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Smartphone Battery Optimization by Reducing Energy Consumption in Network Communications

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Abstract- In this paper, a technique for battery optimization of smartphone is being proposed. 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. This system can be realized in the form of a proximity service (ProSe) which will utilize device-to-device (D2D) communication architecture underlaying Long Term Evolution (LTE) technology in hexagonal cell environment. It is shown through simulations that the proposed system will reduce the probability of outage i.e. the probability of cellular users running out of battery before their target usage time.

Keywords**:** Cooperative Relaying, Battery Optimization, Valued and Valueless battery, Long Term Evolution, D2D communication,

I. INTRODUCTION

Smartphones have emerged into platforms with powerful computational capabilities that generate large amount of data. Smartphones have become an important part of our daily life and we use smartphones more frequently than we used desktop computers to stay connected on internet, reading news, playing games, browsing, watching video and staying connected with friends through social networking websites. On the other hand the smartphones have a strict energy budget and limited lifetime on a single charge. As the battery technology could not keep pace with smartphone technology, a short battery life has always been a major limiting factor for the utility of smartphones. Many research efforts has been put into designing energy efficient protocols and networks to make best use of the available battery capacity over the past few years. Various factors contributing to power consumption in a smartphone are broken down and studied in detail [1], [2]. It is shown that most of the energy of smartphone is consumed in radio communications, together with the backlit screen. This amount is significantly higher than other components such as processor and memory. Although solutions to this problem of prolonging battery life in wireless networks have already been proposed in all layers, but have either considered a single device, or tried to minimize the total power consumption in cooperative schemes. In the context to the cellular networks (LTE in particular), rather than reduction, an entirely new approach is proposed in this paper. The whole idea is based on *redistributing* the existing energy to increase usage time of smartphone battery.

Firstly, the notions of *valued battery lifetime, valueless battery lifetime* and *outage events* are explained. *Valued* battery lifetime is defined as the lifetime of battery of the smartphone when the user is active and does not have access to a power source. Conversely, *valueless* battery lifetime is defined as the remaining battery lifetime of the smartphone after the usage period, when the user gets access to a power source. *Outage events* are instances when the user runs out of (valued) battery before his target usage time.Since the usage patterns of the users varies, the value of their batteries also varies. The proposed system takes advantage of the wide range of battery value created by this diversity of usage. By enabling cooperation, the users are allowed to spend their valueless battery to save someone else’s valued battery, reducing the probability of their outage events and increasing the probability of survival of user’s battery as a result. Cooperative communications represent a new class of wireless communication techniques in which network nodes help each other in relaying information to realize spatial diversity advantages. This new transmission paradigm promises significant performance gains in terms of link reliability, spectral efficiency, system capacity, and transmission range. Cooperative communication has been extensively studied in the literature, and *fixed terminal relaying* (which involves the deployment of low-power base stations to assist the communication between the source and the destination) has already been included in the 4G Long Term Evolution-Advance (LTE-A) standard. The mechanism being used in proposed system for “distributing” battery, is device-to-device cooperative relay underlaying LTE-A networks. This mechanism will help to create direct links between cellular users. A licensed spectrum for D2D operation is proposed in 3GPP release 12 work item [3]. This will benefit in controlling of D2D operation. As a result, the bandwidth and QoS of the communications can be guaranteed. This can also increase system security by making D2D operation transparent to the users. So, as both D2D devices already have a secure connection to the cellular network, a secure D2D connection can be set up automatically (as compared to manual pairing in Wifi and bluetooth). A survey of D2D communications underlaying cellular networks can be found in [4]. One main property of a D2D connection which is of utmost importance for the proposed system is that it consumes significantly less power than a cellular link. This is because on the uplink, the phone needs to cover a much shorter distance to reach a D2D neighbour than to reach a base station. The main component of the signal energy loss over the wireless channel is the distance related path loss. Hence a much lesser signal energy loss is seen with this technology which will in turn minimize the requirement of battery power.

