An Energy Efficient Routing Protocol for Device-to-Device Based Multihop Smartphone Networks

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***Abstract*—Device-to-device (D2D) communication is the need of the hour in the domain of next generation wireless networking and in the rapidly evolving smartphone network world. D2D technology facilitates mobile users to communicate with each other directly, bypassing the cellular base stations. As a popular D2D technique, WiFi-Direct is also a budding new technology that has the ability to set up wireless communications between a group of smartphones. While single-hop D2D based networks have been promising and energy efficient, multi-hop D2D based networks, though demanded in some emerging applications, are not well studied. In this paper, we elaborate the concept of multi-hop smartphone networks based on WiFi-Direct and propose an energy efficient cluster-based routing protocol, QGRP, to address the energy issue of increasing importance due to high energy costs of smartphones. Simulations demonstrate that QGRP can save significant amounts of energy compared to the cases without QGRP.**

***Index Terms*—Smartphone networks; D2D communication; WiFi-direct; energy efficient; routing; group-owner selection**

I. Introduction

Communication on various electrical devices between people is gaining popularity nowadays. With the increasing numbers of application in mobile devices, like smartphones, there is increasing need that people want to share their data with others. People are willing to share their pictures, videos and other files they own with friends or to public, connect and communicate to others by using social network, which finally make the success of Facebook, Twitter, Whatsapp and so on.

Such emergence of smartphones is actually increasing the traffic on cellular networks by running various resource and energy consuming applications. The concept of device-to-device (D2D) communication was introduced to tackle such issues by transferring the load to User Equipments (UEs), smartphones in our case, from the cellular infrastructure [9], [11], [12], [13]. D2D communication is one of the key techniques in 3GPP-LTE. D2D communication increases the energy and spectral efficiency due to physical proximity of the devices. It also brings in low transmission delay and by utilizing the licensed spectrum bands it guarantees QoS and uniform supervision.

Even though 4G LTE and other connection technologies provide high mobility for customers, which is required in the range of the base station, there is still a problem which is the expenses of such a network service. Based on the plans from some popular provider company in United States, the expense of data plan is the biggest part in the whole smartphone plan for customers. It is obvious that if we want to use cellular network service in smartphone, we have to pay data usage. But if we change to other networks, we can avoid this cost. There are some choices: smartphone users can join a WiFi network, and then can share and communicate others via Access Point (AP). Also people can connect one specific device in a short range with Bluetooth, and they still can enjoy part of network service, which is known as single-hop device-to-device connection. But there are some issues with the above mentioned networks as described in [2]. On one hand, cellular networks have to be in the range of AP, where AP is the base station which, however, covers much more places than WiFi router. But, there are users who cannot use network service without Base station, which is a pretty common phenomenon in the countryside, mountain area or inside a building. For each specific user, people pay more than WiFi in common situation. On the other hand, WiFi network service actually is not free, people also need to pay to the provider company, but sometimes company covers the cost for users. Moreover, WiFi networks are not mobile, so all devices have to be in specific range of the AP, which is immovable. So the wireless network service only exists in some areas, but not everywhere.

For single-hop device-to-device connection service, there are many different kinds of technology which can be used to build up this connection, such as Bluetooth, WiFi-Direct [2], [14] and ZigBee. Compared with the other two, WiFi-Direct provides longer connection range and higher data rate, and hence is preferred for high-rate applications such as multi-media data sharing. WiFi-Direct based D2D networks have been shown promising in many ways such as being more energy efficient than direct LTE connections. However, many existing studies focus on WiFi-Direct based single-hop D2D networks, which possesses a lot of limitations for a group. For example, consider a disaster hit area where cellular connections have been broken up while essential emergency messages or information (text, photo etc.) need to be transmitted outside with the best effort service and may be without even acknowledgement. Since the single-hop D2D networks

978-1-4673-6432-4/15/$31.00 ©2015 IEEE

are significantly constrained by the communication ranges, scenarios like these make multihop D2D communications an absolute necessity where users' mobile devices (irrespective of their network providers) will send important information to various disconnected areas or share the data between the victims.

