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Two-Level Game Theory Approach for Joint Relay Selection and Resource Allocation in Network Coding Assisted D2D Communications

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Abstract:

Device-to-device (D2D) communication, which enables direct transmissions between mobile devices to improve spectrum efficiency, is one of the preferable candidate technologies for the next generation cellular network. Network coding, on the otherhand,iswidelyusedtoimprovethroughputinad hoc networks. Thus, the performance of D2D communications in cellular networks can potentially benefit from network coding. Aiming to improve the achievable capacity of D2D communications, we propose a system with inter-session network coding enabled to assist D2D transmissions. We formulate the joint problem of relay selection and resource allocation in network coding assisted D2D communications,andobtaintheoverallcapacityofthe network under complex interference conditions as a functionoftherelayselectionandresourceallocation. To solve the formulated problem, we propose a two -level de-centralized approach termed NC-D2D,which solves the relay selection and resource allocation problems alternatively to obtain stable solutions for these two problems. Specifically, and a greedy algorithm based game allocates limited cellular resources to D2D pairs and relays in NC-D2D, respectively. The performances of the proposed scheme is evaluated through extensive simulations to prove itssuperiority.

Index terms –Device-to-Device communication, network coding, relay selection, resource allocation, game theory

1. INTRODUCTION

Demand for mobile Internet access is growing at a tremendous rate. To satisfy this explosive traffic demand, device-to-device (D2D) communicationshas been proposed for Long Term Evaluation-advanced [1]. In D2D communications, user equipment (UE) in close proximity set up direct links for data transmissions with licensed cellular spectrum resources, instead of through base stations (BSs). The benefitsofsuchproximitycommunicationismanifold [2].extremely high bit rate as well as low end-to-end delay and power consumption due to short-range transmissions. Since the cellular resources can be simultaneously shared and utilized by D2D UEs the spectrum efficiency and reuse gain are improved. In addition, D2D communications enable mobile traffic offloading by user co-operations for content downloading and sharing, also benefits cellular (non-D2D) users. Therefore, D2D communication is expected to be a key feature supported by the next-generation cellular network[3].

2. SYSTEM OVERVIEW ANDMODEL

SystemOverview

We focus on the scenario of a single cell involving multiple D2D pairs, relays and cellular users. In D2D communications, a pair of UEs in close proximity are able to enjoy extremely high data rate by setting up a direct link between them. However, it is well known that the channel quality between two users degrades rapidly as the distance between the transmitter and receiver increase. There are two kind of D2D pairs in the system, i.e., (I) ordinary D2D: two D2D users transmitviathedirectlinkbetweenthem,and(ii)relay

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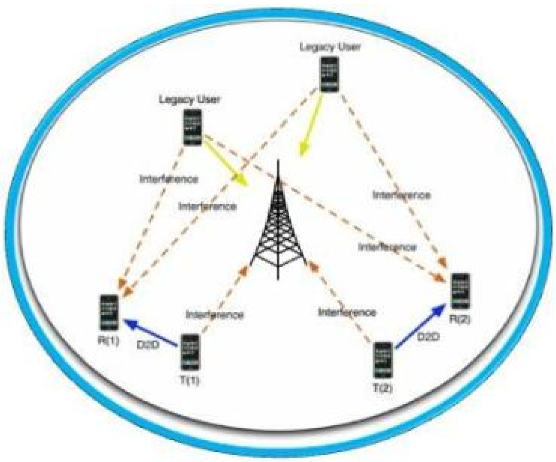
Assisted D2D pair: two D2D users are assisted by a relay aided transmission.



systemmodel

We define the binary variables x $_{d,u,}$ $x_{r,u}$and $y_{d,r}$to depict the relay selection and resource allocation policies for D2D pairs and relays. Specifically, $x_{d,u}$=1 indicates that D2D pair d uses the uplink resource of cellular user u, otherwise $x_{d,u}$=0, while $x_{r,u}$=1 if relayr shares the spectrum resource of u, otherwise $x_{r,u}$=0. Similarly, $y_{d,r}$=1 indicates that relay r assists the D2D pair d's transmission, otherwise$y_{d,r}$=0.