This rest of the paper is organized as follows. In section II, we give a summary of D2D communication underlaying cellular networks, outlining its merits, challenges, and progress in standards. The proposed scheme for smartphone battery optimization is discussed in section III. Section IV gives details of obtained simulation results. The paper is finally concluded in section V.

II. DEVICE TO DEVICE COMMUNICATIONS UNDERLAYING CELLULAR NETWORKS

D2D communications underlaying a cellular network is a promising future wireless networks technology for improving network capacity and the user experience. It has been agreed in 3GPP Release 12, that D2D technology is of high interest for enhancing the capabilities of wireless networks. Previously, D2D communication has been widely used in consumer Bluetooth and the WiFi unlicensed band for individual pairing and connectivity. The connection is activated only when needed through user manual pairing, and there is little concern about privacy, security, and power. In addition, since the density of these individual D2D applications is relatively low, interference is usually not a major issue in these cases. In this article, we envision a *two-tier cellular network* with so-called macrocell and device tiers. The *macrocell tier* involves base station (BS)-to-device communications as in a conventional cellular system. The *device tier* involves D2D communications. If a device connects the cellular network through a BS, this device is said to be operating in the macrocell tier. If a device connects directly to another device or realizes its transmission through the assistance of other devices, these devices are said to be in the device tier. In such a system, the BSs will continue to serve the devices as usual. However, for implementation of battery optimization technique or for any other specific application, devices will be allowed to communicate with each other, creating an adhoc mesh network.When we develop D2D communications underlaying licensed cellular networks, better service guarantee can be provided in a controlled environment. By facilitating the physical proximity of communicating UEs and reuse of spectrum resources, D2D communications has the advantages of high local data rate, offloading the traffic load from the central base station, and increasing cellular capacity. In addition, as D2D communications is short-range transmission, the UE power consumption can be set very low; hence, the battery lifetime of UEs with D2D communications can be extended. In the meantime, these devices for D2D communications need to discover each other constantly and determine service compatibility before communicating with each other. The introduction of D2D communications underlaying cellular networks represents a significant step toward future 5G heterogeneous networks. We are still at an early stage in D2D technology development. There are many challenges to be addressed, including device power consumption for D2D user/device/service discovery, interference management and power control among D2D devices and coexistence with overlay networks, radio link design to compensate for the link budget reduction due to no base station, cluster-level vs. global-scale synchronization, device/user identifiers, open vs. Restricted device discovery, security and privacy protection, user mobility and cluster group management, group communication for public safety, multihop D2D and D2D in heterogeneous networks, seamless service or session transfer with overlay network, and network densification in terms of both number of D2D devices and data communication intensity.

