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Evaluation of a Model to Enhance Resource Allocated to Device-to-Device Communication in CDMA-based Cellular Systems – Resource Capacity Analysis

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Abstract - Development of models for capacity allocated to Device-to-Device (D2D) communication had taken such great advantage in recent researches. Device-to-Device (D2D) communication was first introduced in some standard of wireless communication standard, then in mobile communication during the third generation (CDMA technology). Resource allocated to D2D brought many challenges in mobile communication especially in frequency reuse (design). In this paper, D2D capacity resource allocation was developed based on Shannon mathematic model. We developed a new mathematical model based on Shannon equation to increase the capacity gain and system throughput of resources allocated to D2D in CDMA. Our evaluation was based on two scenarios, one without frequency reuse and another with frequency reuse and the throughput was calculated. The work should help enhancing capacity of resources allocated for D2D users.

Keywords: *Device-to-Device; CDMA; Resource capacity evaluation, system throughput, user equipment, cellular network*

I. INTRODUCTION

The need of frequent communication between nearby devices has become critical. Now with the capacity of smart devices for content share, game play, social discovery, and so on. The conventional uplink and downlink transmission mode in cellular network fails to address this demand efficiently. In order for operators to address this huge demand and to offer their subscribers high connection, operators have to control direct device-to-device communication which has been studied in context of wireless network such as LTE and WIMAX [1], [2], [3]. Before D2D communication in cellular network became topic for researchers, it was already developed in several standards of wireless communication. For example Bluetooth, ZibBec in wireless personal area networks (WPANs), and WI-FI direct in wireless local area networks (WLANs)

Device-to-Device (D2D) communication in cellular networks is defined as direct communication between two mobile users without traversing the base station (BS) or core network. Beside this type of communication, two subscribers with the need to communicate using their mobile phones communicate via base station which connects them to the network [4].

D2D communication on the cellular network brings new challenges and design problem such as optimization of power consumption, resource allocation and reuse of cellular frequencies. In this paper, we evaluated the channel capacity and then we conduct a research on how we can enhance this resource allocated to D2D communication [5].

The investigation of resources allocated to D2D communication based on CDMA. In this paper, the review of the concept of D2D communication based CDMA is detailed in section II. In section III, system and mathematical model. In section VI, throughput calculation and finally, in section V, Results are discussed.

II. D2D COMMUNICATION BASED CDMA

D2D communication refers to as a direct communication between subscribers without passing through Base Station.

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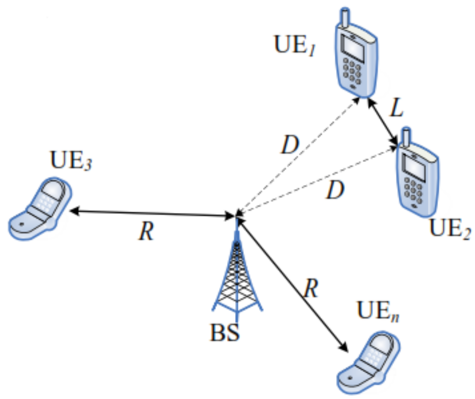

Figure 1: D2D communication in cellular network

When a network is congested and still users need communicate, under this circumstance, the operator has to let subscribers in a given coverage to decide if they can communicate via D2D communication. By there is the existence of a helping infrastructure in Figure2to organize the communication and resource utilization in the cell. Figure 2 illustrates both uplink and downlink interference scenario in D2D communication. For example when uplink frequencies are reused by D2D users in the cell, the base station receive will interference from the D2D user transmitter. To avoid this interference, D2D users communicate using the direct link in two modes which are overlay D2D and underlay D2D.D2D differs from Mobile Ad-hoc Networks (MANET) and Cognitive Radio Networks (CRN) in the way that it is controlled by evolved node B (eNB) [1].