Wedenotethematricesof$x_{d,u,}x_{r,u}$and$y_{d,r}$as$X_{D,}X_R$and Y,respectively.

$$X_{D}=\begin{matrix}1 & 0 & 0\\ 0 & 1 & 0,\\ 0 & 0 & 1\end{matrix}$$

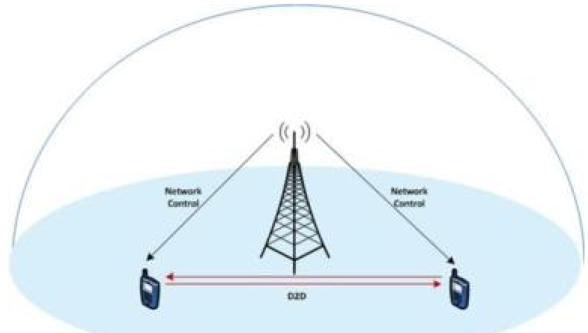
X_R=0 0 1,

Y=1 1 0 0

2.3 Network coding Assists D2D Transmission

Weadoptaninter-sessionnetworkcodingtoassistthe transmissions of D2D pairs. A typical coding region is presented in which consists of two relay assisted D2D pairs and one relay. This scheme is described in [10], [16]. We will first describe the operation of this scheme in our system. Then we will derive the achievable rate of this coding region, and analyze the capacity gain of networkcoding.

For an ordinary D2D pair, the data is transmitted via the direct link between the two devices.



3. PROBLEMFORMULATION

We first derive the achievable capacity of network coding assisted D2D communication and compare it with that of ordinary D2D communications without the assist of network coding and cooperative relays, basedonwhichwethenobtainthesumcapacityofthe network as a function of X_D,X_R andY.

Network Coding Assisted D2DCapacity

α (j)=min{ily$_{i,r\,j}$=1},

β (j)=min{ily$_{i,r\,j}$=1}.

For the coding region of relay r_j,first consider($d^t_{\alpha(j)}$,$d^r_{\beta(j)}$)and

(d^{tr} t t

$_{\beta(j)}$,d $_{\alpha(j)}$). For (d $_{\alpha(j)}$,d $_{\beta(j)}$),the interference from other D2D transmitters, denoted by $I^D_{(d\ \alpha(j),d\ \beta(j)),}$,is

Network CodingGain

To compare the achievable capacities of D2D communications with and without relay assisted network coding, we define the network coding gain G_{NC} as the increased sum capacity by applying relay aided network coding dividing by the sum capacity achieved without applying network coding.

Overall SystemCapacity

To obtain the network sum capacity as a function of XD, X_R and Y, we also need the sum capacities of ordinaryD2Dpairsandcellularusers.Foranordinary D2D pair d_i transmitting via and the sum capacity of all cellularusers.

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ThesumcapacityS$_{cum}$ofthenetwork,involvingall relay assisted D2D users, ordinary D2D users and cellularusers.

Relay Selection & Resource AllocationProblem

The joint optimization problem of relay selection and resource allocation can be formulated as the one that maximizesthesumcapacityc$_{hum}$(X$_D$,XR,Y)withthe decision variables Y and X$_D$, XR, subject to certain systemconstrains.

A D2D pair can only be assisted by one relay or transmit through direct link as an ordinary D2D pair, while a relay either assists two D2D pairs to form a coding region or does not take part in any D2D pair's transmissions.

4. NC-D2DOVERVIEW

Slice relay selection and resource allocation are closely coupled, the optimal solutions for the two problems must be solved jointly, as in the joint optimizations.Thisisbecausechangingthesolutionof relay selection or resource allocation also changes the solution of the other problem. For example, if two ordinary D2D pairs switch to relay assisted mode and form a coding region with a relay, that is, the solution ofrelaysremainatthesamelocations,theinterference from other users and relays actually changes. Therefore, once the solution for relay selection **Y** changes, the solution for resource allocation, **X$_D$** and **X$_R$**, need to be altered accordingly. Resource allocation impacts relay selection in a similarway.

