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Simple Network design and Power allocation for 5G Device-to-Device Communication

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Abstract—The tremendous popularity of smart phones and electronic tablets has spurred the explosive growth of high-rate multimedia wireless services. To alleviate the huge infrastructure investment in the exponential growth of mobile traffic and improve local service flexibility, device-to-device (D2D) communications have been considered for the next generation mobile telecommunications. This has triggered investigation of fifth generation (5G) to utilize D2D communications for heterogeneous networks. D2D communications enable users to transmit signals directly without going through the base station. However, many technical challenges need to be addressed for D2D communications to harvest the potential benefits. This requires learning how to improve the model to better appeal to a wider base and move toward additional solutions. In this paper we provided a simple overview of D2D communications 5G heterogeneous network by means of various Integer Linear programming. Finally, we present experiments on how Fractional knapsack using greedy algorithm can be used for power efficiency and improve throughput, thus allowing of future optimization problems.

I. INTRODUCTION

In the past two decades, there have been tremendous technology development and commercial success in wireless cellular networks. According to a recent report by Cisco mobile-only data traffic is expected to increase 11-fold by 2018 [1]. These days, the Third Generation Partnership Project (3GPP) Long Term Evolution (LTE), which is one of the state-of-the-art fourth generation (4G) cellular communication specifications, is providing broadband data access to over 50 million users around the world. Meanwhile, the dramatic growth of mobile data services driven by wireless Internet and smart devices has triggered the investigation of fifth generation (5G) for the next generation mobile telecommunications [2]–[4]. To help alleviate the huge infrastructure investment in the exponential growth of mobile traffic and improve local service flexibility, device-to-device (D2D) communications have been considered one of the key techniques for 5G [5], [6].

D2D communication technology is a close range data transmission over a direct link, and co-exists with cellular networks. The D2D communication has the advantages of enhancing network throughput, saving the power of the user equipment and increasing an instantaneous data rate, which draw much attention in the recent years [7]. Due to the increasing number of autonomous heterogeneous devices in future mobile networks, an efficient resource allocation scheme is required to maximize network throughput and achieve higher spectral efficiency [8], [9]. Due to co-channel interference caused by spectrum reuse

and limited battery life of user equipments, previous studies on heterogeneous D2D communications into cellular networks mostly focused on how to maximize the spectral efficiency [10]–[13]. Only a few papers have considered power efficiency or energy efficiency for D2D communications. Power control is vital in achieving efficient energy usage and interference coordination in wireless networks [14]. Using too much power entails unnecessary levels of battery drain and interference to all other devices occupying the same signaling resources elsewhere in addition to the eNodeB [15], [16].

Efficient resource management, power control and interference coordination among network nodes in heterogeneous networks are essential to optimize the usage of network resources, and it is expected to be a key feature in the advancement of 5G networks. This requires learning how to improve the model to better appeal to a wider base and move toward additional solutions. In this paper we provided an overview of a D2D communication two-tier 5G heterogeneous network based on [6] by means of various Integer Linear programming (ILP). Finally, we present experiments on how Fractional knapsack using greedy algorithm can be used for power efficiency, thus allowing of future optimization problems. The problem is formulated as described in [17]. Based on the involvement of the cellular operator, we first provide an overview of the categorization for D2D communication.

II. OVERVIEW OF D2D COMMUNICATION TOPOLOGIES

In [6], they identify a two-tier 5G cellular network: *a)* macrocell and *b)* device. In the macrocell tier is the conventional cellular architecture consisting of the eNodeB and device. As for the device tier, this comprises of D2D communications. For more details please refer to [6]. From two-tier communication topologies, 4 models are defined (Figures 1(a) - 1(d)): 1) Device Relaying with Operator Controlled link establishment (DR-OC), 2) Direct D2D Communication with Operator Controlled link establishment (DC-OC), 3) Device Relaying with Device Controlled link establishment (DR-DC) and 4) Direct D2D Communication with Device Controlled link establishment (DC-DC).

