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Research Article

Incorporating D2D to Current Cellular Communication System

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A device-to-device (D2D) group works as relay nodes to aid the information delivery from a source to a destination in cellular communication network. Within this system, we propose a communication mechanism to aid traditional cellular communication and correspondingly borrow some channel resource from traditional cellular communication system for D2D communication. On one side, to aid cellular communication, we propose a modified Alamouti scheme which does not modify the operation at the base station. This makes our proposed scheme consistent with previous cellular communication system. On the other side, there are many competitive D2D groups that want to potentially utilize the borrowed channel resource from traditional cellular system for delivering their own information. We model this competition as a game and utilize game theory technique to solve this competition problem.

1. Introduction

In traditional cellular systems, data is transmitted from the source terminal to the destination terminal via a base station (BS). All traffic is forwarded or relayed by the BS even if the source and the destination are close to each other. This relaying-structure has two drawbacks. First, it incurs long communication latency and high energy consumption. Second, traditional BS can only support limited number of mobiles communicating simultaneously, which does not suit the exponential growth of mobile terminals, especially machine-to-machine (M2M) communications which are mainly adopted to collect signals from sensors and then delivered to the Internet [1–3].

To tackle these two problems, device-to-device (D2D) communication instead of communication via a relay was proposed as a short-distance communication option [4–7]. Firstly, it reduces communication latency and energy consumption due to shorter communication range and fewer transmitters. Secondly, it enlarges system capacity since shorter communication range of D2D communication (can be viewed as a smaller cell) utilizes the spectrum with a higher utilization rate per area and hence has higher system capacity. There are a lot of application scenarios for D2D communication. (1) A group of people climb a mountain or visit a place. (2) A group of friends want to find each other in a prescheduled place. (3) A group of closed-to-each-other cars run in a highway.

Due to D2D's advantages as listed above, how to embed it into current cellular system needs to be carefully designed. In particular, radio resource (e.g., the frequency channel) allocation among these two systems is needed. There are two allocation modes. In the first, these two systems share the radio resource simultaneously, which introduces the interference between the D2D link and cellular link. In the second, these two systems use orthogonal channels.

Most of previous works for D2D communication assumed that D2D users worked in the underlay mode, namely, Mode One [8–11]. A radio resource allocation policy for D2D link is proposed in [12]. The work in [13] limits D2D's transmission power to ensure the quality of cellular links. It is also shown in [14] that power control in relay assisted D2D communication may be a better choice, which benefits from high transmission capacity and power efficiency.

To summarize, all those D2D works do not consider the cooperation between D2D groups with cellular system.

In this work, we let the transmitter of the D2D group help the cellular communication, namely, help the source to relay his signal to the destination, which provides another link. The two signals from these two links (one from BS and the other from the D2D group) can be combined in a certain manner, for example, maximum ratio combining (MRC), to enhance the received signal-to-noise ratio (SNR), which reduces the outage probability and increases the achieved diversity [15]. To implement the above, conventional diversity technique, Alamouti scheme is not compatible, since BS needs to perform conjugation on one of the transmission signals during the collaboration process. We propose a modified Alamouti scheme which does not modify the operation at BS; namely, the operation at the BS is identical to that in traditional cellular system. This kind of cooperation can reduce the delivery time required for cellular communication system and hence the saved time can be rewarded to D2D communication.

During the communication process, free riding, however, exists in the D2D terminal. In this paper, the game theoretical framework [16, 17] can solve this problem, and multi-D2D groups power can be controlled by Nash Equilibria [18]. This scheme can be utilized into high communication efficiency data collection in 5G mobile communication system [19–22], for example.

The organization of this paper is as follows. In Section 2, we first provide preliminaries and then describe the system model. In Section 3, we elaborate the proposed cooperation scheme that incorporates traditional cellular communication and D2D communication. In Section 4, we use game theoretical framework to design the competition among D2D groups. Finally, in Section 5, we draw the conclusions.

2. Preliminaries and System Model

2.1. Preliminaries. We first describe the decode-and-forward (DF) relaying protocol and then illustrate the Alamouti scheme.

