Sum Rate Maximization and Consistency in D2D Communication Based on ACO and Game Theory

Original Scientific Paper

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Abstract *– Cellular network is the most popular network setup among today's wireless communication systems. The primary resource in a cellular system is the spectrum for communication, and owing to the rising number of cellular users, the spectrum that is currently accessible from different service providers is depleting quickly. The resource or channel allocation is the most hindering task in cellular networks. Many efforts have been taken by many researchers to allocate the resources properly in order to increase the channel utilization and it is found that one effective method for reusing the channels inside a cell is device to device (D2D) communication. D2D communication was first developed in order to achieve the fundamental goals of fast data rates, widespread coverage with little latency, energy efficiency, and low per-information transmission costs. The dynamic behaviour of this network set-up again increases the risk of different types of interferences, which is another issue faced by the researchers. In this paper an effort is taken to understand and solve various aspects of channel allocation and Cellular networks have incorporated interference management in D2D communication especially. The two major issues of allocation of resource and management of interference in D2D communication is addressed here. This paper considers the meta heuristic algorithm namely Ant Colony Optimization (ACO) for resource allocation issue and interference management. The sum rate maximization is achieved through Game theory along with the concept of resource exchange in turn to increase the consistency of D2D communication setup. The results demonstrate that our algorithm can significantly increase the sum rate of D2D pairs when compared to other algorithms suggested by related works.*

Keywords*: Cellular Network; D2D Communication; Interference Management; ACO, Game Theory research exchange*

1. INTRODUCTION

In the current era, the cellular system is the point of interest for mobile wireless communication. It is the underlying technology for various requirements like mobile telephones, wireless Internet, various wireless webs, other applications, and much more in mobile wireless communication. It is a wireless technology in which several small geographical areas are equipped with low-power radio antennas known as base stations (BS) [1]. This geographical area under a base station is known as a cell. There will be a central unit to interconnect these antennas, which is known as a Mobile Switching Centre (MSC).

In any wireless system, radio bandwidth is distributed as channels. From this set, only a limited number of channels (radio spectrum) are provided to a service provider. A single channel or block of channels can be allotted to carry out communication between two parties. These channels are usually allotted to a certain cell. The same channel can be reused in different cells that are away from the current cell, ensuring the distance from the current cell is greater than a predefined reusable distance. Channels can be allocated to a cell based on three standard schemes [2]. Every cell in the case of Fixed Channel Allocation (FCA) is given a set number of channels, while in the case of Dynamic Channel Allocation (DCA), channels are assigned to a new cell whenever one is needed from a central repository of channels, and in the case of Hybrid Channel Allocation (HCA), a combination of both FCA and DCA is used. While choosing an allocation technique, certain points must be kept in mind. In a cellular system, it is expected to support diverse services that guarantee various levels of quality. Advanced bandwidth reservation must be performed in order to facilitate and support an uninterrupted communication link through seamless handoff. Finally, the provision of bandwidth reconfiguration depends on the various dynamic cellular environments.

The major challenge related to resource management in the cellular system is the allocation of channels in various cells with little or no interference. Wireless systems are affected with two types of interferences.

ACI and co-channel interference are examples of adjacent channel interference (CCI). Signal-based introduction of ACI, which are adjacent in frequency, when allocated to cell Equipment limitations are the major source of ACI, such as receiver bandwidth, frequency instability, and imperfect filtering. CCI is introduced when the same signals are assigned to different cells close to each other. Figure 1 illustrates the fundamental resource management elements of D2D communication.

