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A Reciprocal-Selection-Based ‘Win–Win’ Overlay Spectrum-Sharing Scheme for Device-to-Device-Enabled Cellular Network

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Abstract: This paper proposes a reciprocal-selection-based ‘Win–Win’ overlay spectrum-sharing scheme for device-to-Device-enabled cellular networks to address the resource sharing between Device-to-Device devices and the cellular users by using an overlay approach. Based on the proposed scheme, the cell edge users intend to lease part of its spectrum resource to Device-to-Device transmission pairs. However, the Device-to-Device users have to provide the cooperative transmission assistance for the cell edge users in order to improve the Quality of Service of the uplink transmission from the cell edge users to the base station. Compared to the underlay spectrum-sharing scheme, overlay spectrum-sharing scheme may reduce spectrum efficiency. Hence, Non-Orthogonal Multiple Access technology is invoked at the Device-to-Device transmitter in order to improve the spectrum efficiency. The Stackelberg game is exploited to model the behaviours of the cell edge users and Device-to-Device devices. Moreover, based on matching theory, the cell edge users and Device-to-Device pairs form one-to-one matching and the stability of matching is analysed. The simulation results show that the proposed reciprocal-selection-based ‘Win–Win’ overlay spectrum-sharing scheme is capable of providing considerable rate improvements for both EUs and D2D pairs and reducing transmit power dissipated by the D2D transmitter to forward data for the EU compared with the existing methods.

Keywords: overlay spectrum-sharing; Device-to-Device; Stackelberg game; matching theory

1. Introduction

1.1. Background

A Device-to-Device (D2D) enabled cellular network was proposed for improving spectral efficiency and throughput of the cellular network, with the aid of direct peer-to-peer communication between the proximity devices [1–3]. More explicitly, in a D2D-enabled cellular network, the closely located user devices may directly connect to each other and bypass the cellular base station (BS), for the sake of reducing the energy consumption and the end-to-end delay. However, enabling D2D communication in a cellular network generates several technical challenges. As one of the important technical challenges, the cellular spectrum-sharing scheme may be classified into two categories, namely underlay and overlay spectrum-sharing strategies [4]. According to the underlay cellular spectrum-sharing scheme, the D2D devices are capable of accessing the same spectrum with cellular users, provided that they do not substantially interfere with the transmissions of cellular users. Hence, when the cellular and D2D users are occupying the same spectrum, the interference between them must be invested for designing appropriate underlay cellular spectrum-sharing scheme [4]. Under the overlay cellular spectrum-sharing scheme, the D2D devices can only access the cellular

channels which are not used by the cellular users. Compared to the underlay scheme, the spectrum efficiency of overlay cellular spectrum-sharing scheme may be limited by assigning a dedicated portion of the cellular spectrum to the D2D communication [4].

1.2. Related Work

D2D communication shares cellular spectrum resource with cellular users in two modes: underlay and overlay. Based on the underlay cellular spectrum-sharing scheme, the cellular users and the D2D devices simultaneously access the same spectrum band. Hence, the interference mitigation between D2D communication and cellular transmission is inevitable and significant [5–8], when underlay cellular spectrum-sharing scheme is exploited. Considering the interference generated by the D2D communications, a fair distribution of the cellular resources shared by the D2D transmission pairs was developed with the aid of Jain's fairness index method [5]. Moreover, in order to minimize the interference caused by multiple D2D transmission pairs which simultaneously share a single cellular link, a power control scheme was proposed for supporting underlay D2D communications [6–8]. Aiming for minimizing the interference generated by multiple D2D transmission pairs which share the spectrum resource in multiple cells, a spectrum-sharing scheme was proposed in [9]. The works in the above literature [5–9] focused on the mitigation of the interference between the underlay D2D communication and cellular transmission. Based on the overlay spectrum-sharing scheme, the cellular users and D2D users intend to access different channels. Hence, the interference between the D2D and cellular users were not considered in [10–12]. Without considering the interference between users, improving spectral efficiency in overlay mode is the main goal [10–12].

Based on cellular spectrum-sharing scheme, the benefits of the D2D-enabled cellular network may be improved with the aid of cooperative communications, where the relay node (RN) forwards the source's data. More explicitly, the cell edge user (EU) may suffer from the poor link quality due to high path loss and deep path fading. However, the D2D transmitter (DT) may be capable of improving the quality of service (QoS) for the cellular users by providing cooperation assistance [13,14]. Based on the underlay cellular spectrum-sharing scheme, many meritorious contributions have been made for improving the performance of the D2D-enabled cellular network and simultaneously reducing the interference generated by the underlay D2D communication with the aid of cooperative communications [4,15–18]. However, few existing works focus on the performance of the D2D-enabled cellular network supporting overlay cellular spectrum-sharing strategies and cooperative transmission [19–21]. Based on the overlay spectrum-sharing scheme, the cellular users and D2D users intend to access different channels. Hence, the interference between the D2D and cellular users were not considered in [13,14,19–21].

Aiming for maximizing system capacity, an overlay spectrum-sharing scheme was proposed for supporting millimeter wave transmitting and D2D communication in [19]. The work in [20] jointly considered incremental relay technology and overlay spectrum-sharing scheme to allow the cellular users to share their transmission resources with the D2D users, instead of treating D2D as interference. Based on the overlay spectrum-sharing scheme, a cooperative D2D communication framework was proposed in [21] for the sake of maximizing transmission rate. However, in order to support the combination of the overlay scheme and cooperative communication, the works in [13,14,19–21] performed the D2D transmissions and the cooperative transmissions within different time slots. Compared to the underlay scheme, the spectrum efficiency of the cooperative overlay schemes in [13,14,19–21] may be reduced. Hence, more efforts are required to improve the spectrum efficiency of the cellular network supporting overlay D2D communication and cooperative communication.

Aiming for improving spectral efficiency, Non-Orthogonal Multiple Access (NOMA) superposes multiple users in the power domain [22,23]. Furthermore, the Successive Interference Cancellation (SIC) technique may be exploited by the receiver for detecting multiple users [22,23]. Hence, an improved spectral efficiency may be achieved when the NOMA is employed by the D2D pairs in order to

simultaneously forward the cellular users' data and convey its own data [24,25]. As we know, NOMA technology has not been considered in overlay D2D cooperation communications in [13,14,19–21]. Considering the combination of NOMA technology and cooperative overlay D2D communication, the transmission power allocated by the DT for the cooperative communication and the D2D transmission may directly affect the transmission rate and the energy consumption of the D2D devices. In order to achieve high energy efficiency, a new framework which aims to find the appropriate data centre is proposed [26] and how to locate the lowest energy consumption route between the user and the designated data centre is addressed [27,28]. Moreover, energy efficiency is achieved by integrating least possible services to satisfy the user requirements given the large number of resources available [29]. In D2D-enabled cellular network, both D2D communications and concurrent transmissions were utilized to achieve high energy efficiency [30]. NOMA is used for concurrent transmissions which is D2D links and cellular links. However, how to allocate power for DT and EU is significant. More explicitly, assuming the transmission power of the DT is limited, if the DT consumes lower transmitter power to forward EU's data, while conveys itself data at higher power, the D2D transmission may achieve an increased rate and consume reduced energy. However, the QoS requirements of EU may not be satisfied. Conversely, if the DT assigns higher power for cooperative transmission and lower power for the D2D communication, the QoS requirement of EU may be guaranteed at the cost of reducing the rate achieved by the D2D communication and increasing the DT's energy consumption for the cooperative communication. Therefore, a NOMA-based optimal power allocation strategy may be required for satisfying the QoS requirement of both the EU and D2D when both the NOMA technology and the cooperative overlay sharing scheme are exploited.

1.3. Contributions and Paper Structure

Against the above backdrop, there are some problems to solve here.

1. To improve QoS of EUs, EUs ask help from D2D pairs. EUs intend to share spectrum resource with D2D pairs in exchange of D2D pairs' relaying data for them. However, how to allocate the spectrum resource between EUs and D2D pairs in overlay mode to achieve Win-Win?
2. Compared to the underlay spectrum-sharing scheme, overlay spectrum-sharing scheme does not consider interference among users but reduces spectrum efficiency. Hence, how to improve spectrum efficiency in overlay spectrum-sharing scheme?

