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Device-to-Device (D2D) Cellular Communication: Group Formation of Devices

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Abstract: In mobile communications, nearby or proximity users can communicate with each other directly without the need of communicating through Base Station. This is called Device–to-Device (D2D) communications. This D2D communication has several benefits like improving spectral efficiency, network capacity and energy efficiency. In this paper, formation of D2D groups and what can be their blocking probability in a cellular cell are discussed. The numbers of groups formed are the devices which are ready for D2D communication. The blocking probability describes which devices are ready to share data with each other when ready for communication and which are not because of geographical, cellular rate and the number of devices in the cell.

Keywords: Device-to-Device (D2D) Communication, D2D group formation, blocking probability, channel allocation.

I. INTRODUCTION

IN the past few years, the immense popularity of smart phones and tablets has dramatically increased. According to Cisco visual networking index [1], smartphones represent only 27 percent of total handsets globally but account for 95 percent of data traffic. This has lead to an increase in high data traffics and bandwidth hungry applications. Considering the current 4G technologies, the huge gap between the actual performance and the expectations cannot be fulfilled. With these increasing demands in bandwidth and data rate, the Third Generation Partnership Project (3GPP) has identified Device-to-Device (D2D) communication as a potential technology to offer high data rate and to offload heavy cellular communication systems. Cellular communication which uses a significant amount of infrastructure generally requires communication to go through a Base Station (BS). If the users are located nearby geographically, the communication going through the BS becomes an inefficient use of energy and frequency spectrum. D2D user transmits data to each other using a direct link between each other rather than going through some infrastructure or evolved nodeB (eNB). This direct transmission is done using dedicated resources as is the case of cellular users or they reuse cellular resources. D2D communications thus allow improving spectrum utilization; enhance network throughput and reducing energy consumption.D2D communication is a very flexible communication technique which has unique advantages compared to the present available communication techniques. A mobile device may have multiple radio technologies, generally which are cellular, Wi-Fi, and Bluetooth. The diversity of these radio accessing technologies in UEs provides for D2D lots of flexibilities in the aspects of resource allocation, link establishment, energy efficiency, applications and services. Figure 1 illustrates an example of D2D communication in LTE-A HetNets. In such a scenario, D2D pairs may exist in the same cell or stretch over other cells, they may communicate as an underlay or overlay to the existing LTE-A network or may even operate in ISM band.D2D has been a part of standards such as IEEE 802.11. In IEEE 802.11, a wireless node senses and decides whether to transmit the data or not. There are three types of gains supported by a cellular infrastructure D2D communication in cellular systems. The proximity of user equipments can allow for extremely high data rates, low delays and low power consumption. The hop gain, suggests using both the downlink and uplink resource when communicating through the cellular mode. The third, reuse gain signifies that radio resources can be simultaneously used by both D2D link and cellular links.

The advantages of cellular D2D communication can be divided into two categories. Firstly, mobile device perspective, where the service and node discovery can be carried out by the network, which results in large energy consumption savings. This is because; the network already knows the positions of the devices connected to its network as well as the services needed by each of the device. The other is network consideration; the advantage to improve the spectral reuse. The spectrum is made available to the set of devices which communicate in an area. As the power level of the user is much less than that of the Base Station, the network can allots the spectrum directly, and thus reuse the spectrum in different regions.

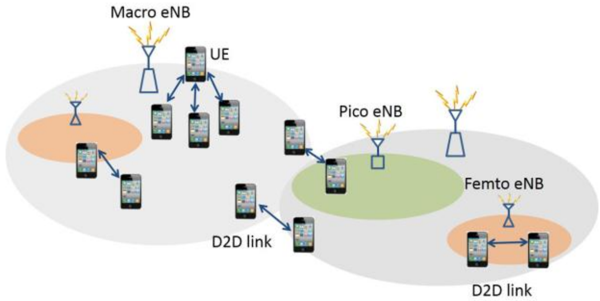

Fig 1. Illustration of D2D communications among multi-tier cells in LTE-A HetNets [2].