2.1.1. Decode-and-Forward (DF). Refer to Figure 1. Transmitter A sends signal toward receiver B via relay R. The link gain between A and R is u, and the link gain between R and B is v. The channel's input-output relationship of the two hops is characterized by

$$\begin{aligned} y_R &= u x_A + w_R, \\ y_B &= v x_R + w_B, \end{aligned} \tag{1}$$

where x_R and y_R denote the output signal and input signal of relay R, respectively. In the DF protocol, the relay node first tries to decode the message from the received signal. If the decoding is successful, the relay reencodes the message using the same codebook as in source A. Otherwise, the relay simply keeps silent.

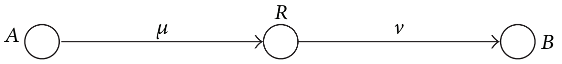

FIGURE 1: Illustration of DF.

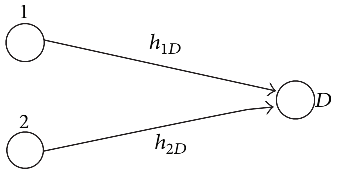

FIGURE 2: Alamouti scheme.

2.1.2. Alamouti Scheme. Refer to Figure 2. Transmitters 1 and 2 send signals simultaneously toward destination D. The link gain between transmitter $i \in \{1,2\}$ and destination D is h_{iD}. The channel's input-output relationship is characterized as

$$y[m] = h_{1D}[m]\, x_1[m] + h_{2D}[m]\, x_2[m] + w[m], \tag{2}$$

where $x_i[m]$ denotes the transmitted signal by transmitter i, $y[m]$ denotes the received signal at destination D, and $w[m]$ denotes the thermal noise at destination D, all at time slot m.

In the Alamouti scheme [23], the two transmitters intend to send two complex symbols u_1 and u_2, respectively, over two consecutive symbol slots. During slot 1, transmitter 1 sends u_1 and transmitter 2 sends u_2; namely, $x_1[1] = u_1$, $x_2[1] = u_2$. During slot 2, transmitter 1 sends $-u_2^*$ and transmitter 2 sends u_1^*; namely, $x_1[2] = -u_2^*$, $x_2[2] = u_1^*$. If we assume that the channel gain remains constant over these two consecutive symbol times, namely, $h_{1D}[1] = h_{1D}[2] \triangleq h_1$, $h_{2D}[1] = h_{2D}[2] \triangleq h_2$, then we have two consecutive received signals as

$$\begin{aligned} y[1] &= h_1 u_1 + h_2 u_2 + w[1], \\ y[2] &= -h_1 u_2^* + h_2 u_1^* + w[2]. \end{aligned} \tag{3}$$

Rewriting it into matrix form and performing the conjugation operation on the lower half matrix, we obtain

$$\begin{pmatrix} y[1] \\ y[2]^* \end{pmatrix} = \begin{pmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{pmatrix} \begin{pmatrix} u_1 \\ u_2 \end{pmatrix} + \begin{pmatrix} w[1] \\ w[2]^* \end{pmatrix}. \tag{4}$$

We observe that the two columns of the square matrix in (4) are orthogonal. Hence, the detection problem for u_1, u_2 decomposes into two separate, orthogonal, scalar problems.

Remark. Throughout this paper, we use x^* to denote the conjugate of the complex number x and $H^\dagger$ to denote the conjugate transpose of the complex matrix H.

2.2. System Model. Refer to Figure 3. There are two subsystems. One is the traditional cellular system, and the other is the D2D system. Node S communicates with node D via BS as a relay, which composes the traditional cellular system. The users that are in a small circle form the D2D communication group due to their closeness to each other; namely, the communication within this group is one hop.

