Resource Allocation with Interference Management in 5G networks

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Abstract

The tsunami of modern devices and application in the current 4G networks has posed significant challenge for the network operators to efficiently manage the resources for the 5G networks. One promising and successful approach is to reuse the available resources intelligently. However, reuse causes interference and the problem is further complicated due to heterogeneous modes of communication and types of interference caused due to small cells and device to device communication. We in this work propose a resource allocation scheme with interference management (IM) in which a user is allocated resources depending on its data rate and the interference it produces on the network. Thus maximizing the overall network throughput and reusability of resources. We formulate our problem as an optimization problem and then use the hypergraph theory to find a sub-optimal solution. Simulation results reveal the effectiveness of our proposal in terms of network throughput.

I. Introduction

The growth of modern network devices and applications over the current network has congested the network due to the limited network resources and high demands. 50 million users are served for broadband services by the 4G network which is expected to grow to two billion users by the end of 2018. This growth of users and limitation of network resources directs the attention for efficient performance enhancement schemes and features. One very successful and promising feature is to reuse the available resources between the users to enhance the resource efficiency. However, if resource management is not well handled it will degrade the network performance as opposed to increase of performance due to interference. As proposed by 5G, the future cellular architecture will be a mix of dense small cells (SC) network (mix of micro, femto and pico cells) along with macro cells [1] which can enhance the performance by well-handled reuse of resources. Furthermore in 5G, the heterogeneous device types and their communication model impose additional challenge due to different demands and quality of service requirements.

In 5G network architecture, resource allocation will be one of the biggest challenge as users would receive multiple interfering signals from other users operating on same resource and connected to different base-stations (BSs) (i.e., macro/pico/femto) as shown in fig. 1. It is well known that if users experience interference on the resources the system performance will degrade significantly. In this paper, we consider multi-tier i.e. macro/ femto and pico with two types of user communication mode i.e. device to base station and device to device as shown in fig.1. We address the downlink resource allocation problem.

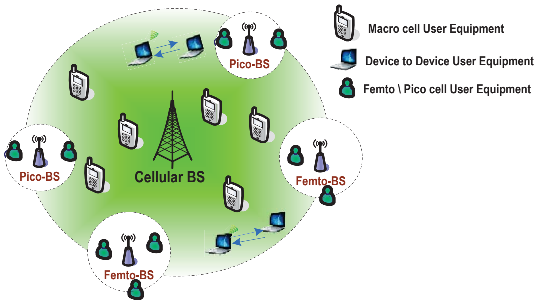

Fig.1. System model

Our aim is to maximize the utility for the complete network by assigning the resources in an efficient manner. We consider fixed user association for our problem. Furthermore, we suppose slowly changing transmit power (fixed power) from all the BSs during a timeslot. This problem is a combinatorial and NP-hard. We use the concept of hypergraph theory [2] by developing a graph based resource allocation scheme for this problem.

The rest of the paper is organized as follows: Section II presents the network model and formulation of our problem and the proposed resource allocation scheme using hypergraphs. Numerical results are illustrated in section III. Finally, we conclude in section IV.

II. System Model and Optimization Problem

We consider a downlink multi-tier heterogeneous network with a BSs, and a set of users U. Here we represent K as the set of transmitters and set J as receivers. We consider C as a set of resources available.

Fig. 1 provides the details of the model, where the large circle is the coverage area of macro cell, and small circles are the coverage areas of small cells. Furthermore, we have device to device communication. It can be observed that users close to the transmitters (i.e. all BSs and D2D transmitter) can receive significant interference if operating on the same channel. In order to maximize the network utility, UEs can be allocated the resource which will provide them with the highest rate. Let r_{kj}^{c} denote the rate of user connected to receiver *j* on resource *c* represented as:

$$r_{kj}^{c} = W\log(1+SINR_{kj}^{c}) \qquad (1)$$

Where *W* is the bandwidth available and $SINR_{kj}^{c}$ is the received SINR on resource *c* for user *k* connected to *j*. Let x_{kj}^{c} be the binary variable to represent the resource allocated to user *k*. Then the optimization problem can be written as:

$$\begin{aligned} &\max_{x_{kj}^{c}} \sum_{c}\sum_{k}\sum_{j} x_{kj}^{c}\log(r_{kj}^{c}) \\ &s.t \sum_{c}\sum_{j} x_{kj}^{c}\log(r_{kj}^{c}) < 1, \forall k, \\ &\sum_{k} x_{kj}^{c}P_{k}^{c}g_{kj}^{c} < C_{th}^{j}, \forall c, \forall j \\ &x_{kj}^{c} \in \{0,1\}, \forall k, \forall c. \end{aligned} \qquad (2)$$

The first constraint guarantees that a user be allocated one resource while the second constraint is the maximum interference (C_{th}^{j}) on a resource *c* set by receiver *j*. Finally there is a binary indicator constraint. This problem is known as a combinatorial problem and thus falls in the NP hard category which can have suboptimal solution [3]. In order to solve this combinatorial problem we use the concept of hypergraph theory. To this end, we assume a centralized solution. The MBS will take information from the whole network to establish a network hypergraph and then perform resource allocation for all network.