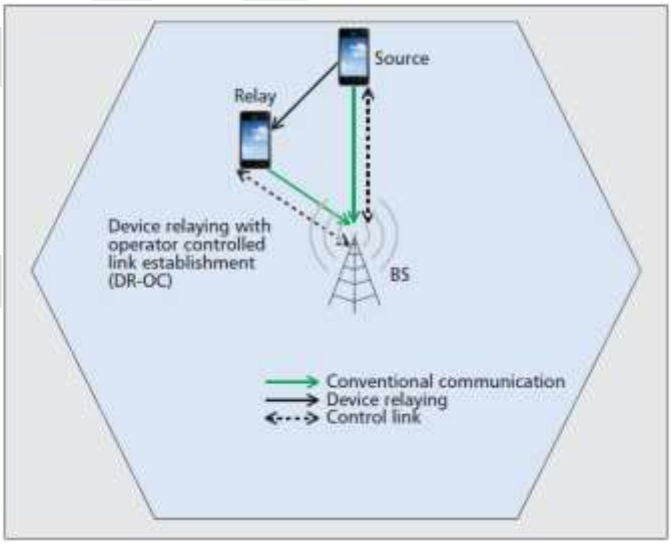


Fig 1. Device relaying with operator controlled link establishment

A simple scenario with Device relaying with operator controlled link establishment (DR-OC) is shown in Fig.1. A device at the edge of a cell or in a poor coverage area can communicate with the BS through relaying its information via other devices. This allows for the device to achieve a higher QoS or more battery life. The operator communicates with the relaying devices for partial or full control link establishment. The advantage of a D2D link compared to a cellular link is that it covers a much shorter distance. The main component of the signal energy loss over the wireless channel is the distance related path loss. Using the nominal values in Table I, we calculate the path loss of the D2D link versus the cellular link according to both UMTS channel model and IST WINNER II channel model [12]. In addition, the eNodeB receiver has better gain (14 dBi) and lower noise figure (5 dB) compared to the UE receiver (0 dBi, 9 dB) [10]. Table II shows that under similar fading conditions and ignoring shadowing, to get the same SNR at the receiver, the cellular UE needs to spend 3 to 4 orders of magnitude more transmission power than the D2D transmitter.

TABLE I
NOMINAL VALUES FOR PATH-LOSS MODEL

Parameter	Value
UE-macro eNodeB distance	300m
D2D UEs distance	10m
Carrier Frequency	2GHz

TABLE II
. PATH-LOSS RESULTS (IN dB)

Channel Model	Cellular	D2D	PL Diff.	TX Power Diff.
UMTS	127	67	60	42
WINNER II	122	73	49	31

III. SYSTEM MODEL

In [8], the notions of valueless and valued battery are introduced as the available battery when the user does or does not have access to a power source, respectively. A method of developing a cooperative system is followed where users with high battery level help carry the traffic of users with low battery level. This scheme helps increase the amount of valued battery in the network, henceforth reducing the chance of users running out of battery early. The whole system is realized in the form of a proximity service (ProSe) which utilizes a device-to-device (D2D) communication architecture under laying LTE-A in a circular cell environment. The proximity service here is named as Battery Deposit Service (BDS). The name is derived from the fact that when a user spends his valueless battery to save another user's valued battery, it can be thought of as "depositing" battery into the network. The user whose valued battery is conserved can be thought of as "withdrawing" battery from the network. The concepts of depositing and withdrawing are used to signify the fact that the benefit of a helper needs not be immediate or reciprocal. In other words, a user receiving help can repay, at a later time, a different user than the one who helps him. This way BDS benefits from the large population of users in the network.

We have 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 main component of the signal energy loss over the wireless channel is the 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

An algorithm for calculating the position of a random user in hexagonal cell is discussed in [9] by spreading users uniformly over the complete cell area. Consider the hexagon shape of Fig.2. Within this coverage area, for the sake of simplicity and perhaps from an intuitive perspective, we may very well assume that mobiles are equally spread. Because of this hypothesis, the joint PDF becomes:

$$f_{XY}(x.y)=\frac{1}{A_{\text{hexagon}}}=\frac{2}{3\sqrt{3}L^2} \quad (x.y)\in D \tag{1}$$

In fact, if it was not for a generic structure and a priori statistical knowledge of users' trends and terrain limitations were available, then the information may have been used to ensure a more complete model. Nonetheless, using [16], we can obtain the marginal distribution for the *X*-component in [17].

$$f_X(x)=\begin{cases}\dfrac{2}{3L} & |x|\le\dfrac{L}{2}\\[2mm] \dfrac{4}{3L^2}\left(L-|x|\right) & \dfrac{L}{2}\le|x|<L\end{cases} \tag{2}$$

From [17], we then determine the Cumulative Distribution Function (CDF) as plotted in Fig. 3

