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# Energy Efficient D2D Application for Increasing Battery Usage of Smartphones

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***Abstract***

*The objective of this paper is to improvise a technique for battery optimization of smartphones. The technique is based on reduction in energy consumed by communication over network. This will be achieved by utilizing cooperative device-to-device communication. The proposed system will allow users with higher battery level to carry traffic of users with lower battery level, thereby reducing the chances of user running out of battery early. It can be implemented in form of a proximity service (ProSe) using the device-to-device (D2D) communication architecture underlying Long Term Evolution-Advance (LTE-A) technology in hexagonal cell environment. The paper also includes the goal to develop a technique for efficient positioning of user equipment and implementation of connection handover for this D2D communication ProSe. The technique for handover is based on Observed Time Difference Of Arrival (OTDOA) positioning approach along with the Positioning Reference Signal (PRS), mentioned in Release 9 of LTE technology. It is shown through simulations that the proposed system will reduce the probability of outage i.e. the probability of the UEs running out of battery power before their target usage time. The scheme will also reduce the probability of connection dropping, thereby improving performance of whole system.*

***Keywords**: Battery Deposit Service (BDS), Device-to-Device (D2D), Long Term Evolution-Advance (LTE-A), Cooperative Relaying, Positioning Reference Signal (PRS), Observed Time Difference of Arrival (OTDOA)*

## 1. Introduction

Many research efforts has been put forth for designing energy efficient protocols and networks for making the best use of the available battery capacity in smartphones. The factors that contribute in increasing power consumption in a smartphone are explained in detail in [1, 2]. It has been seen that the radio communications, along with the backlit screen, consumes most of the energy which is significantly higher than the other components such as a processor or memory. In this work, the issue of increasing smartphones' battery life by reducing power consumption in network communications has been addressed. There have been a variety of solutions proposed in all layers to rectify this problem. These solutions range right from the efficient designs for applications to heterogeneous or mixed cell deployment, from energy-aware scheduling to MIMO. All the attempts of previous works for increasing the battery life in the wireless network have considered either only one device, or have tried to minimize the total amount of power consumed in cooperative schemes. With context to the cellular networks (specifically LTE), rather than reduction, an entirely new approach is being proposed in this work. This approach is made effective by *redistributing* the existing energy in network to increase usage time of battery power.

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Also, until today there is no provision existing for providing handovers for D2D connection links. This is so because there was no such D2D application made which was not device specific, i.e. whatever applications of D2D technology have been discovered, requires communication only between two specific devices. E.g. transfer of data between two devices using D2D connection. So providing handover for such a connection, in case signal strength weakens, will be of no use. However, in a D2D application such as BDS, where specific devices are not required for taking the advantage of service, handover can be of great use and can improve the quality of service. Moreover, specifically for BDS, the power required in performing handover should be very less. So, to achieve this, a location updating algorithm is being proposed in this paper which is based on Observed Time Difference of Arrival of signal from various helper UEs. It is seen that by implementing this algorithm the connection dropping rate is greatly reduced. Also, by employing D2D, the connection blocking rate is also decreased. All this is achieved by no effective increase of power requirements by UE who is seeking help from BDS system.

The device-to-device cooperative relay underlying cellular networks is the physical mechanism used for “distributing” battery. D2D communications underlaying LTE networks are practices of creating the direct links between cellular users. It is being considered that D2D operates on licensed frequency spectrum as mentioned in 3GPP Release 12 work item [3]. A survey on D2D communications underlaying cellular networks is given in [4]. The most important property of D2D connection which is highly significant in this work is that it consumes much less power as compared to a cellular link. This is so because during uplink communication, the phone needs to cover a much smaller distance to reach a D2D neighbour than to reach a base station.

In this work, a user with low battery power requests for help from his neighbour UEs. A selected neighbour UE will act as a relay via a D2D link, which is established with the requester UE bearing the whole cost of the cellular link. Effectively, the neighbour seems to “lend” the battery to the requester to complete the transaction. The randomness of user usage pattern ensures that the helper will run out of battery power at some other time and can receive help. The proposed system will work better as the number of UEs increases. Thus it will draw benefit from the growing trend of smartphone usage.

This system can be implemented in form of a proximity service (ProSe) as described in [5]. Let it be known as the Battery Deposit Service (BDS). In this service, when some UE spends his valueless battery power to save another UE’s valued battery power, it can be considered as “depositing” battery in the network. The UE whose valued battery power is being conserved can be considered as “withdrawing” battery from the network. These concepts of depositing and withdrawing the battery, have been used to signify the fact that benefits of helper needs not be reciprocal or immediate. This means, a user who recieves help can repay, at a later time, to some other user than the one who helps him. In this way, BDS will benefit from a large population of users present in the network.

In this work the complete system is proposed to be implemented in the hexagonal cell environment. It is shown that the path loss incurred while communicating in a circular cell environment is much larger than that in hexagonal cell environment. As previously stated, the major component of loss of signal energy in the wireless channel is distance related path loss; a much lesser signal energy loss is seen with hexagonal cell implementation of system, thus minimizing the battery usage of cell phones and probability of outage. The event driven simulation is generated in MATLAB R2014a.

This rest of the paper is organized as follows. In section II, a summary of D2D communication underlaying cellular networks is given. The proposed scheme for smartphone battery optimization is discussed in section III. Section IV discusses parameters for performance evaluation of system. Section V gives details of obtained simulation results. The paper is finally concluded in section VI.

