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# LIMITS OF CAPACITY INCREASE IN CELLULAR NETWORKS DUE TO THE IMPLEMENTATION OF DEVICE TO DEVICE COMMUNICATIONS

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**ABSTRACT**

(D2D) Device to Device communications is a new approach which proposes the separation of data planes and control, thus revolutionizing the traditional methods of communication. This approach is capable of increasing the capacity of the system significantly by providing three types of gain: proximity gain, hop gain and reuse gain, thus it is considered as an approach for the next generation of cellular networks. However, this type of communications can cause interference within the cellular network if not properly designed. To investigate the possible increase in the system capacity and reduce the effect of interference, a three-step algorithm was proposed and evaluated against three matrices: throughput gain, user capacity and access rate. The simulation results showed that as the D2D pair gets closer to each other the access rate increases and it can reach up to 98%. Also the throughput gain is directly effected by the distance between the D2D pair as it can reach up to 100% when placing the D2D at an area of 100 $m^2$ and decreases gradually when increasing the distance, while placing the D2D pair at the edge of the cell will result in higher throughput gain as it can reach up to 130% at D2D to CU ratio equals to 1. Finally, the simulation results proved that it is possible to add an extra 60% of the already existed users when using the D2D communication within the cell.

**KEY WORDS:** Device-to-Device; LTE networks; Cellular Networks; Up Link; optimization; power control; resource allocation

# الزياده الممكنه في سعه الشبكات الخلويه نتيجه لاستخدام نظام اتصال جهاز بجهاز

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**ملخص**

منظومه اتصال جهاز لجهاز (Device to Device Communication) هي نهج جديد يقترح فصل حزم البيانات عن وحده السيطره بمعني اخر اقامه اتصال مباشر بين الجهازين الخلويين دون الحاجه لنقل البيانات عبر برج الاتصال. هذا النهج يمكن من زياده سعه الشبكه بشكل كبير عن طريق توفير عده انواع من الربح مثل ربح التقارب (Proximity Gain) و بالتالي فهو يعتبر نهج للجيل القادم من شبكات الأتصال الخلويه. من جهة اخرى فان هذا النهج قد يسبب تشويش داخل الشبكه الخلويه اذا لم يتم تصميمه بشكل جيد. للتحقق من الزياده الممكنه في سعه النظام و لتقليل تأثير التشويش داخل الشبكه . تم اقتراح لوغارتيميه تتكون من ثلاث خطوات و تقييمها من ناحية الربح ,الزياده في السعه و معدل الوصول. النتائج اضهرت ان اقتراب ثنائي(D2D) من بعضهما يؤدي في زياد في معدل الوصول قد تصل الى 98%. أيضا الربح يتأثر بشكل مباشر بالمسافه بين ثنائي(D2D) حيث يمكن ان تصل الزياده في الربح الى 100% عندما تكون المسافه بين ثنائي (D2D) اقل من $100\ m^2$ و تقل تدريجيا بزيادة المسافه. بينما وضع ثنائي (D2D) في حافة الخليه يمكن ان يؤدي الى زياده اكبر في الربح و التي قد تصل الى 130% عند نسبه D2D الى CU مساويه الى 1 . أخيرا اضهرت نتائج المحاكاة انه من الممكن زياده سعة النظام بنسبة 60% عند استخدام نظام (D2D).

## 1. ABBREVIATIONS

**3GPP:** third Generation Partnership Project

**BS:** Base Station

**C2B:** Cellular user to Base station

**C2R:** Cellular user To D2D Receiver

**CU:** Cellular User

**D2D:** Device to Device

**DL:** Down Link

**eNodeB:** extended Node B

**FDD:** Frequency Division Duplexing

**LTE:** Long Term Evaluation

**PL:** Path Loss

**QoS:** Quality of Service

**SPM:** Standard Propagation Model

**SINR:** Signal to Interference and Noise Ratio

**UE:** Users Equipment

**UL:** Up Link

## 2. INTRODUCTION AND OBJECTIVES

D2D communications is considered as one of the few concepts that can support the requirements of Advanced-LTE networks (Long-Term-Evaluation) which capable of supporting real time multimedia and a wide range of broadband technologies. D2D communication involves the separation of the data plane from the control. This is done by establishing a direct link between mobile devices using radio resources, while the base station is only involved in signaling and control (Gandotra and Jha, 2016). See Fig. 1. Using the physical proximity of mobile devices, D2D communications can offer a wide range of advantages such as increasing the system capacity and throughput, increasing the number of users, more reliable and wide coverage, increasing the efficiency of the cellular networks by reducing the battery consumption of mobile devices. In addition, it also offers a new type of applications and services (proximity services) such as faster video streaming and P2P (Peer to Peer) file sharing (Asadi et al., 2014).

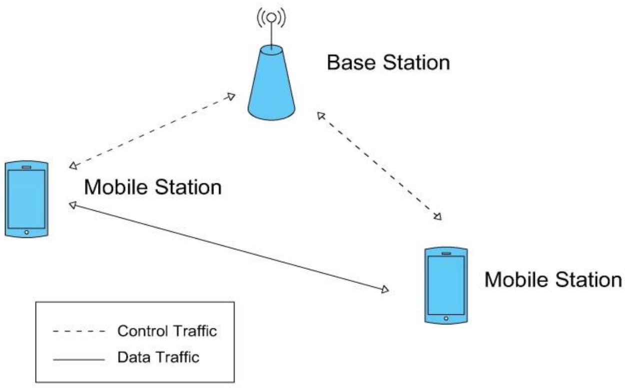


**Fig. 1. Device-to-Device Communication.**

For a realistic solution and to make the channel simulation and the power restraints as close as possible to real life scenarios, the model was based on LTE systems. In order to take advantage of the reuse gain, the system was modeled as a D2D In-Band-Underlay which considered as a main branch of the D2D communication. This system will tighten the reuse factor to 1. The main reasons behind using this system are as follows: it improves the spectral efficiency of the cellular system by taking advantage of the spatial diversity, unlike Out-Band D2D communications, In-Band D2D communications doesn't need a new interface for the frequencies in the cellular devices, furthermore, due to the use of licensed spectrum in the In-Band-Underlay D2D communications, the base station will have a full control on the cellular spectrum thus reducing the interference caused by the D2D communication and guaranteeing a better QoS requirements (Asadi et al., 2014).