In DR-OC (Figure 1(a)) the device relays its message via another device. In this situation the device has poor coverage either inside the cell or the device is at the edge of the cell. The eNodeB communicates with the relay device for partial or full link establishment. With DR-OC the eNodeB

Fig. 1: Various Device-to-device communication Topologies

is responsible for the resource allocation and establishment of links. The eNodeB will be able to authenticate the relay device and encryption in order to maintain privacy. Also, administering spectrum allocation between the various devices is possible.

With DC-OC (Figure 1(b)) the eNodeB assists the devices by means of the control link; however, the source and destination devices are able to talk and interchange data without the need of the eNodeB. The operator controls the link addresses, the authentication, connection control and resource allocation. From this the operator has the oversight over the control plane and data plane of the D2D connection.

On the other hand, DR-DC (Figure 1(c)) does not use the eNodeB. Consequently, the source and destination devices are responsible for managing the communication. To coordinate the communication with each other is either by means of cooperative or non-cooperative. Also, one or several device may be used as relays for the other devices. Not having the eNodeB to control the communication between devices presents more challenges compared to the other model, such as resource allocation [8] [14], connection establishment, relay selection, interference management, mode selection, [14], admission control and power allocation [18], cluster partitioning, and relay selection [19].

Similar to DR-DC, the DC-DC (Figure 1(d)) has no center entity (e.g. server or eNodeB) to monitor the resource allocation between devices. The source and destination devices have direct communication between each other. Therefore, the source and destination device have to use their resources in such a manner to ensure limited problems as DR-DC. Just like DR-DC, the devices will need to periodically broadcast identity information in order to let other devices know of their existence and decide whether or not they can start a D2D direct or device relaying communication [14] [6].

III. TRAFFIC MODEL

The network can be modeled as a graph $G(V, A)$, where V is the set of all vertices (devices and eNodeBs in the area of interest), and A is the set of all arcs (representing the wireless transmission possibilities between the vertices).

Each link $(i, j) \in A$ can be treated as a general queueing system with average input rate (λ_{ij}) and service capacity

(μ_{ij}) . The average delay incurred at the link depends on the traffic. When the traffic constantly exhibits short-range dependent (SRD) characteristics (e.g., VoIP traffic or constant bit rate (CBR)), this will make the link queueing delay to have an exponential distribution with parameter $\mu_{ij} - \lambda_{ij}$. Applying Little's formula [20], the average network average delay T_1 at each hop on a device is computed as:

$$T_1 \cong \frac{1}{\lambda} \sum_{(i,j) \in A} \left[\frac{\lambda_{ij}}{\mu_{ij} - \lambda_{ij}} \right] \quad (1)$$

For long-range-dependent (LRD) traffic (e.g., data traffic or variable bit rate (VBR)), this can be modeled using fractional Brownian motion (fBm) queueing system for each link. The queueing system will have a heavy tailed Weibull distribution [21]. Utilizing Little's formula at each hop, the network average delay T_2 for each device is computed as:

$$T_2 = \tau \cdot \sum_{(i,j) \in A} \left[\frac{\lambda_{ij}}{(\mu_{ij} - \lambda_{ij})^{2H}} \right]^{\frac{1}{2-2H}} \quad (2)$$

where $\kappa(H) = H^H(1-H)^{1-H}$, $H \in [0.5, 1)$ is the Hurst parameter, a is the index of dispersion, and $\tau = \Gamma(1 + \frac{1}{2-2H})[2\kappa^2(H)a]^{\frac{1}{2-2H}}$.