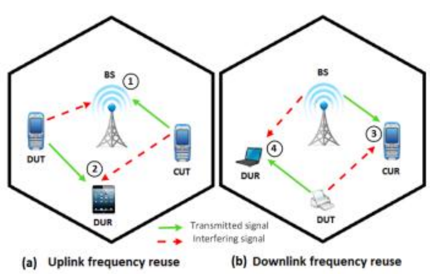

Figure 3: Interference scenario in D2D communication.

Resource allocation can be considered as a way of avoiding interference in D2D communication. The optimized resources allocation such as frequency, and time (CDMA) can help in reducing the effect of interference. CDMA is normal used in the third generation mobile communication. CDMA are broadband systems, in which each subscriber uses the whole system bandwidth (similar to TDMA) for the complete duration of the connection (similar to FDMA) [6], [7].

D2D communication in CDMA systems and its equations, to solve the communication mode selection and power allocation problem jointly for D2D and cellular users has been derived in [2].

III. RELATED WORK

A lot of work was done on this topic but most of them did not considered the capacity as an issue. Reusing the Resources of More Than One Cellular User and other two algorithm were proposed but they do not indicate the way it will increase the system capacity (see Figure 1) [8]. Three sharing modes are mention as non- orthogonal, orthogonal and cellular sharing modes but it focuses on optimization of power and energy [9]. The spectrum reuse protocol where D2D users are only allowed to communicate with each other during the uplink (UL) frame of the network. This is due to the fact that during UL only the base station (BS) is exposed to interference by the D2D users but focuses on the spectrum sharing by analyzing and identifying the interference problem of the primary cellular network caused by the D2D transmitter during the UL and DL phases separately [10].

The system model in [11] contains the inner part and the outer part, where the inner part consists of the traditional UEs which communicate through BS whereas the outer part consists of the D2D UEs which have at least one neighbor within a targeted distance. The author assumes that the large number of resources in inner part is taken as infinite and Poisson point distribution is considered in this case for cellular UEs. It also assumes that the finite number of sources in outer part of the cell for D2D UEs and the corresponding model in this case is the Engset distribution and the number of sources in the inner part is distributed into small cell with a reuse factor of seven so that the number of resources is reduced and consider Engset distribution for both parts by applying the method of sharing available resource where each part uses dedicated resource but the author does not show how their model shall enhance the system capacity since this can accommodate more users. Thus system capacity and throughput should have been considered in this case to ensure better QoS. In this model, a single cell is split into multiple rings, and calculate the system capacity and throughput by considering the control overhead to enhance the system performance.

IV. SYSTEM AND MATHEMATIC MODEL

A. System model

In this work, the evaluation was based on two scenarios: First is where the frequency reuse is not considered and other considers the frequency reuse. There is a single cell which is divided into sub cells for better quality of service (QoS). Sub cells are grouped into two ring Figure 3 scenario 1. In ring 0users communicate through base station (cellular user) and Users in ring 1 communicate through D2D communication, both users in ring 0 and ring 1 share spectrum. No frequency reuse in scenario 1 to avoid interference, frequency is reuse in scenario 2 (ring2) and communications in this ring is D2D. For three rings cell Figure 3 Scenario 2,it is assumed that users in ring 0 and ring 1 use BS to communicate. In the second scenario, it is assumed that some users in Ring 1 can decide to use D2D communication and on the other hand some users on Ring 2 also an decide to communicate using Base Station. By considering that both scenarios use CDMA technology mostly used in 3G, the formulas that used to calculate system capacity are deduced.

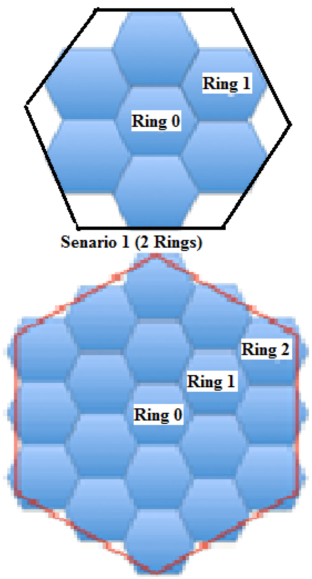

Figure 4: System model, cell splitting

B. *Mathematic model*

The developed equations are based on Shannon capacity equation (1) and reference equation (4) to evaluate and improve channel capacity.