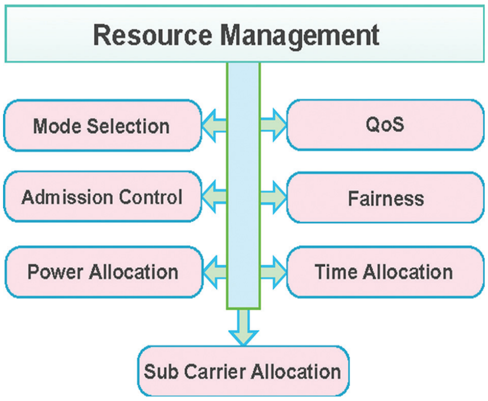

Fig. 1. Resource Management elements in D2D Communication

The service demand for proximity-based services has received increased attention from the Third-Generation Partnership Project (3GPP) (ProSe) [3] for LTE-Advanced. Proximity-based services (ProSe), which require components to be physically close to each other in order to recognise each other and directly communicate, are broadly described in 3GPP Rel. 12 of the LTE-Advanced standard. ProSe aims to advance public security [4]. They started the standardisation procedure for the ProSe radio access network recently. Figure 1 displays a very basic representation of D2D communication relying on the architecture of ProSe.

With 3GPP Release 12, D2D communication was first incorporated into LTE-A. The FCC assigned 700 MHz of the reserved spectrum to this release, which the US's next-generation public safety network has adopted [5].

To use the high bit rate services of today's cellular network, this framework potentially decreases the data rate as well as increases the delay. D2D Communication [6] is the best candidate for it. D2D communication enables mobile devices in close proximity to communicate directly without the involvement of a Base Station (eNB in LTE). It can reuse the channels, already allocated to cellular users, that is, better reuse of the available spectrum. The cell boundaries and areas with weaker signals are served better by this mechanism.

The major benefits identified for device-to-device communication are; one hop communication, spectrum reusability, Higher and better network performance, reduced power consumption, congestion control, fairness, and QoS guarantees [7]. Users have complete control over D2D communication [8].

The first step in establishing D2D links is, identifying and pairing user devices that are at a distance enough to have direct communication. This is achieved during peer device discovery stage. The user's devices will identify their neighbours for direct communication link establishment.

A mathematical framework of scientific tools called "game theory" examines how an individual or group of players will behave and move. In other words, it serves as a decision-making tool for rational players [9]. Because game-theoretic solutions are manifestly self-directed and reliable, they are required for reducing the interference that D2D and cellular broadcasts could produce with one another in cellular networks.

Numerous combinatorial optimisation problems can be resolved using ant colony optimisation (ACO) algorithms. Most of the previous works used heuristic or partial optimal based algorithms. Through simulation experiments, it is possible to see how well these methods perform, but it is still difficult to put them into practise in real-world industrial settings. There are primarily two parts:

Due to the unique user distribution and geographic environment, it is challenging to create a perfect mathematical model for practical implementation scenarios. The computational complexities of these approaches are quite high, especially in D2D communication systems. Implementing these algorithms with interference optimization thus becomes impractical.

The most popular random search techniques to solve intractable problems are metaheuristic algorithms. In practise, metaheuristic algorithms are compliant with optimization and do not necessitate a perfect mathematical model. Modern methods for resolving issues with resource allocation and interference management and power distribution in a D2D system are discussed.

In this paper, examine the communication network under the influence of multiple interfering channels. To increase the overall sum-rate in the D2D system mainly focuses on the metaheuristic optimization for the resource allocation issues. The simulation results show which algorithm performs better than the other metaheuristic algorithms.

The contribution of our research work is mentioned:

- Demonstrate an optimal resource allocation issue under interference management and propose meta heuristic approaches.
- Through numerical experiments on simulated communication networks and wireless channels,

validate the efficiency and adaptability of the proposed metaheuristic methods and search for the potentially best algorithms for this issue.

The following is the paper's structure. In Section 2, the most recent D2D communication research literature rview is described. Section 3, states the problem formulation and findings of D2D and section 4 explains the proposed methodology. Section 5 showcases the findings and outcome are evaluated and finally in Section 6, the whole term paper is concluded.

2. RELATED WORKS

While establishing and maintaining D2D mechanism in standard wireless cellular networks the following challenges need to be addressed effectively. Peer Discovery, Mode Selection and Resource Allocation with Interference Management.