To solve the above problems, this paper proposes a reciprocal-selection-based 'Win-Win' overlay spectrum-sharing scheme (RSWW-OSSS) for the D2D-enabled cellular network supporting overlay spectrum sharing scheme and cooperative transmission among multiple EUs and multiple D2D devices. More explicitly, we developed the following contributions:

1. A RSWW-OSSS is designed for a D2D-enabled cellular network in order to provide a better connective experience for EUs with the aid of cooperative communication. More explicitly, according to the proposed RSWW-OSSS, EUs are capable of achieving an increased rate with the aid of cooperation assistance provided by the D2D devices. Furthermore, in order to perform D2D transmission, the D2D devices intend to forward data for the EUs in exchange for accessing the part of cellular spectrum resource which is not used by the EUs.
2. In order to improve the spectral efficiency, DTs employ the NOMA technology to simultaneously convey EUs' and their own data at different transmit power. SIC is invoked at both the BS and D2D receivers (DRs) for separating the EUs' and DTs' data. As we know, NOMA technology is not introduced in overlay D2D cooperation communications in [19–21].
3. Aiming for maximizing the utilities of both EU and D2D device, their behaviours are modelled as a two-stage Stackelberg game [31–33]. More explicitly, as the leader, EUs calculate the optimal time allocation coefficient in order to maximize its transmit rate. Furthermore, DTs are modelled as the followers which determine the optimal transmit powers for the cooperative transmission and D2D communication, in order to improve the achievable rate of D2D communication

and simultaneously reduce the energy consumed for forwarding EUs' data. The backward induction [34] is invoked for analysing the game and deriving the optimal strategies of EUs and DTs.

- For the sake of achieving a stable matching between multiple EUs and multiple D2D devices, we analyse the algorithmic stability of the proposed RSWW-OSSS with the aid of matching theory [35].

The rest of this paper is organized as follows. The system model is introduced in Section 2. Section 3 describes the proposed RSWW-OSSS. In Section 4, the attainable performance of our scheme is evaluated. Finally, we conclude in Section 5.

2. System Model

2.1. Construction and Assumption

We consider a D2D-enabled cellular network hosting M EUs in the set $m \in \{1, 2, 3, \dots, M\}$ and N D2D transmission pairs in the set $(DT_n, DR_n) \in \{(DT_1, DR_1), (DT_2, DR_2), (DT_3, DR_3), \dots, (DT_N, DR_N)\}$ as well as one BS that assigns the spectrum allocation to the cellular users, as seen in Figure 1. The BS assigns the spectrum band into $C = M$ orthogonal channel with equal bandwidth and each EU is preassigned an orthogonal channel for its data transmission. Hence, the interference among EUs is avoided [36,37]. Based on the considered D2D-enabled cellular network, the DTs are capable of bypassing the BS and directly communicating with the proximity device, namely DRs. The overlay spectrum-sharing scheme is employed for the sake of sharing the spectrum between D2D links and cellular links. More explicitly, the EU with unfavorable channel condition may share part of its spectral resources to a D2D transmission pair in exchange for cooperative transmission assistance. A D2D transmission pair (DT_n, DR_n) intends to provide cooperative assistance for a EU EU_m in order to convey its own tele-traffic by using the cellular spectrum assigned to the EU_m . The EUs cooperative with D2D pairs in overlay mode which cellular link and D2D link occupy different cellular spectrum [38]. Hence, the interference of EUs and D2D pairs is avoided as well.

Both the EUs and DTs are assumed to be limited by the same maximum transmit power P_{MAX} . The channel gain is assumed to be modeled by [39]:

$$h_{ij} = LH^2 d_{ij}^{-\eta} \quad (1)$$

where L denotes the pathloss constant, while H represents the fast Rayleigh fading channel. Furthermore, η represents pathloss exponent and d_{ij} denotes the distance between node i and node j . The notations of the system are listed in Table 1.

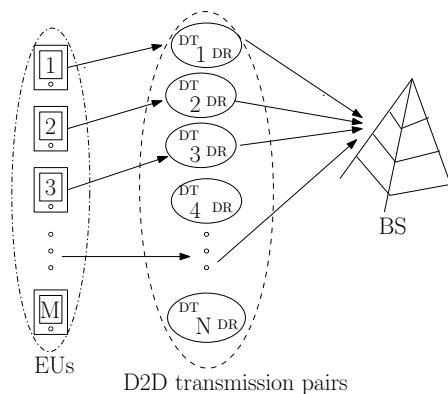


Figure 1. The system model.

Table 1. Table of notation.

| Notation | Physical Meaning |
|-----------|--|
| P_m | EU_m 's transmit power |
| P_n | DT_n 's transmit power |
| P_{MAX} | EUs' and DTs' maximum transmit power |
| h_{mn} | channel gain between EU_m and DT_n |
| h_{bm} | channel gain between EU_m and BS |
| h_{nn} | channel gain between DT_n and DR_n |
| h_{bn} | channel gain between DT_n and BS |
| N_0 | power of AWGN |

2.2. Communication Model

2.2.1. Non-Cooperative Communication Model

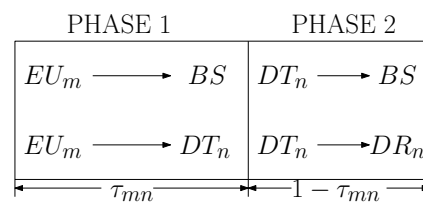
Based on the non-cooperative communication model, the EU_m transmits the data directly to the BS. The attainable transmit rate R_m^{dir} of uplink transmission between the EU_m and the BS may be expressed as:

$$R_m^{dir} = \log_2 \left(1 + \frac{h_{bm}P_m}{N_0} \right) \quad (2)$$

where P_m denotes the transmit power of the EU_m . Furthermore, h_{bm} represents the channel gain of the uplink from the EU_m to the BS and N_0 represents the power of Additive White Gaussian Noise (AWGN).

2.2.2. Cooperative Communication Model

When the EU_m directly transmits its data to the BS, performance may suffer due to the poor link quality. Aiming for improving the connective experience of the EU_m , we design a RSWW-OSSS. Based on the proposed scheme, the original time period T allocated for the EU_m may be divided into two time slots, namely $t_1 = \tau_{mn}$ and $t_2 = 1 - \tau_{mn}$, as shown in Figure 2. Hence, based on the cooperative model, the communications may include two phases, as seen in Figure 2.

**Figure 2.** Time frame structure for cooperation.

- **PHASE 1:** During the first time slot t_1 , the EU_m transmits data to DT_n and BS. The achievable rate of the direct transmission from the EU_m to the BS may be expressed as:

$$R_{EU_m \rightarrow BS} = \tau_{mn} \log_2 \left(1 + \frac{h_{bm}P_m}{N_0} \right) \quad (3)$$

Furthermore, the transmit rate $R_{EU_m \rightarrow DT_n}$ achieved by the transmission from the EU_m to the DT_n may be expressed as:

$$R_{EU_m \rightarrow DT_n} = \tau_{mn} \log_2 \left(1 + \frac{h_{mn}P_m}{N_0} \right) \quad (4)$$

where h_{mn} represents the channel gain of the link from the EU_m to the DT_n .

