use D2D mode, so UEs are free to choose D2D or Cellular mode according to the channel quality experienced by the UE. The social optimization represents the social optimal system, which is a system that the BS knows the real channel quality of each UE and can fully control the transmission mode of them. From *Fig. 4*, obviously, our mechanism, introducing contract theorem and linear search algorithm, in UQBS game improves the system efficiency and the result almost fits the social optimal system.

## VIII. CONCLUSION

D2D Communication has great potential to be a widespread transmission approach under LTE-Advanced Systems. In this paper, we proposed a BS-centric system scheme for D2D resource allocation. By applying game theory, we modeled the selfish behaviors of the BS/UE and derived the equilibrium. Then, we focused on the Unknown Channel Quality(UCQ) problem which exists uniquely in D2D communication. A contract-based mechanism with the linear search algorithm is proposed to resolve the UCQ problem by maximizing the profit of the BS and obviating the deviation of UEs. Simulation result shows that the proposed mechanism improves system efficiency and the performance is close to the optimal system.

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