$$C = B\log_2(1+SNR) \quad (1)$$

Where C is Shannon capacity, B is the bandwidth and SNR is the signal to noise ratio [12].

$$\text{But } SNR = \frac{P_{signal}}{P_{noise}} \quad (2)$$

The equation (1) can be re-written as (3) for capacity calcu lation in CDMA based systems.

$$C = B * \log_2\left(1+\frac{1}{N-1}\right) \quad (3)$$

Where $\frac{1}{N-1}$ is SNR [13]

The capacity calculation in equation 4 is based onD2D reference capacity for CDMA named as existing scheme on the simulation results.

$$C = (1-a)B\log_2 1 + \frac{1}{MN_{CDMA}-1} + aB\ \log_2 1 + \frac{1}{N_{\_d2d}-1} \quad (4)$$

By assuming that single CDMA receiver is deployed, where N is the number of users. This is a simple but gives a useful formula to calculate the capacity of a CDMA system [12].Consider a as the percentage of bandwidth allocated to D2D users (the same as in equation 4), R as the radius of the main cell and r as the radius of small cell (equally subdivided). From equation 3, the capacity of Base Station and D2D combined in non-orthogonal (CDMA with D2D nonOL) can be calculated as

$$C = (1-a)B\log_2\left(1+\frac{1}{N_{CDMA}-1}\right) + MaB\log_2\left(1+\frac{1}{N_{D2D}-1}\right) \quad (5)$$

Where M is the number of small cell given for D2D communication and a is the amount of bandwidth assigned to D2D communication.

$$C = (1-a)\log_2\left(1+\frac{1}{(N_{CDMA}+M\,\frac{N_{d2d}}{2})-1}\right) + MaB\ \log_2\left(1+\frac{1}{\frac{N_{d2d}}{2}-1}\right) \quad (6)$$

Considering the case where some portion of users in ring 0 scenario 1 decide to use D2D communication and other portion of users in ring 1 use Base station communication here defined as backwardcompatibility (CDMA with D2D nonOL ½ back word comp), then the capacity of the system can be given by equation 6.

$$C = B\log_2\left(1+\frac{1}{N_{CDMA}-1}\right) + \frac{M}{Q}\ B\ \log_2\left(1+\frac{1}{N_{D2D}-1}\right) \quad (7)$$

As we said before, scenarios 2 represent frequency reuse. Therefore, by introducing the resource sharing (frequency reuse), where reuse factor Q=3 we obtain CDMA with D2D shared with Q=3 in the equation 7.

C. Throughput calculation

We define the throughput as the total number of bits per second used by the user equipment excluding the number of bits per second used for control overhead. When we say control overhead, we refer to the percentage spectrum used for protocol. The throughput is calculated for both the traditional BS and D2D communication.

The total resources used by the cellular users is **B** for the LTE cellular network and $\boldsymbol{\beta_1}$ describe the percentage of the total spectrum used for protocol control overhead mainly for reference signals and control, then **(1- β_1)** of the total resources are used for data transmission for the users in reality. The total resource is given by the equation (8).

$$B = \beta_1 * B + (1 - \beta_1) * B \quad (8)$$

Throughput for CDMA based

By excluding the spectrum used by protocol control overhead, the total throughput of BS cellular network used can be described by Equation 9. *W* is the total resources used for data only and *SRN* describe the signal to noise ratio.

$$C = Wlog_2(1 + SNR) \quad (9)$$

As usual, we always do our evaluation based on a reference equation 9. As we are interested in improving the resources allocated to D2D communication, we fixed our reference equation from the total resources shared between BS cellular users (W_{BS}) and D2D links (W_{D2D}).

$$\mathbf{W_{BS}} = (\mathbf{1} - \boldsymbol{\beta_1})\boldsymbol{B} \quad \text{And} \quad \boldsymbol{W_{D2D}} = (\mathbf{1} - \boldsymbol{\beta_2})\boldsymbol{B}$$

where $\boldsymbol{\beta_1}$ describe the percentage used as protocol control overhead and $\boldsymbol{\beta_2}$is the total percentage used as control overhead and discovery for D2D links.