In order to solve the relay selection and resource allocation problems jointly while maintaining low computation complexity, our NC-D2D utilizes a de-centralized two-level optimization approach, where relay selection and resource allocation take place alternately. It should be noted that relay selection game is performed based on the link capacities,which requires the spectrum resources allocated to nodes. Similarly, the interference in resources allocated to nodes. Similarly, the interference in resource allocation game is determined by the results of relay selections. In other words, these two games each requires the results of the other game as aninput.

5. Relay Selection Coalition FormationGame

In a coalition game, the players form coalitions to improve the system utility. Since there are two kinds of D2D pairs, we consider two kinds of coalitions in the coalition's formation game. The first kind of coalition is formed by relay and corresponding relay assisted D2D pairs. Let F$_{ry}$represent the coalition of thecodingregionwherer$_j$isin,whichalsoconsistsof D2D pair's d$_{\alpha\ (j)}$ and d$_{\beta\ (j)}$. The number of first-kind coalitions equals to the number of relays in the network, which is fixed. The second kind of coalition is denoted by F$_D$, which consists of all the ordinary D2D pairs in thenetwork.

In this coalition formation game, the players, namely, D2D pairs, swap coalitions in order to optimize the overall system performance. The decision of whether to swap coalition or not should be made according to a pre-defined preference order that applies to all the players. For the sake of achieving high sum capacity, the metric that defines the preference order in our coalition formation game should be related to the system sum capacity, while each node should be able to obtain it by relying only n local network information.

Swapping among Ordinary D2D Pairs and Assisted D2D pairs

Givenaninitializedcoalitionpartition,forD2Dpaird$_i$ in F$_{r\ j}$ and d $_k$ in F$_D$,if the system sum capacity can be increased after d$_i$ and d$_k$ swap their coalitions, then d$_i$ should leave the coding region of r $_j$ to switch to ordinary D2D mode while d $_k$ should switch to relay assisted mode and form coding region with r $_j$. The system sum capacity defines the preference ordersof

One relay aids two D2D pairs' transmissions by performing inter-session network coding. Specifically, we have first formulated the players in terms of swapping coalition. It should be notedthat we do not need to compute the system sum capacity when trying to determining the performance order. ForfixedresourceallocationmatricesX$_D$andX$_R$,such acoalitionswappingdoesnotchangethetransmission capacitiesofotherlinksandcodingregionsexceptthe capacities of F$_{ry}$and d$_o$, due to the fact that the interferences to the rest of the links remains thesame.

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6. Performance Evaluation

In this section, we evaluate the performance of our NC-D2Dtodemonstratethatitiscapableofachieving high system sum capacity and outperforming other existing state-of-the art schemes. We start by introducing our simulation setup. Then the performanceofourrelayselectioncoalitionformation game and resource allocation game as well as the overall performance of NC-D2D are investigated, respectively.

SimulationSetup

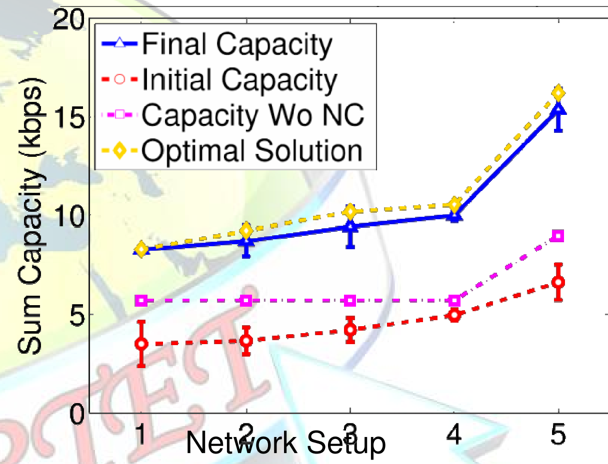
In our simulations, the relays, D2D pairs and cellular usersaredeployedinacell,coveringacircleareawith a radius of 500m, and the BS is located in the cell center. As mentioned in Section 3, we assume Rayleigh fading, and adopt Fries transmission equationtocalculatethepathlossofthetransmitted signal [23]. We set the uplink bandwidth of each cellular user to be 15 kHz. We assume Gaussiannoise with the power of 132dBm for all channels. The transmission power is assumed to be 0dBm for all relaysandD2Dusers,and23dBmforallcellularusers. Theantennagainsofallrelays,D2Dusersandcellular users are set to be identical to 0 dB, while the BS's antennagainissettobe14dBi[6].Theparametersofthe simulated system are also listed.