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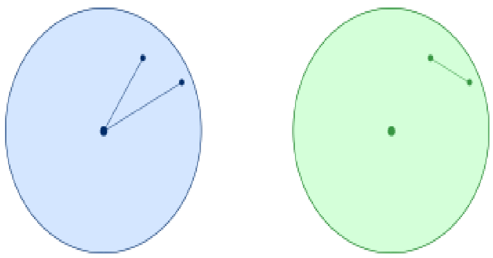
There are challenges and researches going on regarding D2D communications underlaying cellular networks. The interference management is critical as cellular networks need to manage novel interference scenarios which can support D2D communication. Coexisting of D2D communications in heterogeneous networks is worth researching as heterogeneous cellular architecture with mixed deployment of micros and macro base stations is currently the hot topic for research. Multihop D2D communication, which allows UE to be a relay to help other UE, is still under research and not been investigated.
However, in D2D communication, the link resources of cellular users are reused, intracellular interference generated cannot be neglected causing new problems and challenges. Thus, intelligence resource sharing between D2D pairs and cellular users becomes a crucial issue which can generate better quality and efficient multimedia services. In this paper, formation of groups in D2D in a cellular space and what can be the blocking probability of the devices which have the tendency to form D2D pair is discussed.

II. D2D LINKS VERSUS CELLULAR LINKS

In cellular communication, the BS serves as a relay. The radio path of a cellular link consists of two parts: the path from the transmitter to the base station and the path from the base station to the receiver. A D2D link is a single direct path from transmitter to receiver. When comparing the two links, we may not simply assume that the length of a D2D link is equal to the summation of the two paths of a cellular link. The two parts of the cellular link have to be taken into account separately.
A comparison is made between D2D- and cellular links based on the length of the links (i.e. the distance between the two communicating nodes). We perform this comparison as follows: when node A needs to send data to node B, we define a D2D link to be a direct path from A to B. The cellular link is the path from A to the BS. In cellular communication, the BS then forwards the data to B. The up and downlink of the BS are assumed to be separated by means of a channel separation technique.



(a) Cellular Link (b) D2D Link

Fig 2: Cellular Link versus D2D Link

Hence, a D2D link from A to B is compared to a cellular link from A to BS, even though in cellular communication the BS still has to forward the data to B. This is an important assumption for the following analysis. Because the forwarding takes place in a different frequency band, time slot or with different CDMA code, the link from BS to B can be considered separately.

A. Analysis

In a circular cell with radius R, we uniformly distribute N nodes over the area in the cell. If $N \rightarrow \infty$, the average distance from a node to the base station (i.e. the center of the circle) can be determined by weighting all radii and dividing the sum of all weighted radii by the sum of the weights:

$$E(R) = \frac{\int_0^R f(r) r dr}{\int_0^R f(r) dr} \quad (1)$$

where *f(r)* is the weight function, identified with a distribution function of r:

$$f(r) = 2\pi r, \quad 0 < r < R \quad (2)$$

This distribution function weights each radius according to the circumference of a ring with that radius. Filling equation (2) in equation (1) gives:

$$E(R) = \frac{\int_0^R 2\pi r^2 dr}{\int_0^R 2\pi r dr} = \frac{2R}{3} \quad (3)$$

The distance found in equation (3) is the average distance between randomly placed nodes in a circular cell and the base station (Figure 2(a)). D2D links bypass the base station and are formed directly between nodes within the cell (Figure 2(b)).
The computation of the average distance between two random points (nodes) in a circle with radius R can be found in [3] and is given by:

$$E(radius) = \frac{128R}{45\pi} \cong 0.9054R \quad (4)$$

From equations (3) and (4) we learn that using D2D links is on average disadvantageous compared to cellular links, for communications within a circular area with a centrally placed BS. The purpose of D2D links is not to replace, but rather to complement cellular links.

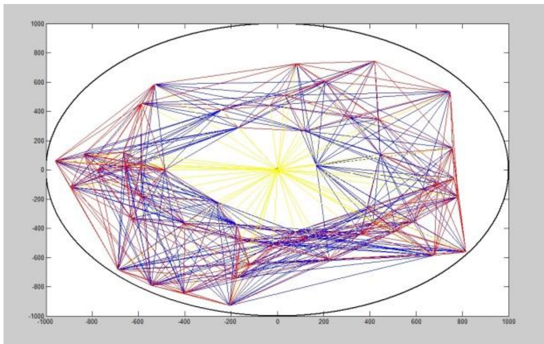


Fig 3: Grouping of D2D Links with a Distance Criterion

It is possible to simulate the scenario in which every node is connected to the other nodes via the shortest link. If the D2D link between a pair of nodes is shorter than both the links from the two individual nodes to the center of the cell, we define this as a duplex-D2D link. If the D2D link is only shorter than the distance from one of the two nodes to the center of the cell, we define this as a simplex-D2D link.