$$C = (1 - a)W_{BS} \log_2\left(1 + \frac{1}{MN_{BS} - 1}\right) + aW_{D2D} \log_2\left(1 + \frac{1}{N_{d2d} - 1}\right) (10)$$

By considering non-orthogonal case, and half of users who can decide to use either BS or D2D equation (11) is obtained.

$$C = (1 - a)W_{BS} \log_2\left(+ \frac{1}{N_{BS} + M * \frac{N_{d2d}}{2} - 1}\right) + MaW_{D2D} \log_2\left(1 + \frac{1}{\frac{N_{d2d}}{2} - 1}\right) \quad (11)$$

In scenario 2 where we have frequency reuse,in this research we consider that Ring 0 has one small cell, Ring 1 has 6 small cells and Ring 2 has M=11.875 equivalent small cells. The same equation are used but here we introduce the case where is shared of resources.

$$C = W_{BS} \log_2\left(1 + \frac{1}{N_{BS} - 1}\right) + \frac{M}{Q} W_{D2D} \log_2\left(1 + \frac{1}{N_{d2d} - 1}\right) \quad (12)$$

V. SIMULATION RESULT AND DISCUSSION

In this work, we consider a single cell scenario split into two rings and three rings scenarios (see Figure 3). a is Considered as the percentage of bandwidth allocated to D2D UE, B as the total bandwidth, R as the radius of the main cell, r as the radius of small cell, M to be the number of cells of D2D, d as the user density N as the total number of users (UE), N as the number of users and Q as reuse factor. More simulation parameters are shown in Table 1.The bandwidth is set to 10 MHz and radius R was set to 1000 m, the number of D2D cells foe scenario 1 is 6 and for scenario 2 is 11.875.

Table 1: simulation parameters for all scenarios

Parameter	Symbol	Value
Bandwidth	B	10 MHz
Cell radius	R	1 Km
Percentage of BW for D2D	a	0.1
Number of D2D cell in scenario 1	M	6
Number of D2D cell in scenario 2	M	11.875
User density	D	100 to 500
Reuse factor	Q	3
Number of users	N	Varies

a. Simulation results for Capacity in scenario 1 and 2.

Figure 4 and Figure 5 shows the capacity for both scenarios according to figure 3. They both show that our proposed approaches can perform better than other approaches.
In general, from figure 4 and figure 5, it is clear that the system can perform better when D2D communication is mixed with usual communication system (using base station) and that system capacity usage is maximized and can accommodate more users.

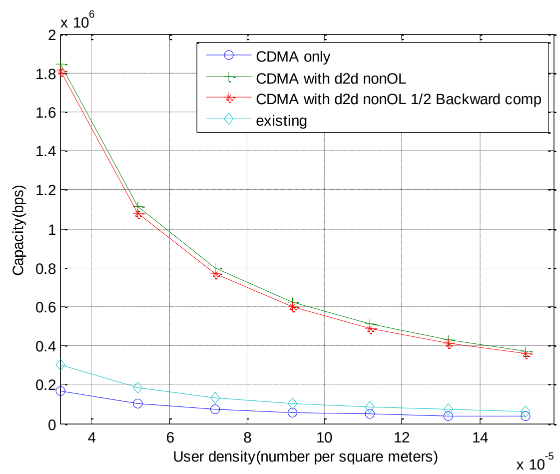

Figure 5: Result for capacity calculation in scenarios 1.

In Figure 6, it is clear that CDMA with D2D in non-orthogonal (CDMA with d2d nonOL) archives higher capacity compared to CDMA with D2D in non-orthogonal with backward compatibility (CDMA with d2d nonOL ½ backward comp) but still these two ideas achieve better capacity compared to CDMA and existing D2D scheme. This is because users on base station was reduced as D2D communication do not use base station for communication, it only monitors when the communication starts and when it ends and hence more users can be hosted on the network. Comparing “CDMA only” and “existing”, the cell capacity is low compared to our two approaches of splitting a cell into two ring cells.