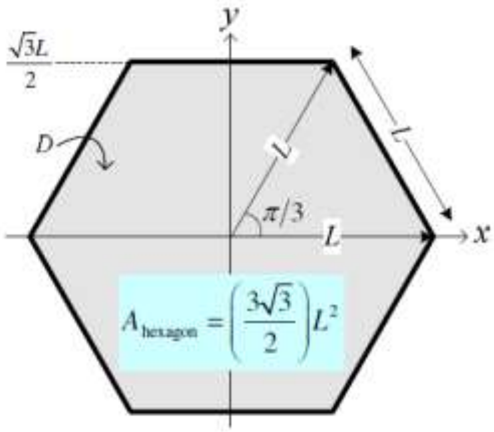


Fig 2. Hexagonal cell

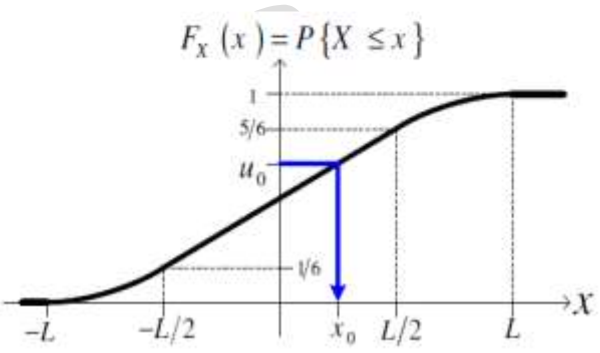


Fig 3. CDF of “x” for a hexagon

Following this further, in regard to random generation, high-level computer languages such as MATLAB®, among others, have the capacity to produce a fairly long pseudorandom sequence of length 2^{1492} from the standard uniform distribution [10].

For any other PDF, provided the corresponding inverse CDF is available in close form, then the *Inverse Transform* method may be used [11]. Hence, we get:

$$x=F_X^{-1}(u)=\begin{cases}L\left\{\sqrt{\dfrac{3u}{2}}-1\right\} & 0<u\le\dfrac{1}{6}\\[2mm] \dfrac{3L}{4}(2u-1) & \dfrac{1}{6}\le u\le\dfrac{5}{6}\\[2mm] L\left\{1-\sqrt{\dfrac{3(1-u)}{2}}\right\} & \dfrac{5}{6}\le u<1\end{cases} \tag{3}$$

Further, given the obvious correlation between random variables of X and Y, and while assuming first the selection of the X-value, then the conditional density for Y becomes:

$$f_{Y|X=x_0}(y)=\begin{cases}U\left(-\sqrt{3}(x_0+L):\sqrt{3}(x_0+L)\right) & -L<x_0\le\dfrac{-L}{2}\\[2mm] U\left(\dfrac{-\sqrt{3}L}{2}:\dfrac{\sqrt{3}L}{2}\right) & \dfrac{-L}{2}\le x_0\le\dfrac{L}{2}\\[2mm] U\left(-\sqrt{3}(L-x_0):\sqrt{3}(L-x_0)\right) & \dfrac{L}{2}\le x_0<L\end{cases} \tag{4}$$

Where $U(a,b)=1/(b-a)$ is the uniform distribution over $x\epsilon(a,b)$. As a consequence of [18] and [19], proper stochastic node scattering becomes evident as manifested by Fig.4.

B. Simulation Model

In order to enable operator-controlled device and service discovery as well as D2D connection set up, the Evolved Packet Core (EPC) must include additional functionalities to manage D2D services. One method to provide those functionalities is suggested in [10], where two new entities are added: D2D Server and Application Server (AppSer). The D2D Server is responsible for maintaining

D2D-enabled devices' identity, coordinating the establishment of D2D connections, as well as storing usage records for charging purpose. The AppSer performs application/service-specific tasks (because one UE can use multiple D2D services at the same time, with BDS being one of those services). As ProSe is an active working item within 3GPP and there is no standard on how a service should be defined yet, the operational flow of BDS is described instead of the exact signaling formats. This operational flow is illustrated in Fig.5. When a UE's battery level goes below a threshold γ_1 or when it verifies that its channel condition is bad (downlink Reference Signal Received Power is less than a threshold), and receiving help is beneficial, it starts looking for help.