Also the TDD (Time Division Duplexing) mode of communication was chosen for the D2D communication, this is mainly because this mode has an inherent ability of realizing the asymmetric data transmission in P2P (Peer to Peer) communication efficiently (Hakola et al., 2010), while FDD (Frequency Division Duplexing) mode was chosen for the cellular communication. Only one full duplex link will be used to carry the D2D communication traffic, thus there will be no need to install separate hardware for the receiver and the transmitter in the terminal devices, as a consequence either the DL (Down Link) or the UL (Up Link) cellular resources will be reused by the link between the D2D pair, for this model it has been decided to use the UL resources due to its ability to reduce the interference caused by the eNodeB by the eNodeB itself, less complex hardware design and higher spectrum utilization (Lin et al., 2014).

The interference and useful links formed due to the UL resource sharing between D2D pair and a cellular user in D2D communication are illustrated in Fig. 2. In general there are two sources of interference that can appear when sharing UL resources in D2D communications. First, interference created from the nearby co-channel CU devices at the same and neighboring cells, this is mainly effecting the receiving D2D devices. This type of interference can be reduced by simply controlling the distance between the D2D receiver and the CU devices (Wei et al., 2014). Second, interference caused by the transmitting D2D devices as well as the co-channel CUs in the neighboring cells, and it is mainly effecting the eNodeB. This type of interference can be avoided if the eNodeB is properly coordinated (Feng et al., 2014), also the eNodeB will experience less interference as it moves away from the D2D transmitter, this is mainly due to the fact that when the SINR is low, it is preferred to use the D2D mode on cell edges (Wei et al., 2014) .

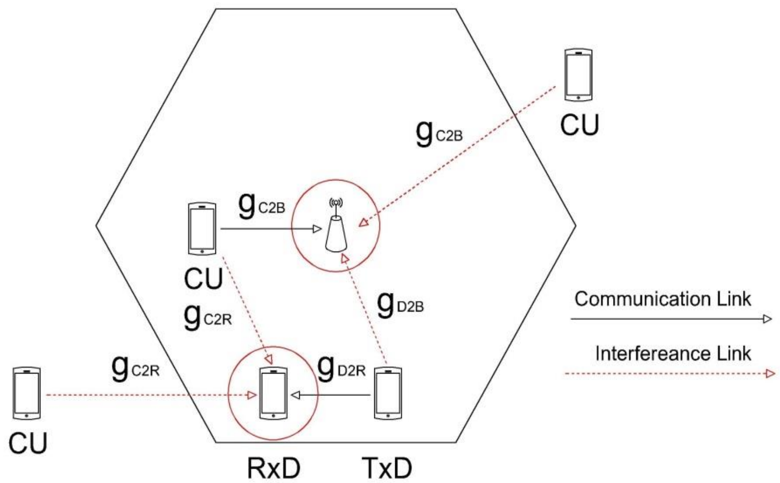


**Fig. 2. D2D pair sharing UL cellular resources.**

In order to calculate a radius for the simulated cells and avoid assuming values for it, a propagation model will be selected for this work. For this model, the operation frequency is chosen to be 2600 MHz, this is mainly because it is one of the most used frequencies in LTE networks (Ofcom, 2013). Also the cell will be assumed as a fully loaded, thus the environment is considered dense urban and the cell is considered micro cell. Depending on the above, the SPM propagation model was chosen for this work among other propagation models, this is mainly because it is applicable to frequencies above 2000 MHz, as well as its suitability to urban environment, besides it is the most adapted model for LTE networks. Equation 1 illustrates the SPM propagation model (Rani, 2012).

$$MAPL = K1 + K2\ x \log(d) + K3\ x \log(h_{Txeff}) + K4\ x\ Diffloss + K5\ x \log(d)\ x \log(h_{Txeff}) + K6\ x\ h_{Rxeff} + K_{clutter}\ x\ f_{clutter} \quad (1)$$

Where $d$ is the cell radius (the distance in meters between the receiver and the transmitter), $Diffloss$ represents the loss occurred due to deviation over an obstructed path and it is normally measured with $dB$, $h_{Rxeff}$ $and$ $h_{Txeff}$ are defined as the effective heights of the receiver and the transmitter respectively and it is measured in meters, $f_{clutter}$ is defined as the average weighted loss because of a clutter, $K_{clutter}$ is defined as the correction coefficient of the clutter attenuation, $K1$ is the constant of frequency and it is measured in $dB$, $K2$ is defined as the constant of distance attenuation, $K3$ and $K4$ are defined as the coefficients of correction for the height of mobile antenna, $K5$ and $K6$ are defined as the coefficients of correction for the height of BS antenna, the coefficient K values are determined based on the terrain type and environment (Rani, 2012).

In order to represent the users mobility within the system, a mobility model will be implemented in this work. In general, there are two types of mobility models: aggregate and individual. For this project, and because the nodes are considered to travel independently within the cell and there is no common behavior between them, thus an individual mobility model is chosen (Bai and Helmy, 2012). Among the various individual mobility models, the Random Walk mobility model was used for the simulation of this work, this is because this project deals with both cellular systems and an ad-hoc system, and unlike other models the Random Walk model is able to simulate the user's movement in both cases (Schindelhauer, 2006). Also because this type of mobility model may generate random and unexpected paths, some may argue that it is not realistic and doesn't represent real life. However, in this work and in cellular communications in general the travel paths of the mobile nodes are not very important, while the exchange operation from cellular mode to D2D mode has much importance (Schindelhauer, 2006).

## 3. PROPOSED ALGORITHM

All the work done in this project as well as the proposed algorithms within the next section is based on Shannon Theorem. Equation 2 represents the throughput.

$$TP = log_2(1 + SINR) = log_2\left(1 + \frac{P\ x\ g}{NoiseP + interference}\right) \quad (2)$$

Where $SINR$ represents the Signal to Interference and Noise Ratio, $TP$ represents the throughput, $NoiseP$ represents the power of the noise, $P$ represents the transmission power of the device, $g$ represents the gain of the channel between the receiver and the transmitter, $interference$ represents the interference effecting the receiver.

The channel gain in this project was modeled based on Chen et al. (2014) taking into account fast fading due to multiple propagation and slow fading due to shadowing. Equation 3 represents the channel gain

$$g_{C2B} = K\beta_{C2B}\gamma_{C2B}{d_{C2B}}^{-PL} \tag{3}$$

Where $g_{C2B}$ represents the channel gain between the CU and the BS it also denotes for path loss between them, $K$ represents a constant which depends on the parameters of the system, $d_{C2B}$ represents the distance between the CU and the BS in meters, $\gamma_{C2B}$ represents the channels slow fading gain with a standard deviation of 7 $dB$ and log-normal distribution, $PL$ represents the exponent of path loss, $\beta_{C2B}$ denotes for the channels fast fading gain with unit mean and exponential distribution.