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Vol. 4, Issue 6, June 2015

The pseudo-code for the link choice is as follows:

```
FOR all nodes j
  FOR all nodes i except node j
      IF distance (j _ center) < distance (j _ i) AND
    distance (i _ cell center) < distance (j _ i)
    THEN there's a duplex-D2D link from node i to node j
  ELSEIF distance (j _ cell center) < distance (j _ i)
    THEN there's a simplex-D2D link from node i to node j
  ELSE there's no D2D link from node i and j;
    node i has a cellular link with the base station
  END if
  END inner for-loop
END outer for-loop
```

In Figure 3 a cell is shown with 50 nodes with the links made based on the above pseudo-code. The red links are duplex-D2D links, blue links are simplex-D2D links and yellow links are normal cellular links.
From this simulation, the number of every link type is listed in Table 1.

Table 1: Link Type and number of Links formed in the analysis

Link Type	Number of Links
Duplex D2D	532
Simplex D2D	442
Cellular	1526
Total	2500

III.GROUPING D2D LINKS

In practice, D2D links can be set-up anywhere in an area. We obviously do not always have the capability of changing the location of communicating nodes. Even if this capability is available, it is not always desirable or possible to change the location of a link, as the link is probably there for a reason.

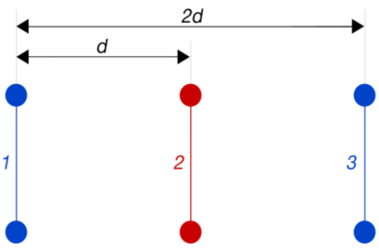

Fig 4: Circular cell with 50 nodes, interconnected via D2D- or via cellular links.

Groups of links are formed by using a distance criterion; only links that are separated from each other by a distance of at least Δ meters may belong to the same group, so that all links belonging to the same group are separated by at least Δ meters. This is illustrated in Figure 4. In this _gure three links are shown. Suppose that $d < \Delta < 2d$, so that the distance between the nodes of link 1 and 2 is less than Δ. From the distance criterion, it follows that link 1 and 2 may not belong to the same group. The same goes for link 2 and 3. Link 1 and 3 however, are separated by a distance larger than and Δ can therefore be placed in the same group. We may take $\Delta = d_{min}$, where

$$d_{min} = \left[10^{\frac{\emptyset + 10\log_{10}(6)}{10n}}\right] d_{D2D_{max}} \qquad (5)$$

If we do so, then all links belonging to the same group fulfill the minimum distance requirement. When all the links in a group - and only the links of that group - operate simultaneously, the minimum SINR used to calculate d_{min} is guaranteed for all links in that group.

A. Signaling

All wireless communication in the licensed spectrum has to be coordinated by the BS covering the area. The coordination is done through signaling. A protocol is necessary to specify how the signaling occurs. Devices eligible for D2D communication have to be informed on which frequency band and timeslot they are allowed to communicate. The initial signaling between the BS and the D2D `candidates' can occur via the timeslots designated for cellular communication. In D2D sessions there are no specified slots for up- and downlink. Hence after a D2D session has been set-up, the involved devices need to signal each other as well, to coordinate and negotiate the upand download times. Pre-defined preambles can be used to specify the start and the end of messages. A mechanism to acknowledge the correct reception of data is also necessary.
To monitor the quality of a link, devices may signal (amongst other QoS parameters) their SINR level. A power control mechanism can then be used to regulate the transmit power.

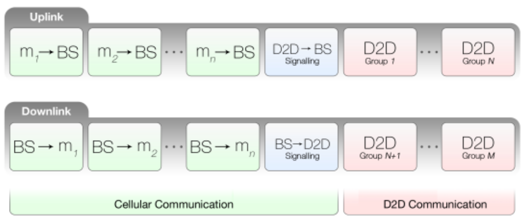

Fig 5: Dedicated slots allocated for D2D both in uplink and downlink

The BS decides in which group a D2D link is placed and in what timeslot a group operates, as shown in figure (5). Over time, new D2D links are created while some existing D2D links are terminated. For optimization reasons, the BS may want to change the group of active D2D sessions. Signaling timeslots in which all devices in a D2D session listen to the BS can be used to receive coordination commands from the BS. The commands are then broadcasted by the BS in one or more signaling timeslot as such. In figure (5) one BS broadcasting timeslot is illustrated.
Finally, the devices in a D2D session have to inform the BS when the communication is terminated. Depending on the traffic pattern, strategies can be developed to, for example, agree upon a time to live of a certain link. Another possibility is to periodically send a message to the BS to stay updated on the status of the link. This transmission of this periodical message has to be in agreement with the BS, so that one or more timeslots for cellular communication is reserved. By doing so, the ongoing cellular communication is not disturbed.