Han et al. [10] put forth a brand-new D2D communication strategy based on socially conscious peer discovery. Here the characteristics, of social network are exploited in an ad hoc peer discovery mechanism. The devices send a well-known synchronization or reference signal sequence for peer finding. To improve D2D communication, Yanru Zhang et al. [11] suggested a novel strategy that takes into account socially conscious factors. The physical wireless network layer and the social network layer, two distinct layers, are used to accomplish it. There is potential for stable D2D connections, by defining the OffSN using the connection degree of users, basis on their daily routes. The mechanism considers data security as well.

Quinghe Du et al. [12] proposed a D2D routing design for an underlying cellular network with interference controlled to support multi-hop D2D transmission. This is an innovative idea, as most of the works were single hop in nature. The main objective of routing is to diminish the end-to-end delay by reducing the hop count and in turn reduces the power consumption for D2D connections.

Xiaoqiang Ma et al. [13] proposed application specific D2D communication network management. They considered two types of applications like streaming and file sharing. Their main objective was to increase the rate of aggregated data. It is noted that careful consideration must be given to the power distribution for both cellular and D2D lines. Yanxiang Jiang et al. [14] proposed an efficient scheme for iterative resource allocation with competent power control. Resources blocks are used by CUs and D2D pairs. The channel gain of all the subcarriers incorporated in the same RB will be the identical. At this point the power control problem is found to be more practical. A non-orthogonal dynamic spectrum sharing mechanism was proposed by Tuong Duc Hoang et al. [15] for D2D communication in a cellular network below. A graph-based approach is used for the formulation of a subband assignment problem. They considered the scenario where single/multiple subbands are allocated for each active D2D link, and at most one D2D link can be allocated by this subband.

Jun Hunang et al. [16] addressed a new scenario. They specifically looked into the problems with resource distribution for a D2D link placed in the overlap or boundary regions of two cells close by. Chih-Yu Wang et al. [17] proposed a trader assisted resource ex-change mechanism for an efficient resource allocation. In this approach a sequence of enthusiastic resource block groups is predefined for D2D communication. Tinghan Yang et al. [18] employed the D2D communication concept in an advanced scenario of full-duplex cellular network. Here both cellular uplink and downlink are used by the Ues to be in touch with each other.

Albowarab et al. [19] proposed a novel approach named as ROOMMATEs for peer discovery in an indoor environment. Compared to the outdoor scenario, the peer discovery in an indoor environment is challenging. It uses WiFi/other wireless signals to locate the UEs. The location tags are used for peer discovery and pairing if two UEs are in the same place. Energy consumption is the major goal of this proposal. Kar et al. [20] developed a mechanism to discover a potential partner. They utilised sounding reference signal (SRS) to listen the uplink channels, which is present in the OFDM symbol's last part of each scheduling sub-frame. Even if it is a simple method as the SRS is readily available in the cellular network, the major difficulty is in the design of the SRS receiver, because of the uplink overhearing behaviour of devices.

AmalAustine et al. [21] proposed a distributed, user-controlled approach. Here is a possible D2D UE chooses a mode on its own, taking into account performance and cost. Managing the reuse mode is difficult in this environment. To increase the fairness of the system, Miaomiao Liu et al. [22] suggested a novel resource allocation technique. Fairness and throughput are compromised in order to guarantee that each user has equal access to system resources. Based on the results of the recommended allocation technique, they created the notion of virtual D2D linkages and framed the channel allocation problem as a 3-D assignment problem. By applying the Kuhn-Munkres method to a particular 2-D assignment problem, they were able to find a solution.

3. PROBLEM FORMULATION AND FINDINGS

Various literatures addressing the major challenges in D2D are addressed in this work. The new technology will become a major enhancement in LTE towards the 5G release. All the work was simulated using various tools, and it was found that it can contribute a great deal to the evolution of wireless communication. The major focus is on improving the spectrum efficiency of cellular network. Apart from that it is found that this technology can improve the throughput, sum rate and many other aspects because it is properly managing the interferences created when reusing the channels in the same cell.