This equation is also used to find the gain of the channel between the D2D receiver and the CU ($g_{C2R}$), see equation 4.

$$g_{C2R} = K\beta_{C2R}\gamma_{C2R}{d_{C2R}}^{-PL} \tag{4}$$

The D2D receiver and D2D transmitter( $g_{D2R}$) , see equation 5

$$g_{D2R} = K\beta_{D2R}\gamma_{D2R}{d_{D2R}}^{-PL} \tag{5}$$

The BS and the D2D transmitter($g_{D2B}$), see equation 6

$$g_{D2B} = K\beta_{D2B}\gamma_{D2B}{d_{D2B}}^{-PL} \tag{6}$$

For each node movement within the cell, the gains of the channel will be recalculated; this is mainly because fast fading and the shadow change with place and time. To make the solution easier, it will be divided into three steps

First, the selection of the communication mode will be made, which is either the D2D mode where communication among users is established by reusing the cellular resources, or the cellular mode where communication among users is established through the BS. The QoS requirement for both the D2D and the CUs is guaranteed by the proposed admission control algorithm. The conditions that a CU user must fulfill in order to communicate in D2D mode are given in equation 7 and equation 8 (Doppler, 2010) and (Belleschi et al., 2011).

$$SINR_{C,min} \leq \frac{P_C\, g_{C2B}}{NoiseP+(P_D\, g_{D2B}+\sum_i(P_{C,i}\, g_{Ci2B}))} \tag{7}$$

$$SINR_{D,min} \leq \frac{P_D\, g_{D2D}}{NoiseP + (P_C g_{\,C2R} + \sum_j (P_{C,j}\, g_{Cj2R}))} \tag{8}$$

Where $P_C$ represents the power requirement for cellular users and it can be calculated using equation 9

$$P_C = \frac{SINR_{C,min}\;\, g_{D2R}(NoiseP + \sum_i (P_{C,i}\, g_{Ci2B})) + SINR_{C,min}\, SINR_{D,min}\;\, g_{D2B}(NoiseP + \sum_j (P_{C,j}\, g_{Cj2R})}{g_{C2B}\, g_{D2R} - SINR_{C,min}\, SINR_{D,min}\, g_{D2B}\, g_{C2R}} \tag{9}$$

Where $0 \leq P_C \leq P_{C,max}$

While $P_D$ which represents the power requirement for D2D transmitter can be calculated using equation 10

$$P_D = \frac{SINR_{D,min}\;\, g_{C2B}(NoiseP + \sum_j (P_{C,j}\, g_{Cj2R})) + SINR_{C,min}\, SINR_{D,min}\;\, g_{C2R}(NoiseP + \sum_i (P_{C,i}\, g_{Ci2B})}{g_{C2B}\, g_{D2R} - SINR_{C,min}\, SINR_{D,min}\, g_{D2B}\, g_{C2R}} \tag{10}$$

Where $0 \leq P_D \leq P_{D,max}$

The D2D pair will only be admitted if the above power requirements are satisfied, otherwise the pair will remain in the regular cellular mode.

Since the interference depends on the distance between the CU and the D2D receiver as stated earlier (a closer distance causes more interference and vice versa), therefore, and in order to satisfy the QoS requirements for both D2D communication and the cellular communication, a minimum distance between the CU and D2D receiver will be set in this project. The following proposition can be obtained by satisfying both the channel gain equation and the power equations above (Doppler, 2010) and (Belleschi et al., 2011):

$$if\ \ \frac{P_{C,max}\, g_{C2B}}{NoiseP + (P_{D,max}\, g_{D2B} + \sum_i (P_{C,i}\, g_{Ci2B}))} \leq SINR_{C,min} \qquad \text{Then}$$

$$d_{C2R,min} = \left[\frac{K\beta_{C2R}\, \gamma_{C2R}\, SINR_{C,min}\, SINR_{D,min}\, P_{C,max}}{g_D\left(P_{C,max}\, g_{C2B} - SINR_{C,min}(NoiseP + \sum_i (P_{C,i}\, g_{Ci2B}))\right) - SINR_{C,min}\, SINR_{D,min}(NoiseP + \sum_j (P_{C,j}\, g_{Cj2R}))}\right]^{\frac{1}{PL}} \tag{11}$$

$$\text{Or } if\ \ \frac{P_{C,max}\, g_{C2B}}{NoiseP + (P_{D,max}\, g_{D2B} + \sum_i (P_{C,i}\, g_{Ci2B}))} > SINR_{C,min} \qquad \text{Then}$$

$$d_{C2R,min} = \left[\frac{K\beta_{C2R}\, \gamma_{C2R}\, SINR_{C,min}\, SINR_{D,min}(P_{D,max}\, g_{D2B} + NoiseP + \sum_i (P_{C,i}\, g_{Ci2B})}{g_{C2B}(P_{D,max}\, g_{D2R} - SINR_{D,min}(NoiseP + \sum_j (P_{C,j}\, g_{Cj2R}))}\right]^{\frac{1}{PL}} \tag{12}$$

Where $g_D = g_{D2R}/g_{D2B}$ , $d_{C2R,min}$ is the minimum distance between the CU and the D2D receiver, Afterwards and in order for the CU to be a reuse candidate, the following condition must be fulfilled.

$$d_{C2R,min} \leq d_{C2R}$$

After admitting the D2D transmitter to the D2D mode and knowing its reuse candidates, the following step is to allocate the optimal power for that D2D transmitter. Maximizing the overall throughput will be the main criteria for choosing an ideal power pair. Equation 13 shows the problem in mathematical expression and it is based on (Belleschi et al., 2011) and (Huang, 2016).

$$(P_C^*, P_D^*) = \arg\max\{log_2(1 + SINR_C^*) + log_2(1 + SINR_D^*)\} \quad (13)$$

$$SNIR_C^* = \frac{P_C^*\, g_{C2B}}{NoiseP + (P_D^*\, g_{D2B} + \sum_i (P_{C,i}\, g_{Ci2B}))} \quad (14)$$

$$SINR_D^* \leq \frac{P_D^*\, g_{D2D}}{\sigma_N^2 + (P_C^*\, g_{C2R} + \sum_j (P_{C,j}\, g_{Cj2R}))} \quad (15)$$

$P_C^* \in \{P_{C1}, P_{C2}, P_{C,max}\}$ And $P_D^* \in \{P_{D1}, P_{D2}, P_{D,max}\}$

In order to choose the power pair $P_C^*$ and $P_D^*$ there must be a predefined set which contain at least one user transmitting at maximum power. The following equations are produced from the SINR and it is represents the set of potential users.