One of the goals of this paper was to form a multi-hop WiFi-Direct based smartphone network, which can exist anywhere without the limitation of the location of AP. And the network should implement as much network service as possible. Based on these needs we tried to implement a mobile ad hoc network which can support every certified smartphone to be AP and to build a multi-hop temporary or long-term WiFi P2P connection in any area. All other devices in the coverage of this AP can join this group to enjoy the connectivity service. As shown in Fig. 1, with WiFi-Direct, devices such as those marked with "GO 1" and "GO 2" can be designated by a central unit (e.g., the base station) or elected by a group of proximal devices in a distributed manner to serve as the group owner (GO, which has the similar sense as commonly known cluster heads). Other devices automatically join the groups as constructed by the GOs. In this case, two devices, which may be too far to establish a D2D link, can communicate through multihop routes with the help of the GOs.

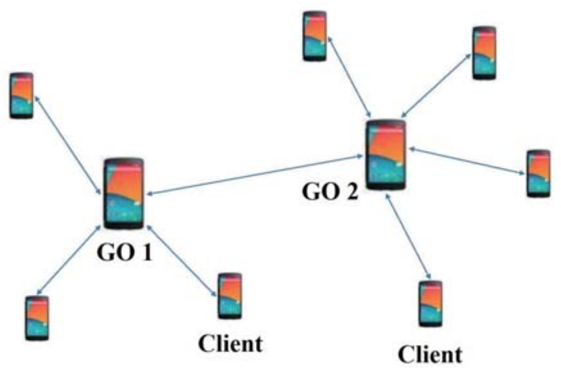

Fig. 1. Multihop Smartphone Framework.

Wi-Fi Direct has its own special topology, which requires a new routing protocol. Since smartphone devices are mobile, there are situations like in a big conference, or outside places where there is no provision for electricity makes it difficult to recharge their batteries. This necessitates devising novel energy-efficient solutions of routing, to increase the lifetime of smartphone networks involved in D2D communications. To the best knowledge of the authors, there are no reports on the routing protocols of such networks.

Exploiting the trade-offs among energy, accuracy, and latency, and using hierarchical (tiered) architectures are important techniques for prolonging network lifetime. In this paper, we borrow the idea from LEACH [3] and HEED [4], probably the most famous routing protocols in the field of wireless sensor networks, and propose a distributed cluster-based routing protocol called Quasi Group Routing Protocol (QGRP), to improve the network energy efficiency. We basically introduced the concept of quasi (pseudo) groups by taking into account the residual energy of the devices in a WiFi-Direct network.

The remainder of this paper is organized as follows. In Section II we give an overview of the WiFi-Direct and D2D System Model and also present the D2D based multi-hop smartphone networks. In Section III we propose our new energy efficient routing protocol. Section IV includes the simulation results and analysis, and Section V finally concludes the paper.

II. D2D BASE MULTI-HOP SMARTPHONE NETWORKS

As proposed and analyzed in [6] and [11], a smartphone network can increase its energy efficiency and improve network throughput by establishing D2D connection between the devices. The basic idea is to form clusters of smartphone devices, in which a particular member in each cluster, the cluster head (Group Owner), will be relaying the aggregate traffic of that whole cluster. However, the clusters can only be formed if there is good WiFi connectivity between the cluster members.

