Bandwidth Price Optimization for D2D Communication Underlaying Cellular Networks

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Abstract—The device-to-device (D2D) communications has been recently proposed for reducing the cellular network traffic by directly connecting the local nodes. In this paper, we consider a cellular based primary network co-existing with a cognitive D2D pair. The primary network consists of a BS and multiple traditional cellular users which can sell their spectrum to the D2D user. In addition, under low interference conditions, the spectrum can be simultaneously shared between cellular users and D2D capable users, which is called non-orthogonal sharing mode (NOS). Therefore, in the auction, the D2D transmitter has three types of service providers (SP) or sharing modes. The SPs are operating on different frequency spectrums and a D2D capable pair intends to share these spectrums. This situation is formulated as a auction game where a D2D transmitter bids a demand curve and each SP offers a supply curve. The Nash equilibrium point of the auction game is obtained analytically.

I. INTRODUCTION

Cognitive radio is a promising method to solve the spectrum scarcity problem [1]–[5]. Certain radio resources could be employed by cognitive radio network, i.e. the secondary system, provided that it does not cause an adverse interference to the primary system, a.k.a. spectrum owner or licensee. Recently, technologies based on the concepts of cognitive radio networks have been used for the design of Device-to-Device (D2D) communications in cellular networks [6]–[8]. In this paper, we consider two types of spectrum access models, namely, spectrum underlay and dynamic exclusive-use model [9]. At different points in time, the device-to-device (D2D) capable users are accessing the spectrum, and the types of wireless service using that spectrum can be changed. Under low interference conditions, the radio spectrum can be simultaneously shared between cellular users and D2D capable users, which is called spectrum underlay model. On the other hand, in a dynamic exclusive-use model, a spectrum owner can trade its own spectrum to a cognitive radio user, and thus can earn revenue. This spectrum can then be accessed by a cognitive D2D user for a certain period of time (i.e. an on-demand time-bound spectrum lease [10]). This trading is referred to as a secondary market [11], [12]. Considering that interference minimization is a key point and multiple D2D pairs sharing the same resources can bring large benefits on system capacity, in [13] the problem is formulated as a auction game among D2D devices and the detailed non-monotonic descending price auction algorithm is proposed. In [14], the problem of competitive pricing in a dynamic spectrum access is addressed using an oligopoly market where few firms compete with each other in terms of price to gain the highest profit. For this purpose, a Cournot model is proposed in [14] to model the interaction among secondary users and service providers (SP). However, in Cournot model, it was assumed that all requested bandwidth is provided by the primary user and price is forced from the primary user to secondary users. Authors in [15] proposes a double auction mechanism in dynamic spectrum sharing problem, which allows the suppliers and the bidders to play an auction game that involves supply strategy for suppliers and price bid strategy for bidders. In this way, suppliers do not have any contribution to the price and bidders do not have any contribution to the amount of bandwidth which is not an appropriate assumption. In addition, none of these works calculated the Nash equilibrium analytically.

In this paper, the system consists of the BS, multiple traditional users and a D2D pair of users that communicate using licensed spectrum resources. Both the BS and traditional users are capable to provide bandwidth for the D2D users. Moreover, it is possible that the D2D and cellular users re-use the same spectrum, causing interference to each other. Thus, the D2D transmitter is able to operate in orthogonal spectrum modes via BS or traditional users, or it can operate in non-orthogonal mode by sharing the same bandwidth with other existing users. In this way, we can consider the BS, traditional cellular user, and D2D devices as our players (suppliers and demanders) and BS as our broker. Therefore, the BS is responsible for providing demand for the D2D capable device and purchasing the spectrum capacity from the BS and users. In our model, the BS and the D2D user are trying to maximize their own payoff in a bandwidth auction game. Inspired by [16], it is assumed that the D2D user bids a demand curve and each service provider offers a supply curve which is the price as a function of bandwidth. Each point on the supply and demand functions represents the desired amount of selling and buying bandwidth at the specified level of price for the D2D user and service providers, respectively. The clearing price and bandwidth for the D2D user and SPs are obtained by balancing

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the supplies and demand. Then, the problem is solved with complete information and the corresponding Nash equilibrium point of the game is achieved.