D2D pairs and cellular users are uniformly randomly distributed in the cell. We simply assume that when two users are within the proximity of (10, 100) m, they are able to form a D2D pair. The relays are uniformly randomly deployed on a circle with radius 250 m, centered at the BS.

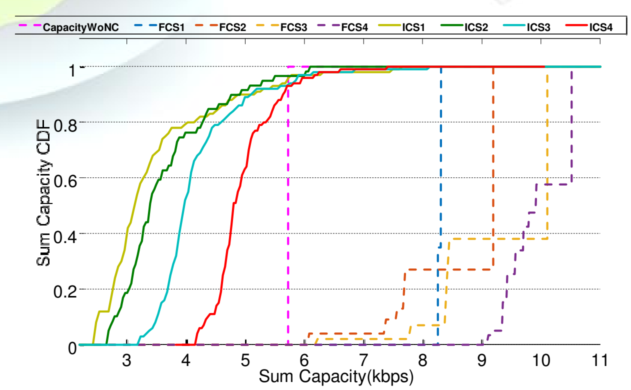
Weevaluateourschemeinfivedifferentnetwork setups. The numbers of D2D pairs and cellular users in network setups 1 to 4 are identical, which are 12 and5,respectively.Thenumbersofrelaysinnetwork setups1to4aresetto3,4,5and6,respectively.The locations of D2D pairs and cellular users in setups 1 to 4 are identical. That is, we only change the numbers of relaysand

Simulation Parameters.

Parameter	Symbol	Value
UplinkBandwidth	W	15kHz
Gaussiannoisepower	N	-132 dBm
D2D, relay transmission power	P_TD, P_TR	0 dBm
Cellular transmission power	P_TU	23 dBm
User transmitter antenna gain	GDT, GRT, GUT	0dBi
User receiver antennagain	GDR, GRR, GUR	0 dBi
BS receiver antennagain	GBS_R	14



Comparison of sum capacities in relay selection coalition game under network setups 1 to 5.



Comparison of sum-capacity CDFs in relay selection coalition game under network setups 1 to 4.

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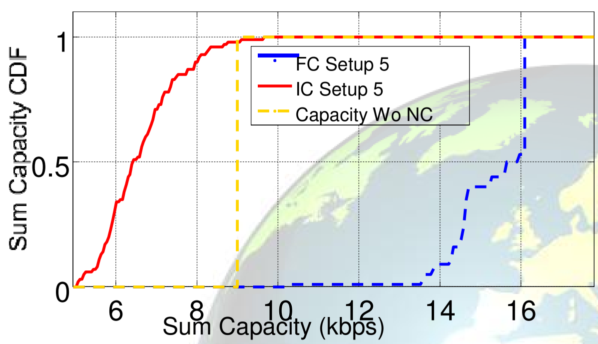
Relays' locations in network setups 1 to 4. The network topology of setup 5 is different from setups 1 to 4, with 6 relays, 18 D2D pairs, and 8 cellular users.

Since neither the relay selection problem nor the resource allocation problem is convex, NC-D2D only guarantees stable local optimal solutions, which is partially determined by the initial value. Hence we simulate 100 times for each topology and scenario, and evaluate the mean value and the cumulative distribution function (CDF).



Comparison of sum-capacity CDFs in relay selection coalition game under network setup 5.

6.1 Resource Allocation Game performance Evaluation

We next evaluate the performance of the resource allocation game in these five setups. The mean values of the system sum capacities under different network setups are plotted. Since we focus on the performance ofresourceallocationinthispart,weomitthecapacity achieved without network coding. It can be seen that our resource allocation game outperforms considerablytherandomallocation,gameoutperforms considerably the random allocation, where each D2D pair and relay uniformly and randomly select one cellular user to share its uplinkresource.

7. CONCLUSIONS

In this paper, we have introduced network coding to enhance the performance of D2D communications underlying cellular networks, where joint problem of relay selection and resource allocation under realisticsystem constraints for the network coding assisted D2D communications underlying cellular network.

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