The D2D group may help the source relay its transmitted signal to the destination, which provides another branch of

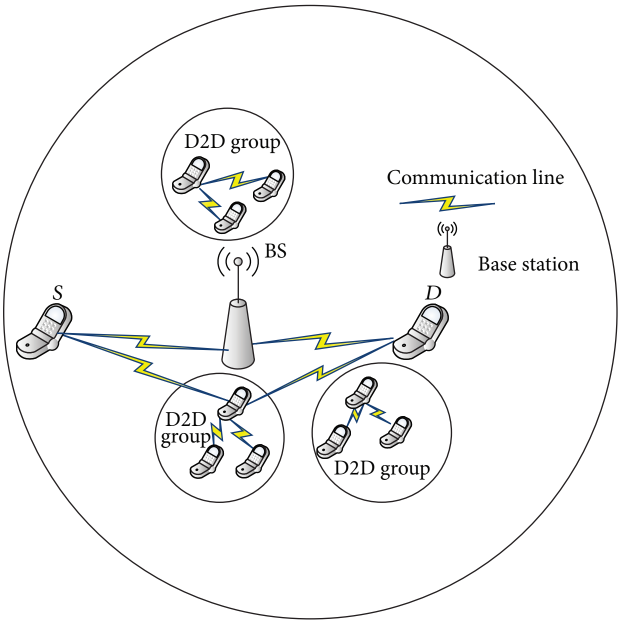

Figure 3: Illustration of relay D2D communications.

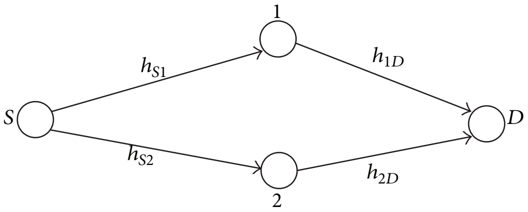

Figure 4: The relay network model.

link. The two signals arriving at the destination from these two links can be combined in a certain manner, for example, maximum ratio combining (MRC) to enhance the received SNR. According to Shannon's capacity formula, the achieved rate is correspondingly increased, which brings the following benefits. The completion time of the *S*-*D* communication link can be reduced and the reduced time (reduction of time) may be rewarded to the D2D users for communication.

The cellular communication in the above model can be simplified to the model in Figure 4, where node 1 represents *BS* and node 2 represents a relay node, which is acted by a member of the D2D group. We assume node i is subject to power constraint p_i, $i \in \{S, 1, 2\}$. The two relays are assumed to be operated in full-duplex mode (the half-duplex mode can be easily obtained by halving the transmission time between the first and the second hop). We consider the slow fading scenario, and the link gains are random. The link gains between node S and node i and between node i and node D are represented by h_{Si} and h_{iD}, respectively, $i \in \{1, 2\}$.

Let $x_i(m)$ be the transmitted symbol from node S to node i at time m, $i \in \{S, 1, 2\}$. We also let $y_i(m)$ and $w_i(m)$ be, respectively, the received symbol and the thermal noise at node i at time m, $i \in \{1, 2, D\}$. Each channel's input-output relationship is represented by the following formulas:

Table 1: Standard Alamouti.

	BS	D2D
Slot 1	u_1	u_2
Slot 2	$-u_2^*$	u_1^*

$$
\begin{aligned}
y_i(m) &= h_{Si}\sqrt{P_S}x_S(m) + w_i(m), \\
y_D(m) &= \sum_{i=1}^{2} h_{iD}\sqrt{P_i}x_i(m) + w_D(m),
\end{aligned}
\tag{5}
$$

subject to $\mathrm{Var}\{x_S(m)\} \le P_S$ and $\mathrm{Var}\{x_i(m)\} \le P_i$ for $i = 1, 2$ and $w_i(m), w_D(m) \sim \mathscr{CN}(0, n)$.

