Promoting Relay-Assisted Device-to-Device Communication in Cellular Networks By Reward Mechanisms

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Abstract—**Relay assisted Device-to-Device (D2D) communication further improves the efficient utilization of resources of cellular networks by relaying traffic between two User Equipment (UEs) which are not in D2D communication range. While the traffic of Base Station (BS) is offloaded leveraging direct communication between UEs, it is envisioned that the adoption of D2D communication may not be materialized without incentive to users since they have already subscribed monthly data plan. In this paper, we first find the achievable data rate both in relay assisted D2D link and cellular link. We then calculate the utility of BS, relay UE and content/traffic destination UE based on the achievable data rate. When the utility of a UE is positive, it takes part in relay assisted D2D communication without reward, otherwise it asks reward from the BS. We simulated our proposal under various scenarios and found that many UEs have positive utility in relay assisted D2D link. This incentivizes UEs to take part in relay assisted D2D communication without reward even if they have already subscribed data plan.**

Index Terms—**Relay, D2D communication, data rate, reward, cellular network.**

I. Introduction

THE proliferation of high performance mobile devices such as smartphones, tablets etc., and constant use of them to access the Internet in cellular networks has strained BSs. These devices are frequently used to access SNS services and/or upload/download video, audio, photos, etc., to/from servers generating a huge amount of traffic [1]. Cellular networks are also evolving and increasing their network capacity by integrating new technologies and shifting their paradigms. The current 4G cellular network also known as 3GPP LTE-Advanced [2], supports D2D communication and is evolving in 5G with security [3]. Unlike complex technologies involved in accommodating high demand of users, D2D can significantly improve resource utilization of wireless cellular networks by letting a pair of D2D devices which are in proximity of each other to communicate directly instead of communicating via Base Station (known as evolved Node (eNB) Base Station in LTE. Hereafter we use eNB) [4], [5]. In D2D communication, two devices called User Equipment (UEs), which are in proximity of each other, can establish a direct communication link using licensed band. Because of their proximity, there is limited interference from other users even if they use the same licensed band. Since D2D communication can be established by sharing channel, the eNB can provide service to other UEs using the same channel thereby increasing the throughput of the network [6], [7]. It is assumed that the eNB as the central controller determines which devices will take part in D2D communication for maximization of throughput and efficient use of spectrum [8]. However, in practice, cellular users pay for their data plan. They may not take part in D2D communication without any incentive from the BS. Therefore, in order to attract users to take part in D2D communication, it is essential that incentive mechanism is available even though they have already paid for the data plan. If they take part in D2D communication, cellular network traffic will be offloaded.

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In [9], [10], authors propose contract-theoretic model in which the BS hires the UEs as employees to fulfill the content transmission task using D2D communication. The UEs, as employees, select contracts that are best fit to their own preferences and obtain reward for using D2D communication. However, in many situation, the content sender and the receiver are not within the D2D distance. A relay node which is within the D2D distance to the content sender and the receiver is needed to relay the content. If the content provider is not within the D2D distance to the relay, the BS may also directly send the content to the relay which will relay it to the receiver.

In this paper, we investigate how the content receiver will benefit if it receives content via the relay [11], [12]. In our proposal, when a new cellular user requests content from eNB, the eNB first finds if there is a content provider and a relay which is within the D2D distance (communication range) to the content provider and the content requester. We assume that the eNB has some mechanism of finding the content provider and the relay within its coverage area and how it does is beyond the scope of this paper [13]. If it finds them, it calculates achievable data rate via the relay and the cellular link (i.e. directly from the eNB) and sends the information to the content requester. The content requester will then decide if it will take part in D2D communication, i.e., receive content via the relay with reward or without it.

The paper is organized as follows. In section II, we present the related works. In section III, we present system model and utility of UEs and eNB. In section IV, we show performance evaluation, simulation results and analysis of our proposal followed by conclusions in section V.