$$P_{D1} = \frac{SINR_{D,min}\,(NoiseP + P_{C,max}\, g_{C2R} \sum_j (P_{C,j}\, g_{Cj2R}))}{g_{D2R}} \quad (16)$$

$$P_{D2} = \frac{P_{C,max}\, g_{C2B} - SINR_{C,min}(NoiseP + \sum_i (P_{C,i}\, g_{Ci2B}))}{SINR_{C,min}\, g_{D2B}} \quad (17)$$

$$P_{C1} = \frac{P_{D,max}\, g_{D2R} - SINR_{D,min}\,(NoiseP + \sum_j (P_{C,j}\, g_{Cj2R}))}{SINR_{D,min}\, g_{C2R}} \quad (18)$$

$$P_{C2} = \frac{SINR_{C,min}(NoiseP + P_{D,max}\, g_{D2B} + \sum_i (P_{C,i}\, g_{Ci2B}))}{g_{C2B}} \quad (19)$$

Then the combination that gives the best power for the CU and D2D will be chosen by picking the one that aims to increase the throughput as much as possible

Up to this point, and because it meets the requirements of the predefined SINR and the power constraints as well as identifying the reuse candidates, the D2D pair was admitted to the D2D mode. At least one reuse candidate will be available for the D2D pair. Now, the reuse partner that guarantees the highest throughput gain will be selected from the set of candidates. The throughput gain is the difference between the throughput obtained from the cellular mode (where both the D2D pair and the CU communicate through the BS) and the throughput obtained from joining both the D2D mode and the cellular mode. The following paragraph describes the resource allocation in more details.

First, calculating the throughput achieved by the cellular mode. For this throughput, three links will be presented from the communication of the D2D pair through the base station: one uplink for the CU communication, one downlink from the eNodeB to the D2D receiver, one uplink from the D2D transmitter to the eNodeB. The equation are listed below (Feng et al., 2014).

$$TP_C = log_2\left(1 + \frac{P_{C,max}\, g_{C2B}}{(NoiseP + \sum_i (P_{C,i}\, g_{Ci2B}))}\right) + log_2\left(1 + \frac{P_{D,max}\, g_{D2B}}{(NoiseP + \sum_i (P_{C,i}\, g_{Ci2B}))}\right) + log_2(1 + \frac{P_{BS}\, g_{B2R}}{NoiseP + (\sum_i (P_{BS}\, g_{Bi2R}))} \tag{20}$$

Second, the throughput achieved by both the cellular and D2D communications is determined. For this throughput, tow links will be presented: an uplink for the CU communications as well as an uplink between the D2D transmitter and D2D receiver.

$$TP_{sum} = log_2\left(1 + \frac{P_C\, g_{C2B}}{NoiseP + P_D\, g_{D2B} + \sum_i (P_{C,i} g_{Ci2B})}\right) + log_2\left(1 + \frac{P_D\, g_{D2R}}{NoiseP + P_C\, g_{C2R} + \sum_i (P_{C,j} g_{Cj2R})}\right) \tag{21}$$

Where $P_C$ and $P_D$ represent the selected power pair. In the case of only cellular communication is active, one resource block will be reused by each link and thus three resource blocks will be consumed, while in the case of both D2D and cellular communication are active, only one resource block will be shared between the two links, thus the first case will be normalized to only one resource block in order to have fair compression.

Next, we calculate the gain of the D2D throughput as follows:

$$TP_{gain} = TP_{sum} - TP_{C,normilized} \tag{22}$$

Also the percentage of the throughput gain within the cell is calculated using the following expression

$$\%_{gain} = \frac{\sum_j TP_{gain}}{\sum_i TP_{C,consumed}}\, x100 \tag{23}$$

Notes:

- The throughput gain for every CU candidate will be calculated and compared to each other and reported to the D2D pair, thus choosing the CU that gives the highest throughput gain for resource sharing
- If more than one D2D pair exists, the algorithms will be repeated to allocate the best resources to these D2D pairs. Also it is worth mentioning that a CU can only share its resource with one D2D pair
- At each node movement, all the steps above will be performed again and the channel gain and the distances will be recalculated
- The inter-cell interference effecting the middle cell will be considered in all equations

# 4. SIMULATION

## 4.1. Uplink Budget Analysis

The uplink budget analysis is used to estimate the maximum path loss between the user terminal and the base station, then the obtained path loss with a proper propagation model are used to predict the maximum cell coverage (cell radius)

### 4.1.1. Path Loss

All the parameters used for the analysis are listed in Table 1.

**Table 1. Link budget parameters.**

| | |
|---|---|
| $\boldsymbol{Transmitter - UE}$ | |
| $A)\ Maximum\ Transmission\ Power$ | $23\ dBm$ |
| $B)\ Antenna\ Gain$ | $0\ dBi$ |
| $C)\ Body\ Loss$ | $0\ dB$ |
| $D)\ ERIP$ | $23\ dBm = A + B + C$ |
| $\boldsymbol{Receiver - eNodeB}$ | |
| $E)\ RF\ Noise\ Figure$ | $3\ dB$ |
| $F)\ Thermal\ Noise$ | $-121.4\ dBm$ |
| $G)\ Noise\ Floor$ | $-118.4\ dBm = E + F$ |
| $H)\ SINR$ | $-6\ dB$ |
| $I)\ Receiver\ Sensitivity$ | $-124.4\ dBm = G + H$ |
| $J)\ Interference\ Margin$ | $2.3\ dB$ |
| $K)\ Cable\ Loss$ | $2\ dB$ |
| $L)\ Antenna\ Gain$ | $13\ dBi$ |
| $M)\ MHA\ Gain$ | $2\ dB$ |
| $\boldsymbol{Propagation}$ | |
| $N)\ Location\ Probability\ at\ Cell\ Border$ | $99\%$ |
| $O)\ Shadowing\ Standard\ Deviation$ | $7\ dB$ |
| $P)\ Fade\ Margin$ | $16.31\ dB = Normal\ Inv(N) * O$ |
| $Q)\ Penetration\ Margin$ | $10\ dB$ |
| $Maximum\ Allowed\ Path\ Loss$ | $131.79\ dB = D - I - J - K + L + M - P - Q$ |

The UE (Users Equipment) body loss involves only the voice traffic and as illustrated within the above table it is set to 0dB, this is because, unlike the data traffic, the voice traffic holds the

UE near the mobile users head. On the receiver's side, the thermal noise is determined by multiplying $the\ Bandwidth\ x\ Tempreture\ (290K) x\ k(Boltsmann\ Constant)$. The bandwidth is set to 180 kHz assuming one resource block allocation per each user, thus the resulted thermal noise is -121.4 dBm. (3GPP, 2014), (Kumar and Shukla, 2014) and (3GPP, 2013).