If the decoding in each relay node is successful, the output of the relay node can be represented by

$$
x_i(m) = x_S(m). \tag{6}
$$

We assume that $P_1 = P_2 = \kappa P_S$. Define signal-to-noise ratio (SNR) $\Gamma \triangleq P_S/n$. The received SNR at relay i is denoted by $\Gamma_i(h_{Si})$ and is equal to $|h_{Ai}|^2\Gamma$. The received SNR at destination D is denoted by $\Gamma_D(h)$, whose expression depends on the transmission scheme. Correspondingly, we define $R_S(h)$ as the end-to-end information rate from source S to destination D. According to Shannon's capacity formula, the end-to-end information rate is equal to

$$
R_S(h) = \log_2\left(1 + \Gamma_D(h)\right). \tag{7}
$$

An outage event occurs if the instantaneous end-to-end rate $R_S(h)$ falls below a certain threshold, R_{thd}. Outage probability is the probability of occurrence of an outage event; that is, $p_{\mathrm{out}} \triangleq \Pr\{R_S(h) < R_{\mathrm{thd}}\}$. According to (7), there is a one-to-one correspondence between $R_S(h)$ and $\Gamma_D(h)$. Therefore, the outage probability can be obtained by comparing $\Gamma_D(h)$ with a certain threshold, Γ_{thd}. More specifically, we have $p_{\mathrm{out}} \triangleq \Pr\{\Gamma_D(h) < \Gamma_{\mathrm{thd}}\}$.

3. Proposed Cooperation Scheme

The key idea is that the D2D group serves as another branch of link for aiding the *S*-*D* communication. In this case, the received signal at D may be enhanced by appropriate signal processing method, and hence the completion time may be shortened. The reward is that the saved time can be granted to the D2D group for short-distance D2D communication.

3.1. Protocol Description. After receiving the signal from the source, the BS and the D2D group combine Alamouti protocol with DF. Note that simply using the standard Alamouti scheme as shown in Section 2.1.2 will have drawback. Detailed explanation is as follows.

The standard Alamouti schedule is shown in Table 1. In a transmission block, the BS (relay 1) transmits u_1 and $-u_2^*$ in two consecutive time slots, respectively. We observe that

Table 2: Modified Alamouti.

	BS	D2D
Slot 1	u_1	$-u_2^*$
Slot 2	u_2	u_1^*

the BS in the second slots performs a conjugation operation followed by a negative operation, which is not consistent with traditional cellular system (for traditional cellular system, the BS should perform uniform operation on the signals for all users, namely, transmits u_1 and u_2 in the block). For this reason, we propose a modified Alamouti scheme which does not need to alter the operation at the BS. The modified Alamouti schedule is shown in Table 2. We observe that the operation in the BS (relay 1) is exactly what the BS does in traditional cellular system. Therefore, the modified Alamouti scheme can be easily incorporated into traditional cellular system in a consistent manner. We call the modified Alamouti combined with DF MADF for short.

3.2. Performance Analysis. To analyze the performance of MADF, we rephrase its protocol description. Each relay first decodes the message from the received signal. If the decoding is successful, the relay reencodes the message using the same codebook adopted in source S. Otherwise, if the decoding fails, the relay will not forward the signal to the destination. The transmissions of the relays follow the modified Alamouti scheme.

After receiving the signal from the source, the transmit symbols of relays are constructed in the following way:

$$u_{im} \triangleq x_i(m) = x_S(m), \tag{8}$$

where $i = 1, 2$ and $x_S(m)$ is the symbol from the previous block.

As the modified Alamouti scheme shows, in the first time slot, relay 1 transmits u_{11} and relay 2 transmits $-u_{22}^*$; in the second time slot, relay 1 transmits u_{12} and relay 2 transmits u_{21}^*. Note that the BS transmits the original signal in this block which is consistent with the operation in traditional cellular system. The output symbols at destination node D are

$$\begin{aligned} y_D(1) &= \sqrt{\kappa P_S}\left(h_{1D}u_{11} + h_{2D}\left(-u_{22}^*\right)\right) + w_D(1), \\ y_D(2) &= \sqrt{\kappa P_S}\left(h_{1D}u_{12} + h_{2D}\left(u_{21}^*\right)\right) + w_D(2), \end{aligned} \tag{9}$$

which is equivalent to

$$\begin{pmatrix} y_D(1) \\ y_D^*(2) \end{pmatrix} = H\sqrt{\kappa P_S}\begin{pmatrix} x_S(1) \\ x_S^*(2) \end{pmatrix} + w_D, \tag{10}$$

where

$$\begin{aligned} H &\triangleq \begin{pmatrix} h_{1D} & -h_{2D} \\ h_{2D}^* & h_{1D}^* \end{pmatrix}, \\ w_D &\triangleq \begin{pmatrix} w_D(1) \\ w_2^*(2) \end{pmatrix}. \end{aligned} \tag{11}$$