 

## 2. Device to Device Communication

Device relaying had made it possible for the devices within a network to operate as transmission relays for each other and function as a massive ad hoc mesh network. Since the users' data is routed through other user devices in such a two-tier cellular system, high security should be maintained for privacy. To ascertain a minimal impact on the performance of existing macrocell eNodeBs, the two-tier network needs to be developed with smart interference management ideas and appropriate resource allocation schemes. Furthermore, new pricing models should also be designed for tempting devices to readily participate in such a type of communication.

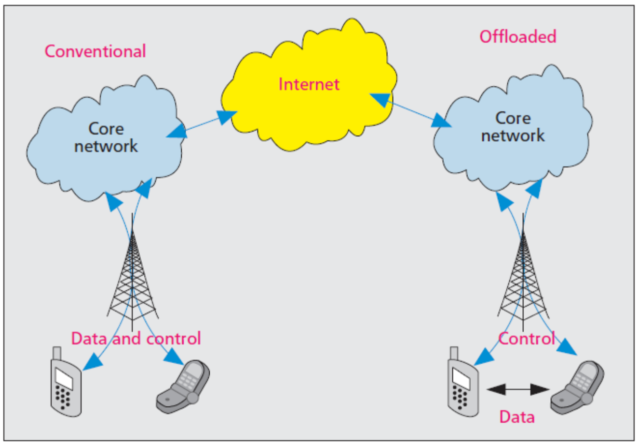


**Figure 1. A Conventional Cellular and D2D Network Scenario**

In the past, cellular operators did not consider D2D communication as a method to enhance the performance of cellular networks because the effect of D2D communication is limited to local communication services. However, as mobile applications based on proximity of mobile devices become increasingly popular, cellular operators are considering introducing D2D communication into cellular networks. When operators enable D2D mode in their cellular infrastructure, they are able to come across various gains in contrast to the typical infrastructure-based system; for example, raised system throughput of the whole network, enhanced energy efficiency, and reduced network traffic load, as shown in Figure 1. D2D communication can be divided into two parts: inband D2D communication and outband D2D communication.

1. **Inband D2D** — The communication under this category occurs on licensed spectrum (i.e., cellular spectrum is being used for both D2D links and cellular links).Inband D2D is further catogorized as *underlay* and *overlay D2D*. In underlay D2D communication, the radio resources used by both cellular and D2D communication are same whereas, in overlay communication D2D links are given dedicated cellular resources.
2. **Outband D2D** — D2D communication under this category uses unlicensed spectrum. The motivation for selecting outband D2D communication is the idea of eliminating interference issue caused between D2D and cellular links. However, only limitation with outband D2D is that cellular devices with atleast two wireless interfaces (*e.g.*, LTE and Wi-Fi) can use it, thereby having simultaneous D2D cellular communication.

The current work on LTE D2D device discovery and D2D communication mainly focuses on technical details including discovery signal design, resource allocation and scheduling, synchronization mechanisms, channel models, and D2D evaluation methodology. Complementing 3GPP, the IEEE 802.11 Infrastructure Service Discovery Study Group has done much work on proximate discovery and communication with low energy, long range (up to 500 m), and large scale (up to 1000 mobile devices) for mobile social networks since 2010. Simultaneously, efforts in IEEE 802.11s, 802.11ac, and 802.11ah may make D2D possible and attractive. The IEEE 802.15.8 Peer Aware Communication Task Group defined the physical and medium access control (PHY and MAC) layer specifications and optimizations for infrastructure less communications with fully distributed coordination in May 2012. Additionally, the D2D feature is also included in IEEE 802.16n.

The major gain of D2D communication is the inherent security it provides. The reason is that in D2D data are not conveyed via Internet clouds, and thus are not saved anywhere but on the intended devices.

## 3. System Model

In [5], the notions of valued battery and valueless battery have been introduced as the amount of the smartphone battery when the user is active without having any access to power source or the amount smartphone battery remaining after the usage period, when the user have access to some power source, respectively. A method of developing cooperation between users is followed which allows them to spend their valueless battery power to save somebody else's valued battery power, thereby decreasing their probability of outage. The device-to-device cooperative relay underlying cellular networks is the physical mechanism used for "distributing" battery. This scheme helps in increasing the quantity of valued battery power in the network, henceforth reducing the cases of UEs running out of battery early. This system is implemented in form of a proximity service (ProSe) as described in [5]. It is known as the Battery Deposit Service (BDS). These concepts of depositing and withdrawing the battery, have been used to explain the fact that the benefits of helpers need not to be reciprocal or immediate. This means that a user who receives help can repay, at a later time, to some other user than the one who helped him. In this way BDS will be beneficial to large number of users. Here, it is being proposed to implement the whole system in hexagonal cell environment. It is shown that the path loss incurred while communicating in a circular cell environment is much larger than that in hexagonal cell environment. As previously stated, the major component of loss of the signal energy in the wireless channel is due to distance related path loss; a much lesser signal energy loss is seen with hexagonal cell implementation of system, thus minimizing the battery usage of cell phones and probability of outage.