II. SYSTEM MODEL

We consider a single cell in a cellular based primary network which is cable of supporting D2D underlay communication. Each mobile user within a cell can operate in the traditional cellular mode or in the D2D mode. The traditional cellular mode is the communication via BS. To operate in D2D mode, there should be a pair of users which satisfy the distant and interference constraints. That is, if the source and destination users are within a cell and they are close enough not to interfere much other existing cellular users, they are called D2D users $U^d_1$ and $U^d_2$, respectively. All the coordinations are done at the BS, and thus, the communication demand should be sent to the BS to setup up a session. The BS processes the demand and allows the D2D communication if the following conditions are satisfied:

- The interferences experienced by other cellular users are below a threshold.
- The interference received at the receiving potential D2D pair is also acceptable.
- The cellular operator is under heavy load and it prefers to reduce its revenue by offloading part of its demand to D2D users which do not consume a separate allocated bandwidth.

Once the D2D mode is chosen for a pair of user, we should allocate resources for the D2D users. The sharing of resources between D2D and traditional cellular users is determined by the BS. Here, similar to [7], we consider three resource allocation modes for the D2D pair:

- Non-Orthogonal Sharing mode (NOS): D2D and cellular users re-use the same resources, causing interference to each other.
- Orthogonal Sharing mode (OS): D2D communication gets part of the resources and leaves the remaining part of resources to the cellular user. There is no interference between cellular and D2D communications.
- Cellular Mode (CM): The D2D users communicate with each other through the BS that acts as a relay node. Note that this mode is conceptually the same as a traditional cellular system.

We optimize the bandwidth price and quantities in all of these modes, to understand what can be optimally reached in a D2D system based on NOS, OS, and CM. Hence, in the D2D system, there are three options for the $U^d_1$ to communicate to $U^d_2$. Assume that the system is based on orthogonal frequency division multiple access (OFDMA) which is compatible with LTE-A networks. The BS is responsible for the bandwidth allocation and it is also acts as a broker to maximize the profit of both the operator and users. For three modes stated above, the BS has the following procedure for the bandwidth allocation:

1) The BS can allocate some subcarriers to the D2D pair as long as interference received at the traditional users are within a margin and interference at $U^d_2$ is tolerable. We call this allocated bandwidth as $s_1$. In this mode, $U^d_2$ gets some earnings and BS ensures that the interference from $U^d_1$ does not cause problem for the rest of cellular users.

2) In the OS mode, one or several of the traditional cellular users, named $U^n_n$, $n = 1, \ldots, N$, act as bidders by providing part of their subcarriers to the D2D pair. The allocated bandwidth in this case is denoted as $s_j$, $j = 2, \ldots, N + 1$, and the BS gives some incentive to the users to encourage them to collaborate when they are in the idle state.

3) In the CM mode, the BS acts as a relay node, and it should provide the uplink bandwidth $B_{UL}$ plus the downlink bandwidth $B_{DL}$ to the D2D pair, and the D2D user should pay the bandwidth price to the operator. Thus, the allocated spectrum becomes $s_{N+2}$.

Based on three options stated above, there are three type of players ($U^d_1$, $U^d_2$, and the operator) who act as service providers for the D2D transmitter $U^d_1$. Thus, service provider (SP) $j$ wants to sell its available spectrum $s_j$, i.e., subcarriers in a OFDMA based wireless access system at price $\alpha^d_j$ per unit spectrum or bandwidth) to the D2D user $U^d_1$. Note that $U^d_2$ do not sell the separate spectrum. Indeed, the coordinator (BS) provides the spectrum $s_j$ to the D2D pair. Thus, D2D nodes can co-exist with other cellular users in that spectrum without allocating a separate bandwidth. In this case, since $U^d_2$ suffers from the interferences from the coexisting users, we put her in the seller side.

The D2D transmitter $U^d_1$ utilizes adaptive modulation for transmissions on the allocated spectrum. The spectrum demand of the D2D user depends on the transmission rate due to the adaptive modulation in the allocated frequency spectrum and the price charged by the service providers. With adaptive modulation, the transmission rate can be dynamically adjusted based on the channel quality. By treating interferences as noise, the spectral efficiency of transmission by the $U^d_1$ in NOS mode can be obtained from [17]

$$k_1 = \log(1 + K \gamma_1), \quad K = \frac{1.5}{\ln(0.2/\text{BER}_{\text{tar}})}$$