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International Journal of Advanced Research in Computer and Communication Engineering
Vol. 4, Issue 6, June 2015

B. Grouping Algorithm

We assume that the BS is responsible for the set-up and allocation of time slots for D2D links. In the analysis we also assume that the position of the nodes is known to the BS and that nodes are stationary. In reality, the position of devices may not be known exactly at every moment, but there are many possibilities to approximate the position of a device.

We want to minimize the number of necessary time slots in order maximize the capacity of the cell in terms of time slots. Hence we want to create as few groups as possible, i.e. we want to maximize the number of links in every group.

This problem can be formulated as the graph coloring problem in graph theory. Graph coloring in its simplest form, is a way of coloring the vertices of a graph such that no two adjacent vertices share the same color.

Thus, Greedy Grouping Algorithm was used to minimize the number of groups formed in this paper. The pseudo code for the algorithm is as follows:

```
Make a list of all the vertices, by decreasing degree
Create a first group and place the first vertex in this group
WHILE not all vertices are placed in a group
   Try to place the next vertex in an existing group, starting at
   the first group, then the second group, etc.
   If not possible, create a new group for the vertex
END while
```

IV. CHANNEL ALLOCATION AND BLOCKING PROBABILITY

Blocking in telecommunication systems is when a circuit group is fully occupied and unable to accept further calls. Due to blocking in telecommunications systems, calls are either queued (but not lost) or are lost (all calls made over congested group of circuits fail). Such systems are called queuing systems (*delay systems*) and lost-call systems respectively. The fraction of time a trunk request is denied because every channel is busy is blocking probability. This probability is usually specified for a given system.

The allocation of channels to cells in a cellular network is channel allocation. Once the channels are allocated, cells may then allow users within the cell to communicate via the available channels. Channels in a wireless communication system typically consist of time slots, frequency bands and/or CDMA pseudo noise sequences, but in an abstract sense, they can represent any generic transmission resource. There are three categories for assigning these channels to cells (or base-stations). They are

- Fixed Channel Allocation,
- Dynamic Channel Allocation and
- Hybrid Channel Allocation.

A. Fixed Channel Allocation

Fixed Channel Allocation (FCA) systems allocate specific channels to specific cells. This allocation is static and may not be changed. For efficient operation, FCA systems typically allocate channels in a manner that maximizes frequency reuse. Thus, in a FCA system, the distance between cells using the same channel is the minimum reuse distance for that system. The problem with FCA systems is quite simple and occurs whenever the offered traffic to a network of base stations is not uniform. Consider a case in which two adjacent cells are allocated N channels each. There clearly can be situations in which one cell has a need for $N+k$ channels while the adjacent cell only requires $N-m$ channels (for positive integers k and m). In such a case, k users in the first cell would be blocked from making calls while m channels in the second cell would go unused. Clearly in this situation of non-uniform spatial offered traffic, the available channels are not being used efficiently. FCA has been implemented on a widespread level to date.

B. Dynamic Channel Allocation

Dynamic Channel Allocation (DCA) attempts to alleviate the problem mentioned for FCA systems when offered traffic is non-uniform. In DCA systems, no set relationship exists between channels and cells. Instead, channels are part of a pool of resources. Whenever a channel is needed by a cell, the channel is allocated under the constraint that frequency reuse requirements may not be violated. There are two problems that typically occur with DCA based systems.

- First, DCA methods typically have a degree of randomness associated with them and this leads to the fact that frequency reuse is often not maximized unlike the case for FCA systems in which cells using the same channel are separated by the minimum reuse distance.
- Secondly, DCA methods often involve complex algorithms for deciding which available channel is most efficient. These algorithms can be very computationally intensive and may require large computing resources in order to be real-time.

C. Hybrid Channel Allocation Schemes

The third category of channel allocation methods includes all systems that are hybrids of fixed and dynamic channel allocation systems. In HCA schemes, the total number of channels available for service is divided into fixed and dynamic sets. The fixed set contains a number of nominal channels that are assigned to cells as in the FCA schemes and, in all cases, are to be preferred for use in their respective cells. The dynamic set is shared by all users in the system to increase flexibility. Request for a channel from the dynamic set is initiated only when the cell has exhausted using all its channels from the fixed set.