*A. Spreading of users in hexagonal cell*

Radius in circular cell is uniform but it changes with hexagonal implementation. So, instead of considering the radius of cell, length of side of hexagon (L) is being considered. Using this, the density (Y) of users when length of side (X) is equal to a particular value ($x_0$) is given by [7, 8]:

$$f_{Y|X=x_0}(y) = \begin{cases} U\left(-\sqrt{3}(x_0+L) : \sqrt{3}(x_0+L)\right); & -L \le x_0 < -\frac{L}{2} \\ U\left(\frac{-\sqrt{3}L}{2} : \frac{\sqrt{3}L}{2}\right); & \frac{-L}{2} \le x_0 \le \frac{L}{2} \\ U\left(-\sqrt{3}(L-x_0) : \sqrt{3}(L-x_0)\right); & \frac{L}{2} \le x_0 < L \end{cases} \quad (1)$$

 

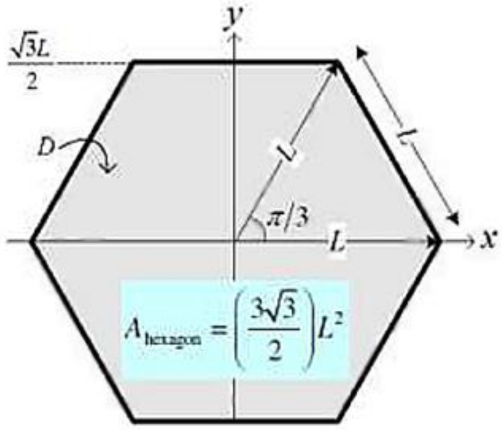

**Figure 2. Hexagonal Cell Statistics**

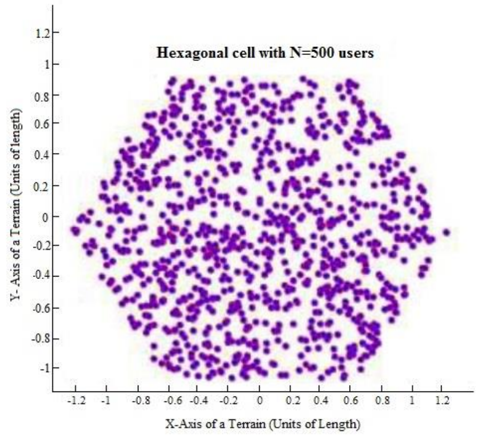


**Figure 3. Spreading users in Hexagonal Cell**

Where, $U(a,b) = 1/(b-a)$ is the uniform distribution over $x\epsilon(a,b)$. As a consequence of [13] and [14], proper stochastic node scattering becomes evident as manifested by Figure 4.

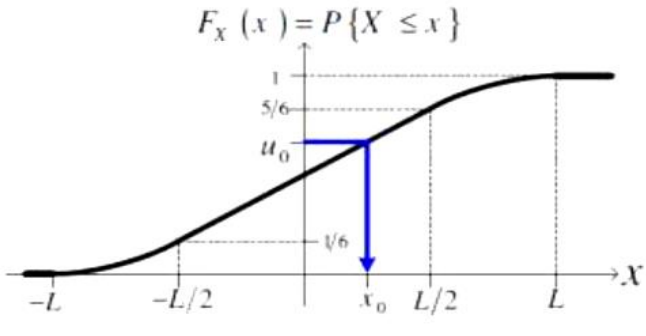

**Figure 4. CDF of "x" for a Hexagon**

*B. Algorithm for BDS*

In order to allow operator-controlled device and service discovery along with D2D connection set-up, the EPC must have additional functionalities for managing D2D services. One of these methods, to provide the enlisted functionalities, is suggested in [6], where two totally new entities are added in the system. They are the D2D Server and the Application Server (AppSer). The first entity (*i.e.*, D2D Server) is designed to handle and maintain D2D-enabled device identities, coordinate the establishment of the D2D connections and store the usage records for charging purpose. The AppSer is designed to perform application and service related tasks (because a single UE can use various D2D services simultaneously, with BDS being one of them). The operational flow of BDS is illustrated in Figure 5. When a UE's battery power level starts to go below a certain threshold value $\gamma_1$ or when it checks that the channel condition is running bad *i.e.*, the downlink RSRP is less than particular threshold and receiving help is beneficiary, it starts to look up for help. The process followed next will be as follows:

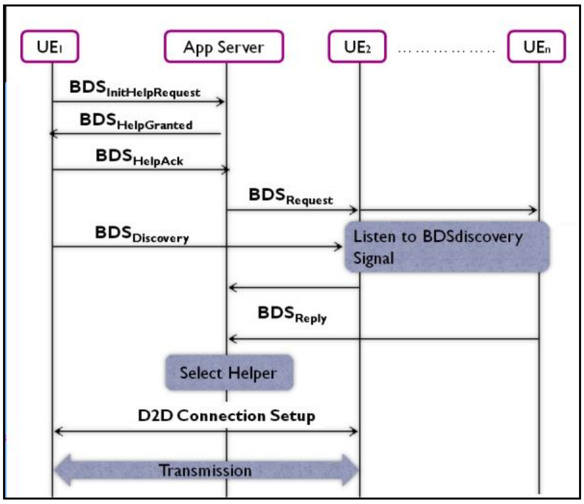


**Figure 5. Operational Flow of the Battery Deposit Service. Here, UE$_1$ is Helpee and UE$_2$ is the Serving Helper**

1. First, UE will send $\boldsymbol{BDS_{InitHelpRequest}}$to the Application Server. Lets name it as UE$_1$.

2. The Application Server will respond with $\boldsymbol{BDS_{HelpGranted}}$message and will allocate time-frequency resource to UE$_1$ for a neighbour discovery signal.