IV. OPTIMIZATION MODELS

A. A network design problem

In the network, each arc (i, j) in A has a cost of sending a packet along the arc, and where each vertex i in V has a value b_i describing the supply or demand of that vertex. For the network, there is a set of demands, which is represented by S . Each demand $s \in S$ originates from a node $o_s \in V$, terminates at another node $t_s \in V$ and is associated with an amount of traffic, denoted by b_s . Let N be the maximum number of established links. The problem is formulated as described in [17], and all variables are defined below.

f_{ij}^s : continuous variables, representing whether demand s passes through link (i, j) ;
 λ_{ij} : continuous variables, representing the load of link (i, j) .
 y_{ij} : binary variables, representing whether link (i, j) is established (=1) or not (=0).

$$\min T_1/T_2 \quad (3)$$

subject to:

$$\sum_{j:(i,j) \in A} f_{ij}^s - \sum_{j:(j,i) \in A} f_{ji}^s = \begin{cases} b_s, & i = o_s \\ -b_s, & i = t_s, s \in S \\ 0, & \text{otherwise} \end{cases} \quad (4)$$

$$\sum_{s \in S} f_{ij}^s \leq \lambda_{ij}, (i, j) \in A \quad (5)$$

$$0 \leq f_{ij}^s \leq y_{ij} * b_s, \quad s \in S, (i, j) \in A \quad (6)$$

$$\sum_{(i,j) \in A} y_{ij} \leq N \quad (7)$$

The objective is to minimize the delay, i.e., either T_1 or T_2 . The interpretation of the constraints is as follows:

(4): This is the flow conservation rule. For each demand, the amount of traffic outgoing from a node minus the amount of the traffic incoming to this node equals to the required amount b_s if this node is the origination of the demand, equals to $-b_s$ if this is node is the termination of the demand, and equals to 0 if this node is the intermediate node.

(5): This expresses the relation between the flow variables f_{ij}^s and the link load variables x_{ij} .

(6): If there is a flow passing arc (i, j) , then arc (i, j) should be selected.

(7): The number of established links is smaller than the constant N .

The above model is the non-linear mixed integer program due to the non-linear objective function. This can be linearized according to the work in [22], and solved by the commercial solver.

To apply the above model to network in Figure 1(a), each demand $s \in S$ originates from a device $o_s \in D$ and terminates at the eNodeB $t_s \in B$. When it is applied to the network in Figure 1(b), each demand $s \in S$ originates from a device $o_s \in D$ and terminates at another device $t_s \in D$. When applying the model to the network in Figure 1(c), the eNodeB will be excluded from the set of vertexes. While applying the model to the network in Figure 1(d), the source node and the destination of each demand is directed connected.

B. A power allocation problem

We introduce the constant $\mathcal{W}_{ij}$ to represent the power used for transmitting data from i to j , c_{ij} to represent the capacity of link (i, j) , and C_i to denote the total available power of node i . We define continuous variables x_{ij} which represent the proportion of data transmitted on link i, j over its capacity. For Figures 1(a) – 1(d), we have the following schedule model.

$$\max \sum_{(i,j) \in A} \mathcal{W}_{ij} x_{ij} \quad (8)$$

subject to:

$$\sum_{j \in V} c_{ij} x_{ij} \leq C_i, \quad i \in V \quad (9)$$

$$0 \leq x_{ij} \leq 1, \quad i, j \in V \quad (10)$$

$$\sum_i^n \sum_j^n z_{ij} = m \quad (11)$$

$$x_{ij} \leq z_{ij} \quad \text{for } i, j \in V \quad (12)$$

The objective is to maximize the total amount of power while providing quality data over all links. The constraints are explained below.

(9): The amount of data transmitted from node i should not be bigger than the maximum capacity of node i and agreed upon capacity over the network.

(10): x_{ij} is the proportion of the transmitted data on link (i, j) over the capacity of the link.

(11): Expressing that m links are selected from all candidate links for the control link to manage and the device (e.g. the power level a device is able to use).

(12): If a link is used, then this link can be selected.