II. Related Works

In [14], authors have proposed a relay selection scheme for uplink and D2D communications for efficient use of the spectrum. The scheme extends the coverage and improves the throughput under shadow fading environment. In [15], authors consider downlink relay services in cellular network. When a device wants service from a relay it buys the service by paying with electronic token to the relay. When a relay wants to provide the service using its resources, it does so to acquire electronic tokens. Authors model each device's decision problem whether to buy/sell the relaying services. In [16], authors propose mathematical framework for estimating energy saving of a relay assisting a pair of communicating wireless devices. They identify the energy saving zone between the pair where a relay residing in the zone is energy efficient. Authors in [17] propose a scheme based on double auction theory to improve the performance of cell-edge users with energy efficiency in cooperative cellular networks. In [18], authors applied various network coding techniques in relay-assisted D2D communication and proposed an algorithm to select the most suitable relay to maximize the throughput of D2D pair. Authors in [19] have applied relay assisted D2D communication to improve the network throughput with video files cashed in user equipment.

The above related works either consider cooperative receivers and relays in D2D communications for energy efficiency and improving throughput or the receivers pay to the relay to increase its downlink capacity. However, in general it is assumed that many receivers will not be cooperative and expect some kind of reward for taking part in relay assisted D2D communication or they need to be informed that their utility is high in relay assisted D2D communication compared to the cellular communication.

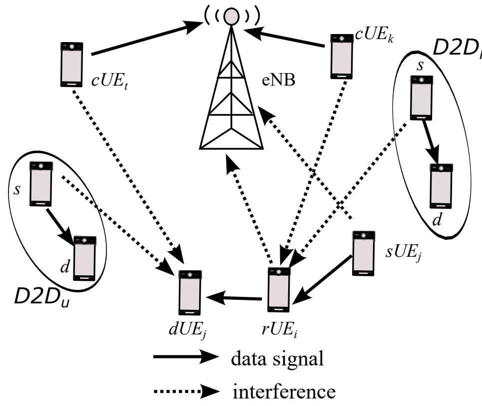

Fig. 1. Uplink Interference

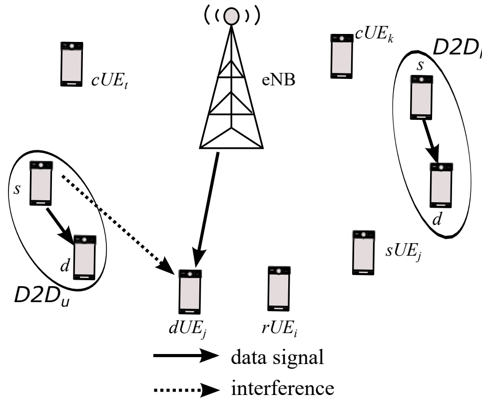

Fig. 2. Downlink Inteference

III. System Model and Utility

We consider only one cell of a cellular network with one eNB at the center of the cell. Within the coverage area of the eNB, there are several cellular User Equipment ($cUEs$) which are served by the eNB and D2D User Equipment pairs in which one is a content requester/receiver and the other is a content provider/sender. When a content receiver, i.e., content destination, UE (dUE), requests the eNB for content, the eNB may directly serve dUE or provide an opportunity to receive the content via a relay UE (rUE). It is assumed that the content provider, i.e., sender UE (sUE), is in proximity of rUE and the rUE is in proximity of the dUE. The dUE may willfully agree to receive the content via rUE if it is advantageous for it to do so. If not the dUE will ask for reward from the eNB for receiving content via rUE. The receiver dUE makes the decision based on its utility which is calculated using the achievable data transmission rates from rUE, i.e., D2D link and eNB, i.e., cellular link.

A. Data Transmission Rate

When a receiver dUE is receiving content via a relay rUE, we consider only uplink case since resource sharing in this case affects only the eNB, which can easily mitigate it by coordination. Figure 1 shows interference to the receiver dUE when it receives content from rUE in D2D link. In the figure, dUE_j is subject to interference from cUE_t and $D2D_u$ pair as it shares channel with them. Similarly, rUE_i is also subject to interference from channel sharing cUE_k and $D2D_l$ pair. The data transmission rate is related to the Signal to Interference plus Noise Ratio (SINR). We present the achievable data transmission rate via relay and directly from eNB in section III-A1 and section III-A2 respectively. We assume that the eNB selects the most appropriate relay and the relay agrees to relay the content, i.e., the utility of the selected relay is always positive. Therefore we do not calculate SINR of the relay here.