3. After the acknowledgment from UE$_1$ is received by Application Server (not shown in Figure 5), it will multicast a message $\boldsymbol{BDS_{Request}}$to all of the BDS-enabled UEs in cellsite. This message will include the resources for UE$_1$'s discovery signal, $\boldsymbol{BDS_{Discovery}}$.

4. Now, all the available helpers, whose battery power level is above a certain threshold $\gamma_2$, will listen to the resource unit. The helper who is able to detect UE$_1$'s discovery signal will report to the Application Server through a message, $\boldsymbol{BDS_{Reply}}$.

5. After getting a list of potential helpers for UE$_1$, the Application Server will run a helper selection algorithm to determine the appropriate helper for UE$_1$. In this system, there can be various flexible helper selection algorithm designs that can be used to achieve different goals.

6. At the end of this helper selection procedure, a UE is selected to help UE$_1$ (UE$_3$ in Figure 5). The Application Server sends information on this association to the D2D Server which will now implement the connection establishment procedure. In the terminology used in this work, UE$_1$ is reffered as the *helpee*, and UE$_3$ is reffered as the

*helper*. All through the complete duration of this service, data from $UE_1$ is relayed via $UE_3$ to the eNodeB.

### C. Helper Selection Criterion

Various selection algorithms can be included in the application server for helper selection. Application Server runs a helper selection algorithm to determine the helper for intended helpee, together with the duration of this association. To assist the selection algorithm, additional information about the potential helpers can be passed to the Application Server through BDSReply.

Some possible selection algorithms include:

- *Max-battery:*UE with the highest remaining battery in the potential helper list is selected. This algorithm minimizes the impact to the helper.
- *Proximity*: UE closest to UE1 is selected. Proximity can be derived from the received signal strength of the discovery signal. This algorithm minimizes the energy consumption of the requester.

To enforce fairness amongst all BDS participants, a virtual currency system can be set up where users pay for each help session. This algorithm can be used to manage user incentive.

### D. Observed Time Difference of Arrival (OTDOA) Positioning Technique

OTDOA is the time interval observed by UE between the arrivals of signal from two different sources. If signal from source 1 is received at instant $t_1$ and signal from source 2 is received at instant $t_2$ then OTDOA = $(t_1- t_2)$ .The OTDOA scheme utilizes the Positioning Reference Signal (PRS) which provides measurement of time taken by signal to reach from source to destination. PRS has been included in LTE signaling scheme for providing timing reference [9].

PRS parameters:

$N_{PRS}$ : No. of sub-frames containing PRS information
$I_{PRS}$ : Parameter used to calculate values of $T_{PRS}$ & $D_{PRS}$
$T_{PRS}$ : Periodicity of PRS sub-frames
$D_{PRS}$ : Offset of 1st PRS sub-frame from sub-frame no. 0

**Table 1. Parameters for PRS**

| PRS configuration Index $I_{PRS}$ | PRS periodicity $T_{PRS}$ (subframes) | PRS subframe offset $\Delta_{PRS}$ (subframes) |
|---|---|---|
| 0 – 159 | 160 | $I_{PRS}$ |
| 160 – 479 | 320 | $I_{PRS}-160$ |
| 480 – 1119 | 640 | $I_{PRS}-480$ |
| 1120 – 2399 | 1280 | $I_{PRS}-1120$ |
| 2400-4095 | Reserved | |

*1). Generate Transmitter & Receiver Configuration:*As in [10] and [11],for getting a transmission scenario, a set of helper configuration is generated with the number of helpers taken as N. For simplicity, here N is taken as 4. The configurations are derived from Reference Measurement Channel (RMC) R.5 which describes a 3 MHz bandwidth Downlink Shared Channel transmission using 16-QAM modulation. Each helper is allotted a unique D2D user id and values for $N_{PRS}$, $I_{PRS}$ are set. Each helper is randomly spaced around the helpee UE. The positions of the helpers and the UE are plotted for convenience. The reference UE lies at (0,0) and the helpers are distributed evenly around the UE within D2D connection range i.e. 100m span. This plot is shown in Figure 6. For each helper, a signal is transmitted, by reference UE, consisting solely the PRS. This is done by creating an empty resource grid and then generating and mapping PRS onto the grid. The resultant grid is now OFDM modulated to generate a waveform for transmission as shown in Figure 7.

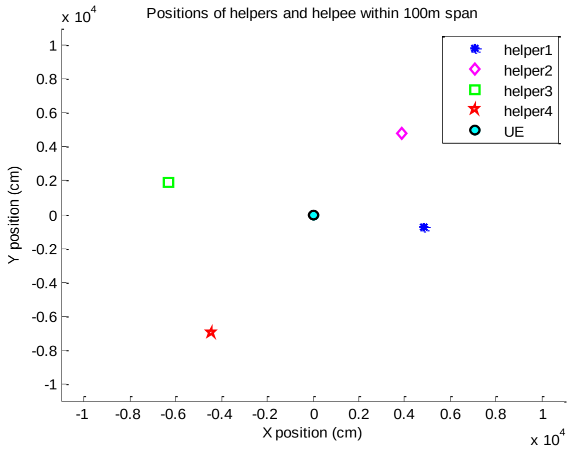


**Figure 6. Positions of the helpers and the helpee UEs**

The OFDM signals to be transmitted from UE are given by:

$$x(k) = \sum_{k=0}^{N-1} X(k)W^{-nk}, \qquad n = 0,1, \ldots\ldots, N-1 \tag{2}$$

and the analog form of these signals are:

$$x(t) = \sum_{k=0}^{N-1} X(k)e^{j2\pi fkt} \tag{3}$$

where $f$ is the fundamental frequency and the time width of one OFDM symbol $T$=1/$f$.