- **PHASE 2:** During the second time slot t_2 , the DT_n simultaneously transmits EU_m 's and itself data with the aid of NOMA technology. The DT_n transmits its own data to DR_n with the power of P_{mn}^D where $P_{mn}^D = \alpha_{mn}P_n$, while forwards the EU_m 's data with the power of P_{mn}^B where $P_{mn}^B = (1 - \alpha_{mn})P_n$. Moreover, α_{mn} is power allocation coefficient. Equation (5) describes the data sent by the DT_n when the NOMA technology is employed.

$$y = \sqrt[2]{P_{mn}^B S_{mn}^1} + \sqrt[2]{P_{mn}^D S_{mn}^2} \quad (5)$$

where S_{mn}^1 is the EU_m 's data which has to be forwarded by the DT_n , while S_{mn}^2 denotes the DT_n 's data. The total power consumed by the DT_n during the phase 2 is denoted by P_n , which is equal to P_{MAX} . The SIC technology is invoked at both the BS and the DR_n for the sake of separating EU_m 's and DT_n 's data. During phase 2, the Signal to Interference Plus Noise Ratio (SINR) of the EU_m 's data received by the BS may be given by:

$$SINR = \frac{h_{bn}(1 - \alpha_{mn})P_n}{ah_{bn}\alpha_{mn}P_n + N_0} \quad (6)$$

where h_{bn} represents the channel gain of the link from the DT_n to the BS. Moreover, a represents the relationship between the power P_{mn}^D and P_{mn}^B . According to the NOMA and the SIC technologies, if DT_n forwards EU_m 's data at a higher transmit power, namely $P_{mn}^B > P_{mn}^D$, a is equal to 1. Otherwise, the value of a is 0, as shown in Equation (7).

$$a = \begin{cases} 1 & P_{mn}^B > P_{mn}^D \\ 0 & P_{mn}^B \leq P_{mn}^D \end{cases} \quad (7)$$

When the BS receives data from DT_n , SIC technology is exploited to separate the EU_m 's and DT_n 's data. Then, both the previous data from the EU_m in phase 1 and the later data from the DT_n in phase 2 are combined by the BS with the aid of Maximum Ratio Combining (MRC) [40,41]. The SINR of the merged data may be expressed as:

$$SINR_{MRC} = \frac{h_{bn}(1 - \alpha_{mn})P_n}{ah_{bn}\alpha_{mn}P_n + N_0} + \frac{h_{bn}P_m}{N_0} \quad (8)$$

After receiving the data from DT_n , DR_n separates the DT_n 's and EU_m 's data with the aid of SIC technology. The SINR of the DT_n 's data may be expressed as:

$$SINR_{D2D} = \frac{h_{nn}\alpha_{mn}P_n}{bh_{nn}(1 - \alpha_{mn})P_n + N_0} \quad (9)$$

where h_{nn} represents the channel gain of the D2D link. Coefficient b represents the relationship between the power P_{mn}^D and P_{mn}^B , which may be given by:

$$b = \begin{cases} 1 & P_{mn}^B \leq P_{mn}^D \\ 0 & P_{mn}^B > P_{mn}^D \end{cases} \quad (10)$$

3. Joint Cooperative Spectrum-Sharing Scheme

3.1. Utility of EU_m

During phase 1, EU_m transmits its data to DT_n and BS. After successfully receiving EU_m 's data, DT_n conveys both the EU_m 's data and its own data to BS and DR_n , with the aid of the NOMA technology during phase 2. Provided that the BS successfully receive the data from DT_n , SIC is invoked at the BS for separating the EU_m 's data and DT_n 's data. Then the BS combines the direct transmission

from EU_m within phase 1 and the relayed transmission from the DT_n during phase 2 with the aid of MRC. Hence, the utility of EU_m may be expressed as:

$$\begin{aligned} U_{mn}^{EU}(\tau_{mn}, \alpha_{mn}) &= R_{mn}^C = (1 - \tau_{mn}) \log_2(1 + SINR_{MRC}) \\ &= (1 - \tau_{mn}) \log_2 \left[1 + \frac{h_{bn}(1 - \alpha_{mn})P_n}{ah_{bn}\alpha_{mn}P_n + N_0} + \frac{h_{bm}P_m}{N_0} \right] \end{aligned} \quad (11)$$

3.2. Utility of DT_n

During phase 2, DT_n has to consume a part of the power, namely $P_{mn}^B = (1 - \alpha_{mn})P_n$, to forward the EU_m 's data, in exchange of the opportunity to access the cellular spectrum for D2D communication. Hence, the utility of the DT_n may be expressed as:

$$\begin{aligned} U_{mn}^{D2D}(\tau_{mn}, \alpha_{mn}) &= R_{mn}^{D2D} - \frac{P_{mn}^B}{P_n} \\ &= (1 - \tau_{mn}) [\log_2(1 + SINR_{D2D})] - \frac{P_{mn}^B}{P_n} \\ &= (1 - \tau_{mn}) \left\{ \log_2 \left[1 + \frac{h_{nn}\alpha_{mn}P_n}{bh_{nn}(1 - \alpha_{mn})P_n + N_0} \right] \right\} - (1 - \alpha_{mn}) \end{aligned} \quad (12)$$

where R_{mn}^{D2D} is the achievable transmit rate of the D2D link by accessing the the cellular spectrum and $\frac{P_{mn}^B}{P_n}$ is the loss of DT_n .

3.3. Analysis of the Proposed Two-Stage Stackelberg Game

According to the considered system model, the interaction between the EU_m and the DT_n may be modeled as a two-stage Stackelberg game where one is the leader and the other is the follower. EU_m owns the authorised spectrum and shares the the authorised spectrum with DT_n in the propose RSWW-OSSS. Moreover, in economic matters, the leader of Stackelberg game is the one who decides the strategy firstly and the follower decides the strategy based on the leader's strategy. Hence, EU_m is the leader, and the DT_n is the follower [42,43]. More explicitly, during Stage I, the EU_m first calculates the optimal time allocation coefficient τ_{mn}^* for the sake of maximizing its utility. During stage II, as the follower of Stage I, DT_n calculates the optimal power allocation coefficient α_{mn}^* for the sake of maximizing its utility. According to the proposed two-stage Stackelberg game, the strategies in different stages have sequential dependence. Hence, the backward induction is introduced to analyse the game and to derive the solution, namely Stackelberg equilibrium. Based on the backward induction [34], we commence from the DT_n 's strategies in Stage II, given the EU_m 's time allocation strategy. Then, based on the analysis of DT_n 's optimal power allocation coefficient, namely α_{mn}^* , the optimal time allocation of EU_m in Stage I, namely τ_{mn}^* is derived.

3.3.1. DT_n 's Strategy in Stage II

Given the time allocation coefficient τ_{mn}^* offered by the EU_m in Stage I, DT_n has to calculate the optimal power allocation coefficient α_{mn}^* for the sake of maximizing its utility. Hence, the optimal power allocation coefficient α_{mn}^* may be expressed as:

$$\alpha_{mn}^* = \arg \max_{\alpha_{mn}} U_{mn}^{D2D}(\alpha_{mn}, \tau_{mn}^*) \quad (13)$$

$$s.t. \quad R_{mn}^C \geq \zeta R_m^{dir} \quad (14)$$

$$0 < \tau_{mn}^* < 1 \quad (15)$$

$$0 < \alpha_{mn} < 1 \quad (16)$$

$$\forall m \in \{1, \dots, M\}, \forall n \in \{1, \dots, N\} \quad (17)$$

The first constraint guarantees that EU_m is willing to cooperate. The EU_m has a transmit rate requirement of R_{req} , which the DT_n should help achieve. Hence, transmission rate R_{mn}^C achieved by the cooperative communication has to be higher than the EU_m 's target rate, namely $R_{mn}^C \geq \xi R_m^{dir}$. ξ is the rate requirement coefficient.