A detailed comparison is made based on a wide variety of aspects of D2D communication in cellular system. These aspects are clearly represented in Table I. Three potential scenarios were taken into account, with Scenario-I outlining a user-oriented strategy in which each D2D link is given a sub band, with a maximum of one D2D link being given this sub band. In Scenario-II, a resource-oriented method is described, where each active D2D connection is given access to several subbands, with each subband being assigned to a maximum of one D2D link.

The spectral efficiency is very much affected by the mode selection, especially the D2D modes. Even if the overlay mode is a good mitigation for managing interference in cellular and D2D systems, it reduces spectral efficiency. Researchers suggested a number of ways to implement D2D using underlay mode to manage the interference in an optimised manner. From the literature it is seen that the interference management in underlay networks were managed by proper power control. Usually, different link power is used for cellular and D2D link. The cellular link will have a higher power allocation compared to the D2D link in order to minimise the interference caused by the D2D link to a cellular link, when both are using the same channel [23].

Research spanned from the basic single cell scenario to multi cell scenario for D2D communication. It is very useful to provide good service to the user equipment's lying at the cell boundary, where usually the nearby cells overlap and signals from both the cells will be available. The major obstacle in this is the proper hand-off management. We cannot expect both the devices in D2D communication will move to the same cell. The selection of channels in the new cell also needs to repeat the resource allocation steps in-order to resume D2D communication.

In most of the work, the allocation of resources is centralised. It is more effective than ad hoc manner as the eNB holds more information about the network status. If any issues regarding device distance or interference occur, the service will toggle back to the infrastructure approach. In a dynamic environment like a cellular system this switching is not feasible. The D2D links will be no longer reliable if it does not consider the dynamic aspects of cellular system. But some recent literatures address that dynamic re-allocation can improve the sustainability of D2D communication and thus the spectral efficiency. Exchanging resources can significantly improve the life of D2D links. Another aspect is the cooperative communication between devices. This will clearly ensure the reliability of the link between devices. As the distance between the devices increases, an intermediate node will act as a relay to the destination device. The drawback is the increased number of hops in communication.

Table 1. Summary of State-of-the-Art Research works

Ref. No	Scenario	Approach	Objective	Mpdal	Multi-D2D& Cellular Links	Theoretical Performance Analysis	Optimal Solution	Single Cell	Allocation	Dynamic Reallocation	Mode
[4]	ad hoc	Optimization	Peer Discovery	PA	No	Yes	Yes	Yes	Network	Static	1H, BS
[5]	ad hoc	Optimization	Neighbor Discovery	NA	No	Yes	Yes	Yes	Ad Hoc	Static	1H, BS
[6]	ad hoc	Optimization	Neighbor Discovery	PA	No	No	Yes	Yes	Ad Hoc	Static	1H, BS
[7]	II	Optimization	Joint mode election& spectrum partitioning	SA	Yes	Yes	Yes	Yes	Ad Hoc & Network	Dynamic	1H, BS
[8]	II	Optimization	Spectrum Sharing	SA, PA	Yes	Yes	Yes	Yes	Network	Static	1H, BS
[9]	II	Optimization	Improve packet transmission, reduce network load.	Yes	Yes	Yes	Yes	Yes	Network	Static	1H, BS
[10]	II	Optimization	System throughput and fairness	PA	Yes	Yes	Yes	Yes	Network	Dynamic	IH, BS
[11]	II	Optimization	Mode Selection, Packet Scheduling	RBA	Yes	No	Yes	Yes	Network	Static	1H, BS
[12]	II	Optimization	Aggregated Data Rate, Weighted Cell Utility	PA	Yes	Yes	Yes	Yes	Network	Static	1H, BS
[13]	I	Optimization	Spectrum and Energy Efficiency	RBA, PA	Yes	Yes	Yes	Yes	Network	Static	1H, BS
[14]	I, II	Graph based and Optimization	Weighted Sum Rate	SA, PA	Yes	Yes	Yes	Yes	Network	Static	1H, BS
[15]	I, II	Game theoretic Optimization	BS Sum rate, sum rate gain	SA, PA	Yes	Yes	Yes	No	Network	Static	1H, BS

