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Resource Allocation and Interference Mitigation in Cluster based Device-to-Device Communications for 5G Massive MIMO Mobile Heterogeneous Cellular Network: A Cooperative Game Theoretic Approach

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Abstract

Device-to-Device (D2D) communications is an emerging technology in 5G heterogeneous cellular network (HCN), where mobile devices has a choice to share the data with each other's and also share the resources, without interacting the cellular network. Cluster based resource allocation in D2D communications using cooperative game theory is proposed in this paper to increase the Signal to Interference plus Noise Ratio (SINR) and throughput of the network. We propose a cooperative game theory for resource allocation to the devices (players) in each cluster to maximize their data transmission rate. Massive Multiple Input Multiple Output (MIMO) base station assigned resources for devices into the cluster using proposed algorithm (Table 2) with utility function, and assigned resources for neighbor clusters using proposed algorithm (Table 3) to mitigate the cross tier interferences. We calculate SINR, spectral efficiency (SE) and throughput of the proposed network and compared with existing approaches.

1. Introduction

Heterogeneous cellular network (HCN) is an emerging and promising technology for 5G [1] mobile network. To connect massive number of mobile devices in indoor and outdoor communication, HCN provides different types of base stations depending on the power consumption such as for outdoor communication, macrocell, microcell, pico cell and for indoor communication, femtocell gives better performance in energy consumption [2] and increases throughput of the network. In this paper we have used MIMO base station and femtocell base stations in the HCN network. MIMO base station has huge number of directing horizontal and vertical antennas [1] for direct transmission which enhances energy efficiency, SE and increases throughput of the network. The directional antennas reduce the cross tier interferences and reuse time frequency increase the available spectrum of the network.

D2D communications [1] is a key technology of 5G for connecting massive number of devices communicates with each other devices directly bypassing the access points and cellular base stations. Data transmission between two devices, mmWave communications (30 GHz to 300 GHz) is very efficient for future 5G network.

Game theory [2] is very essential for resource allocation, network selection in mobile network. Game theory classified into two type's cooperative and non cooperative game, depending on the behavior of the players.

In this paper we proposed resource allocation and interference mitigation in D2D communications under MIMO base station in HCN using cooperative game theory. We defined two types of D2D communications depend on the interaction with the cellular network, D2D direct communications and D2D cellular communications.

Definition 1 (D2D direct communications): In this type of communications, mmWave spectrum bands are used for mobile devices, directly communicate with each others to exchange information and transmit data between them within a cluster. In this type communications there is no needs to cellular network for transmit the data.

Definition 2 (D2D cellular communications): In this type of communications both mmWave and cellular spectrum bands are needed. Data transmission between mobile devices into the cluster are done by mmWave spectrum bands, and when the data will transmit from inside cluster to outside cluster via cellular network, cellular spectrum bands are needed.

The paper is organized as follows: Section 2 discusses the motivation and contributions of the scheme, Section 3 describe the system model of MIMO based D2D communications HCN. Section 4 discusses the game theoretic model for resource allocation. Mathematical model is described in Section 5. Section 6 determines the SINR, SE, and throughput of the network and finally conclusion is presented in Section 7.

2. Motivation and contribution

To increase spectral efficiency, D2D communications [1] have been great attention in future heterogeneous [3] mobile network. In mobile network, resource allocation is very important to reduce the interferences and it increases the quality of services of the network. Our aim is to deals with this problem and allocates the resources using cooperative game theory in cluster based D2D communications. The contributions of the proposed work are:

1. We proposed cluster based D2D communications using mmWave and cellular spectrum bands. mmWave bands are used for direct communications between mobile devices within a cluster and cellular bands needed for access the cellular network.
2. We allocate the resources to the clusters and within the cluster using cooperative game theory.
3. Analysis the spectrum using Vector Signal Generator (VSG) and Vector Signal Analyzer (VSA).

3. System model

We consider a MIMO base station, several femtocell base stations and the mobile devices are placed under coverage area of both type of base stations as shown in Figure 1.