1) SINR at Content Destination UE when Content is received via Relay: SINR at dUE_j in Fig. 1 is as shown in equation 1.

$$\begin{aligned} SINR_{dUE_j} &= \frac{P_{rUE_i} G_{ij}}{N + I + I_{c_t} + I_{d2d_u}} \qquad (1) \\ where & \\ I_{C_t} &= \sum\nolimits_{C_t} P_{cUE_t} G_{tj} \\ I_{d2d_u} &= \sum\nolimits_{j \neq u} P_{S_{d2d_u}} G_{uj} \end{aligned}$$

I_{C_t} is the interference from cellular cUE_t to dUE_j. I_{d2d_u} is the interference from $D2D_u$ to dUE_j. P_{rUE_i} is the transmit power of relay rUE_i. $P_{S_{d2d_u}}$ is the transmit power of sender S_{d2d_u} in $D2D_u$. P_{cUE_t} is the transmit power of cellular cUE_t. G_{ij} is the channel gain between rUE_i and dUE_j. G_{uj} is the channel gain between S_{d2d_u} and dUE_j. G_{tj} is the channel gain between cellular cUE_t and dUE_j. N is additive white Gaussian noise. I is inter-cell interference. Channel gain or link gain can be modeled in terms of distance between a sender and the corresponding receiver as $G_{ij} = (d_{ij})^{-\alpha}, G_{uj} = (d_{uj})^{-\alpha}, G_{tj} = (d_{tj})^{-\alpha}$. α is the path-loss exponent which is constant and generally set to be $1.6 \leq \alpha \leq 6$. d_{ij}, d_{uj} and d_{tj} are the distances between the pairs (rUE_i, dUE_j), (S_{d2d_u}, dUE_j), and (cUE_t, dUE_j)

respectively. Equation 1 can be expressed in terms of distance as shown in equation 2.

$$\begin{aligned} SINR_{dUE_j} &= \frac{P_{rUE_i}(d_{ij})^{-\alpha}}{N+I+I_{c_t}+I_{d2d_u}} \\ where & \\ I_{C_t} &= \sum\nolimits_{C_t} P_{cUE_t}(d_{tj})^{-\alpha} \\ I_{d2d_u} &= \sum\nolimits_{j\neq u} P_{S_{d2d_u}}(d_{uj})^{-\alpha} \end{aligned} \quad (2)$$

The achievable data rate R_{dUE_j} of dUE_j with co-channel interference, i.e., when channel is shared, is expressed as shown in equation 3, where W is the channel bandwidth. Hereafter, without loss of generality and for simplicity, we assume that $W = 1$.

$$R_{dUE_j} = W\log_2\left(1+\frac{P_{rUE_i}(d_{ij})^{-\alpha}}{N+I+I_{C_t}+I_{d2d_u}}\right) \quad (3)$$

2) SINR at Content Destination UE when Content is received from eNB: When a receiver dUE_j is joining as a cellular UE, i.e., receiving the content from the eNB in cellular link, it experiences interference from D2D pair, which it will share the channel with, as shown in Fig. 2. The SINR it experiences can be expressed as shown in equation 4 and its achievable data rate can be expressed as shown in equation 5.

$$SINR_{eNB_j} = \frac{P_{eNB}(d_{eNBj})^{-\alpha}}{N+I+I_{d2d_u}} \quad (4)$$

$$R_{eNB_j} = W\log_2\left(1+\frac{P_{eNB}(d_{eNBj})^{-\alpha}}{N+I+I_{C_t}+I_{d2d_u}}\right) \quad (5)$$

Here P_{eNB} is the transmit power of eNB and d_{eNBj} is the distance between eNB and dUE_j.