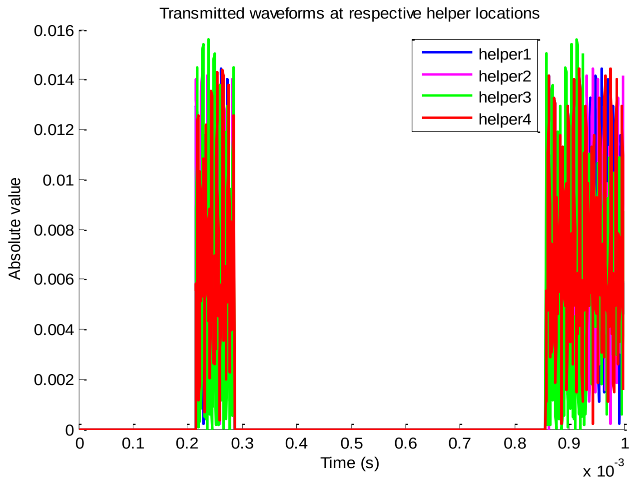


**Figure 7. Transmitted Waveforms at Respective Helper Location**

The signal $x(t)$ are transmitted through the wireless channel and the channel impulse response is

$$h(t) = \partial(t - t_k) \tag{4}$$

where $t_k$is transmission time from the anchor node kto the destination node.

 

The received signal $y(t)$ through the channel is expressed as:

$$y(t) = x(t - t_k) \tag{5}$$

These received waveforms are plotted in Figure 8. The arrival time of incoming signals from each helper are established at the UE by just correlating the incoming signal with a localy generated PRS with the D2D user identity of each helper. The peak correlation value of signal from each helper is used as delay estimate to permit comparison. A plot of received signal correlations is shown in Figure 9.

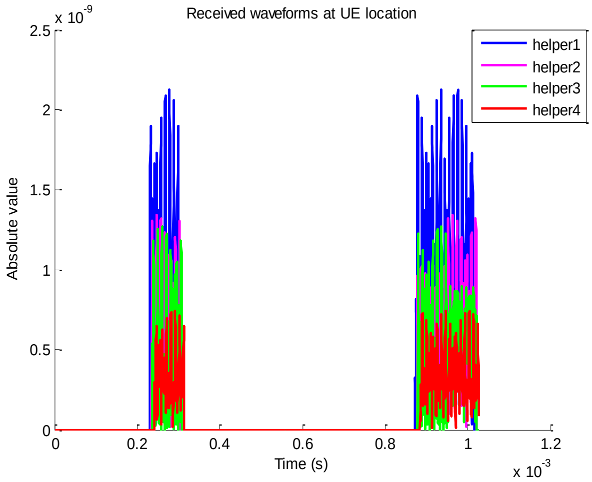


**Figure 8. Received Waveforms at UE Location**

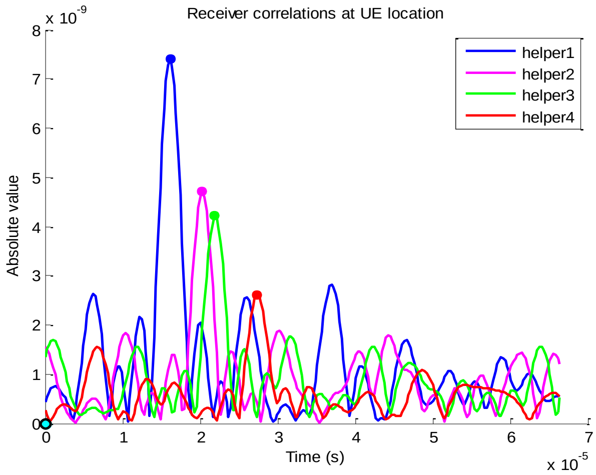


**Figure 9. Signal Correlations at UE Location**

*2). Compute TDOA and plot constant TDOA hyperbolas:* With the help of arrival times, time differences of arrival instances between each pair of helpers are calculated. A particular value for TDOA between a pair of helpers can be obtained as a result from UE being positioned at any random location where two circles, each centered on a helper, intersect each other. The two circles will have radii which differ by the distance covered at speed of light in specified time difference. The complete set of possible UE positions across all the possible radii for one circle (with the other circles maintaining a radius appropriate to time difference as already described) forms a hyperbola. The "hyperbolas of constant delay difference" for each pairs of helpers are then plotted relative to the known helper positions and their intersection gives the position of UE. Figure 10 shows the positions of helpers and helpee (UE) and the corresponding hyperbolas of constant delay difference.