where $\gamma_1 \triangleq \frac{P_0|h_d|^2}{\sigma^2 + I_2}$, $h_d$ denotes the channel coefficient between $U^d_1$ and $U^d_2$, and $\text{BER}_{\text{tar}}$ is the target bit-error-rate (BER). The D2D transmit power $P_d$ is adjusted by the controller at the BS to satisfy the interference constraint at the cellular nodes. The parameters $\sigma^2$ and $I_2$ are variance of AWGN noise and power of interference at the receiving D2D node $U^d_2$. Note that we assume static channels with path-loss model and we have $|h_d|^2 = (d_0/d_{1,2})^\nu$ where $d_{1,2}$ is the distance between nodes $U^d_1$ and $U^d_2$, $\nu$ is the path-loss exponent, which is typically lies in the range of $2 \leq \nu \leq 6$, and $d_0$ depends on the operating frequency.

For the OS mode, the spectral efficiency of transmission by the $U^d_1$ is given by

$$k_i = \log_2(1 + K \gamma_j),$$
respectively.

specified level of price for the user and service providers, the desired amount of selling and buying bandwidth at the Each point on the supply and demand functions represents

that $U_j$ is located at the BS. The broker knows the supply function

ties are conducted by a central entity, called the broker which

resources effectively by assigning the bandwidth from SPs to

transmitter. Balancing the bandwidth supplies and demand,

is located in the range of the proposed

transmit power emitted from $BS$, which indicates channel quality, and $P_c$ is the transmit power in the CM mode. In (3), we assumed the distance of the D2D pair to the BS is much larger than $d_{1,2}$, and thus, $d_{1,BS} \approx d_{BS,2}$, and channel reciprocity exists for the uplink and downlink transmissions. The term $\frac{1}{2}$ in (3) is due to the two hop transmission via BS and it is assumed that the uplink and downlink links have equal bandwidth.

In our model, $N$ traditional cellular users, base station and $U_2^d$ are SPs and form a supply side, and $U_1^d$ is a service user or demand side. Both sides are the players who want to maximize their own payoff in a bandwidth auction game. It is assumed that $U_1^d$ bids a demand curve and each service provider offers a supply curve which is the price as a function of bandwidth. Each point on the supply and demand functions represents the desired amount of selling and buying bandwidth at the specified level of price for the user and service providers, respectively.

We assume a uniform price auction. All the auction activities are conducted by a central entity, called the broker which is located at the BS. The broker knows the supply function offered by each SP, and the demand function of the D2D transmitter. Balancing the bandwidth supplies and demand, a uniform price is cleared for SPs and the D2D user. After clearing the price, the broker is responsible for allocating the resources effectively by assigning the bandwidth from SPs to the D2D user. This scenario is shown in Fig. 1

III. BANDWIDTH AUCTION GAME MODEL

Considering a D2D user and $N + 2$ competing service providers, including $U_2^d$ from the D2D pair, $N$ traditional cellular users, and BS, the demand and supply functions are as follow

$$\lambda = -\alpha^D d + \beta^D,$$

$$\lambda = \lambda^S_j d + \beta^S_j, \quad j = 1, 2, \ldots, N + 2,$$

where $\lambda$ is the clearing price, $d$ is the purchased (demand) bandwidth by $U_2^d$ and $s_1, s_n, n = 1, 2, \ldots, N$, and $s_{N+1}$ are the supply (sold) bandwidth variables of $U_2^d$, traditional cellular users, and BS, respectively. The parameters $\alpha^D, \beta^D$ represent demand-side bandwidth dependent and demand-side bandwidth-independent prices at $U_2^d$, respectively. Also, $\alpha^S_j$ and $\beta^S_j$ represent supply-side bandwidth dependent and supply-side bandwidth-independent prices at the $j$th SP, respectively. Note that $\alpha^D, \beta^D, \alpha^S_j$, and $\beta^S_j$ are the positive numbers and represent the strategy of the players. The decreasing demand curve presented in (4) means that the D2D user buys more in lower prices and less in higher prices and suppliers sell more in higher prices and sell less in lower prices, which is economically meaningful.