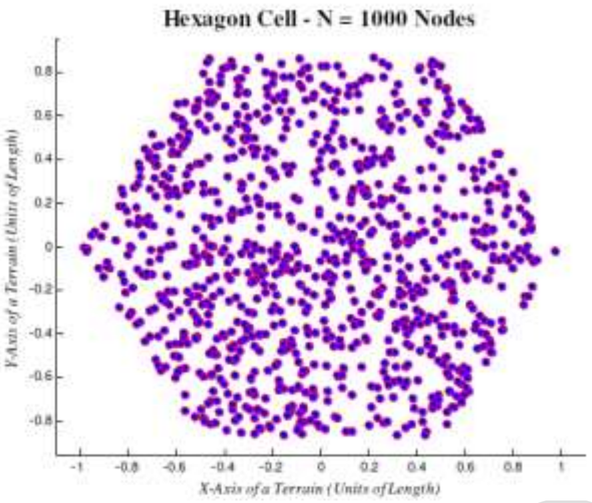


Fig 4. Random nodes within a hexagon

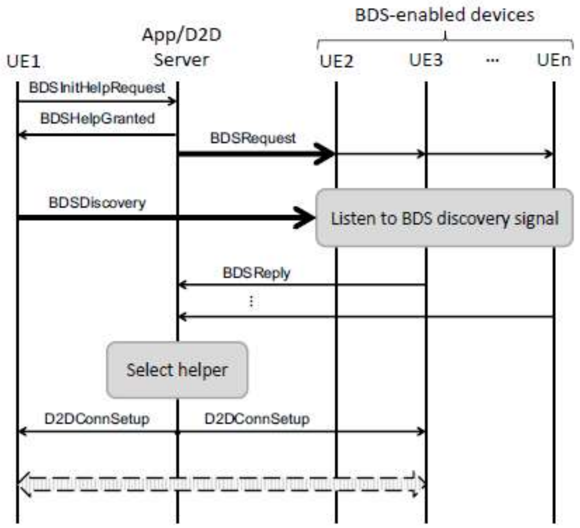


Fig 5. Battery Deposit Service operational flow. Here UE1 is the helpee and UE3 is the selected helper. UE2 is BDS enabled but is not in the proximity of UE1

The process followed next will be as follows:

1) The UE sends *BDSInitHelpRequest* to the AppSer. Let us name this UE1.
2) The AppSer responds with a *BDSHelpGranted* message where a time-frequency resource is allocated to UE1for a neighbor discovery signal.
3) After receiving the acknowledgment from UE1 (not shown in Fig.5, the AppSer sends a multicast message *BDSRequest* to all BDS-enabled UEs in the cell. This *BDSRequest* message includes the scheduled resource for UE1's discovery signal, *BDSDiscovery*.
4) All available helpers, whose battery level is above another threshold γ_2, listen to this resource unit. Any helper who is able to hear UE1's discovery signal will report to the AppSer through a message *BDSReply*.
5) After receiving the list of potential helpers for UE1, the AppSer runs a helper selection algorithm to determine the helper for UE1, together with the duration of this association. In this framework, the helper selection algorithm can be flexibly designed to achieve different goals.
6) By the end of this helper selection process, a UE is chosen to help UE1 (UE3 in Fig.5). The AppSer sends this association to the D2D Server which implements the connection establishment procedure. In our terminology, UE1 is called the *helpee*, and UE3 is called the *helper*. Throughout the duration of the association, data from UE1 is relayed to the eNodeB through UE3.