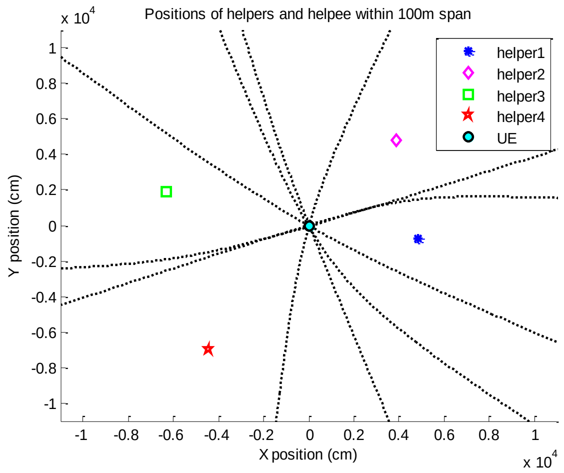


**Figure 10. Positions of Helpers and Helpee UEs and the Corresponding Hyperbolas of Constant Delay Difference**

*3). Connection Handover:* A handover of D2D connection will be required if any of the following situations persists.

a) Signal reception from helper UE to helpee UE is not proper or is weak.
b) Helper UE battery is going below the “helping threshold” which is the threshold battery level of helper UE above which it can serve as a helper.
c) Helper UE is moving out of D2D connection ranges i.e. 100m span radius.

In conditions (a) & (b), handover will automatically be requested by helpee UE. However, in condition (c), eNodeB can automatically detect that a handover is needed if it follows location update algorithm for both helper and helpee UE as discussed previously.

### *E. Security Implications*

Since BDS is implemented as a proximity service, it guarantees all the security that will be offered by proximity service design. Moreover, D2D communication network is inherently secure. The main reason behind this is in D2D data is not conveyed using internet cloud. Hence, the data will not be saved anywhere but on the intended device. In addition to this, encryption in LTE is performed at $UE_1$ and the eNodeB and therefore $UE_3$ detects only the encrypted traffic. Hence, confidentiality of $UE_1$ is protected. With encryption it is also ensured that the $UE_3$ cannot insert its own data into $UE_1$’s data stream. Thus data integrity is also protected. Furthermore, a temporary ID is used for $UE_1$ instead of its real identity; therefore $UE_3$ cannot learn whose traffic it is carrying. So, $UE_1$’s privacy is completely protected. The BDS also does not incurs more security risks than what already can be obtained by an eavesdropper.

### *F. Models for generating simulation environment*

The various models adapted for generation of desired simulation environment are as follows:

*1) Traffic model*: The simulation model uses Poisson traffic models in traffic scenario analysis. It has been seen that Poisson processes are widely used in traffic modeling because of their capability of effectively capturing the aggregate traffic caused due to extensive number of sources. Using this approach, the uplink data is allowed to arrive in bursts, with inter-arrival time being 30 seconds. The size of each data burst is modeled as a geometric random variable.

2) *Channel model:* In this work, the WINNER II urban macro-cell model and WINNER II indoor model has been used for designing regular uplink connections and D2D connections respectively [15] and [16]. Shadowing is also modeled by utilizing lognormal distributions with parameters as specified in WINNER II documentation.

3) *Mobility:* In this work, a modification of the RandomWaypoint Model has been used to simulate user mobility. The problem with Random Waypoint Model is that, it focuses more over the center of the cell than the edge. It is hence modified to generate a uniform distribution of user location and is named as the Random Duration Model. In this model, a user selects a random direction and a random travel duration, along with a random speed, as a uniform random variable at every step of simulation, instead of selecting a new destination or waypoint. A random pause time is also implemented after every travel period considering the fact that people are not always in state of motion in real life.

## 4. Performance Evaluation Framework

The performance of the proposed system is evaluated on the basis of following parameters:

### *A. Power consumption*

In LTE, a UE's uplink transmit power is controlled by Eq (11). The formula is based on path loss between the UE and either the relay or eNodeB ([17, 18])

Transmit Power ($Pt_o$ in dB) = - K - PG + E + L'- G - H + C + PathLoss (dB) (6) where, the various parameters are as enlisted in Table I. The path loss can be calculated by using channel model. In addition to this, after transfer of every data burst, the eNodeB allows UE to stay in RRC CONNECTED state for some more time. In this state, the UE consumes appreciable amount of energy than that in RRC IDLE state. The duration during which the UE stays in the RRC CONNECTED state is decided by the eNodeB. After modeling this factor as well as the other circuitry-related energy consumption, it is added to all transmissions as a constant component (both D2D and regular uplink).

### *B. Usage time*

Here the usage time of a UE is the time duration from the start of the simulation to the instant when the UE runs out of battery power. It can be estimated as below:

$$U = \sigma_t * \sqrt{2\pi} * \left\{ e^{-\frac{\mu_t^2}{2\sigma_t^2}} - e^{-\frac{(t-\mu_t)^2}{2\sigma_t^2}} + \left[ t - \frac{t-\mu_t}{F\left(\frac{t-\mu_t}{\sigma_t}\right)} \right] \right\} \quad (7)$$

where,

$F(x)$ = Gaussian CDF of x

$\sigma_t$ = variance of total time involved in BDS

$\mu_t$ = mean total time involved in BDS

### C. *Probability of outage*

It is defined as the probability of the cellular users running out of their battery power before the target usage time. It is given by :

$$P_{outage} = 1 - F\left(\frac{t-\mu_t}{\sigma_t}\right) \quad (8)$$

where, F(x) = Gaussian CDF of x

### D. *Connection Dropping Probability (CDP)*

It is measured as in [12]:

$$CDP = \frac{(v_d t)^n}{n!} e^{-v_d t}, n \geq 0 \quad (9)$$

where, ϑd = Connection Drop rate
t = Duration of connection
n = confirmed connection drops

$$\vartheta \mathrm{d} = \frac{NRLF}{NAC} \quad (10)$$

where, NRLF = Number of Radio Link Failures, and
NAC = Number of Accepted Connections into the cell.
NAC includes the new connections which were initiated from within the cell, and the connections which were handed to it before.