Multiplying (10) by $H^\dagger$, we obtain

$$H^+\begin{pmatrix} y_D(1) \\ y_D^*(2) \end{pmatrix} = H^+H\sqrt{\kappa P_S}\begin{pmatrix} x_S(1) \\ x_S^*(2) \end{pmatrix} + H^\dagger w_D, \tag{12}$$

where $H^\dagger H = \operatorname{diag}(\lambda, \lambda)$ and $\lambda \triangleq \{|h_{1D}|^2 + |h_{2D}|^2\}$.

The received SNR at destination D is then given by

$$\begin{aligned} \Gamma_D^{\mathrm{MADF}}(h) &= \Gamma_D(\Phi_1, \Phi_2) \\ &= \left(\Phi_1\left|h_{1D}\right|^2 + \Phi_2\left|h_{2D}\right|^2\right)\kappa\Gamma, \end{aligned} \tag{13}$$

where, for $i = 1, 2$,

$$\Phi_i \triangleq \begin{cases} 1, & \text{if } \Gamma_i \geq \Gamma_{\mathrm{thd}}, \\ 0, & \text{otherwise}. \end{cases} \tag{14}$$

We claim the following.

Theorem 1. *MADF yields a lower outage probability than traditional cellular network.*

Proof. If BS fails in the decoding, then traditional method fails in the decoding at final destination D since BS will keep silent. In MADF, final destination D may or may not be able to recover the message depending on whether relay two succeeds in the decoding and final destination succeeds in the decoding. If it is positive, then MADF outperforms traditional method. Otherwise, they have the same outage performance.

If BS succeeds in decoding, then traditional cellular method achieves received SNR at D as $\Gamma_D(1, 0) = \kappa|h_{1D}|^2\Gamma$, while MADF achieves $\Gamma_D(1, 1) = (|h_{1D}|^2 + |h_{2D}|^2)\kappa\Gamma$, which is greater than the traditional cellular system. This can be transformed to the fact that MADF outperforms traditional cellular system in terms of outage performance.

Summarizing the above two cases, we claim that MADF outperforms traditional cellular system in terms of outage probability. □

Note that the inverse of outage probability represents the time duration required to finish the information delivery. We hence conclude that MADF saves delivery time. The saved time can be rewarded to the D2D group for D2D communication. How to utilize this borrowed channel is illustrated in the next section.

4. D2D Competition within Game Theoretical Framework

In view of the above description, traditional communication framework cannot meet increasingly huge demand of communication. Our proposed scheme alleviates such heavy burden by attracting D2D communication into using traditional cellular communication channel. Besides, such scheme does not alter the operation at BS and hence can be applied into current cellular system seamlessly.

However, in practice, there are many D2D groups that potentially want to communicate. If they want to borrow the communication channel of the cellular system, a fair channel allocation scheme should be designed for many competitors. Game theory is a good option for providing a fair resource allocation among many competitors in a distributed fashion. Under noncooperative game theoretical framework where each user is selfish, the notion of Nash Equilibrium (NE) is normally considered as a good steady state that evaluates the systems steadiness. In an NE state, no user will benefit by unilaterally deviating from the current strategy selection [24].

In this section, we formulate the competition among D2D groups within noncooperative game theoretical framework. Detailed mechanism is as follows.

Each D2D group wants to communicate within a group. Many D2D groups compete for the channel resource of traditional cellular system. Channel allocation rule is the channel which will be awarded to the D2D group that acts as relay for cellular communication. On one hand, one member in a D2D group may serve as the relay and hence this group grabs the channel for communication. This member has power consumption for serving as relay, but he enjoys the D2D communication; the other members within this group will benefit without payment, for example, power consumption for relaying. On the other hand, other D2D groups do not have power consumption for relaying, but they do not get the channel resource for D2D communication.