B. Utility of eNB

Utility function of eNB when dUE_j receives the content via relay in D2D communication mode is expressed in terms of increased data rate of eNB and the reward it offers to dUE_j and rUE_i as shown in equation 6. In rest of the following equations, we assume that reward is either in the form of data speed, monetary unit, or the cost of resources consumed by UEs whichever is the most appropriate in equations. In some cases, it may be transformed in an appropriate value suitable for the equation.

$$U_{eNB(j)} = R_{dUE_j} - cT_T + \delta \quad (6)$$

Here R_{dUE_j} is achievable data rate at the content destination dUE_j due to relay assisted D2D communication and δ is the channel that is freed due to co-channel sharing by dUE_j, i.e. receiving content via relay than directly from eNB due to which eNB can now accommodate more UEs. T_T as shown in equation 7 is the total reward eNB pays to dUE_j and rUE_i for taking part in relay assisted D2D communication.

$$T_T = RW_i + RW_j \quad (7)$$

Here, RW_i and RW_j are the reward paid to the relay rUE_i and content receiver dUE_j respectively. $c > 0$ is the unit cost of the eNB.

C. Utility of Relay

Relay uses power to relay data which is expressed as shown in equation 8.

$$P_{rUE_i} = \frac{\gamma_T(I_{T_j}+N)}{(d_{ij})^{-\alpha}} \quad (8)$$

Here, γ_T is the SINR threshold for the relay to decode and I_{T_j} is the total interference at the destination dUE_j. The utility of relay rUE_i can be expressed as in equation 9.

$$U_{rUE_i} = RW_i - P_{rUE_i} \quad (9)$$

Here, RW_i is the reward from eNB. The utility of the relay is the reward minus the power it uses to relay the data.

D. Utility of Content Destination UE

Content receiver node may receive data without reward if its achievable data rate from relay is more than the achievable data rate from eNB, otherwise it requests reward to receive data from the relay. The utility of content receiver dUE_j is expressed as shown in equation 10.

$$U_{dUE_j} = max((RW_j - R_{dUE_j}),(R_{dUE_j} - R_{eNB_j})) \quad (10)$$

The utility of a receiver depends upon the achievable data rate and the reward that is offered. If the achievable data rate from the relay is higher than from eNB, the eNB may not give more reward, i.e., higher than the data rate from the relay. In such a case, the receiver will not seek for reward and receive data from the relay as the data rate from the relay is higher than from the eNB. If not reward will be offered and $(RW_j - R_{dUE_j}) > (R_{dUE_j} - R_{eNB_j})$ will hold. If the eNB does not want to offer reward, the receiver will receive data directly from the eNB as the achievable data rate from the eNB is higher than from the relay.

IV. Performance Evaluation

When eNB receives request for content from a new content requester (dUE_j), it searches for a content provider (sUE_j) and a relay (rUE_i) where the relay is within the D2D communication distance to the content provider and the content requester. If it finds both of them, it calculates the achievable data rates R_{dUE_j} and R_{eNB_j} for dUE_j. It sends R_{dUE_j}, R_{eNB_j} and locations of sUE_j and rUE_i to dUE_j. Upon receiving the above information, the dUE_j recalculates R_{dUE_j} and R_{eNB_j} for confirmation. If R_{dUE_j} is greater than R_{eNB_j} it replies to the eNB that it will receive the content via the relay without any reward, if not it will reply asking reward for receiving the content from the relay. When the eNB receives the reply without reward it establishes D2D communication mode between sUE_j, rUE_i and dUE_j. If it receives reply with reward, it offers the reward which dUE_j may or may not accept it. If the dUE_j accepts the reward, the eNB will form D2D communication link between sUE_j, rUE_i and dUE_j, otherwise the eNB will serve the dUE_j in cellular mode.