### E. *Connection Blocking Probability (CBP)*

Offered load on $h^{th}$ D2D link is given by:

$$\rho_h = \frac{\lambda_h^D}{\mu} \quad (11)$$

Offered load on $h^{th}$ cellular link is given by:

$$\delta_h = \frac{\lambda_h^C}{\mu} \quad (12)$$

Probability of blocking in case of D2D implementation is then given by:

$$P_{D2D} = \sum \frac{\prod_{h=1}^{N_D} \rho_h + \prod_{h=1}^{N_C} \delta_h}{\prod_{h=1}^{N} U_h} \quad (13)$$

Probability of blocking in case of static (non-D2D) implementation is then given by:

$$P_{Static} = \sum \frac{\prod_{h=1}^{N_C} \delta_h}{\prod_{h=1}^{N} U_h} \quad (14)$$

where, $\lambda^D$ = Arrival Rate for D2D connections
$\lambda^C$ = Arrival Rate for cellular connections
$1/\mu$ = mean holding time of each connection

### F. *Simulation Parameters*

The simulation parameters are summarized in Table II.

## 5. Simulation Results

The proposed model has been implemented as an event-driven simulation in MATLAB environment. A summary of the parameters used is given in Table I. The value of constant energy cost factor is evaluated using the report of power consumption during the RRC CONNECTED state of UEs. It is considered that the UEs are moving with an average speed of 3 kmph. The discontinuous reception period (DRX) is taken to be 160 ms and the release timer is set to 5 seconds [19].

 

**Table II. Parameters for Simulation of BDS**

| Parameters | Values |
|---|---|
| Cell Radius | 500 m |
| No. of Ues | 500 |
| Speed of Ues | 0.1 – 3 m/s |
| Pause duration | 0 – 300 s |
| Walk duration | 30 – 300 s |
| Path loss compensation factor ($\alpha$) | 0.8 |
| Communication battery budget | 300 J |
| Base power ($P_o$) | -69 dBm |
| Maximum transmit power ($T$) | 24 dBm |
| Modulation order | QAM 16 |
| Carrier frequency | 2 GHz |
| eNode B antenna height | 25 m |
| UE antenna height | 1.5 m |
| Cooperation threshold $\gamma_1,\gamma_2$ | 0.3, 0.3 |
| Cooperation path loss threshold | 110 dB |
| SNR ($E_b/N_o$) ($E$) | 3.3 dB |
| Noise Margin ($K$) | 3 dB |
| Processing Gain ($PG$) | 27.95 dB |
| Handoff gain ($H$) | 5 dB |
| Log Normal fade margin ($L'$) | 11.3 dB |
| Cell Antenna gain ($G$) | 10 dB |
| Cable Loss ($C$) | 2 dB |
| No. of PRS sub frames ($N_{PRS}$) | 2 |
| PRS Index ($I_{PRS}$) | 0 |
| System Bandwidth (MHz) | 10 |
| Subcarrier bandwidth (W) (KHz) | 15,30 |
| Number of Subcarriers available at eNodeB ($K_{BS}$) | 480 (when W = 15 KHz) 240 (when W = 30 KHz) |
| Mean Arrival Rate (λ) (calls/unit time) | 1 to 80 |
| Fraction of calls arriving at BS (f) | 0.5 |

The values of rest of the parameters are also selected so as to simulate a realistic scenario for simulation. The helper selection algorithm is dependent on proximity of helper as well as the battery level of helper (the helper which is closest and is having an optimum level of battery is selected). In addition to $\gamma_1$ and $\gamma_2$, another important factor which influences the degree of cooperation in the network is the strength of $BDS_{Discovery}$ signal. It denotes the size of the neighborhood in which a user can seek help. The simulation is initialized with UEs located at uniformly random locations within a hexagonal cell and having a random battery level.

The results of performing BDS simulation in hexagonal environment are shown in Figure 11(a) (b) & (c). Figure 11(a) shows that a much lesser transmission power is required when the system is implemented with hexagonal cell geometry. This certainly affects the battery usage time of smartphone as shown in Figure 11(b). Hexagonal cell implementation provides greater battery usage time than circular cell implementation during cooperative usage. Figure 11(c) shows the increase in probability of survival of UE battery with cooperative usage in case of both hexagonal and circular cell implementation.