V. PERFORMANCE ANALYSIS

The setup is considered for 250 links and fixed link lengths. The path loss considered is 4. The frequency is set to be 2 GHz. The radius of the cell is 1000m. The numbers of nodes considered for analysis are 25. The SINR is 6dB. The cell is populated with 250 randomly placed links (500 nodes) of equal length. For channel allocation, various scenarios have been considered. A traffic load of 1000 users is considered where every test case is tested including Fixed, Dynamic and Hybrid channel allocation.

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The channels allocated are for MSC. Reserved channels are taken into account for calculating the blocking probability which is done as

$$r = \frac{MSC\ Reserved\ Channels\ Size}{BS\ Fixed\ Channel} \qquad (6)$$

We start with a fixed link length for all links of 1000 meters and decrease the link length to 500, 250, 100, 50 and finally 10 meters. The nodes are uniformly distributed in the cell.

Figure 6 shows the formation of groups formed with fixed link lengths using 250 links. The height of a bar corresponds with the fraction of groups that are needed relative to the total number of links. Hence the lower a bar, the higher the efficiency in terms of the number of groups that are utilized relative to the number of groups that would be needed if every individual link would be assigned its own group.

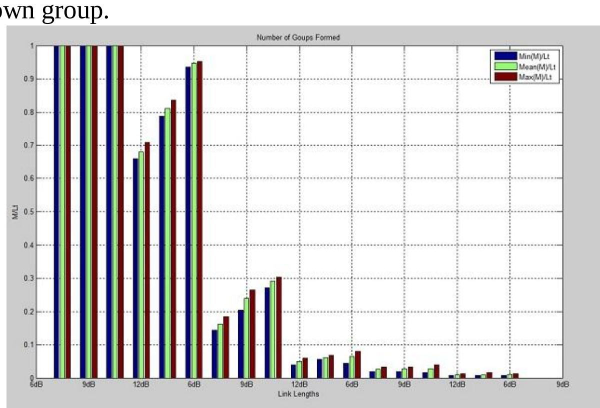

Fig 6: Number of Groups f\Formed

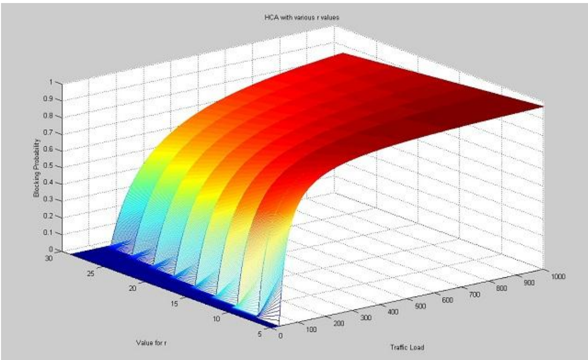

Fig 7: Hybrid Channel Allocation with various r values

These bar plots give us a better view of what happens when certain parameters are changed and allow us to compare scenarios with each other in an easier way, because the number of groups is normalized with the total number of links.

As the link lengths decrease, more links can be placed in the same group, so fewer groups are necessary to accommodate all links. In Figure 6, it can be seen that as the link lengths decrease, a higher SINR can be guaranteed at a lower `cost', where in this case the `cost' is the number of necessary groups. The reason for this is that the d_{min} increase to guarantee a higher minimum SINR is smaller when the maximum link length is shorter, hence more D2D links fit in the same group.

In channel allocation, the numbers of fixed channel allocated for Base Station are 10. Figure 7 shows when the load is less the blocking probability is minimum. As the load increases, the blocking probability also increases, which is 1 at the end where all the users are trying to connect to all the links available.

VI. FUTURE WORK

The calculation of energy efficiency can be done using throughput which is the next proposed work for this paper [5]. It can be taken forward in calculating the energy efficiency of both D2D links and cellular links and a comparison may be made for better mode of communication in limited cellular region. Considering D2D communications as a technology for future wireless generation especially for cellular communications, the work carried out till now has mainly consisted of uplink resource sharing for optimizing energy efficiency. As D2D communications is capable of working in different modes, the work can be proposed for downlink resource sharing. The work can be further increased for orthogonal and cellular mode of communication. The world is moving towards 5th generation cellular technology and D2D communication can thus be an effective technique for communication considering its energy efficiency and spectral resource sharing capability.

VII. CONCLUSION

The greedy grouping strategy is the most efficient in terms of the number of groups when the links are short, of equal size and not clustered. When the traffic load is less, all devices or users get connected that means there is no blocking of the devices for communication. As the load increases, the blocking probability also increases, which is 1 at the end where all the users are trying to connect to all the links available.

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