We propose a back-off timer based [25] mechanism for these users to compete for this channel. Each user randomly sets a back-off timer. The user that times out first will serve as relay and he notifies the other users to stop timing. Afterwards, the group that contains this user as member starts D2D communication.

Game Setting. Totally, there are G D2D groups with all the members in the gth group denoted by set $\mathcal{U}^g$. In D2D group $g \in \{1, 2, \ldots, G\} \triangleq \mathcal{G}$, its ith member m_i^g randomly picks a back-off timer, τ_i^g, which is a random variable and follows the exponential distribution, $\tau_i^g \sim \exp(\lambda_i^g)$. Each user chooses the value separately.

Utility Formulation. If user $m_{i^*}^g$ serves as relay, then his utility is

$$\mathcal{U}_{i^*}^g = \alpha_{i^*}^g p_{i^*}^g + \beta_{i^*}^g \min\left(\tau_1^1, \ldots, \tau_{n_1}^1, \tau_1^2, \ldots, \tau_{n_2}^2, \ldots\right), \quad (15)$$

where $p_{i^*}^g$ is the transmission power of $m_{i^*}^g$ when he serves as relay and $\alpha_{i^*}^g$ and $\beta_{i^*}^g$ are the weighting coefficients for transmission power $p_{i^*}^g$ and weighting time. For users with different power savings, $\alpha_{i^*}^g$ will be different. Define $\tau_{i^*}^g \triangleq \min(\tau_1^1, \ldots, \tau_{n_1}^1, \tau_1^2, \ldots, \tau_{n_2}^2, \ldots)$. Actually the above utility is cost and hence the smaller the better. The other users within group g have utility

$$\mathcal{U}_i^g = \beta_i^g \min\left(\tau_1^1, \ldots, \tau_{n_1}^1, \tau_1^2, \ldots, \tau_{n_2}^2, \ldots\right), \quad i \neq i^*. \quad (16)$$

For members in other groups, the utility is

$$\mathcal{U}_j^h = \beta_j^h \min\left(\tau_1^1, \ldots, \tau_{n_1}^1, \tau_1^2, \ldots, \tau_{n_2}^2, \ldots\right), \quad h \neq g. \quad (17)$$

Instead of considering each user's utility, we consider each group's utility. The utility of group g is

$$\mathcal{U}^g = \sum_{i=1}^{n_g} \mathcal{U}_i^g = \sum_{i=1}^{n_g} \beta_i^g \tau_{i^*}^g + \alpha_{i^*}^g p_{i^*}^g. \quad (18)$$

The utility of group $h \neq g$ is

$$\mathcal{U}^h = \sum_{i=1}^{n_h} \mathcal{U}_i^h = \sum_{i=1}^{n_h} \beta_i^h \tau_{i^*}^g. \quad (19)$$

We formulate a noncooperative game. The game involves G players, with each player being a D2D group. Each group tries to minimize the value of its utility. For simplicity, we assume that the duration of each timer follows the exponential distribution, $\exp(\lambda)$, with value of parameter λ yet to be determined. We in the following will derive how each user determines such a value so that an NE can be obtained. We apply the following theorem to obtain NE and the corresponding values.

Theorem 2. *The strategies of players in a game form an NE if, for each player, given the strategies of other players, the expected cost of player i is the same regardless of its chosen values of back-off times [26].*

We apply Theorem 2 to determine the values of λ's. Suppose that user $m_{i^*}^g$ in group g chooses $\tau_{i^*}^g = \tau$. On one hand, if τ is smaller than all $\tau_i^h \in \mathcal{U}^1 \cup \mathcal{U}^2 \cdots \cup \mathcal{U}^G \setminus \{m_{i^*}^g\}$, user $m_{i^*}^g$ serves as relay node to aid traditional cellular communication after waiting for τ units of time, and thus the utility obtained by group g is $\sum_{i=1}^{n_g} \beta_i^g \tau + \alpha_{i^*}^g p_{i^*}^g$, where $\alpha_{i^*}^g p_{i^*}^g$ denotes relaying power consumption cost and $\sum_{i=1}^{n_g} \beta_i^g \tau$ denotes waiting cost.