C. Helper Selection Criterion

Various selection algorithms can be included in the application server for helper selection. As discussed in [12], the sum of the transmission power required for *helpee-helper* and *helpee-eNodeB* arms of a relayed transmission can be lower than that of a direct transmission to eNodeB. The factors that determine choosing the helpers are the remaining battery lifetime of the helpee, the elapsed battery lifetime of the helper acting as relay, and transmission powers required for both helpee and helper. The cost of relaying is sum of the cost for helpee to transmit to the helper, and the cost for the helper to transmit to the eNodeB. Since the remaining battery lifetime and the required transmit powers are independent input parameters, the cost of a connection is the product of remaining battery lifetime and transmit power. For a 2-hop relayed connection, the general formula for the cost of a relayed connection is given by:

$$\boldsymbol{Cost(R) = R_m * T_{mr} + E_r * T_r} \tag{5}$$

where,

R_m is normalized remaining battery life of helpee
T_{mr} is required transmission power to a helper relay in watts
E_r is normalized elapsed battery life of a helper relay

T_r is required transmission power to the eNodeB from helper relay in watts
In the simulation, a lower cost value given by (5) is desired.

The cost of transmitting directly to the eNodeB is given by

$$\mathbf{\mathit{Cost}\ (\mathit{D}) = R_m{*}T_{md}} \tag{6}$$

where, T_{md} is the required transmission power in watts for a direct connection from UE to eNodeB. The costs of both direct and relayed connections are calculated by the eNodeB, which then does an optimization for the entire cell to find out best helpee helper pairs. While finding helpee-helper pairs, the following constraints are made by eNodeB.

1) $\mathbf{T_{mr} + T_r \leq T_{md}}$ (7)
This constraint is necessary since the relays are other UEs. The energy expended by the UE is valuable and this constraint ensures that the relayed connection consumes lower energy than the direct connection.

2) $\boldsymbol{Rm > Er}$ (8)
This constraint ensures that helpee is not draining the battery of helpers with a lower battery lifetime than its own.

3) The UE with least remaining battery lifetime gets to choose the helper first, so that the outage probability can be reduced. This constraint is implemented by arranging the UEs in ascending order of their remaining battery lifetime and then selects helpers for them.

The general condition selecting a helper relay is given by

$$\boldsymbol{Cost(R) < Cost(D)} \tag{9}$$

The UE selects a helper with lowest *Cost*(*R*) as given in (5). After an UE becomes a helper, it is no longer available for remaining UEs, as we assume that a helper can handle only one helpee at a time. In this paper, we assume that the remaining battery lifetime, $\boldsymbol{R_m}$, and the Elapsed battery lifetime $\boldsymbol{E_r}$, are random numbers between 0 and 1, with a uniform distribution. Assuming a linear relationship between remaining/elapsed battery lifetime and maximum allowed transmission power, the value for the latter is given by

$$\mathbf{\mathit{T} = T_m{*}R_m} \tag{10}$$

where, *T is* the Maximum Transmit power in watts given in Table III. Outage for the UE is calculated by comparing the transmit power *Tmr* required to transmit to its selected helper and the UE's maximum transmit power *Tm*. If *Tmr* is greater than *Tm*, an outage occurs.

D. Security Implications

Since BDS is a ProSe service, it has all security guarantees that will be offered by ProSe design. The D2D communication is inherently secure. The reason is that in D2D data are not conveyed via Internet clouds, and thus are not saved anywhere but on the intended devices. In particular, since encryption in LTE is done at UE1 and the eNodeB, UE3 sees only encrypted traffic. As a result, UE1's confidentiality is protected. Encryption also ensures that UE3 cannot insert its own messages into UE1's data stream. Thus data integrity is protected. A temporary ID (C-RNTI) is used instead of the real identity of UE1; therefore UE3 does not learn whose traffic it is carrying. Thus UE1's privacy is protected. The BDS does not incur any more security risk than what can already be obtained by an eavesdropper.

E. Performance Evaluation Framework

To study the energy consumption breakdown on smartphone, researchers have either opened up phones and recorded power consumed by each component [3], or recorded total power consumption and switched on/off different components [11]. The consensus is that network communications and the display are the two biggest contributors, significantly higher than other components such as memory and processor. By reducing the power consumed by communications, our system provides a considerable gain for the overall battery life.

1) Traffic model

The simulation model uses Poisson traffic models in for traffic scenario analysis. Poisson processes are very common in traffic modeling because they capture well the aggregate traffic caused by a large number of sources (in this case application). The uplink data is modeled to arrive in bursts, with inter-arrival time equals 30 seconds. The size of each burst is modeled as a geometric random variable.