[16]	I, II, III	Optimization, Graph Coloring	Network Performance and spectrum utilization	RBA, PA	Yes	Yes	Yes	Yes	Network	Static	1H, 2H, BS
[17]	I, II, III	Optimization, Graph Based	Spectral Efficiency	RBA	Yes	Yes	No	Yes	Network	Dynamic	1H, BS
[18]	I	Multi hop route optimization	hop count minimization	SA	Yes	Yes	No	Yes	Ad Hoc	Static	1H, 2H, BS

There are some recent techniques that have been proposed to minimise the hop count and thus the delay of direct communication between devices. Increasing the number of links utilising same resource will obviously increase the spectral efficiency. Most of the recent works address this aspect in a decent manner. According to the study performed on various literature few common aspects are considered and are represented in Table 1.

4. PROPOSED METHODOLOGY

The proposed work was on the basis of our previous work, which combined Ant Colony Algorithm for better resource allocation and the resource exchange mechanism in order to improve the consistency of the D2D link in the cellular system. Apart from reducing the interference in the organization due to the reuse of frequency, another add on mechanism is proposed in order to maximize the sum rate in the system using a Game theory mechanism, as shown in the Fig. 2.

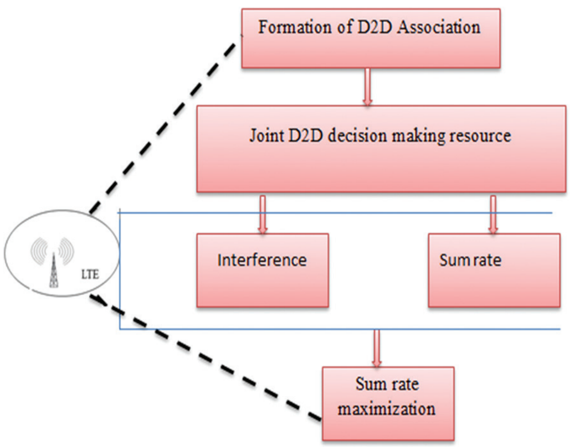

Fig. 2. Framework for the System

The interference caused by the increasing number of D2D pairs in a cell and the number of RBGs assigned to a cell to initiate the resource exchange are the two criteria that are taken into consideration. The suggested D2D resource exchange framework introduces the Trading-based Resource Exchange (TREX) method to address the resource exchange issue.

4.1 RESOURCE EXCHANGE

Resource exchange can make a link between two directly connected devices more reliable. The eNodeB must allocate resources after assessing the cell's present condition. The mechanism for resource selection is not yet known. The goal of this work is to sustain D2D linkages with the least amount of interference and the longest possible lifetime while considering the likelihood of introducing resource exchange to a cellular system.

When an additional D2D pair joins and seeks an RBG, or a D2D pair's RBG contribution expires, and one or more D2D pairs renew their CQIs, the eNodeB may initiate a resource exchange. The revised D2D pair set or CQIs may contain the favourable exchange sequence whenever the aforementioned circumstances arise. If a sequential exchange is discovered, by issuing the most recent RBG grants to the pair heads, the eNodeB can force all pairs in the series to trade resources. The alerted D2D pairs will accept and use the newly authorised RBG in the subsequent transmission. After the exchange process is complete, both D2D pairs will use the recently swapped RBGs for their respective D2D communications. Additionally, an exchange between an eNodeB and a D2D pair is feasible. The eNodeB may give this D2D pair an unallocated RBG in exchange for the RBG it currently owns. In this case, just one D2D pair is informed by the resource sending the signal.