Based on Equation (12), the second derivative of $U_{DT}(\alpha_{mn}, \tau_{mn})$ is smaller than zero, namely $\frac{d^2 U_{D2D}}{d\alpha_{mn}^2} < 0$. Hence, $U_{D2D}(\alpha_{mn}, \tau_{mn})$ is a convex function of α_{mn} . Therefore, the optimal power allocation coefficient of α_{mn}^* may be calculated by solving the KKT conditions [44], as shown in Equation (18).

$$\begin{aligned} \alpha_{mn}^* = & \arg \max_{\alpha_{mn}} U_{mn}^{D2D}(\alpha_{mn}, \tau_{mn}^*) \\ & = \frac{h_{bn}P_n - N_0 \left[\left(1 + \frac{h_{bm}P_m}{N_0} \right)^{\frac{\xi}{1-\tau_{mn}^*}} - 1 - \frac{h_{bm}P_m}{N_0} \right]}{h_{bn}P_n + ah_{bn}P_n \left[\left(1 + \frac{h_{bm}P_m}{N_0} \right)^{\frac{\xi}{1-\tau_{mn}^*}} - 1 - \frac{h_{bm}P_m}{N_0} \right]} \end{aligned} \quad (18)$$

3.3.2. EU_m 's Strategy in Stage I

Given the DT_n 's optimal power allocation coefficient $\alpha_{mn}^*(\tau_{mn}^*)$ which is calculated in Stage II, the EU_m derives the optimal time allocation coefficient for maximizing its utility. Based on the DT_n 's optimal power allocation coefficient $\alpha_{mn}^*(\tau_{mn})$ which is calculated in Stage II, the EU_m 's optimal time allocation coefficient of τ_{mn}^* may be expressed as:

$$\tau_{mn}^* = \arg \max_{\tau_{mn}} U_{EU}^{mn}(\tau_{mn}, \alpha^*(\tau_{mn})) \quad (19)$$

$$s.t. \quad U_{mn}^{D2D} \geq 0 \quad (20)$$

$$0 < \tau_{mn} < 1 \quad (21)$$

$$0 < \alpha_{mn}^* < 1 \quad (22)$$

$$\forall m \in \{1, \dots, M\}, \forall n \in \{1, \dots, N\} \quad (23)$$

where U_{mn}^{D2D} is the utility of DT_n as shown in Equation (12). The first constraint guarantees that DT_n is willing to cooperate. The utility of DT_n is at least zero. $U_{mn}^{D2D} = 0$ is the minimum requirements when DT_n cooperates with EU_m .

Proposition 1. Given the DT_n 's optimal power allocation coefficient of $\alpha_{mn}^*(\tau_{mn}^*)$, EU_m 's optimal time allocation coefficient, namely τ_{mn}^* is the unique solution of the following equation:

$$(1 - \tau_{mn}^*) \log_2 \left\{ 1 + \frac{h_{nn}\alpha^*(\tau_{mn}^*)P_n}{bh_{nn}[1 - \alpha^*(\tau_{mn}^*)] + N_0} \right\} - [1 - \alpha^*(\tau_{mn}^*)] = 0 \quad (24)$$

See proof in Appendix A.

Let us now prove the existence and the uniqueness of the Nash Equilibrium for the proposed two-stage Stackelberg game.

Definition 1. A strategy profile $(\tau_{mn}^*, \alpha_{mn}^*)$ is a Nash Equilibrium of the proposed two-stage Stackelberg game, if:

$$U_{mn}^{EU}(\tau_{mn}^*, \alpha_{mn}^*) \geq U_{mn}^{EU}(\tau_{mn}^*, \alpha_{mn}^*), \quad (25)$$

$$U_{mn}^{D2D}(\tau_{mn}^*, \alpha_{mn}^*) \geq U_{mn}^{D2D}(\tau_{mn}^*, \alpha_{mn}^*). \quad (26)$$

As above discussion, Equation (12) is convex. Hence, the optimal power allocation coefficient α^* exists and is unique. Then we have $U_{DT}(\tau, \alpha^*) \geq U_{DT}(\tau, \alpha)$. Furthermore, based on the Proposition 1,

we have $U_{EU}(\tau^*, \alpha^*) \geq U_{EU}(\tau, \alpha^*)$. Therefore, according to the Definition 1, strategy profile (τ^*, α^*) is the Nash Equilibrium of the proposed two-stage Stackelberg game. The proposed two-stage Stackelberg game algorithm to determine the Stackelberg equilibrium is shown in Table 2.

Table 2. The proposed two-stage Stackelberg game algorithm.

| |
|--|
| Require |
| Let EU_m and DT_n exchange their profile information. |
| DT_n's Strategy in Stage II: |
| ▷ Given the time allocation coefficient τ_{mn}^* offered by the EU_m in Stage I. |
| ▷ DT_n calculates the optimal power allocation coefficient α_{mn}^* according Equation (18) |
| EU_m's strategy in Stage I: |
| ▷ Given the optimal power allocation coefficient α_{mn}^* (τ_{mn}^*) which is shown in Equation (18) |
| ▷ EU_m calculates the optimal power allocation coefficient τ_{mn}^* which is the solution of Equation (24) |
| $(\tau_{mn}^*, \alpha_{mn}^*)$ is the Nash Equilibrium of the proposed two-stage Stackelberg game. |

3.4. Matching Game for EUs and D2D Pairs

As seen in Figure 1, there are multiple EUs and multiple D2D transmission pairs in the considered system model. In order to maximizing the utility given by Equation (11), EU_m intends to share its spectrum resource with a best D2D transmission pair (DT_n, DR_n) . On the other hand, a D2D transmission pair (DT_n, DR_n) intends to provide cooperative assistance for an appropriate EU in order to win a transmission opportunity within the licensed band for its own traffic, while simultaneously maximizing its utility formulated by Equation (12). Hence, based on the matching theory, both the EUs and the DTs in our system are considered as a pair of disjoint sets. Each EU intends to be matched with an appropriate DT who can provide a higher transmit rate. On the other hand, a DT is matched to an appropriate EU for the sake of pursuing higher utility. Hence, the spectrum-sharing problem can be formulated as a matching game, which is capable of producing a cooperative matching between an EU and a D2D transmission pair. Based on matching theory, we define a cooperative matching as follow:

Definition 2. A one-to-one matching between M and N can be represented by a one-to-one correspondence $\Omega(*)$, where $\Omega(m) = n$ if and only if $\Omega(n) = m$ and $\Omega(m) \in N, \Omega(n) \in M$, for $\forall m \in M, \forall n \in N$.

According to Definition 2, in the two-sided matching market, each EU selects one D2D pair namely $\Omega(m) = n$, while each D2D pair selects one EU, namely $\Omega(n) = m$ for $\forall m \in M, \forall n \in N$. Based on the Definition 2, a matching algorithm is developed for the sake of producing cooperative matchings between multiple EUs and multiple D2D pairs in the considered system, as shown in Table 3.

Before any offer is made to the D2D transmission pairs, each EU first calculates the optimal time allocation coefficients $\{\tau_{m1}^*, \tau_{m2}^*, \dots, \tau_{mn}^*\}$ for $0 < m \leq M$ and $0 < n \leq N$, by playing the proposed two-stage Stackelberg Game with different D2D transmission pairs. Then, each EU constructs a preference list of potential D2D transmission pairs, which can satisfy the EU's rate requirement, namely $R_{mn}^C \geq \zeta R_m^{dir}$. More explicitly, the EU_m constructs a preference list L^{EU_m} , which orders the potential D2D pairs according to the optimal time allocation coefficients. Thus, the preference list for EU_m is given by: $L^{EU_m} = \tau_{m1} < \tau_{m2} < \dots < \tau_{mn}$ for $0 < n \leq N$. Based on the optimal power allocation coefficients $\{\alpha_{1n}^*, \alpha_{2n}^*, \dots, \alpha_{mn}^*\}$ for $0 < m \leq M$ and $0 < n \leq N$, generated by the proposed two-stage Stackelberg Game in Section 3.3, DT_n constructs a preference list of potential EUs which may share the licensed spectrum with it. More explicitly, the DT_n constructs a preference list L_n^{D2D} , according to the transmit power consumed by forwarding data for different potential EUs. Hence, the preference list for DT_n is given by: $L^{D2D_n} = \alpha_{1n} < \alpha_{2n} < \dots < \alpha_{mn}$ for $0 < m \leq M$. According to the preference list, the EU_m first offers the optimal time allocation coefficient τ_{mn}^* to the first D2D of its preference list, namely DT_n , which requires the shortest time slot for D2D transmission, as shown in Table 3. If DT_n receives a proposal from EU_m which is in its preference list, DT_n and EU_m form a cooperative matching, provided that DT_n has not been matched. However, if the DT_n is already matched with $EU_{\hat{m}}$, the DT_n

may accept the proposal from EU_m , when lower transmit power is required for forwarding EU_m 's data. Based on the proposed RSWW-OSSS, each DT only has a single cooperative partner. Hence, DT_n has to divorce its current cooperative pair $\Phi(EU_{\hat{m}}, DT_n)$ and proceeds to form the new pair $\Phi(EU_m, DT_n)$. If the DT_n rejects the proposal from EU_m , the EU_m sends the optimal time allocation coefficient τ_{mi}^* to the next favourable cooperative partner, namely DT_i in the preference list. Then EU_m repeats the above discovery procedure either until it finds an appropriate partner or is rejected by all potential D2D transmission pairs.