TABLE I
SIMULATION PARAMETERS

Parameters	Values
Radius of Cellular Coverage	500m
D2D Distance	30m
Number of Active cellular UE	40
Noise Spectral Density	-74dBm/Hz
Maximum eNB Transmit Power	40W
Maximum UE Transmit Power	200mW
Path-loss exponent α between eNB to UE	3.5
Path-loss exponent α between UE to UE	4

A. Simulation Results and Analysis

In our simulation, we put 1000 cellular UEs randomly in a circular area of 500 meter radius with eNB at the center. We choose 40 cellular UEs randomly as active UEs, i.e., channel they have occupied will be shared by content provider, relays and the content receiver in D2D communication mode. Other parameters used in simulation are shown in Table I. Non-active UEs are chosen randomly as content requester, relay and content provider. Relay and content provider which are within D2D communication range are chosen randomly. The simulation is executed 1000 times in each scenario to find the percentage of content requesters whose utility is positive.

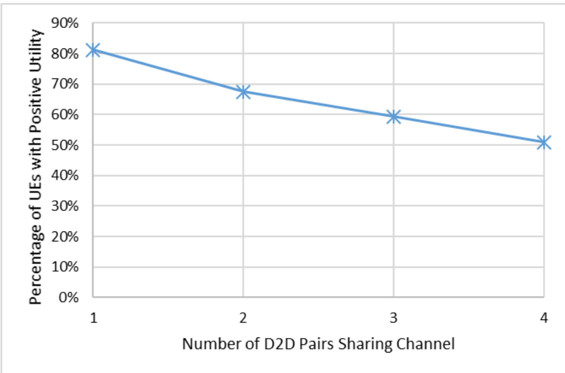

Fig. 3. Percentage of UEs receiving contents via relay without reward as D2D pairs vary

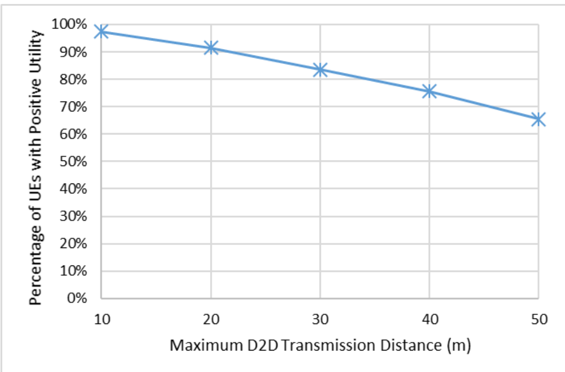

Fig. 4. Percentage of UEs receiving contents via relay without reward as D2D distance varies

When the utility of UEs is positive, they receive content via relays without reward from eNB because the achievable data rate via the relay is higher than the achievable data rate from eNB in cellular link. Figure 3 shows that as the

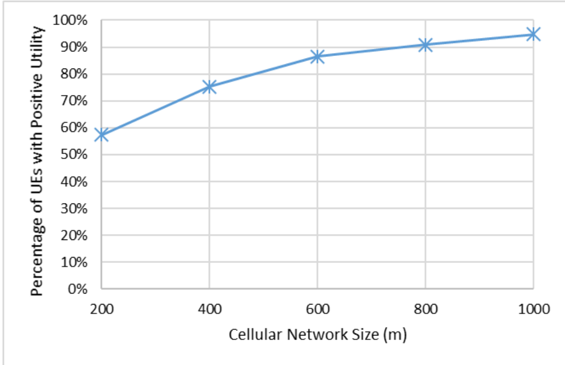

Fig. 5. Percentage of UEs receiving contents via relay without reward as network size varies

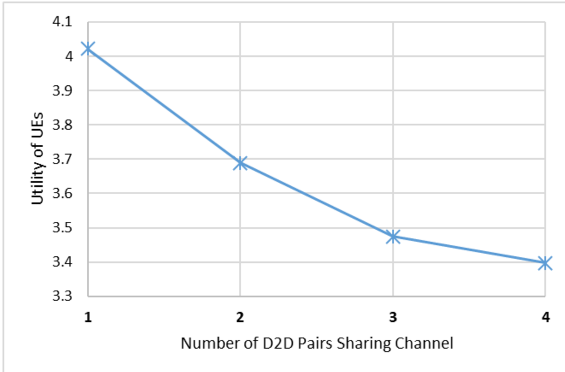

Fig. 6. Utility of UEs without reward as D2D pairs vary

number of D2D pairs that share channel with the content receiving UEs increases, the percentage of UEs with positive utility decreases, i.e., there will be less UEs receiving content via relay without reward. When channel sharing D2D pair increases SINR at the content receiver decreases causing achievable data rate to decrease.