The price is cleared when the total supply becomes equal to the demand

$$d = \sum_{j=1}^{N+2} s_j.$$  

(5)

Using equations (1) and (5), we have

$$\frac{\beta^D - \lambda}{\alpha^D} = \sum_{j=1}^{N+2} \frac{\lambda - \beta^S_j}{\alpha^S_j}.$$  

(6)

Therefore, the price is cleared as follows:

$$\lambda = \frac{\sum_{j=1}^{N+2} \beta^S_j}{\alpha^S_j} + \frac{1}{\alpha^S_j}.$$  

(7)

Note that $\lambda$ is the same for suppliers and it is a reasonable assumption since it is located in the range of the proposed prices of SPs. Since the price is cleared, the amount of bandwidth for each seller and buyer is determined according to their supply and demand functions as follow

$$s_j = \frac{\lambda - \beta^S_j}{\alpha^S_j}, \quad j = 1, 2, \ldots, N + 2,$$

$$d = \frac{\beta^D - \lambda}{\alpha^D},$$  

(8)

respectively. Also, the following conditions should be held

$$0 \leq s_j \leq s_j^{\max}, \quad j = 1, 2, \ldots, N + 2,$$

$$0 \leq d \leq d^{\max},$$  

(9)

where $s_j^{\max}$ and $d^{\max}$ are the maximum financial capacity of service provider $j$ and maximum request of the D2D, respectively. If any of the lower bound inequalities in (9) is violated, the corresponding demand/supply is set to zero. In the same way, if any of the upper bound inequalities is violated the corresponding demand/supply is set to the maximum capacity/request accordingly. The broker is responsible for purchasing the extra bandwidth from SPs and compensating the lack of supply for the user.
The payoff function of service providers is defined as follow
\[ \pi_j^S = \lambda s_j - C_j(s_j), \quad j = 1, 2, \ldots, N + 2, \]  
where \( C_j(s_j) \) is the cost of providing the bandwidth equal to \( s_j \) which is different for different types of suppliers and can be considered as a linear function of bandwidth as
\[ C_1(s_1) = (a_2^d + a_2^S) s_1 \]  
\[ C_j(s_j) = a_j^S s_j, \quad j = 2, \ldots, N + 1, \]  
\[ C_{N+2}(s_{N+2}) = a_{N+2} s_{N+2} \]  
where \( a_j^d \) is the price of the bandwidth that the D2D user 2 has paid to BS for purchasing the bandwidth and \( a_j^S \) is the unit cost of interference imposed on D2D user 2. In (11), \( a_j^d \) is a low price that \( U_j^S \) has paid to BS. The parameter \( a_j^S \), \( j = 2, \ldots, N + 1 \) is the price of the bandwidth that the cellular user \( j - 1 \) has paid to BS for purchasing the bandwidth, and \( a_{N+2} \) denotes the price associated with providing bandwidth for BS.

The payoff function of D2D user 1 is also defined as follows
\[ \pi_j^D = U(d) - \lambda d, \]  
where \( U(d) \) is the utility function of D2D user 1, defined as follows \[ U(d) = \sum_{j=1}^{N+2} r_j k_j s_j \]  
where \( r_j \) is the revenue of the D2D user per unit of the achievable transmission rate when operating under SP \( j \). This parameter can be interpreted as the D2D user preference.

The goal of each player, including the D2D user and service providers is to adjust his/her strategy (the coefficients of the supply and demand functions) to gain more payoff. However, since the price is a function of the strategies of all players, as it is stated in (7), this problem is a game problem rather than an optimization problem.

The optimal strategy of the players and solution of the game depends on the information available to the players. In the complete information case, the Nash equilibrium point of the game would be an optimal solution of the game, when the game is fully competitive and players decide simultaneously. However, in incomplete information case, the players are not aware of other players’ payoff function, and as a result, they cannot reach to equilibrium point in one shot. In the incomplete information case, the players learn their optimal strategy using the available information and historical data gained by the game repetition.

In the following, the problem is solved with complete information and the corresponding Nash equilibrium point of the game is achieved. Next, in incomplete information case, a gradient based method is proposed for learning the optimal decision of the players when the game is repeated. In addition, the convergence of the learning decisions to Nash equilibrium point (which is calculated in complete information case) of the game is examined.

For brevity in the mathematical calculations, in the rest of the paper we assume that \( \alpha^D \) and \( \alpha_j^S \) are some positive fixed constants and \( \beta^S \) and \( \beta^D \) are the strategies of the SP \( j \) and the D2D user, respectively.