When eNodeB is down or the traffic is slowdown, the D2D pair can also dynamically initiate a resource swap in delay-sensitive applications. All D2D pairs can communicate with one another thanks to the maintenance of this shared RBG. D2D pairings should pay attention to the shared RBG in order to hear requests from other D2D pairs. Every 3n+1 sub frame, all D2D couples may use a slotted-ALOHA technique to access the shared RBG. A D2D pair head can transmit its own and necessary RBGs to other nearby D2D pairs in the same service area by using the shared RBG. If the other D2D pair head who is in possession of the requested RBG is in favour of the exchange as well, they may answer the demand in the subsequent subframe of the collective RBG. In the third subframe, after receiving an acknowledgement from the new D2D pair head, both pairs switch over to the newly traded RBGs and can begin using them for D2D broadcasts. Both pairings should inform the eNodeB about the exchange following it so that it can keep track of the allocation of RBG positions.

The aforementioned mode lessens the eNodeB's load by shifting various duties from the eNodeB to the D2D pairs. Additionally, it decreases the time required for eNodeB-triggered exchanges and CQI reporting signals. Additionally, relatively stable channels and surroundings are preferred. The eNodeB can further reduce the overhead in the case of channels that are comparatively stable, or overloaded networks by mandating that all D2D resource exchanges operate in D2D-triggered mode.

A centralised resource exchange system called T-REX run on the eNodeB. According to the gathered CQIs, In the D2D service zone, it established the resource exchange sequences for each D2D pair. The CQIs from each D2D pair within a service region are first collected using the T-REX approach. The preference of each D2D pair on RBGs is then developed in accordance with the available CQIs. The T-REX technique then builds an exchange graph using D2D pair preferences. By looking for cycles in the trade graph, the exchange order is in turn determined by the mechanism. Then, it is requested that all D2D pairs and traders involved carry out resource exchanges in accordance with the chosen exchange order. A D2D pair encounters differing levels of interference in different RBGs. The more interference-free an RBG is, the more useful the D2D pair.

4.2 D2D INTERFERENCES GRAPH REPRESENTATION

The eNB initially creates a fully linked weighted graph as an inner model of the mutual interference conditions among contemporaneous D2D links (as if all were allotted the same resources). The data that the UEs submitted to the eNB was used to construct this graph. Particularly, each UE reports details regarding the received power resulting from whichever possible corresponding D2D transmission. The UEs may be able to obtain this interference information by using methods like the D2D peer discovery approach, which was not examined in this study. Figure 3 illustrates how the eNB graphs the acquired interference levels.

The edges are weighted, and depending on the actual channel circumstances, these weights correspond to the degree of mutual interference among a few potentially corresponding D2D transmissions. We introduce the Interference Level Indicator (ILI) concept to quantify this. ILI accepted values on an interval scale with customizable minimum and maximum values. The scale's min/max values reflect the estimated interference's min/max in the present topology, while all values in between are determined equally.

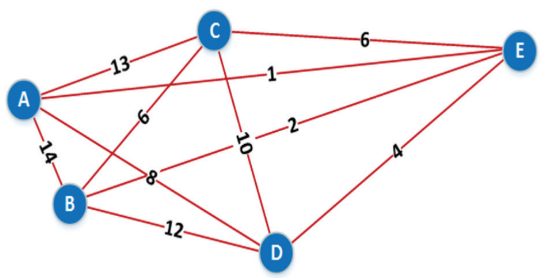

Fig. 3. D2D pairs Interference graph

A scale can thus depict 100 different levels of interference, A [0-1] scale, however, merely shows the presence or absence of interference. The mapping of interference values to ILIs is done by the eNB. Since all vertexes can interact with one another, the resulting graph is fully connected when zero values are removed from the equation, either significantly or barely. Consequently, in this form, the likelihood of safe spectrum sharing increases with decreasing node weights due to reduced mutual interference.