### 4.1.2. Cell Radius

In order to solve for the radius, equation 23 was derived from the path loss equation:

$$d = 10^{\frac{MAPL-[K1+K3x\log\left(h_{Txeff}\right)+K4\ x\ DiffLoss+K6xh\ _{Rxeff}+K_{clutter}+f_{clutter}]}{K2+6.55\ K5\ x\ log(h_{Txeff})}} \quad (23)$$

The value of MAPL (Maximum Allowed Path Loss) will be taken from previous calculations, while K coefficients values will be taken based on (Rani, 2012) assuming fully loaded cell and urban dense environment, see Table 2 for the rest of the values.

## 4.2. Assumptions

The following assumptions were made during the development of the proposed algorithms

- The CSI (Channel State Information) for all the links within the cell is assumed to be fully known by the base station
- Only one RB (resource block) will be allocated for each mobile user, also each D2D pair can only share one RB, meaning that each RB can have at most toe links: D2D and cellular
- only one receive antenna and one transmit antenna will be available for all mobile terminals
- a fully loaded cell is assumed for the cellular mode, 50 cellular user and 50 pair (100) communicating with each other which gives a total of 150 users

## 4.3. Simulation Parameters

In order to have a fully loaded system of 150 users and because the simulation involves cellular communications in FDD mode, a bandwidth of 20 MHz for the UL and 10 MHZ for the DL were dedicated. The maximum transmit power of the BS is set to 46 dBm (3GPP, 2010) [18], also the maximum and minimum power of the mobile UEs were set to 23 dBm and -40 dBm respectively (3GPP, 2014). The values of the path loss constant and exponent are taken from the simulation performed in (Feng, 2013) while the log normal distribution of the shadowing is taken based on the requirements (3GPP, 2013), all other parameters are illustrated in Table 3.

**Table 2. SPM Model Parameters.**

| $Parameter$ | $Value$ | $Parameter$ | $Value$ |
|---|---|---|---|
| $MAPL$ | $131.79\ dB$ | $K4$ | $0.8$ |
| $f$ | $2600\ MHz$ | $K5$ | $-6.55$ |
| $h_{Txeff}$ | $1.5\ m$ | $K6$ | $0$ |
| $h_{Rexff}$ | $30\ m$ | $K_{\ clutter}$ | $1$ |
| $K1$ | $16.375$ | $f_{clutter}$ | $0$ |
| $K2$ | $48$ | $DiffLoss$ | $2\ dB$ |
| $K3$ | $5.83$ | $d$ | $\cong 550\ m$ |

**Table 3. General simulation parameters.**

| $Parameters$ | $Values$ |
|---|---|
| $UL\ bandwidth - Resource\ Blocks$ | $20\ MHz - 100\ PRBs$ |
| $DL\ bandwidth - Resource\ Blocks$ | $10\ MHz - 50\ PRBs$ |
| $Maximum\ PS\ transmit\ Power\ (P_{BS})$ | $46\ dBm$ |
| $Maximum\ UE\ transmit\ Power\ (P_{C,max}, P_{D,max})$ | $23\ dBm$ |
| $Minimum\ UE\ Transmit\ Power\ (\ P_{min})$ | $-40\ dBm$ |
| $Minimum\ UE\ SINR\ (SINR_{C,min}, SINR_{D,min})$ | $-6\ dB$ |
| $Path\ Loss\ Exponent\ (PL)$ | $4$ |
| $Path\ Loss\ Constant\ (K)$ | $0.01$ |
| $Noise\ Power\ (NoiseP)$ | $-121.4\ dBm$ |
| $Slow\ Fading\ Standard\ Deviation$ | $7\ dB$ |
| $Samples$ | $1000$ |
| $Maximum\ Number\ of\ UEs\ Per\ Cell$ | $150$ |
| $Number\ of\ D2D\ Pairs$ | $10\%, 20\%, \dots \dots.,100\%\ of\ Active\ CUs$ |

## 4.4. Mobility Modeling

Fig. 3 illustrates the implemented system with four mobile nodes at each cell. The simulation will be performed for only the middle cell where the D2D pairs wishing to communicate are designated with blue filled circles. The initial position of mobile nodes is generated randomly within the simulation area using the Random Walk mobility model and the number of nodes within the cell is kept constant in such a way that nodes will bounce back when it tries to cross to another cell. At each step, the coordinates of the nodes will be changed in a way that each node doesn't exceed a maximum distance of 25 meters and within the interval of$(0.2\pi)$. The maximum experienced speed will not exceed 90 km/hr, assuming a time interval of one minute between steps. In order to get the channel gain of a certain links, at each node movement the distances of the communication links and the interference links within the middle cell and neighboring cells will be recalculated. Also After admitting the D2D users to the D2D mode, the minimum distances between the D2D pair receiver and each CU will be calculated.

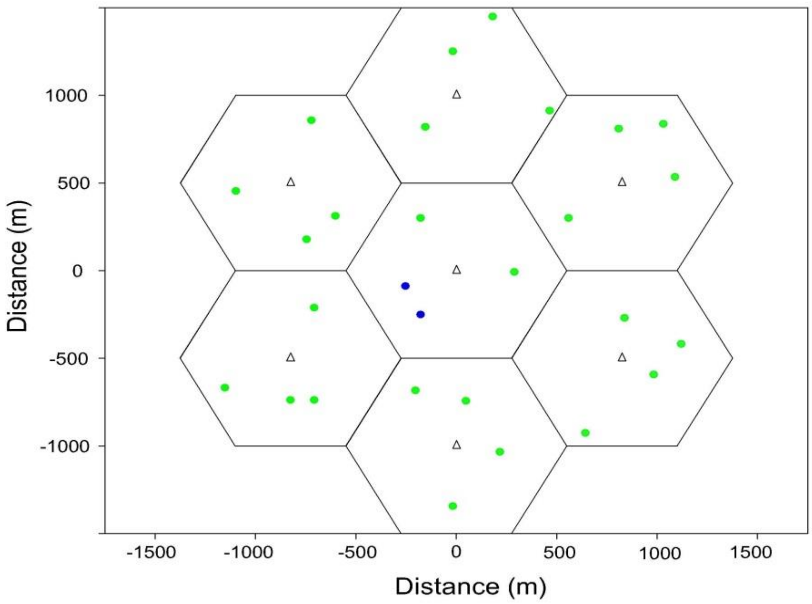


**Fig. 3. Random Walk simulation.**

## 5. SIMULATION RESULTS AND DISCUSSION

Fig. 4 shows the cell throughput for D2D pair communicating with a CU through the eNodeB, the throughput is normalized to one RB per CU. While Fig. 5 illustrates the throughput achieved when both the cellular and D2D communications coexist in the cell and one RB is shared. Afterwards, and by subtracting the throughput achieved in Fig. 4 from that achieved in Fig. 5 the throughput achieved by the D2D communication is obtained as can be seen in Fig. 6, in this figure we can observe that at certain steps, the gain has a negative value, this means that cellular communication alone gives a better throughput than that achieved by the coexistence of both modes. Therefore, even if the SINR requirements are met, it is better for the D2D user to remain within the conventional mode.