Table 3. The proposed matching algorithm.

Initialization:

Let L_m^{EU} and L_n^{D2D} be the preference list of EU_m and DT_n respectively.

Repeat:

```

for all  $\forall m \in \{1, \dots, M\}$   $EU_m$  do
  if  $EU_m$  is not matched
     $\triangleright EU_m$  broadcasts proposal  $\phi(m, n)$  to favourable  $DT_n$  according to  $L_m^{EU}$ .
    Set  $i = 0, V_m = 0$ .
    while  $V_m = 0$  and  $i \leq n$  for  $0 < n \leq N$ 
       $\triangleright i = i + 1, n = m_i$ .
      if  $EU_m$  in the preference list  $L_n^{D2D}$  of  $DT_n$ 
        if  $DT_n$  is not matched
           $\triangleright DT_n$  accepts the proposal  $\phi(m, n)$ , set  $V_m = 1$ .
        if  $DT_n$  is matched with  $EU_{\hat{m}}$ 
          if  $\alpha_{\hat{m}n} > \alpha_{mn}$ 
             $\triangleright DT_n$  rejects the former  $EU_{\hat{m}}$  and accepts the proposal  $\phi(m, n)$  of  $EU_m$ , set  $V_m = 1$ .
          else
             $\triangleright$  set  $V_m = 0$ .
    for all  $\forall n \in \{1, \dots, N\}$   $DT_n$  do
      if  $DT_n$  achieves more than one proposal
         $\triangleright DT_n$  selects the one who requires lower transmit power.
    for all  $\forall m \in \{1, \dots, M\}$   $EU_m$  do
      if  $EU_m$  is already matched with  $DT_{\hat{n}}$ 
        if  $DT_{\hat{n}}$  divorces matched pair  $\phi(m, \hat{n})$ 
           $\triangleright EU_m$  is not matched.

```

Until: Each EU are either assigned to one of the D2D pairs or rejected by all of D2D pairs in L_m^{EU} .

The complexity of the proposed matching algorithm is $O(MN)$ when each EU was rejected by $N - 1$ D2D pairs of its preference list and cooperates with the final D2D pair of its preference list. However, when each EU receives the cooperation from the first D2D of its preference list, the complexity of the proposed matching algorithm is $O(M)$. For example, $M = 20$ and $N = 30$. The worst case performance is $O(600)$ and the best case performance is $O(20)$.

A common and realistic assumption in a cooperative communication network is that both the EUs and D2D pairs are selfish. It implies that both EUs and D2D pairs intend to maximize their own utilities when they are seeking for an appropriate cooperative partner. Hence, bearing in mind the selfish behaviour of the EUs and D2D pairs, it is necessary to analyse the stability of the proposed matching algorithm. Let us first introduce the definition of 'stable matching'. Let $m \succ_n \hat{m}$ denote DT_n prefers EU_m to $EU_{\hat{m}}$.

Definition 3. A stable matching is not blocked by the EU_m and $D2D_n$ pair $\Phi(m, n)$, such that $n \succ_m \Omega(m)$, $m \succ_n \Omega(n)$ and $\Omega(m) \in N, \Omega(n) \in M$, for $\forall m \in M, \forall n \in N$.

See proof in Appendix B.

Definition 3 illustrates that the specific EU and D2D pair, which constitute a cooperative pair according to our RSWW-OSSS can not simultaneously change their strategies for pursuing higher utilities, if they select another D2D pair or EU as their cooperative partner.

4. Simulation Results

Simulation Configuration

In order to evaluate the achievable performance of the proposed RSWW-OSSS, we consider a cellular network with radius 500 m where a BS is located in the center of the cell. Furthermore, EUs are randomly located on the edge of the cellular network. D2D transmission pairs are randomly distributed across the entire network. The maximum power of both the each EU and each D2D pairs are assumed to be 0.1 W [13]. Rate requirement coefficient ξ is set to be 2.5. The simulation parameters are summarized in Table 4 [13,39].

Table 4. Simulation Configure Parameters.

| Parameters | Value |
|---------------------------------------|-----------|
| Cell radius | 500 m |
| Noise power(N_0) | −114 dBm |
| D2D link distance | 50 m |
| Each EU Tx power | 100 mW |
| Each D2D pair Tx power | 100 mW |
| Pathloss constant(L) | 10^{-2} |
| Pathloss exponent(η) | 4 |
| Rate requirement coefficient(ξ) | 2.5 |
| Number of EUs(M) | 20 |

We consider the pricing and spectrum leasing scheme (PSLS) which was proposed in [13] as the cooperative benchmarker of our scheme. The D2D transmission pair in the PSLS shares the spectrum resources with the cellular users by using the overlay approach. More explicitly, based on the PSLS, the DT provides cooperative assistance for the EU in order to obtain a D2D transmission opportunity and to improve the QoS of the uplink transmission from the EU to the BS. After successfully forwarding EU's data, the DT in the PSLS conveys its own data during the successive sub-timeslot [13]. It is noted that power allocation was not considered in the PSLS [13].

Figure 3 compares the attainable rates of both the uplink transmissions from EUs to BS and the D2D transmissions versus the different number of D2D transmission pairs. Given the number of D2D transmission pairs, the proposed RSWW-OSSS is capable of achieving higher rates for both the EUs and the D2D transmission pairs than the PSLS which was proposed in [13], as seen in Figure 3. More explicit, when the number of D2D pairs is 20, the achievable rate of EUs in our RSWW-OSSS is about 12% more than that in PSLS and the achievable rate of D2D pairs in our RSWW-OSSS is about 28% more than that in PSLS. When the network hosts more D2D transmission pairs, the attainable rates of EUs are significantly improved by our RSWW-OSSS, due to the increased number of potential D2D transmission pairs which can provide cooperative assistance for the EUs, as seen in Figure 3. When the number of D2D transmission pair is increased from 4 to 20, more D2D transmission pairs may share the cellular spectrum for D2D communications. Therefore, the achievable rate of D2D communications is increased when the D2D network becomes larger, as shown in Figure 3. However, when the number of D2D transmission pairs is more than 30, the achievable rates of D2D communications almost reach the saturation point, because all the EUs are matched with appropriate D2D transmission pairs.

Figure 4 illustrates the transmit power consumed by the DTs for forwarding EUs' data versus the different number of D2D transmission pairs. As shown in Figure 4, compared to the PSLS, our RSWW-OSSS is capable of decreasing the power for forwarding EU's data with the aid of the proposed two-stage Stackelberg game and the proposed matching algorithm. When the D2D network becomes larger, cooperative matchings may be generated due to the increased number of D2D transmission pairs which can be the potential cooperative partner of EUs. Hence, the transmit power for forwarding EUs' data is increased when the network hosts more D2D transmission pairs. However, when the number of D2D transmission pairs is more than 30, all the EUs may be matched

with an appropriate D2D transmission pair. Hence, the number of cooperative matchings may not increase when more than 30 D2D transmission pairs intend to share cellular spectrum with the EUs. It implies that the transmit power for forwarding EUs' data may be saturated, when the number of D2D transmission pairs is more than 30, as seen in Figure 4. When given the number of D2D pairs is 37, the saturated transmit power for forwarding EUs' data in our RSWW-OSSS is about 2.5 W while the saturated transmit power for forwarding EUs' data in the PSLs is about 3.4 W. The saturated transmit power for forwarding EUs' data in our RSWW-OSSS is 26% less than that in PSLs.