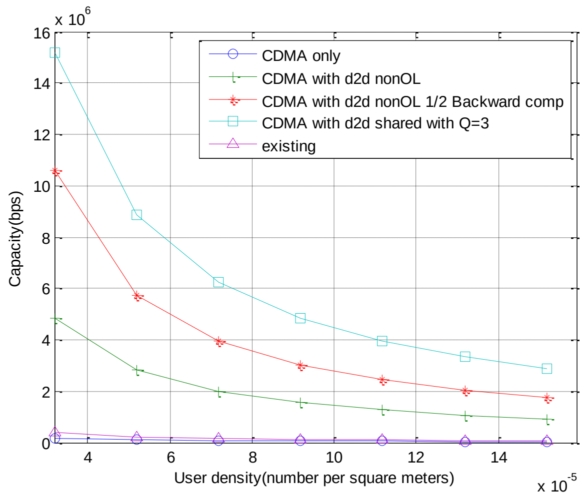

Figure5: Result for capacity calculation in scenarios 2.

In figure: 5, the reuse factor of Q=3 (frequency reuse) achieves higher capacity compared to “CDMA with D2D in non-orthogonal with backward compatibility” and “CDMA with D2D in non-orthogonal” but still all the three approaches achieves higher capacity compared to “existing” and “CDMA only” the reason being the same as for Figure 7.

b. **Simulation results for throughput calculation in scenario 1 and 2.**

To calculate the throughput, we compared in ideal case when control overhead is not considered and in realistic case when the control overhead is considered. This was done to see how control overhead can affect the capacity of the network. According to the simulation results, it shows that control overhead affects the network capacity but in our proposed approaches results higher capacity compared to the “existing” and “CDMA only”.

In Figure 6 and Figure 7, CDMA only is the throughput when all users are pure cellular users, and no users use D2D to communicate. CDMA with D2D in non-orthogonal (CDMA with D2D nonOL) curve is the throughput when all users in Ring 0 are using base station while all users in Ring 1 use D2D. The CDMA with D2D in non-orthogonal with backward compatibility (CDMA with D2D nonOL ½ Backward comp) curve is the throughput when all users in Ring 0 plus half of users in Ring 1 are using Base station while the remaining users in Ring 1 and Ring 0 use D2D communication. The “existing” curve is the throughput when only one small cell in Ring 1 is using D2D and other are using Base station.