In Fig. 4, we show the effect of D2D communication distance. As the distance increases SINR decreases as the received signal power at the content receiver decreases resulting decrease in achievable data rate via relay compared to directly from eNB. Thus the percentage of UEs asking for reward increases as the D2D distance increases. It is desirable to have D2D transmission distance shorter to encourage users to take part in relay assited D2D communication without reward.

Fig. 5 shows how the percentage of UEs receiving content via relays without reward changes as the network size varies. As the network size increases the interference at content receiver decreases resulting higher SINR, i.e., higher achievable data rate in relay link than cellular link, thus percentage of UEs receiving content via the relay without reward increases as the network size increases. In a larger network size, the density of given active cellular UEs as well as D2D pairs will be less, i.e., less interference at the content receiver. It is a preferable scenario for eNB because the number of reward seeking UEs will be less.

Figure 6, Fig. 7 and Fig. 8 show the average utility of UEs which are receiving contents via relay without reward. In Fig. 6, utility decreases as the number of D2D pair sharing channel increases due to higher interference from channel sharing UEs. Similarly in Fig. 7, the utility decreases as the

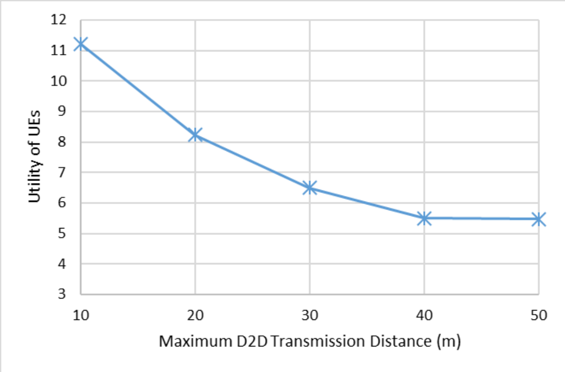

Fig. 7. Utility of UEs without reward as D2D distance varies

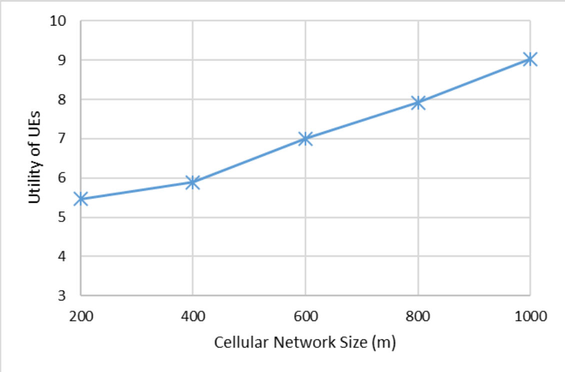

Fig. 8. Utility of UEs without reward as network size varies

D2D distance increases. This is also due to lower SINR at receiving UEs due to increase in transmission range. In Fig. 8, we see that utility increases as the network size increases because there are less number of UEs nearby for interference.

V. Conclusions

In this paper, we presented utilities of UEs in terms of achievable data rate for making decision to receive content via relay without reward or with reward. If the utility is positive, UEs will receive content via relay without reward otherwise they will ask reward. From the simulation, we find that all UEs will not ask for reward for receiving content via relay, i.e., taking part in relay assisted D2D communication. We also presented the utility of UEs which take part in relay assisted D2D communication without reward. From the simulation, we see that the number of UEs taking part in relay assisted D2D communication is higher in shorter D2D distance, less number of D2D pairs sharing channel and larger eNB coverage area. Although it is important to formulate relay selection scheme for efficient use of spectrum and energy efficiency as mentioned in related works, it is equally important to inform users about achievable data rate in relay assisted D2D communication and cellular link in order to promote D2D communications in cellular networks.

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