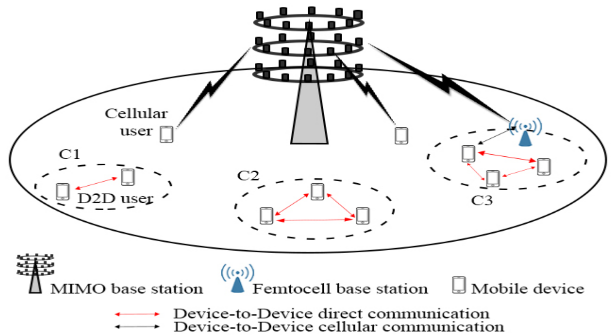

Figure 1. Cluster based D2D communications under MIMO 5G HCN.

In Figure1, there are three clusters are present in the proposed network. C1 and C2 are considering as a D2D direct communications with mmWave spectrum bands. They exchange information between them without interacting the cellular network. C3 is the D2D cellular communications where a femtocell present into the cluster and mobile device send their data to outside C3 through femtocell. In proposed HCN, mmWave bands and cellular bands are used.

The algorithm for resource allocation into the cluster is described in Table 2 with utility function Eq. (1) using cooperative game theory. The algorithm for resource allocation for adjacent clusters is described in Table 3.

4. Cooperative game theoretic approach

The mapping between game theory components and proposed network is described in Table 1.

Table 1 The mapping between game theory and proposed network

Game components	Proposed network environment
Players	Devices into the clusters
Strategies	Proposed algorithm: devices, spectrums
Payoffs	Reduces interferences using utility function
Resources	mmWave bands and cellular bands

The utility function for allocating resources for devices into the cluster using cooperative game theory is expressed in Eq. (1) as follows,

$$u(U_x, S) = I * (U_x, U_y) * S \quad (1).$$

Where, U_x denotes the device and U_y denote the neighbor device of U_x. S is the spectrum band used for transmits the data. I is the interferences between U_x and U_y.

The resource allocation for devices into the cluster is discussed in Table 2.

Table 2 Resource allocation into the cluster

Input:

- N_d: Number of devices into the cluster
- S_{mW}: Number of mmWave spectrum bands allocated for device in each cluster

Output:

Spectrum bands allocates in D2D pairs

1. **Start**
2. **For** $i = 1 : N_d$
3. **For** $j = 1 : S_{mW}$
4. S_s spectrum band allocates for device N_d when value of utility function Eq. (1) is minimum, where $S_s \in S_{mW}$
5. **End for**
6. **End for**
7. **End**

The resource allocation for adjacent clusters is discussed in Table 3.

Table 3 Resource allocation for adjacent clusters

Input:

- N_c : Number of clusters present in the network
- S_{cL} : Number of cellular spectrum band sets allocated for clusters

Output:

Different spectrum sets allocated for adjacent clusters

1. **Start**
2. **For** $i = 1 : N_c$ clusters
3. S_p spectrum band set is allocated to cluster N_c, where $S_p \in S_{cL}$
4. S_q spectrum band set is allocated to the adjacent cluster of N_c, where $S_q \in S_{cL}$ and $S_p \cap S_q = \phi$
5. **End for**
6. **End**

5. Mathematical model

The parameters and values are summarized in Table 4 to develop the mathematical model of D2D communications in MIMO HCN.

Table 4 Parameters

Parameter	Definition	Value
P_j	Transmission power between D2D pairs within a cluster for device *j*	0.1 w
G_j	Channel gain for device *j* in a cluster	6 dBm
$P_{j,i}$	Interference power between device *j* and neighbor cluster *i*	8 dBm
$G_{j,i}$	Channel gain between device *j* and neighbor cluster *i*	3 dBm
$P_{p,s}$	Power transmission by mobile device *p* on subcarrier *s*	0.2 w
$G_{p,s}$	Channel gain by mobile device *p* on subcarrier *s*	8 dBm
$P_{p,s,q}$	Interference power between neighbor cellular mobile devices *p* and *q* on subcarrier *s*	10 dBm
$G_{p,s,q}$	Channel gain between neighbor devices *p* and *q* on subcarrier *s*	5 dBm

5.1 SINR calculation of the proposed network

For D2D direct communications, we assume that in a cluster *n* no. of mobile devices are present and they create *m* no. of D2D pairs based on the application they share.

The SINR for device *j* in a cluster is determined as,

$$SINR_j = \frac{P_j G_j / \sqrt{D_j}}{\sigma^2 + m * (\sum_{j=1}^{n} (P_j G_j / \sqrt{D_j})} \quad (2).$$

Where D_j represents the distance between two mobile devices in a D2D pair, and σ^2 represents the additive white Gaussian noise.