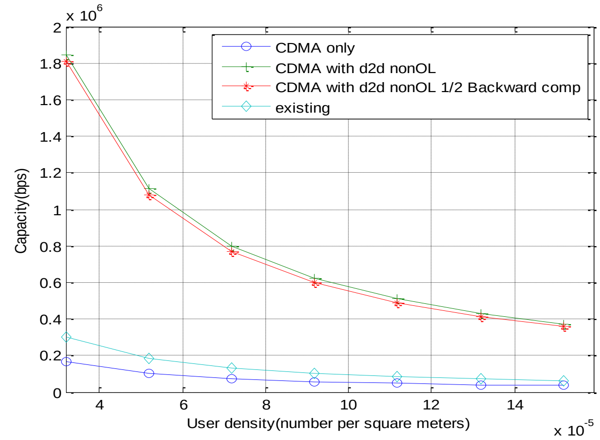

Figure 6a: throughput in ideal case

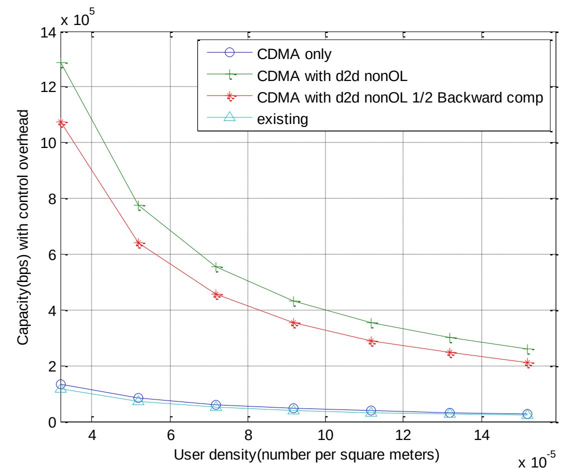

Figure 6b: the throughput in Realistic case

By comparing the capacity and throughput for CDMA in scenario 1, *Figure 6.a*shows the capacity when control overhead is not considered whereas in *Figure 6b* the control overhead was considered. This is the reason why the capacity in *Figure 6b* has reduced but we observe that our approaches still achieve the higher capacity and throughput

Another observation is that *Figure 6.a*has higher capacity compared to F*igure 6.b.* This means that some bandwidth was taken by control overhead.

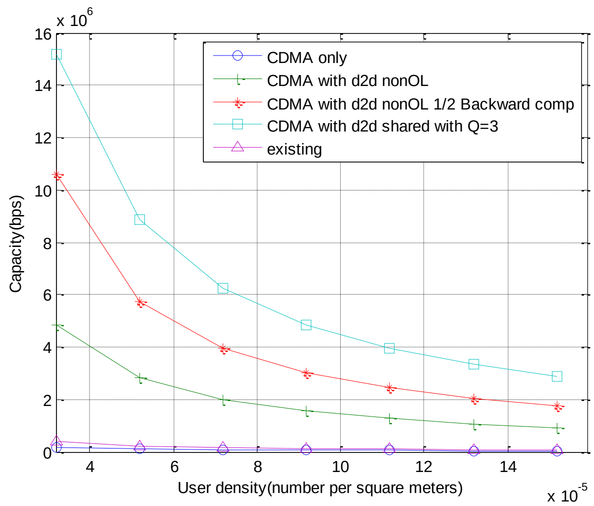

Figure 7a: the throughput in ideal case

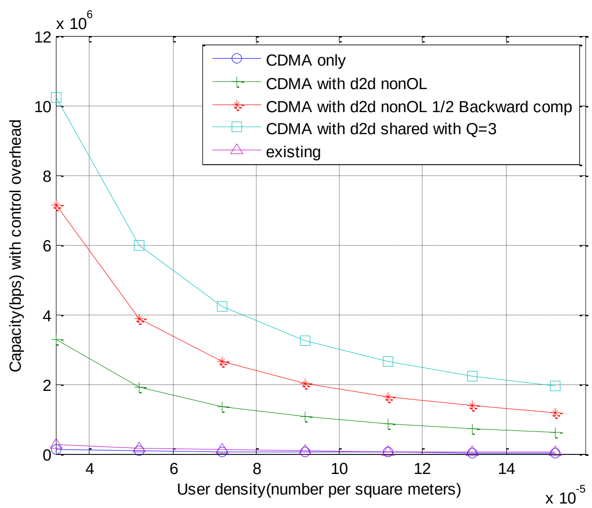

Figure 7b: the throughput in Realistic case

In this case the curve remains the same only one new curve "CDMA with D2D shared with Q=3" is added with is the reuse factor Q.

Scenario 2, the capacity and the throughput for CDMA one can easily see that the gain in terms of capacity is not as higher in realistic case compared to ideal case *Figure 7 a* and *b*. This is due to the fact that the realistic case describes the throughput as the capacity only used for the data transmission which means that in realistic case, bandwidth is lost for control overhead.

VI. CONCLUSION

This paper evaluates and proposes the method to improve the capacity of resources allocated to device-to-device communication. This study was conducted based on two scenarios, first without frequency reuse and then with reuse of frequency. Simulation results show that a significant capacity gain is obtained when D2D is used together with normal communication (through Base Station). According to throughput the results obtained, it is conclude that a high capacity can be achieved when D2D and BS users use non-overlapping bandwidth.All the analysis in this work is based on CDMA. Extending this work to OFDMA technology and including FDD by using both scenarios. This will be discussed in our future work.

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