In the network graph model, nodes A through E stand in for five D2D requests, whereas nodes 1–15 represent ILIs. These concurrent D2D queries are close together in this scenario since the ILI linking vertexes A and B is 14, since the ILI connecting A and E is 1, indicating that they are far apart and most likely not interfering with one another at all.

5. RESULT AND DISCUSSION

In NS3, the planned method is modelled. The outcomes of the simulation are contrasted with three other comparable methods that used resource exchange techniques. They were built on greedy cycle-complete preferences and the Trader-Assisted Resource Exchange (TREX) technique with two strategy proof preferences (RAN and DRAN) (CYC). First, we find the number of D2D pairs that affect the interference of the T-REX mechanism. We maintain 15 RBGs and increase the number of D2D pairs in the simulation from 6 to 15.

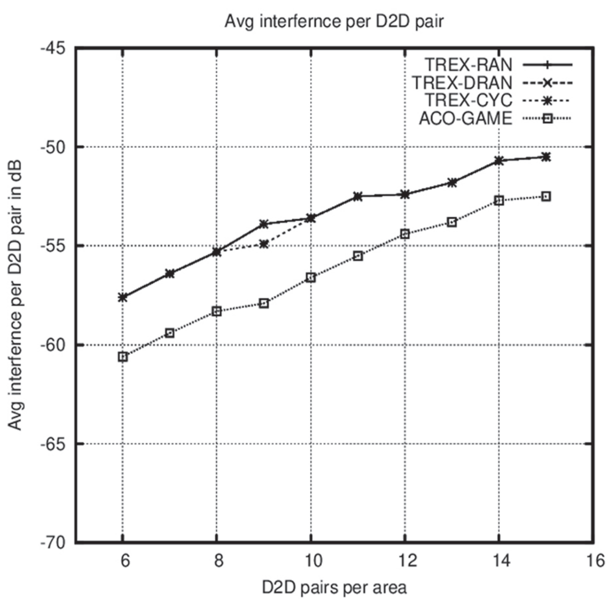

Fig. 4. Interference Vs D2D pairs per area

Fig. 4 shows that when the number of D2D pairs grows, the interference level rises for all T-REX routes. Because there are fewer RBGs available for exchange, there are fewer opportunities for improvement through the exchange. The BS's reduced ability to produce RBGs is what led to this outcome.

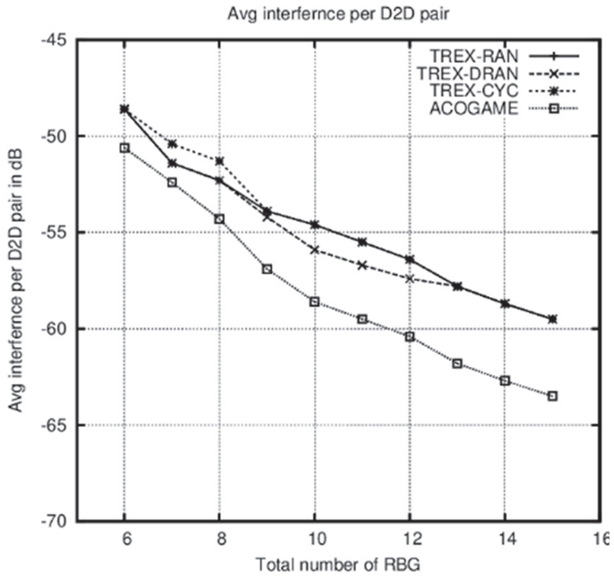

Fig. 5. Interference Vs Total number of RBG

Next, we simulate using six D2D pairings while increasing the amount of RBGs accessible from six to fifteen. The outcomes are displayed in Figure. 5. We discover that as the number of RBGs shown increases, interference in all schemes decreases and the interference mitigation provided by the T-REX mechanism in the Random scheme increases.