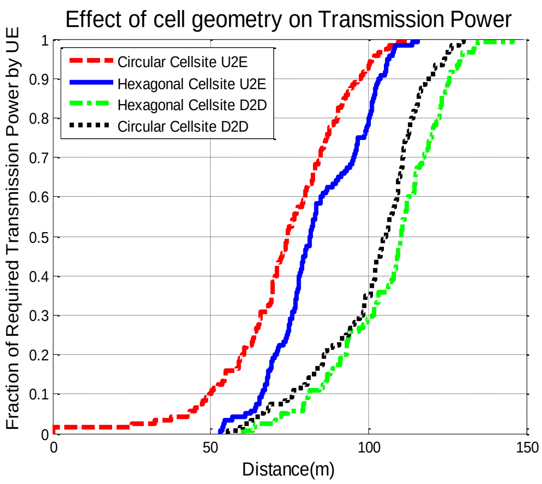


**Figure 11. a) Plot of Required Transmission Power by UE for Communication**

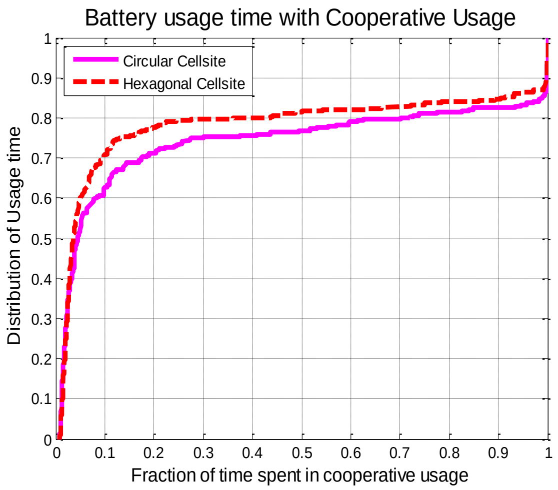


**Figure 11. b) Plot of Battery Usage Time of UE**

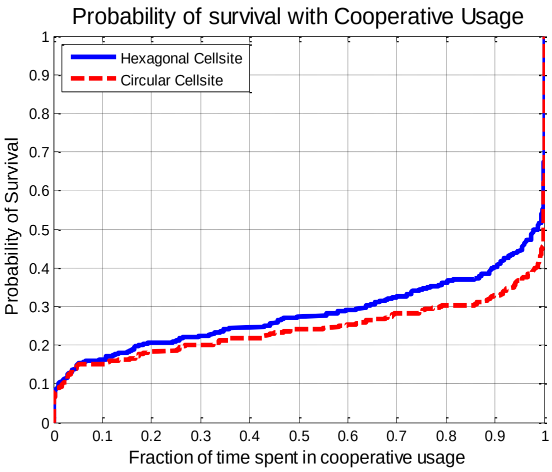


**Figure 11. c) Plot of Probability of Survival with Cooperative Usage**

Also, the OTDOA simulation results show that the connection dropping probability of D2D connections will be considerably reduced by introducing the proposed handoff scheme. This is shown in Figure 12. Moreover, the blocking probability would be reduced due to use of D2D connection scheme. This is shown in Figure 13.

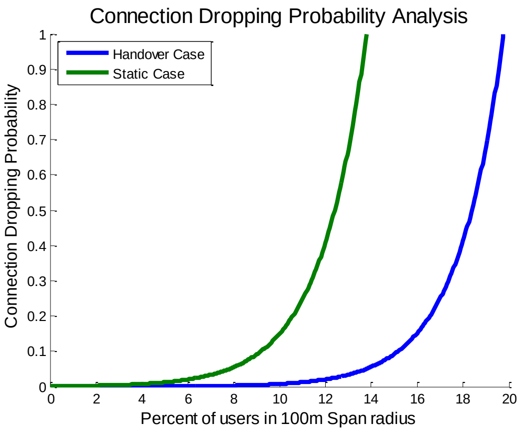


**Figure 12. Connection Dropping Probability Analysis with and without Handover Implementation**

## 6. Conclusion

In this paper, a cooperative system, the Battery Deposit Service, has been simulated as a new solution to prolong smartphone' battery life, in hexagonal cell environment. The notions of *valueless* and *valued battery* have been used to denote the available battery on a user's phone with and without access to a power source, respectively. This system allows users to expend their valueless battery to help conserve valued battery for others. Users who receive help (*helpees*) utilize low-cost D2D links to tunnel their traffic to the neighbouring helpers. The helpers relay those data over the more expensive cellular links. In effect, the helpers carry the burden of communication energy cost for the helpees. Variation in usage ensures that a user will play both roles of helper and helpee at some different times. It is described that how the system can be designed in form of a 3GPP proximity service. It is confirmed that BDS reduces the probability of users not meeting their usage expectation (*probability of outage*) through a realistic simulation in hexagonal cell environment. Also, the paper simulates a positioning algorithm for finding the position of a transmitter, given TDOA measurements computed from the received signal for at least three receivers. A simulation study illustrated the TDOA problem in general and the performance of the suggested algorithm. Based on this positioning algorithm, a D2D connection handover scheme is also discussed in the paper which will help in decreasing both the D2D connection dropping and blocking probability considerably as shown in Figures 12 and 13. The results obtained can be used as a reference model for evaluating and optimizing an operating BDS network.

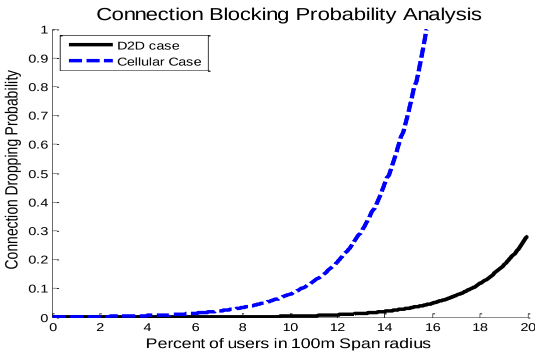


**Figure 13. Connection Blocking Probability Analysis with and without D2D Implementation**

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