Algorithm 1: Resource Allocation Algorithm:

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Phase-1 Hypergraph Construction
repeat  For $\forall j \neq \phi$ (i.e., for all receivers)
    1. Each receiver finds the independent and cumulative interferer by comparing it with the predefined interference threshold of receiver i.e. $C_{th}^{j}$.
    2. An edge is drawn between all the interferers.
untill All receivers j find the interferers.
Phase-2 Hypergraph Coloring Algorithm
repeat  $\forall k \neq \phi$ (i.e., for all transmitters)
    While $\forall c \neq \phi$:
        If color c is not assigned to any neighbor,
        assign color to k.
        Else
        Leave vertex uncolored
Until All transmitter k are checked.
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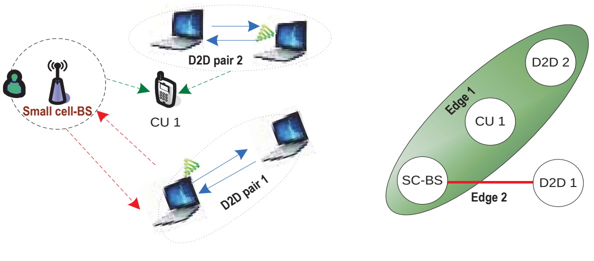
There are two phases to our proposed solution. The first phase is hypergraph construction and second phase is resource allocation. In our problem, vertices represent the cellular UEs and the D2D pairs, and edges indicate that the interference between connected vertices [2]. The interference hypergraph can be build based on the received signal strength (RSSI) from other vertices. A hypergraph is similar to traditional graph but differs such that the edges consist of any subset of the given set of vertices instead of exactly two vertices [2]. Formally, let *X = {x₁, . . . , xₙ}* be a finite set of vertices, a hypergraph *H* on *X* is a set of *E = (e₁,..eₘ)* of subsets of *X* such that:

$$\bigcup_{i}^{m} e_{i} = X \qquad (3)$$

The elements $x_1,\ldots x_n$ of *X* are vertices of hypergraph *H*, and the sets $e_1, e_2, \ldots, e_m$ are the hyperedges. The benefit of using a hypergraph instead of traditional graph is it can model collective interference from a group of transmitters and is modeled in our second constraint [4]. Fig. 2 shows an interfering network topology and a hypergraph for the given network topology.



(a) Interference **(b) Hypergraph**

Fig 2: Interference model and hypergraphs.

Fig. 2 (a) shows us a scenario where the red dotted arrow represent independent interferer and green dotted arrow line represent cumulative interferer. An independent interferer means that the transmitter produce enough interference to breach the tolerance level e.g. D2D pair 1 is an independent interferer for

SC-user. On the other hand, the cumulative interferer alone cannot produce enough interference but if its interference is combined with other transmitters it can cause enough interference to breach the interference tolerance level e.g. If both SC-BS and D2D pair 2 use the resource at the same time it will cause enough interference on CU1. Fig. 2 (b) shows us the hypergraph with three edges. We can observe Edge 1 is a subset of three vertices and represent the mutual interference scenario whereas Edge 2 represent the case of independent interferer [3].

In the second phase, we use the hypergraph coloring algorithm for coloring vertices [4]. Note that each color represent the resources and if we do not have enough colors we leave the vertices uncolored. This indicates that we do not have enough resources to accommodate all the users in the network. However, the best users that will maximize the network throughput will be accommodated. It should be noted that hypergraph coloring algorithm is a greedy algorithm which can be executed in polynomial time as shown in Algorithm 1.

III. Numerical Results

In this section, we perform numerical results under various topologies and scenarios to demonstrate the performance and effectiveness of the RB allocation algorithm. The network topology for our simulations contains a set of 3 BSs, with an number of users and D2D pairs which are randomly located inside circles of radius of r1 = 500 m and the communication radius of each D2D pair is randomly chosen to be within the range of (20- 40) m. We consider a network with 20 users out of which there are 10 D2D and 10 cellular users, with 10 channels/resource blocks (RBs). Finally, the maximum BS transmission power is fixed to 43 dBm which is uniformly dived among the available RBs whereas all the D2D pairs transmit with a varying power over simulation runs ranging from 20 to 24 dBm. Note that, statistical results stated are averaged over a large number of independent runs of random locations of D2D pairs, CUs and RB gains.

In Fig. 3, the achievable throughput are shown with respect to three different maximum interference tolerance thresholds set by the all receivers i.e., C_{th} = −110;−100;−80 dB. In this simulation, we increased the number of users (i.e., transmitters) and observed that the average throughput increases with more users under all scenarios, which, however, saturates as the number of users becomes sufficiently large. This is because of the limited number of RBs (r = 10) available and users are only allowed to use one RB each. It can be observed that the throughput is high when the tolerance level is high i.e. -80dB compared to when tolerance level is low i.e. −110dB. High tolerance level indicate that the receivers can tolerate more interference whereas low tolerance level means otherwise.

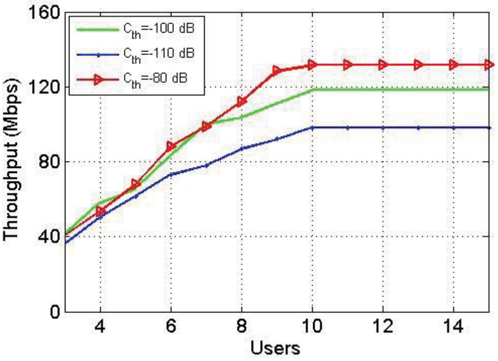


Figure. 3 Throughput of Users.

IV. Conclusions

The reusability of resources in the current cellular architecture leads to a higher network throughput but if interference management is not considered it may degrade the performance. We in this work, propose a resource allocation problem with interference constraint which is solved using hypergraph. Our proposal will allow network to maximize the throughput of the user and resource reusability for the network. Simulation results reveal the convergence in terms of user throughput which validates our preposition. In future, we intend to keep variable power levels for different BSs and would study the effect of resource allocation.

Acknowledgement

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