2) Power consumption

In LTE, a UE's uplink transmit power is controlled by equation (11). The formula is based on path loss between the UE and either the relay or eNodeB ([13], [14])

$$\textbf{Transmit Power } (Pt_o \textbf{ in dB}) = -K - PG + E + L - G - H + C + \textbf{PathLoss(dB)} \qquad (11)$$

where, the various parameters are as enlisted in Table III.

The path loss can be calculated by using channel model. In addition, after every data burst, the eNodeB lets the UE stay in RRC CONNECTED state for a little longer. In this state, the UE consumes notably more energy than RRC IDLE state. The duration that the UE stays in RRC CONNECTED state is configured by the eNodeB. This factor is modeled as well as other circuitry-related energy consumption as a constant component added to all transmissions (both D2D and regular uplink).

3) Channel model

WINNER II urban macro-cell model for regular uplink connections and WINNER II indoor model for D2D connections [15]. Shadowing is modeled by lognormal distributions with parameters given in WINNER II documentation.

4) Mobility

In this work, we use a modification of the Random Waypoint Model to simulate user mobility. The Random Waypoint Model has a weakness that it favors the center of the cell more than the edge. The modified model, which we call the Random Duration Model, generates a uniform distribution of user location. In this model, instead of choosing a new destination (waypoint) as a uniform random variable at each simulation step, a user chooses a random direction and random travel duration, together with a random speed. A random pause time is also implemented after each travel. This simulates the fact that in real life, people are not always moving. All of the mentioned distributions are uniform. This design has been chosen to account for the fact that it is possible for D2D connections to exist between adjacent cells.

IV SIMULATION RESULTS

The paper implemented an event-driven simulation in Matlab. The parameters that we use are summarized in Table III. The constant energy cost factor is derived from the report of power consumption in RRC CONNECTED state of UEs moving at 3 kmph with discontinuous reception period (DRX) set to 160 ms and release timer set to 5 seconds [13]. The other parameters are also chosen to simulate a realistic scenario. The helper selection algorithm is based on proximity (the closest helper is selected). Besides γ_1 and γ_2, another factor influencing the degree of cooperation in the network is the signal strength of BDSDiscovery. This dictates the size of the neighborhood in which a user seeks help. We simulate the effect of this design parameter by fixing the radius over which a UE can find potential helpers. Our simulation is initialized with a snapshot of the network where the UEs are located at uniformly random locations within a hexagonal cell. Each UE has a random battery level.