On the other hand, if $\exists h \in \mathcal{G} \setminus \{g\}$ such that one member in group h sets a timer smaller than τ and it is the smallest among all timers of all groups, in this case, all users in group g do not need to aid traditional cellular communication and hence the utility of group g is $\sum_{i=1}^{n_g} \beta_i^g \tau$. Note that we have $\min\{\tau_1, \tau_2, \ldots, \tau_l\} \sim \exp(\Sigma_l \lambda_i)$, where $\tau_i \sim \exp(\lambda_i)$. Therefore τ is the minimum within all groups except group g. Therefore, $\tau \sim \exp(\lambda_{-\mathcal{U}^g})$ where $\lambda_{-\mathcal{U}^g} \triangleq \sum_{g=1}^{G} \sum_{i=1}^{n_g} \lambda_i^g - \sum_{i=1}^{n_g} \lambda_i^g$ with $-\mathcal{U}^g \triangleq (\cup_{k=1}^{G} \mathcal{U}^k) \setminus \mathcal{U}^g$.

The expected utility of group g can be written as

$$\begin{aligned} &\int_{s=0}^{\tau} \sum_{i=1}^{n_g} \beta_i^g s \lambda_{-\mathcal{U}^g} e^{-\lambda_{-\mathcal{U}^g} s} ds \\ &\quad + \int_{s=\tau}^{\infty} \left(\sum_{i=1}^{n_g} \beta_i^g \tau + \alpha_{i^*}^g p_{i^*}^g \right) \lambda_{-\mathcal{U}^g} e^{-\lambda_{-\mathcal{U}^g} s} ds \qquad (20) \\ &= \frac{\sum_{i=1}^{n_g} \beta_i^g}{\lambda_{-\mathcal{U}^g}} + \left(\alpha_{i^*}^g p_{i^*}^g - \frac{\sum_{i=1}^{n_g} \beta_i^g}{\lambda_{-\mathcal{U}^g}} \right) e^{-\lambda_{-\mathcal{U}^g} \tau}. \end{aligned}$$

Thus, if $\alpha_i^g p_i^g = \sum_{i=1}^{n_g} \beta_i^g / \lambda_{-\mathscr{U}^g}$, the strategies form a Nash Equilibrium. This can be done by choosing

$$\lambda_{\mathscr{U}} = \frac{1}{G-1} \sum_{g=1}^{G} \sum_{k=1}^{n_g} \frac{\sum_{i=1}^{n_g} \beta_i^g}{\alpha_k^g p_k^g} - \frac{\sum_{i=1}^{n_g} \beta_i^g}{\alpha_i^g p_i^g}, \tag{21}$$

for all $\mathscr{U} \in \{\mathscr{U}_1, \mathscr{U}_2, \ldots, \mathscr{U}_G\}$, where $\lambda_{\mathscr{U}}$ denotes the parameter of exponential distribution that the duration of the minimum timer of this group, which is a random variable, follows.

Theorem 3. *If each group, say group g, chooses $\tau_{\mathscr{U}^g} \sim \exp(\lambda_{\mathscr{U}^g})$ as set by (21), then these strategies form a Nash Equilibrium.*

The λ's in a group need to satisfy

$$\sum_{i=1}^{n_g} \lambda_i^g = \lambda_{\mathscr{U}^g}, \tag{22}$$

subject to constraint $\lambda_i^g > 0$. Detailed values chosen for λ_i^g's may be implemented by voting for a group leader and let him allocate the values that satisfy (22). In practice, for simplicity, we can choose $\lambda_i^g = \lambda_{\mathscr{U}^g} / n_g$ for all $i \in \mathscr{U}^g$.