The SINR for *k* no. of clusters present in the network is determined as,

$$SINR_{D2D\_D} = \frac{P_j G_j / \sqrt{D_j}}{\sigma^2 + \sum_{i=1}^{k} (m * (\sum_{j=1}^{n} (P_{j,i} G_{j,i} / \sqrt{D_{j,i}}))} \quad (3).$$

Where $D_{j,i}$ distance between device *j* and neighbor cluster *i*

For D2D cellular communications, the SINR for mobile device *p* on subcarrier *s* is determined as,

$$SINR_{p,q} = \frac{P_{p,s} G_{p,s}}{N_0 \Delta f + P_{p,s} G_{p,s}} \quad (4).$$

The SINR for *r* no. of cellular mobile devices present in the network is determined as,

$$SINR_{D2D\_C} = \frac{P_{p,s} G_{p,s}}{N_0 \Delta f + \sum_{q=1}^{r} P_{p,s,q} G_{p,s,q}} \quad (5).$$

Where N_0 is the white noise spectral density and Δf is the subcarrier spacing

5.2 SE calculation of the proposed network

For D2D direct communications, the SE for device *j* in a cluster is determined as,

$$SE_j = \log_2 \left(1 + \frac{P_j G_j / \sqrt{D_j}}{\sigma^2 + m * (\sum_{j=1}^{n} (P_j G_j / \sqrt{D_j})} \right) \quad (6).$$

The SE for *k* no. of neighbor clusters present in the network is determined as,

$$SE_{D2D\_D} = \log_2 \left(1 + \frac{P_j G_j / \sqrt{D_j}}{\sigma^2 + \sum_{i=1}^{k} (m * (\sum_{j=1}^{n} (P_{j,i} G_{j,i} / \sqrt{D_{j,i}}))} \right) \quad (7).$$

For D2D cellular communication, the SE for mobile device *p* on subcarrier *s* is determined as,

$$SE_{p,q} = \log_2 \left(1 + \frac{P_{p,s} G_{p,s}}{N_0 \Delta f + P_{p,s} G_{p,s}} \right) \quad (8).$$

The SE for *r* no. of cellular mobile devices present in the network is determined as,

$$SE_{D2D\_C} = \log_2 \left(1 + \frac{P_{p,s} G_{p,s}}{N_0 \Delta f + \sum_{q=1}^{r} P_{p,s,q} G_{p,s,q}} \right) \quad (9).$$

5.3 Throughput calculation of the proposed network

For D2D direct communications, the throughput for device *j* in a cluster is determined as,

$$TP_j = S_{D2DD} * A_D * \log_2 \left(1 + \frac{P_j G_j / \sqrt{D_j}}{\sigma^2 + m * (\sum_{j=1}^{n} (P_j G_j / \sqrt{D_j})} \right) \quad (10).$$

Where A_D denotes area of each cluster, and S_{D2DD} is the spectrum band used for D2D direct communications

The throughput for *k* no. of neighbor clusters present in the network is determined as,

$$TP_{D2D\_D} = S_{D2DD} * A_D * \log_2 \left(1 + \frac{P_j G_j / \sqrt{D_j}}{\sigma^2 + \sum_{i=1}^{k} (m * (\sum_{j=1}^{n} (P_{j,i} G_{j,i} / \sqrt{D_{j,i}}))} \right) \quad (11).$$

For D2D cellular communications the throughput for mobile device *p* on subcarrier *s* is determined as,

$$TP_{p,q} = S_{D2DC} * A_C * \log_2 \left(1 + \frac{P_{p,s} G_{p,s}}{N_0 \Delta f + P_{p,s} G_{p,s}} \right) \quad (12).$$

Where A_c denotes area of cellular network, and S_{D2DC} is the spectrum band used for D2D direct communications

The throughput for *r* no. of cellular mobile devices present in the network is determined as,

$$TP_{D2D\_C} = S_{D2DC} * A_C \log_2\left(1+\frac{P_{p,s}G_{p,s}}{N_0\Delta f+\sum_{q=1}^{r}P_{p,s,q}G_{p,s,q}}\right) \quad (13).$$

6. Result and discussion of proposed method

Agilent EXG VSG N5172B 9 KHz -13.6 GHz and Agilent VSA N9010A 10Hz -13.6 GHz are used for analysis the spectrum. For simulation and calculation we used Matlab R2015a.