After selecting the best CU for the D2D pair depending on the throughput gain in Fig. 6, the total throughput gain achieved by the existence of the D2D communication after selecting the best resource will be calculated as can be seen in Fig. 7**.** From the figure we can conclude that the D2D communication has increased the cellular throughput gain significantly.

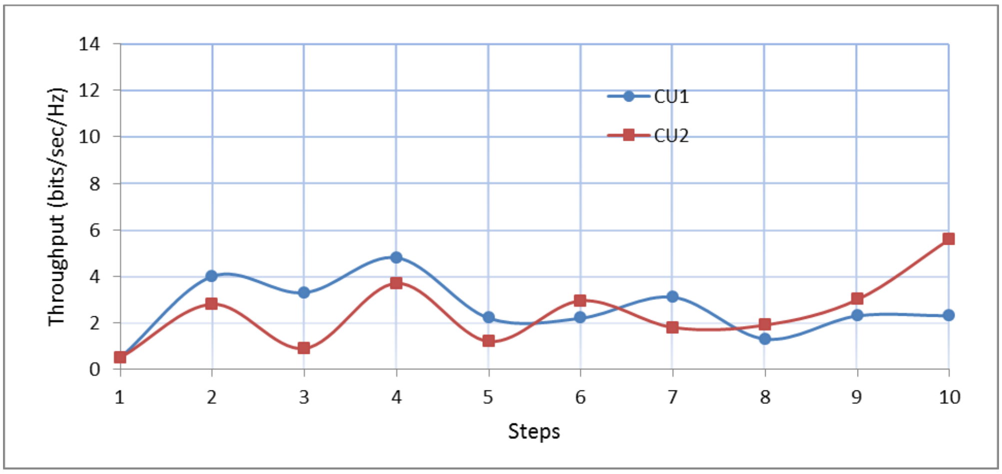


**Fig. 4. The throughput achieved by the CUs.**

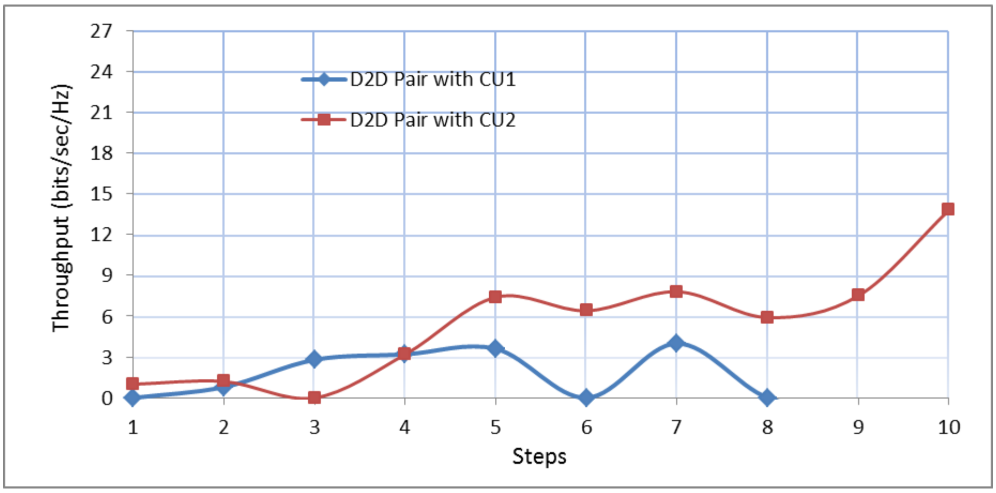


**Fig. 5. Throughput achieved by both the D2D pair and CU when resources are shared.**

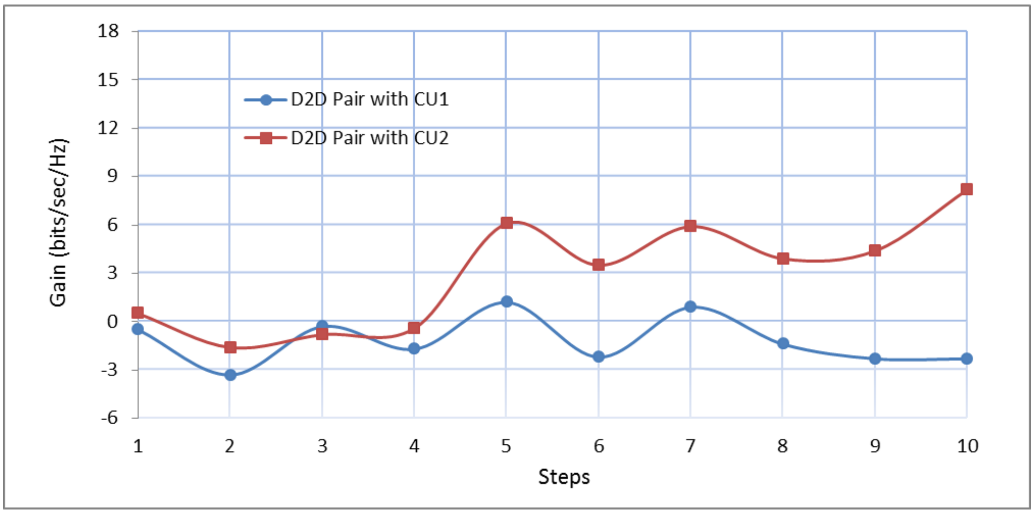


**Fig. 6. Throughput gain by the D2D communication.**

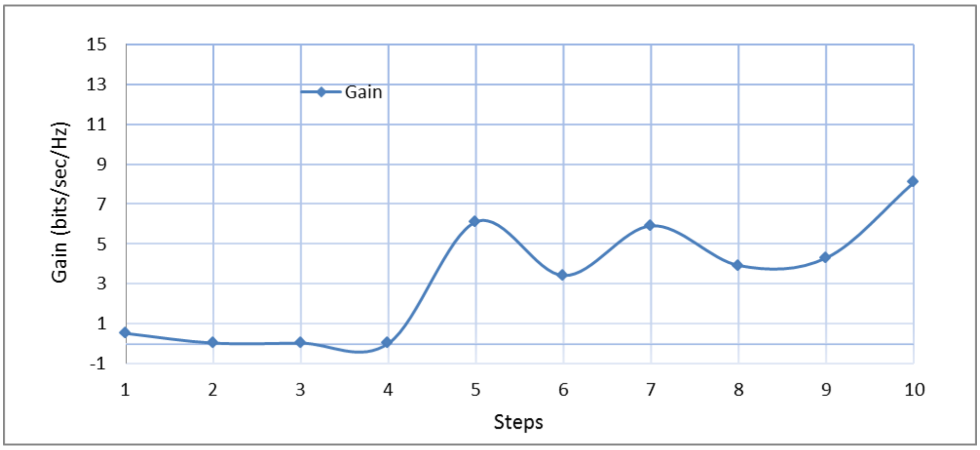


**Fig. 7. Overall throughput gain.**

The access rate is known as the rate at which the D2D pairs are communicating through the D2D mode and it is presented in fractions. To illustrate this, one D2D pair was simulated with 10 CUs (10% resource sharing). The distance between the D2D receiver and the D2D transmitter was kept small by placing them at 100 $m^2$ area, and then the area was increased till it reached 500 $m^2$. From Fig. 8 and as expected the access rate is directly effected by the distance between the D2D receiver and transmitter. As can be seen at areas less than 300 $m^2$ over 90% of communication will be via D2D mode and it will decrease gradually with increasing the distance. It worth mentioning here that at some cases although the D2D pair will be admitted to the D2D node for satisfying the SINR requirements, it will not communicate through the D2D mode unless better performance than the cellular mode is achieved

The throughput gain for the same case mentioned above was simulated using the same distances between the D2D transmitter and receiver. From the Fig. 9 it is very clear that the throughput gain is directly dependent on the distance between the D2D pair where high gain can be obtained at small distances and vice versa. At an area of 500 $m^2$ the throughput gain was about 20% which still a considerable amount of gain when compared to that of cellular networks. These results coincided with that obtained in Fig. 8 (more access rate more gain).

In this paragraph the cell was divided into two zones, zone 1 represents the area at the edge of the cell while zone 2 represents the area near the BS as can be seen in Fig. 10. Then a simulation was done to illustrate the differences in the access rate achieved when placing the D2D pair in zone 1 and then zone 2 and varying the D2D to CU ratio (amount of cellular resources), the results of the simulation are illustrated in Fig. 11**.