In the Nash equilibrium point of the game, no player could earn more payoff by individually changing his/her strategy. Considering the reaction function of a player as the best strategy of a player to strategies of other players, Nash equilibrium point can be interpreted as the crossing point of reaction function of all players. The reaction function of a player could be obtained by the first derivative of the payoff function. In our problem, the reaction function of the users and service providers are as follows
\[ \frac{\partial \pi_j^S}{\partial \beta_j^S} = 0, \quad \frac{\partial \pi_j^D}{\partial \beta_j^D} = 0, \]  
for \( j = 1, \ldots, N + 2 \). Or equivalently, from (10) and (14), we have
\[ \frac{\partial \lambda}{\partial \beta_j^S} s_j + \frac{\partial s_j}{\partial \beta_j^S} - \frac{\partial C_j(s_j)}{\partial \beta_j^S} = 0, \]  
\[ \frac{\partial U(d)}{\partial \beta_j^D} - \frac{\partial d}{\partial \beta_j} + \frac{\partial \lambda}{\partial \beta_j^D} = 0. \]  
After making derivatives, we have
\[ \left( \sum_{j=1}^{N+2} \frac{\beta_j^S}{\alpha_j^S} \right) \left( \frac{2}{K} - \alpha_j^S - \alpha_j \left( 1 - K \alpha_j^S \right) - \beta_j^S \right) \left( K (\alpha_j^S)^2 \right) = 0 \]  
\[ \left( \sum_{j=1}^{N+2} \frac{\beta_j^S}{\alpha_j^S} \right) \left( -\alpha_j^D + \frac{2}{K} \right) + \alpha_j^D \sum_{j=1}^{N+2} \frac{r_j k_j s_j}{\alpha_j^S} - \beta_j^D \left( K (\alpha_j^S)^2 \right) = 0 \]  
\[ K = \frac{1}{\alpha_j^D} + \sum_{j=1}^{N+2} \frac{1}{\alpha_j^S}. \]  
Therefore, we obtain \( L \beta = c \), where
\[ \beta = [\beta_1^S \ldots \beta_{N+2}^S \beta_D]^T \]  
\[ L = [l_{j,i}]_{(N+3) \times (N+3)} \]  
\[ l_{j,j} = \frac{2}{K} - 1, j = 1, 2, \ldots, N + 2 \]  
\[ l_{j,i} = \frac{2 - K \alpha_i^S}{K \alpha_j^S}, \quad j, i = 1, 2, \ldots, N + 2, \quad i \neq j \]  
\[ l_{j,(N+3)} = \frac{2 - K \alpha_j^S}{K \alpha_i^S}, \quad j = 1, \ldots, N + 2, \]  
\[ l_{(N+3),i} = \frac{2 - K \alpha_i^D}{K \alpha_j^D}, \quad i = 1, \ldots, N + 2 \]  
\[ c^T = [c_1, \ldots]_{1 \times (N+3)} \]
Nash strategy
Nash strategy
−2
20
25
30
35
40
r
set a high value for
the D2D user to operate in the NOS mode, it is reasonable to
the traditional cellular user. Regarding Table II, to encourage
D2D service provider is considered to be lower than that of
the NOS mode, as shown in (1), the channel quality for the
D2D pair distance. In addition, because of the interference in
since the BS to D2D node distance is usually longer than the
mode is considered to be lower than other service providers,
the receiver, as stated in (2). The channel quality for the CM
that the channel quality
a

of the game would be:

Note that the channel quality
of the game by changing the channel quality between 9-22.
In Fig. 2. Fig. 2 and Fig. 3 shows the Nash equilibrium point
CM modes on the Nash equilibrium point of the game is shown

and a D2D transmitter as a demand user. The parameters of
We consider a cognitive radio environment with a BS, a tra-
tional Rayleigh distributed channels with normalized variance.

Therefore, the necessary and sufficient condition for existence
unique Nash equilibrium point is \( \det(L) \neq 0 \).

IV. Simulation Results

In this section, we provide numerical results, for indepen-
dent Rayleigh distributed channels with normalized variance.
We consider a cognitive radio environment with a BS, a tra-
tional cellular user and a D2D receiver as service providers
and a D2D transmitter as a demand user. The parameters of
the players are shown in Table I and II. The target BER for
the users is BER_{tar} = 10^{-4}. In Table I, \( a_1 = a_2^U + a_2^D \), where
\( a_2^U = 8 \) and \( a_2^D = 1.8 \), for the D2D service provider. Note
that the channel quality \( \gamma_i = \gamma, \) \( i = 1, \ldots, N \), is the SNR at
the receiver, as stated in (2). The channel quality for the CM
mode is considered to be lower than other service providers,
since the BS to D2D node distance is usually longer than the
D2D pair distance. In addition, because of the interference in
the NOS mode, as shown in (1), the channel quality for the
D2D service provider is considered to be lower than that of
the traditional cellular user. Regarding Table II, to encourage
the D2D user to operate in the NOS mode, it is reasonable to
set a high value for \( r_1 \).