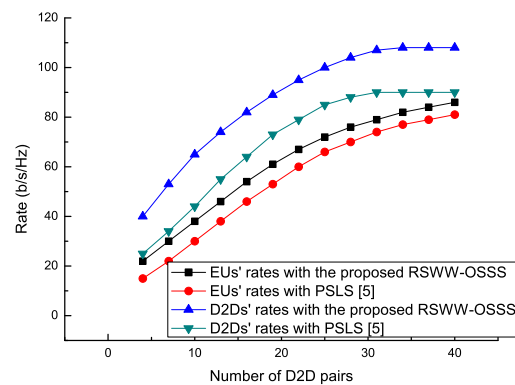


Figure 3. Sum-rate of EUs and D2D pairs versus different numbers of D2D transmission pairs when the number of EUs is 20.

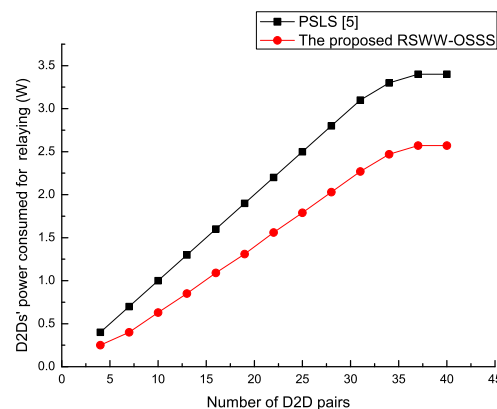


Figure 4. D2D pairs consumed power for relaying data versus different numbers of D2D transmission pairs when the number of EUs is 20.

In order to evaluate the performance of the proposed RSWW-OSSS, we consider a stable matching with the fixed time allocation (SM-FTA) as the cooperative benchmarker of our RSWW-OSSS. Based on the SM-FTA, an EU shares a fixed portion of the whole time slot to its cooperative partner. Additionally, a stable matching with the fixed power allocation (SM-FPA) is introduced as another cooperative benchmarker of our RSWW-OSSS. Based on the SM-FPA, the transmit power which is allocated by a DT for forwarding EU's data is fixed. Furthermore, we also introduce a random-matching-based overlay spectrum-sharing (RM-OSS) scheme, where both the EUs and the DTs calculate their optimal strategies by playing the proposed two-stage Stackelberg Game. However, according to the RM-OSS scheme, an EU is randomly matched with a D2D transmission pair which is capable of satisfying its transmit rate requirement.

Figure 5 shows our comparison between the total rates of EUs achieved by our RSWW-OSSS, the SM-FTA, the SM-FPA as well as the RM-OSS versus different numbers of D2D transmission pairs.

Furthermore, Figure 6 compares the total rates of D2D transmissions achieved by our RSWW-OSSS, the SM-FTA, the SM-FPA as well as the RM-OSS versus different numbers of D2D transmission pairs. Compared to the benchmarker schemes, the proposed RSWW-OSSS is capable of significantly improving the attainable rates for both the D2D communications and the uplink transmissions from EUs to BS, as shown in Figures 5 and 6. More explicit, when the number of D2D pairs is 20, the achievable rate of EUs in the proposed RSWW-OSSS is 62 b/s/Hz which is about 100% more than that in RM-OSS, 48% more than that in SM-FPA and 22% more than that in SM-FTA, while, the achievable rate of D2D pairs in our RSWW-OSSS is 91 b/s/Hz which is about 111% more than that in RM-OSS, 52% more than that in SM-FPA and 34% more than that in SM-FTA. Given the number of D2D pairs, the RM-OSS scheme achieves the lowest transmit rate, because that both the EUs and DTs randomly select their cooperative partner without considering the other potential cooperative partners, as seen in Figures 5 and 6. According to the total transmit rate of the uplink transmissions and that of the D2D communications shown in Figures 5 and 6, the SM-FTA outperforms the SM-FPA. Based on the SM-FPA, less DT can afford the total power for successfully forwarding EU's data and for conveying its own data, due to the fixed power allocation and maximum power constraint. Hence, compared to the SM-FTA, the SM-FPA reduces the number of cooperative matching. Observe in Figures 5 and 6 that the total transmit rate of uplink transmissions and that of D2D communications are increased when the network hosts more D2D transmission pairs, due to the increased number of EUs' potential cooperative partners.

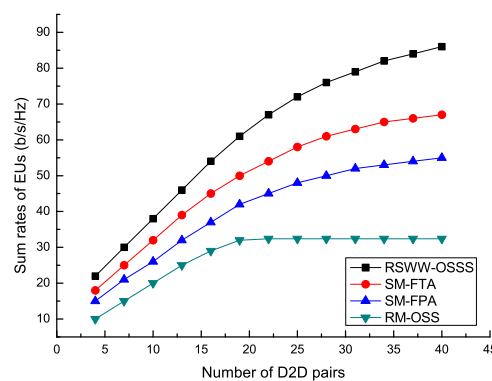


Figure 5. Sum-rate of EUs versus different numbers of D2D transmission pairs when the number of EUs is 20.

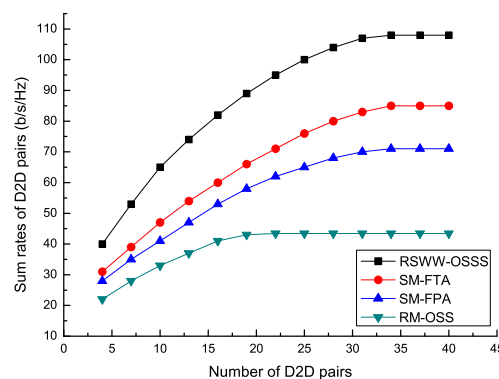


Figure 6. Sum-rate of D2D pairs versus different numbers of D2D transmission pairs when the number of EUs is 20.

5. Conclusions

This paper proposed a RSWW-OSSS for supporting overlay D2D communication and cooperative uplink transmission in a cellular network hosting multiple EUs and D2D transmission pairs. Based on the proposed RSWW-OSSS, the EUs intend to improve the QoS with the aid of cooperative assistance provided by the D2D transmission pairs. Moreover, the D2D transmission pairs are encouraged to forward data for the EUs, in exchange for accessing the cellular spectrum to convey their own data. In order to further improve the spectrum efficiency, NOMA technology is used by the D2D transmission pairs to simultaneously transmit the EU's and its own data within the same spectrum and at different transmission power. In this paper, the behaviours of EUs and D2D pairs are modelled as a two-stage Stackelberg game. Furthermore, the backward induction is exploited to derive the optimal strategies for the sake of maximizing the utilities of both the EUs and the D2D transmission pairs. Moreover, a one-to-one stable matching algorithm is developed for the sake of generating the stable cooperative matchings between the EUs and the D2D transmission pairs. Finally, we analyse the stability of the matchings generated by the proposed matching algorithm. The simulation results show that the proposed RSWW-OSSS is capable of significantly providing EU_m the transmission rate 41% higher than the non-cooperative direct transmission rate R_m^{dir} . Moreover, the D2D transmissions can achieve 105 b/s/Hz by exclusively occupying EUs' licensed spectrum resource. According to the simulation results, the proposed RSWW-OSSS performs greater than exiting methods as well.