To establish a WiFi P2P network, one of the Wi-Fi devices (device supported and certified by WiFi-Direct hardware) needs to be compliant with WiFi-Direct to establish a P2P connection with other devices who want to join this group (cluster). There are two roles in a P2P Group: P2P Group Owner (GO) and P2P Client. Device acting as AP to manage the WiFi P2P Group and other clients, is referred to GO, which is only one in each WiFi P2P network. Then P2P Clients are devices connected to P2P GO to enjoy network service. Among all devices in one area, one who is willing to be the GO, establish a WiFi P2P group first, then into which other device can join as clients. So all clients in the same group within the coverage of GO, can communicate and share data with other devices without any help of fixed network, like a cellular network. There are only direct connections between clients and GO, but not between two clients. The reason is before sharing routing message via socket communication, all clients have only one choice of next hop, which is the GO.

A. *Group (Cluster) Formation*

Devices start the search process on social channels, which includes sending a Probe Requests and waiting for the Probe Response on selected channel. This process, known as Discovery process, starts from performing a traditional WiFi scan to using a new discovery algorithm, which consists of listening channel selection among 1, 6 and 11 in the 2.4 Ghz band and Probe message exchange. Once one device receives the Probe Response, it will starts GO Negotiation process. GO Negotiation is implemented with 3-way handshake of Request, Response and Confirmation. In the message of GO Negotiation, an Intent Value (integers from 0 to 15) is included to show the willingness to be a GO of one device. Therefore, the device with higher Intent Value becomes GO in this P2P Group. After GO Negotiation, WPS (WiFi Protected Setup) helps to provide the network security of P2P Group. The authentication algorithm of Wi-Fi Direct is WPA 2. The final part of establishing process is to assign IP address for each device. Following DHCP protocol, GO assigns IP address to itself and all clients.

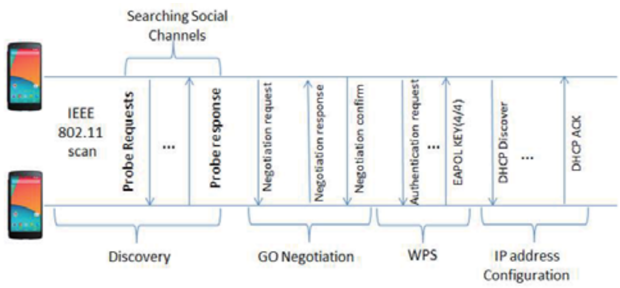

Fig. 2. WiFi-Direct Group Formation.

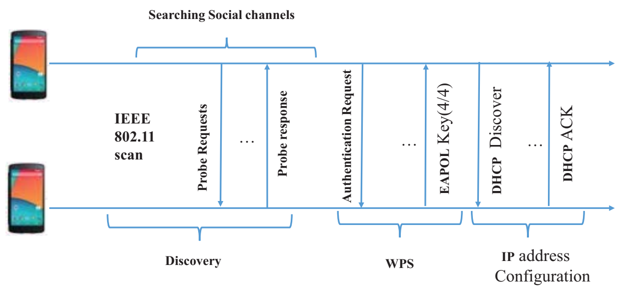

Fig. 3. WiFi-Direct Group Formation Without GO Negotiation.

Fig. 2 illustrates the process of group formation when implementing the P2P Group between two devices, including the extra message exchanges for the D2D scheme.

Additionally in situations that one device is chosen as a GO before the discovery process or one device is willing to join an already existing P2P Group, the procedure of message exchanging is different from the previous one. As shown in Fig. 3, there is no GO Negotiation process.

B. GO Transfer

WiFi-Direct does not allow the role transferring of GO within a P2P Group, as per the WiFi-Direct Specification. In this way, once GO device leaves the GO group, then group is torn down and has to be re-established using some of the specified procedures. However, our proposed algorithm requires the GO to change dynamically, based on their probabilities of becoming an owner and their residual energies. So, as described in [5], the GO sends a message with the list of members of the group and the residual energies of the group members, to the newly provisioned GO. Also the currently serving GO broadcasts a message which every group client need to acknowledge to complete the GO transfer process. The GO transfer process is shown in Fig. 4.