The effect of changing the channel quality in NOS, OS, and
CM modes on the Nash equilibrium point of the game is shown
in Fig. 2. Fig. 2 and Fig. 3 shows the Nash equilibrium point
of the game by changing the channel quality between 9-22.
Note that the channel quality \( \gamma_i = \gamma, \) \( i = 1, \ldots, N \), is the SNR
at the receiver, as stated in (1). In the Nash equilibrium point,
by increasing the channel quality, the strategies of the users
become larger, since they are willing to buy more bandwidth
due to more satisfaction and the strategies of the service
providers become smaller, since they are willing to sell more
due to more demand. In addition, it is obvious from matrix
L and vector c, that if the slopes of supply/demand function
increase/decrease with the same order, the Nash equilibrium
point is not changed.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>( a_i^U )</th>
<th>( r_1 )</th>
<th>( r_2 )</th>
<th>( r_3 )</th>
<th>( \gamma_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>User1: D2D user ( U_1^d )</td>
<td>0.5-5-50</td>
<td>4.5</td>
<td>3</td>
<td>3</td>
<td>0.05-0.1</td>
</tr>
</tbody>
</table>

TABLE II

The Users Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>( a_i^U )</th>
<th>( r_1 )</th>
<th>( r_2 )</th>
<th>( r_3 )</th>
<th>( \gamma_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>User1: BS</td>
<td>0.6,6,60</td>
<td>9</td>
<td>10-20 dB</td>
<td>0.05-0.1</td>
<td></td>
</tr>
</tbody>
</table>

TABLE I

The SPS Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>( a_i^S )</th>
<th>( \gamma_i )</th>
<th>( r_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP1: D2D user ( U_2^d )</td>
<td>0.6,6,60</td>
<td>9.8</td>
<td>20-30 dB</td>
</tr>
<tr>
<td>SP2: Traditional user ( U )</td>
<td>0.45,4,5,45</td>
<td>8</td>
<td>30-40 dB</td>
</tr>
<tr>
<td>SP3: BS</td>
<td>0.6,6,60</td>
<td>9</td>
<td>10-20 dB</td>
</tr>
</tbody>
</table>

![Fig. 2. Nash strategies of SPs in different channel qualities \( \gamma_1, \gamma_2 \), and \( \gamma_3 \), as shown in Table III, in a network with BER_{tar} = 10^{-4}.](image)

![Fig. 3. Nash strategies of the D2D user \( U_1^d \) in different channel qualities \( \gamma_1, \gamma_2 \), and \( \gamma_3 \), as shown in Table III, in a network with BER_{tar} = 10^{-4}.](image)

Fig. 4 and 5 show the profit of the user and service
providers in the Nash equilibrium points, respectively. It is
shown that, although the simultaneous changing the slope
of supply and demand function has not any effect on Nash
equilibrium point, but it has a significant effect on profit. We
can see that the lower slope of the supply/demand functions
leads to higher payoff for both service providers and the
user. The reason is that lower slopes lead to an agreement
with larger amount of bandwidth in same price, which is
more beneficial for both parties. In addition, it is shown that
increasing the channel quality for users result in more profit
for both service providers and the D2D user. This is a good
incentive for service providers to offer bandwidth in high
quality channels to amend their performance and satisfy their
users, simultaneously. Moreover the service provider with the
lowest cost of bandwidth (\( a_2 = 8 \)) earns more payoff which is
an expected result. The same results would be happened with
different revenue coefficients for users.

V. Conclusion

We considered a single cell network consists of the BS,
multiple traditional users and a D2D pair of users that com-
communicate using licensed spectrum resources. In this paper, we proposed a new scheme based on supply and demand curves for SPs and D2D user, instead of bidding a constant value of price or bandwidth by SPs and D2D user as their bids. This results in the possibility of reaching an agreement in wider ranges of price and bandwidth. It was shown that the game has a unique explicit Nash equilibrium point under a simple condition. Simulation results showed that increasing the channel quality results in more profit for both service providers and the D2D user. This is a good incentive for service providers to offer bandwidth in high quality channels to amend their performance and satisfy their users, simultaneously.

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