There are two time slots while NOMA is used during the second time slot for the sake of improving the spectrum efficiency. In future work, NOMA will be exploited in both the first time slot and the second time slot. EUs decide their transmission power during the first time slot while D2D pairs decide their transmission power during the second time slot versus two equal time slots, namely $t_1 = t_2 = 0.5 T$.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

In order to prove the Proposition 1, τ_{mn}^* is replaced with τ , α_{mn}^* is replaced with α , U_{mn}^{EU} is replaced with U_{EU} and U_{mn}^{D2D} is replaced with U_{D2D} . Given the optimal power allocation coefficient of DT which is derived by Equation (18) in the stage II of the Stackelberg game, the EU's optimal time allocation coefficient, namely τ may be calculated in terms of Equations (19)–(23). Hence, the KKT conditions of Equations (19)–(23), may be expressed as follows:

$$\left\{ \begin{array}{l} \frac{dU_{EU}}{d\tau} + \mu \frac{dU_{D2D}}{d\tau} = 0 \\ \mu U_{D2D} = 0 \\ U_{DT} \geq 0 \\ \mu \geq 0 \end{array} \right. \quad (A1)$$

where μ is a constant which is a KKT multiplier. According to Equation (A1), the EU's optimal time allocation coefficient of τ can be calculated by setting μ to be positive and U_{DT} to be 0, namely $\mu > 0$ and $U_{DT} = 0$. Therefore, we have

$$(1 - \tau) \log_2 \left\{ 1 + \frac{h_{mn}\alpha(\tau)P_2}{bh_{mn}[1 - \alpha(\tau)] + N_0} \right\} - [1 - \alpha(\tau)] = 0 \quad (A2)$$

Then, to calculate the solution of Equation (A2). Letting

$$f(\tau) = (1 - \tau) \log_2 \left\{ 1 + \frac{h_{nn}\alpha(\tau)P_2}{bh_{nn}[1 - \alpha(\tau)] + N_0} \right\} - [1 - \alpha(\tau)] \quad (\text{A3})$$

then we have $\frac{df}{d\tau} < 0$. Hence, $f(\tau)$ is a monotonically decreasing function of τ . It implies that $f(0) > 0$ for $\tau = 0$ and $f(1) < 0$ for $\tau = 1$. Therefore, the equation of $f(\tau) = 0$ has a unique solution τ^* , namely $f(\tau^*) = 0$, for $0 < \tau^* < 1$. Hence, the EU's optimal time allocation coefficient of τ^* is the unique solution of Equations (24) and (A2).

Appendix B

Assuming that the cooperative matching $\Phi(m, n)$ generated by our RSWW-OSSS is blocked, we have $\alpha_{mn} < \alpha_{m^*n}$, where EU_{m^*} is the current cooperative partner of DT_n according to the proposed matching algorithm. Based on our RSWW-OSSS, the EU_m provides a proposal to the best D2D transmission pair according to its preference list. If EU_m fails to find a cooperative partner at the first round, it repeats the procedure by looking for next D2D transmission pairs in its preference list, as seen in Table 3. Hence, according to the definition of blocking pair, EU_m first selects DT_n as its cooperative partner for shorter time slot for D2D transmission, but DT_n intends to provide cooperative transmission assistance for another EU EU_{m^*} for the sake of minimizing its lower transmit power for forwarding EU's data, namely $\alpha_{mn} > \alpha_{m^*n}$. Hence, EU_m has to find next favourable D2D transmission pairs in order to form a cooperative pair based on the proposed matching algorithm. However, this contradicts the assumption of $\alpha_{mn} < \alpha_{m^*n}$. Hence, $\Phi(m, n)$ cannot be a blocking pair. According to the rate requirement of EU_m , none of matched EU would become a blocking individual, because its partner provides higher rate than non-cooperative direct rate R_m^{dir} for the sake of improving its QoS. Furthermore, based on our RSWW-OSSS, a D2D transmission pair cannot be granted a transmission opportunity within the licensed spectrum if it is not matched to a EU. Therefore, no blocking pairs and/or blocking individuals are part of the cooperative matching generated by our matching algorithm, which implies that our RSWW-OSSS is capable of producing a stable cooperative matching.

References

1. Poulakis, M.I.; Gotsis, A.G.; Alexiou, A. Multicell Device-to-Device Communication: A Spectrum-Sharing and Densification Study. *IEEE Veh. Technol. Mag.* **2018**, *13*, 85–96. [CrossRef]
2. Ahmed, M.; Shi, H.; Chen, X.; Li, Y.; Waqas, M.; Jin, D. Socially Aware Secrecy-Ensured Resource Allocation in D2D Underlay Communication: An Overlapping Coalitional Game Scheme. *IEEE Trans. Wirel. Commun.* **2018**, *17*, 4118–4133. [CrossRef]
3. Ghavami, H.; Moghaddam, S.S. Outage Probability for Underlying Device to Device Communications. In Proceedings of the 2016 8th International Symposium on Telecommunications (IST), Tehran, Iran, 27–28 September 2016; pp. 353–358.
4. Ferdouse, L.; Ejaz, W.; Raahemifar, K.; Anpalagan, A.; Markandaier, M. Interference and Throughput Aware Resource Allocation for Multi-class D2D in 5G Networks. *IET Commun.* **2017**, *11*, 1241–1250. [CrossRef]
5. Ningombam, D.D.; Shin, S. Outage probability analysis of device-to-device communications with frequency reuse-2 in fractional frequency reuse method. In Proceedings of the 2018 International Conference on Information Networking (ICOIN), Chiang Mai, Thailand, 10–12 January 2018; pp. 341–345.
6. Katsinis, G.; Tsiropoulou, E.E.; Papavassiliou, S. Joint Resource Block and Power Allocation for Interference Management in Device to Device Underlay Cellular Networks: A Game Theoretic Approach. *Mob. Netw. Appl.* **2017**, *22*, 539–551. [CrossRef]
7. Ningombam, D.D.; Shin, S. Radio resource allocation and power control scheme to mitigate interference in device-to-device communications underlying LTE-A uplink cellular networks. In Proceedings of the 2017 International Conference on Information and Communication Technology Convergence (ICTC), Jeju, South Korea, 18–20 October 2017; pp. 961–963.

8. Ningombam, D.D.; Hwang, S.; Shin, S. A Novel Resource Sharing Mechanism for Device-to-Device Communications Underlying LTE-A Uplink Cellular Networks. In Proceedings of the 2018 Tenth International Conference on Ubiquitous and Future Networks (ICUFN), Prague, Czech Republic, 3–6 July 2018; pp. 829–833.
9. Katsinis, G.K.; Tsiropoulou, E.; Papavassiliou, S. On the Performance Evaluation of Distributed Resource Block and Power Allocation in D2D-enabled Multi-Cell Networks. In Proceedings of the 14th ACM Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor & Ubiquitous Networks, Montevideo, Uruguay, 10–14 April 2017; pp. 77–84.
10. Ningombam, D.D.; Hwang, S.; Shin, S. Overlay Inband D2D-e Network Using Fuzzy C-Means Clustering for Disaster Situations. In Proceedings of the 2018 European Conference on Networks and Communications (EuCNC), Ljubljana, Slovenia, 18–21 June 2018; pp. 288–292.
11. Kiwan, D.; El Sherif, A.; El Batt, T. Cooperative D2D communications in the uplink of cellular networks with time and power division. In Proceedings of the 2018 Wireless Days (WD), Dubai, United Arab Emirates, 3–5 April 2018; pp. 80–85.
12. Klaiqi, B.; Chu, X.; Zhang, J. Energy-and Spectral-Efficient Adaptive Forwarding Strategy for Multi-Hop Device-to-Device Communications Overlaying Cellular Networks. *IEEE Trans. Wirel Commun.* **2018**, *17*, 5684–5699. [[CrossRef](#)]
13. Yuan, Y.; Yang, T.; Xu, Y.; Hu, B. Cooperative spectrum-sharing between D2D Users and Edge-Users: A Matching Theory Perspective. In Proceedings of the 2016 IEEE 27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), Valencia, Spain, 4–8 September 2009; pp. 1–6.
14. Dinh-Van, S.; Duong, Q.; Shin, O.-S. User Grouping for Device-to-Device Communications Underlying Cellular Networks. In Proceedings of the 2014 IEEE 11th Consumer Communications and Networking Conference (CCNC), Las Vegas, NV, USA, 10–13 January 2014; pp. 563–568.
15. Moualeu, J.M.; Hamouda, W.; Takawira, F. Cognitive Coded Cooperation in Underlay Spectrum-Sharing Networks Under Interference Power Constraints. *IEEE Trans. Veh. Technol.* **2017**, *66*, 2099–2113. [[CrossRef](#)]
16. Ma, C.; Li, Y.; Yu, H.; Gan, X.; Wang, X.; Ren, Y.; Xu, J.J. Cooperative spectrum-sharing in D2D-enabled Cellular Networks. *IEEE Trans. Commun.* **2016**, *64*, 4394–4408.
17. Yang, L.; Wu, D.; Cai, Y. Social Aware Joint Link and Power Allocation for D2D Communication Underlying Cellular Networks. *IET Commun.* **2018**, *12*, 493–500. [[CrossRef](#)]
18. Fan, L.; Dong, Z.; Yuan, P. The Capacity of Device-to-Device Communication Underlying Cellular Networks with Relay Links. *IEEE Access* **2017**, *11*, 1241–1250. [[CrossRef](#)]
19. Swetha, G.D.; Murthy, G.R. Selective Overlay Mode Operation for D2D Communication in Dense 5G Cellular Networks. In Proceedings of the 2017 IEEE Symposium on Computers and Communications (ISCC), Heraklion, Greece, 3–6 July 2017; pp. 704–709.
20. Li, J.C.F.; Lei, M.; Gao, F. Device-to-device (D2D) Communication in MU-MIMO Cellular Networks. In Proceedings of the 2012 IEEE Global Communications Conference (GLOBECOM), Anaheim, CA, USA, 3–7 December 2012; pp. 3583–3587.
21. Cao, Y.; Jiang, T.; Wang, C. Cooperative Device-to-Device Communications in Cellular Networks. *IEEE Wirel. Commun.* **2015**, *22*, 124–129. [[CrossRef](#)]
22. Yang, Z.; Xu, W.; Pan, C.; Pan, Y.; Chen, M. On the Optimality of Power Allocation for NOMA Downlinks with Individual QoS Constraints. *IEEE Commun. Lett.* **2017**, *21*, 1649–1652. [[CrossRef](#)]
23. Gendia, A.H.; Elsabrouty, M.; Emran, A.A. Cooperative Multi-Relay Non-Orthogonal Multiple Access for Downlink Transmission in 5G Communication Systems. In Proceedings of the 2017 Wireless Days, Porto, Portugal, 29–31 March 2017; pp. 89–94.
24. Zhang, Z.; Ma, Z.; Xiao, M.; Ding, Z.; Fan, P. Full-Duplex Device-to-Device-Aided Cooperative Nonorthogonal Multiple Access. *IEEE Trans. Veh. Technol.* **2017**, *66*, 4467–4471.
25. Zhao, J.; Liu, Y.; Chai, K.K.; Che, Y.; Elkashlan, M.; Alonso-Zarate, J. NOMA-Based D2D Communications: Towards 5G. In Proceedings of the 2016 IEEE Global Communications Conference (GLOBECOM), Washington, DC, USA, 4–8 December 2016; pp. 1–6.
26. Aldawsari, B.; Baker, T.; England, D. Trusted Energy-Efficient Cloud-Based Services Brokerage Platform. *Int. J. Intell. Comput. Res. (IJICR)* **2015**, *6*, 630–639. [[CrossRef](#)]