For each link (i, j) , there may exist different power levers for transmitting data. Let k denote the the number of power levels. Sometimes we can also obtain the estimated traffic load for each link (i, j) . For the selection of $\mathcal{W}_{ij}$, it can be either $\mathcal{W}_{ij}^s = \max \{\mathcal{W}_{ij}^1, \mathcal{W}_{ij}^2, \dots, \mathcal{W}_{ij}^k\}$ or $\mathcal{W}_{ij} = \max \left\{ \frac{\mathcal{T}_{ij}^1}{\mathcal{P}_{ij}^1}, \frac{\mathcal{T}_{ij}^2}{\mathcal{P}_{ij}^2}, \dots, \frac{\mathcal{T}_{ij}^k}{\mathcal{P}_{ij}^k} \right\}$, where $\mathcal{T}_{ij}^k$ represents throughput and $\mathcal{P}_{ij}^k$ is the power level for each data item to be sent over link (i, j) . Thus *residual* (i.e., remaining power) to be used.

V. RESULTS

Device power consumption for supporting a large numbers of antennas with very wide bandwidths is a key challenge due to the varies traffic load [23]. This present a significant challenge in leveraging the gains of multi-antenna for power consumption in the analog-to-digital (A/D) conversion for data traffic [24], [25]. From this it was decided to focus on uneven power consumption in relation to fixed (SRD) and variable data rate (LRD) for power scheduling.

We consider both SRD (constant bit rate (CBR)) and LRD (variable bit rate (VBR)) traffic models when deriving network delays and power performance for the ILP proposed models. For LRD traffic model, the index of dispersion a is set to a half of the link capacity and Hurst parameter H is chosen to be 0.7. The results are presented in Figures 2-3.

Since our DC-DC and DC-OC models provided us the same results for (Figures 1(a) and 1(b)), we just present one of them. In Figures 2(a) -2(b) we have the overall delay on a single hop for CBR-SRD and VBR-LRD traffic while increasing the sending rating. The traditional method had lower delays when compared to the proposed method, this is due to the proposed method having a large throughput as the sending rate is increased. The the amount of power used is a light

Fig. 2: Single hop for DC-DC and DC-OC model

Fig. 3: Multihops for DR-DC and DR-OC model

higher for Figure 2(c) compared for the proposed method for Figure 2(d). This shows by having a CBR traffic for both the traditional and proposed will affect the amount of power used. By having a VBR, it will allow the proposed system to focus not only on powers levels but the variable bits.

Next set of results are from Figures 3(a)-3(d) for a multihop topology. Similar to DC-DC and DC-OC, we presented both models DR-DC and DR-OC (Figures 1(c) and 1(d)) as one set of results. While it does not show in Figure 3(a), there is a small increase in delay of 0.1% in the proposed method. For the the VBR the proposed method had higher delays. This is due to the proposed method having a larger throughput as the sending rate is increased. As for the power levels, the proposed model has utilities less power to transmit data as

some in Figures 3(c)-3(d). This means power levels can be improved in a many hop environment.

TABLE I: % of Change in Throughput and Power

Parameters	Methods	
	Variable Power & Variable Data Rate	Variable Power & Constant Data Rate
Throughput	35.8%	52.6%
Power	10.8%	-2.3%

In Table I summaries the overall results in using $\max \{ \dots \}$ from the ILP proposed we modeled in relation to network delay and power performance from the Figures. We had an improvement by 35.8% and 52.6% in throughput with $\frac{T_{ij}^k}{P_{ij}^k}$ compared to just using $\mathcal{W}_{ij}$. There is improvement is power

usage for the VBR and CBR model used more power with $\frac{\tau_{ij}^k}{p_{ij}^k}$. Despite this, it will not present any interference to all other devices with the increased power usage due to (9).

VI. CONCLUSION

In this paper, we have taken a simple overview of ILP for D2D and the usage of Fractional knapsack using greedy algorithm. By doing this examination it will allow further insight into the applicability of power control, throughput and delay for D2D communications by quantifying its performance with respect to an utility optimal scheme. These results tend to suggest that the a VBR behaviour will have impact of D2D communications, therefore, allowing of future optimization problems.

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