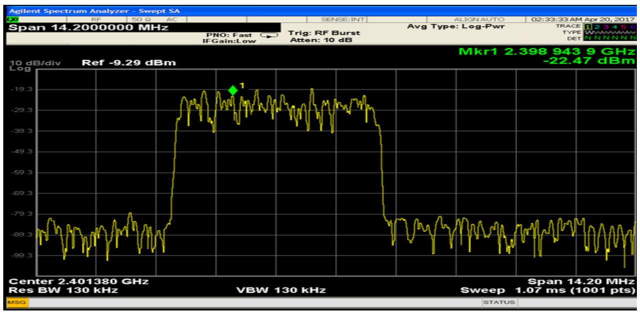

Figure 2. Signal spectrum for D2D communications.

Figure 2 represents the snap shots which are taken from VSG and VSA to show the signal spectrum for D2D communications and the power is – 9.29 dBm and frequency is 2.4 GHz.

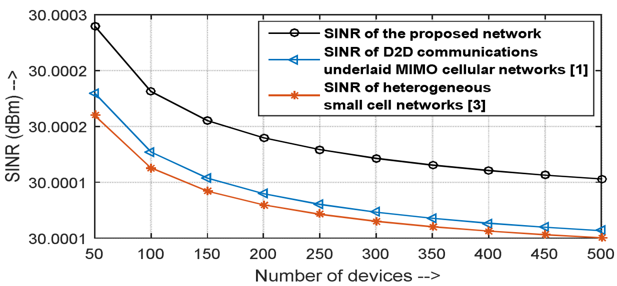

Figure 3. Comparison of SINR between proposed network and existing approaches [1, 3].

The SINR in proposed network, D2D communications underlaid MIMO cellular networks [1], and heterogeneous small cell networks [3] are represented in Figure 3.

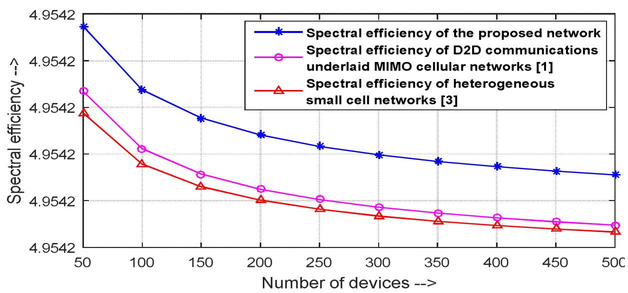

Figure 4. Comparison of SE between proposed network and existing approaches [1, 3].

The SE in proposed network, D2D communications underlaid MIMO cellular networks [1], and heterogeneous small cell networks [3] are represented in Figure 4.

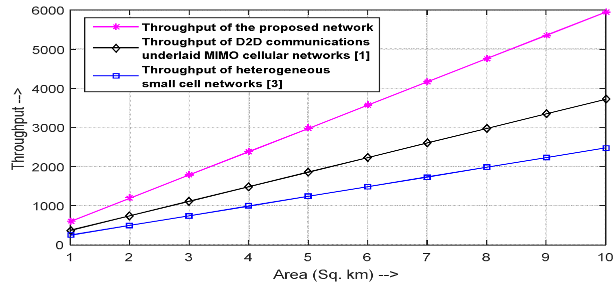

Figure 5. Comparison of throughput between proposed network and existing approaches [1, 3].

The throughput in the proposed network, D2D communications underlaid MIMO cellular networks [1], and heterogeneous small cell networks [3] are represented in Figure 5. Figure 5 shows that the proposed network increases throughput approximately ~ 37% - ~ 58% than the existing D2D communications underlaid MIMO cellular networks [1] and heterogeneous small cell networks [3] respectively.

7. Conclusion

In this paper, we proposed resource allocation and interference mitigation in cluster based D2D communications using cooperative game theory for 5G MIMO HCN. The above results demonstrate that the proposed scheme increases SINR, SE than the existing approaches. Proposed network increases throughput approximately ~ 37% and ~ 58% than the existing approaches. Hence the proposed approach is referred as spectrum efficient and high data rate scheme.

8. Acknowledgements

Department of Science and Technology (DST) for DST-FIST, Reference No.: SR/FST/ETI-296/2011.

9. References

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