** From the figure we can conclude that it is more likely for the D2D pair located in zone 1 to communicate via D2D mode when compared to the pair in zone 2. Also, it is very clear that the D2D to CU ratio has an adverse effect on the access rate, this is mainly because when increasing the ratio of D2D to CU (high number of D2D pairs, small number of CUs), the amount of cellular resources available will be decreased and thus less access rate. At the other hand, when decreasing it (small number of D2D pairs, high number of CUs) the amount of available cellular resources will be increased and thus increasing the access rate.

The following paragraphs shows the results of the simulation done to illustrate the difference in throughput gain when placing the D2D pair in zone 1 and then zone 2 and varying the D2D to CU ratio (amount of cellular resources). From the Fig. 12 it is very clear that the gain obtained when placing the D2D pair at zone 1 is much higher than that when placing the pair at zone 2, as it reached up to 130% when the cellular resources are fully used which approximately double the value of that obtained when all the users are communicating via the BS, while it only reached 45% when placing the D2D pair at zone 2 with fully utilized cellular resources. This is a significant increase in capacity and it shows the ability of D2D communication if the interference it causes is properly dealt with. Furthermore, the figure shows that regardless of the pairs location (zone 1 or zone 2) the highest throughput gain will be obtained when the cellular resources are fully used (D2D to CU ratio =1).

As mentioned earlier the cell consists of 50 D2D pairs (100 user) plus 50 cellular users. In the case of no D2D communication, half of the D2D pairs (50 user) and 50 of the cellular users (a total of 100 user) will use the UL taking advantage of the resources in the 20 MHz band, while the other half (50 user) of the D2D pair will use the DL taking advantage of the resources in the 10 MHz band, and thus the cell can't accommodate more than 150 users. At the other hand, and when the D2D mode is enabled, the 50 cellular users will be shared by the 50 D2D pairs, thus 50 spaces will be available in the DL and other 50 in the UL, thus an additional 100 user can be admitted. The 50 of the 100 that uses the UL also will be shared by other 50 D2D pairs. This will lead to a total increment of 100% in the total cell capacity assuming fully loaded cell and 100 % access rate, but as shown earlier within Fig. 11, only arround 60% access rate can be obtained for fully loaded cells, thus the practical increase in capacity will be around 60%.

Finally, it worth mentioning that unlike other algorithms such as those proposed by (Huang, 2016; Lin et al., 2015; sun et al., 2016), the proposed algorithm was able to increase the total capacity of the network up to 60% while maintaining a high level of QoS (Quality of Service) .