TABLE III
SIMULATION PARAMETERS

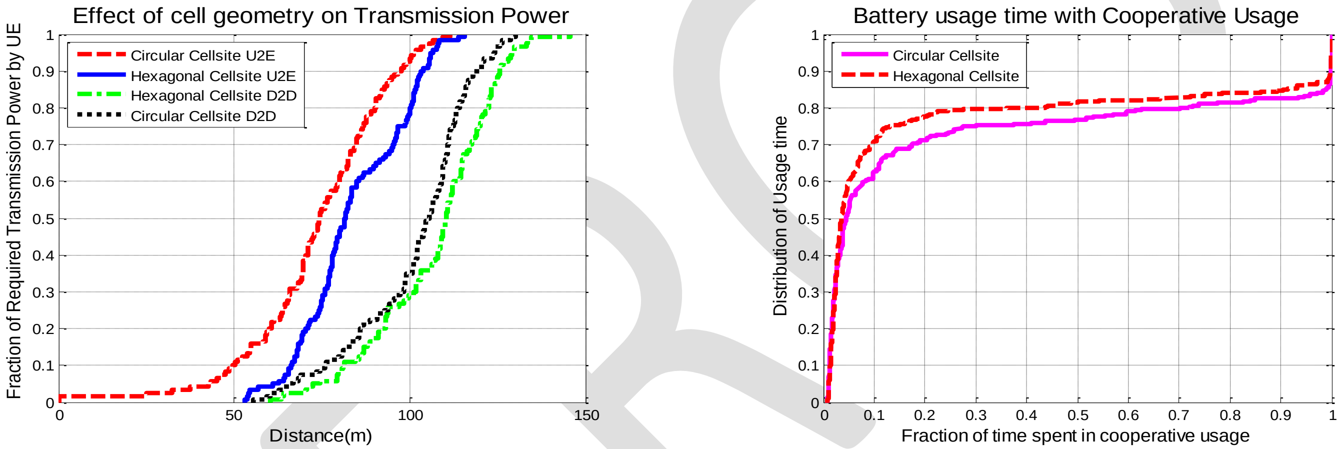
Parameters	Values
Cell Radius	500 m
No. of UEs	500
Mean data inter-arrival time	30 s
Mean burst size	7800 bytes
Speed	0.1 – 3 m/s
Pause duration	0 – 300 s
Walk duration	30 – 300 s
Path loss compensation factor α	0.8
Constant energy cost factor	15 mJ
Communication battery budget	300 J
Base power P_o	-69 dBm
Maximum transmit power T	24 dBm
Modulation order	QAM 16
Code rate	1/3
Carrier frequency	2 GHz
eNode B antenna height	25 m
UE antenna height	1.5 m
No. of walls for indoor NLOS	1
Cooperation threshold γ_1,γ_2	0.3, 0.3
Cooperation path loss threshold	110 dB
Cooperation radius	30 m
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

The results of simulation are shown in Fig.6. Fig.6(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 Fig.6(b). Hexagonal cell implementation provides greater battery usage time than circular cell implementation during cooperative usage. Fig.6(c) shows the increase in probability of survival of UE battery with cooperative usage in case of both hexagonal and circular cell implementation.

We show the average amount of valued battery for "survived" UEs as a percentage of the total battery capacity for various expected usage durations in Table IV. It can be seen that our system maximizes effectively the useful battery of the users.

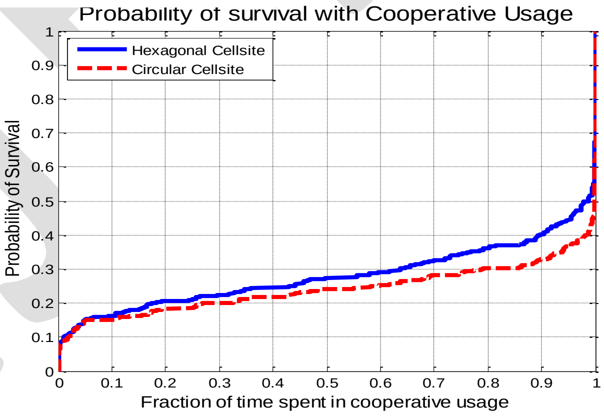
TABLE IV
AVERAGE AMOUNT OF VALUED BATTERY AFTER VARIOUS EXPECTED USAGE DURATIONS

Expected Usage Duration (h)	**Valued Battery with Cooperation**	
	Hexagonal Cell	**Circular Cell**
6h	33%	31%
8h	28%	20%
10h	24%	12%



6(a) Plot of required transmission power by UE for communication

6(b) Plot of transmission power required by UE



6(c) Plot of probability of survival of UE's battery

Fig 6. Results of Simulation. Here the usage time of a UE is the period from the start of the simulation until the UE runs out of battery

V CONCLUSIONS

In this paper we have simulated cooperative system, the Battery Deposit Service, as a new solution to prolong smartphone' battery life, in hexagonal cell environment. We have used the notions of *valueless* and *valued battery*, being the available battery on a user's phone when he does or does not have access to a charger, respectively. Our 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 neighboring 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. We describe how our system can be implemented as a 3GPP proximity service. We confirm that BDS reduces the probability of users not meeting their usage expectation (*probability of outage*) through a realistic simulation in hexagonal cell environment.

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