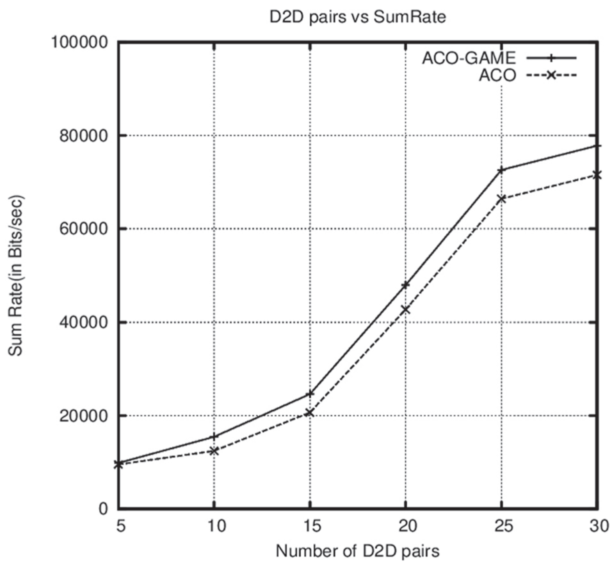

Fig. 6. Number of D2D pairs Vs Sum Rate

The system sum rate vs the quantity of D2D pairs is depicted in Figure 6. It is evident that as there are more D2D pairs, the sum rate of both schemes increases monotonically. However, because there are a finite number of subcarriers and a finite amount of bandwidth, increasing the D2D user base could result in more co-channel interference between the D2D link and the cellular link, which the system might not be able to adequately mitigate. The best performance was obtained with the proposed approach we used with ACO-Game Theory.

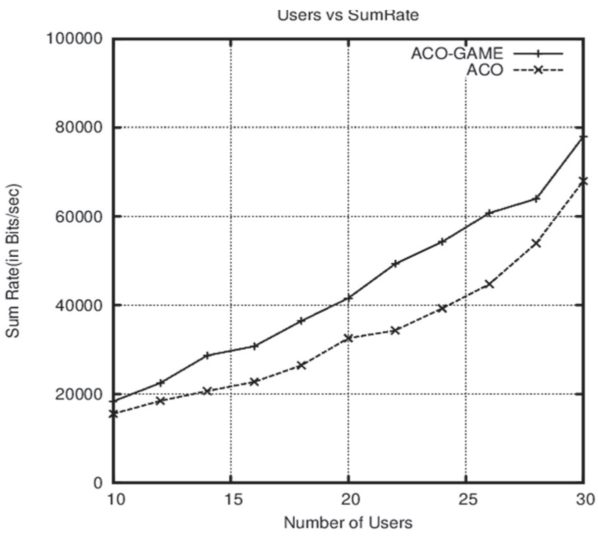

Fig. 7. Number of users Vs Sum rate

Fig. 7 displays various sum rates attained with various D2D user counts. As more D2D users join the network, it is evident that the network's sum rate rises as well. As a result, Ant Colony Optimization can maintain more D2D linkages with little disruption.

6. CONCLUSION

A thorough analysis of current research on device-to-device communication in cellular networks is carried out. According to the main difficulties in D2D communication, such as peer discovery, mode selection, resource allocation with interference, and power management, we classify the currently done work. In this paper, the sum rate maximisation of D2D pairs using ACO-Game theory, when compared to ACO optimisation algorithms, achieved better results in terms of number of users and D2D area. The strengths and weaknesses of this literature are assessed, and a few recommendations for improvements are suggested. The application of Game theory along with Ant Colony Optimisation and resource exchange frameworks can produce considerable optimisation in D2D communication in a cellular network. In this case, an attempt is made to use a resource-sharing mechanism to keep the D2D link alive for as long as is practical. When cellular or D2D link interference threatens another D2D link, swapping takes place. By extending a D2D link's lifespan, this tactic can improve the network's stability.

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