27. Baker, T.; Ngoko, Y.; Tolosana-Calasan, R.; Rana, O.F.; Randles, M. Energy Efficient Cloud Computing Environment Via Autonomic Meta-Director Framework. In Proceedings of the 2013 Sixth International Conference on Developments in Systems Engineering, Abu Dhabi, United Arab Emirates, 16–18 December 2013; pp. 198–203.
28. Baker, T.; García-Campos, J.M.; Reina, D.G.; Toral, S.; Tawfik, H.; Al-Jumeil, D.; Hussain, A. GreeAODV: An Energy Efficient Routing Protocol for Vehicular Ad Hoc Networks. In Proceedings of the ICIC 2018: Intelligent Computing Methodologies, Wuhan, China, 15–18 August 2018; pp. 670–681.
29. Baker, T.; Asim, M.; Tawfik, H.; Aldawsari, B.; Buyya, R. An energy-aware service composition algorithm for multiple cloud-based IoT applications. *J. Netw. Comput. Appl.* **2017**, *89*, 96–108. [[CrossRef](#)]
30. Niu, Y.; Liu, Y.; Li, Y.; Chen, X.; Zhong, Z.; Han, Z. Device-to-Device Communications Enabled Energy Efficient Multicast Scheduling in mmWave Small Cells. *IEEE Trans. Commun.* **2018**, *66*, 1093–1109. [[CrossRef](#)]
31. Ahmad, I.; Feng, Z.; Hameed, A.; Zhang, P.; Zhao, Y. Spectrum-sharing and Energy-Efficient Power Optimization for Two-tier Femtocell Networks. In Proceedings of the 2014 9th International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM), Oulu, Finland, 2–4 June 2014; pp. 156–161.
32. Ali, R.E.; Seddik, K.G.; Nafie, M.; Digham, F.F. A Pricing-Based Cooperative spectrum-sharing Stackelberg Game. In Proceedings of the 2014 12th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt), Hammamet, Tunisia, 12–16 May 2014; pp. 226–232.
33. Yin, R.; Yu, G.; Zhong, C.; Zhang, Z. Distributed Resource Allocation for D2D Communication Underlying Cellular Networks. In Proceedings of the 2013 IEEE International Conference on Communications Workshops (ICC), Budapest, Hungary, 9–13 June 2013; pp. 138–143.
34. Mas-Colell, A.; Whinston, M.D.; Green, J.R. *Microeconomic Theory*; Publishing House of Oxford University Press: Oxford, UK, 1995.
35. Errapotu, S.M.; Wang, J.; Li, X.; Lu, Z.; Li, W.; Pan, M.; Han, Z. Bid Privacy Preservation in Matching-Based Multiradio Multichannel Spectrum Trading. *IEEE Trans. Veh. Technol.* **2018**, *67*, 8336–8347. [[CrossRef](#)]
36. Wu, Q.; Li, G.Y.; Chen, W.; Ng, D.W.K. Energy-Efficient D2D Overlaying Communications with Spectrum-Power Trading. *IEEE Trans. Wirel. Commun.* **2017**, *16*, 4401–4419. [[CrossRef](#)]
37. Katsinis, G.; Tsiropoulou, E.E.; Papavassiliou, S. Multicell Interference Management in Device to Device Underlay Cellular Networks. *Future Internet* **2017**, *9*, 44. [[CrossRef](#)]
38. Asadi, A.; Wang, Q.; Mancuso, V. A Survey on Device-to-Device Communication in Cellular Networks. *IEEE Commun. Surv. Tutor.* **2014**, *16*, 1801–1819. [[CrossRef](#)]
39. Feng, D.; Lu, L.; Wu, Y.Y.; Li, G.Y.; Feng, G.; Li, S. Optimal Resource Allocation for Device-to-Device Communications in Fading Channels. In Proceedings of the 2013 IEEE Global Communications Conference (GLOBECOM), Atlanta, GA, USA, 9–13 December 2013; pp. 3673–3678.
40. Guo, Q.; Yu, L. An Outage-Optimal Distributed Coded Cooperation Scheme Based on Opportunistic Relaying. In Proceedings of the 2009 IEEE Wireless Communications and Networking Conference, Budapest, Hungary, 5–8 April 2009; pp. 1–5.
41. Chen, B.; Chen, Y.; Chen, Y.; Cao, Y.; Zhao, N.; Ding, Z. A Novel spectrum-sharing Scheme Assisted by Secondary NOMA Relay. *IEEE Wirel. Commun. Lett.* **2018**, *7*, 732–735. [[CrossRef](#)]
42. Chu, Z.; Le, T.A.; Nguyen, H.X.; Nallanathan, A.; Karamanoglu, M. A Stackelberg-Game Approach for Disaster-Recovery Communications Utilizing Cooperative D2D. *IEEE Access.* **2018**, *6*, 10733–10742. [[CrossRef](#)]
43. Han, Y.; Tao, X.; Zhang, X. Power allocation for device-to-device underlay communication with femtocell using stackelberg game. In Proceedings of the 2018 IEEE Wireless Communications and Networking Conference (WCNC), Barcelona, Spain, 15–18 April 2018; pp. 1–6.
44. Chong, E.K.P.; Zak, S.H. *An Introduction to Optimization*, 4th ed.; Sun, Q., Bai, J., Eds.; Publishing House of Electronics Industry: Beijing, China, 2015; ISBN 9787121267154.