5. Conclusion

In this work, a device-to-device (D2D) group aids the transmission of traditional cellular communication. We present a modified Alamouti scheme which does not modify the operation at BS and hence make the scheme consistent with traditional cellular communication system. The saved time in traditional communication is rewarded to D2D users for communication. Game theory technique is designed to tackle the competition among many D2D groups that potentially want to utilize the rewarded channel for D2D communication.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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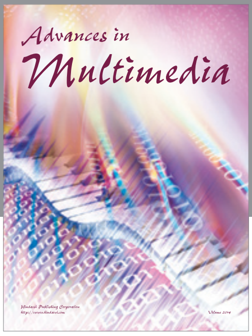
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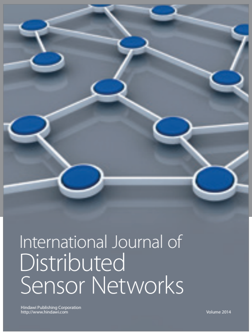
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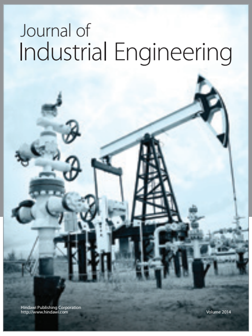
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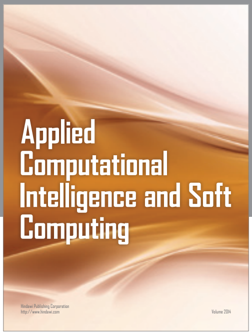
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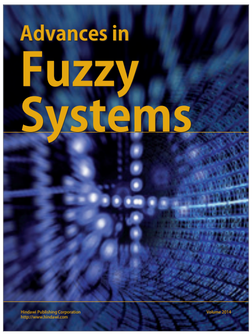
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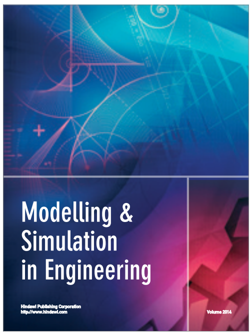
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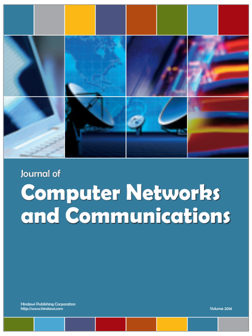
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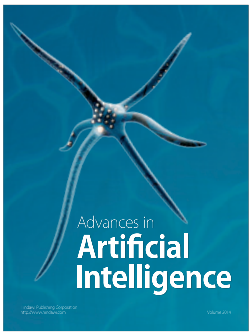
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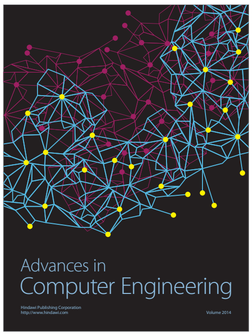
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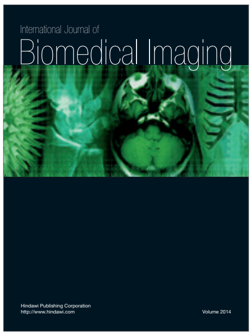
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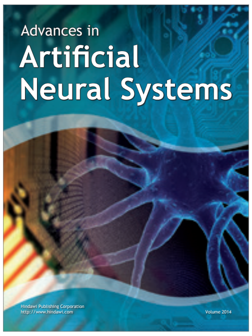
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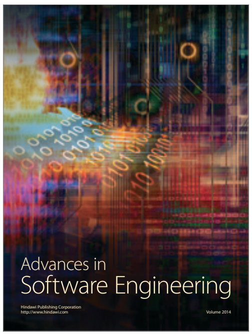
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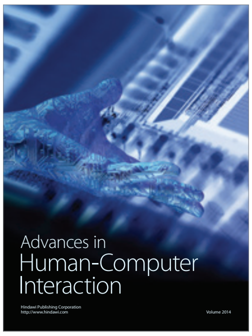
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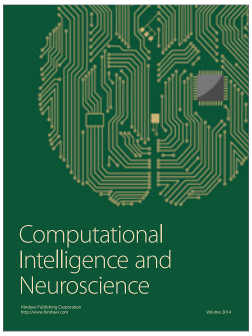
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