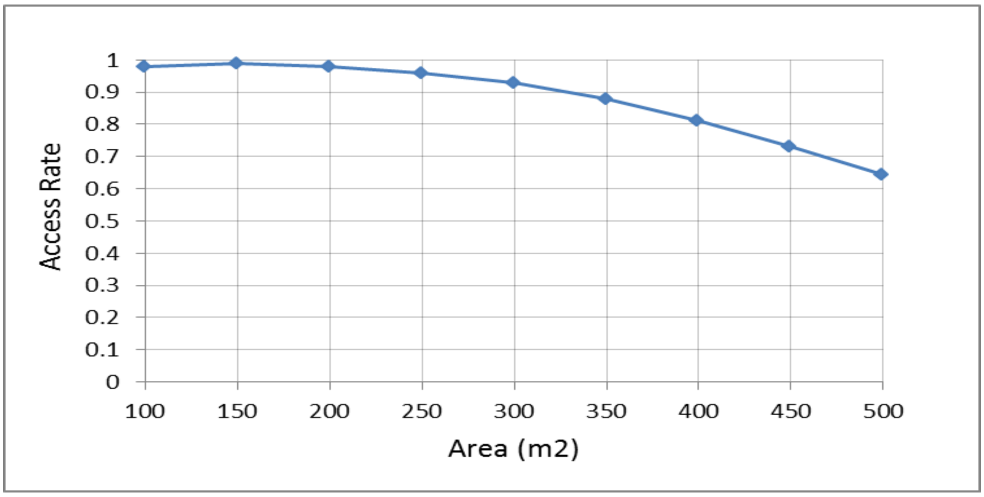


**Fig. 8. Relationship between the access rate and D2D distance.**

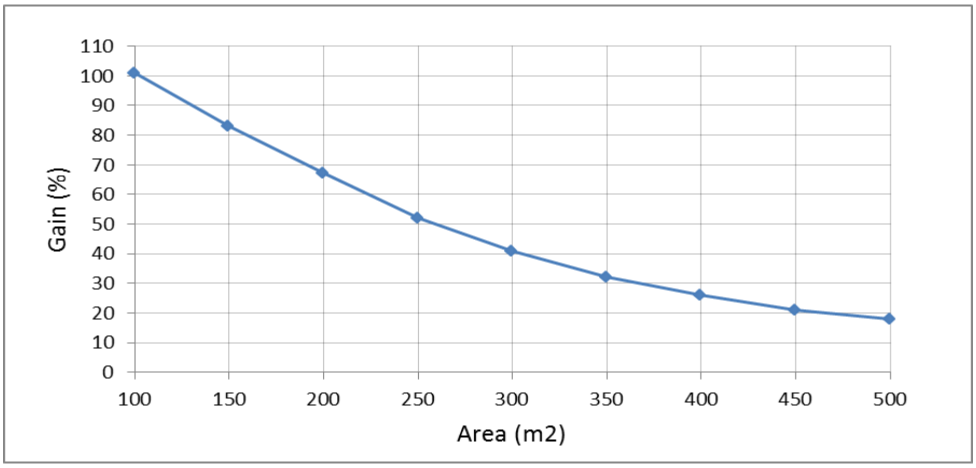


**Fig. 9. Relationship between throughput gain and D2D distance.**

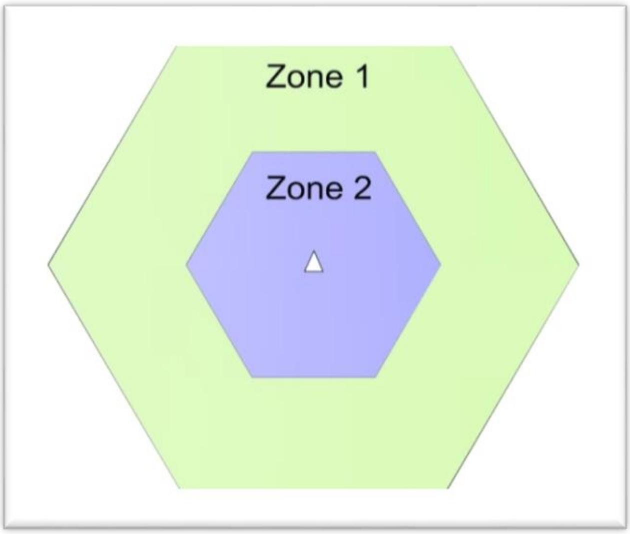


**Fig. 10. Illustration of zone 1 and zone 2.**

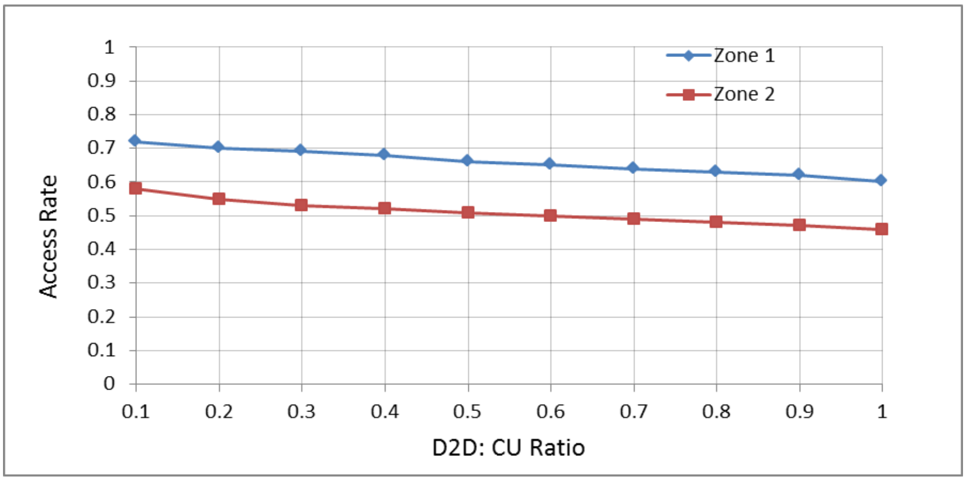


**Fig. 11. Access rate in different zones within the cell.**

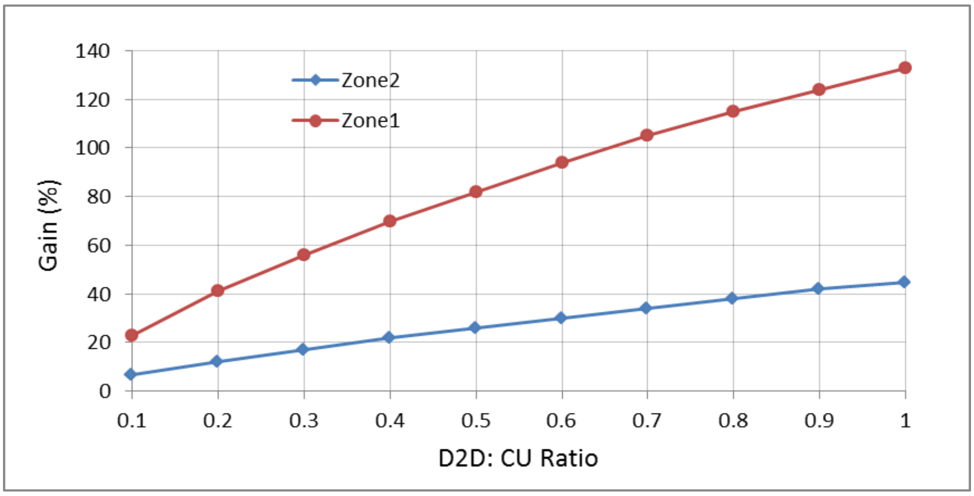


**Fig. 12. Throughput gain in different zones within the cell.**

## 6. CONCLUSIONS

As mentioned earlier, D2D communications suggests the separation of data planes from the control, and thus increasing the system's capacity and throughput gain, yet it introduces an extra interference which can be very damaging if not properly designed. In this work and in order to overcome that interference and maximize the potential increase in capacity, three novel interference aware algorithms were suggested and implemented using MATLAB software. The proposed algorithms were evaluated against three matrices: throughput gain, user capacity and access rate. According to the simulation results as the D2D pair get closer to each other the access rate increases and it can reach up to 98%, also higher access rate can be obtained when placing the D2D pair at the cell edges when compared to those adjacent to the BS as it can reach up to 60% to 70% depending on the D2D to CU ratio. Also the simulation shows that the throughput gain is directly effected by the distance between the D2D pair as it can reach up to 100% when placing the D2D at an area of 100 $m^2$ and decreases gradually when increasing the distance, while placing the D2D pair at the edge of the cell will result in higher throughput gain as it can reach up to 130% at D2D to CU ratio equals to 1. Also the simulation results proved that it is possible to add an extra 60% of the already existed users when using the D2D communication within the cell.

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