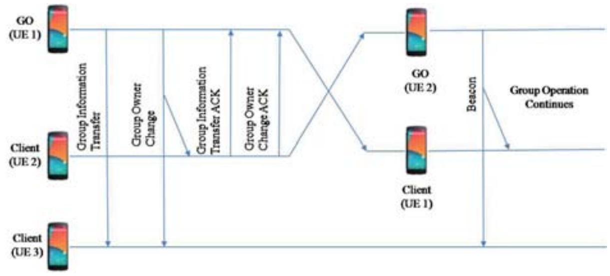

Fig. 4. GO Transfer.

III. Virtual Hierarchical Distributed Cluster Algorithm for Smartphone Networks

In this section, an improvement over the clustering protocol LEACH, using the power aware mechanism of HEED, for smartphone networks is presented. We have already discussed about extending the routing protocol used in wireless sensor networks to WiFi-Direct clusters using D2D communication. One major drawback of this protocol is that size of the cluster (group) is not limited, clusters in LEACH may be very small or very large in size. In large clusters sensor nodes deplete energy faster because of the transmission distance. Here we proposed a solution to this problem by introducing the concept of a quasi or pseudo group. We have assumed that the smartphone devices uses WiFi for inter group communications and uses LTE when the group owners communicate with the base station. The working of the algorithm can be divided into two phases.

A. Cluster Head Selection and Cluster Formation Algorithm

In the proposed algorithm, group owner (GO) selection and group formation is done in same manner as LEACH. The operation of this new algorithm (QGRP: Quasi Group Routing Protocol) is generally divided into two phases, the set-up phase and the steady-state phase. In the set-up phase, the GOs are selected and groups are organized. In the steady-state phase, the actual data transmissions to the sink take place. In the proposed QGRP algorithm, few nodes are randomly selected as GOs. This role is rotated to all devices to balance the energy dissipation of the smartphones in the network. We have considered a mobility model, where the UEs can change their location after a round of data transmission (after the completion of steady-state phase) is completed in a group.

During the set-up phase, when the groups are being created, each device decides whether or not to become a GO for the current round. This decision is based on a predetermined fraction of nodes and the probability $P_i(t)$ given by following equation, similar to LEACH.

$$P_i(t) = \begin{cases} \frac{k}{N - k \cdot (r \, mod \, \frac{N}{k})} & C_i(t) = 1 \\ 0 & C_i(t) = 0 \end{cases}$$

where k is the total number of groups, N the total number of devices, $C_i(t)$ is the indicator function determining whether or not node has been a cluster head in the most recent

$(rmod(N/k))$ rounds. If the devices have initially different levels of energy left, we can define the probability as a function their residual energies relative to the total energy remaining in the network.

$$P_i(t) = \min\{\frac{E_i(t)}{E_{total}(t)}, 1\}$$

Where $E_i(t)$ is the current energy of the ith device and

$$E_{total}(t) = \sum_{i=1}^{N} E_i(t)$$

In QGRP, the optimal number of GOs is estimated to be about 5% of the total number of devices.

Each device that has elected itself a GO for the current round broadcasts an advertisement message to the rest of the devices in the network. All the non-GO devices (clients), after receiving this advertisement message, decide on the group to which they will belong for this round. This decision is based on the received signal strength of the advertisement messages. In this way cluster formation is done in QGRP.

After GO receives all the messages from the devices that would like to be included in the group and based on the number of devices in the group, the GO creates a TDMA schedule and assigns each device a time slot when it can transmit.

B. The Quasi Group Formation Algorithm

One of the solutions to efficiently utilize the energy in LEACH protocol is formation of a quasi group (QG) in large groups formed by LEACH protocol. Once the GO formation is complete, proposed algorithm searches for eligible groups to form a QG within itself. For formation of a QG each device of the group sends its power level to GO. The idea of power levels is borrowed from HEED.

Based on the power levels, GO selects the members for QG as shown in Fig.6. There are four groups (A, B, C and D) as shown. In group A, devices residing at distant locations form the QG.

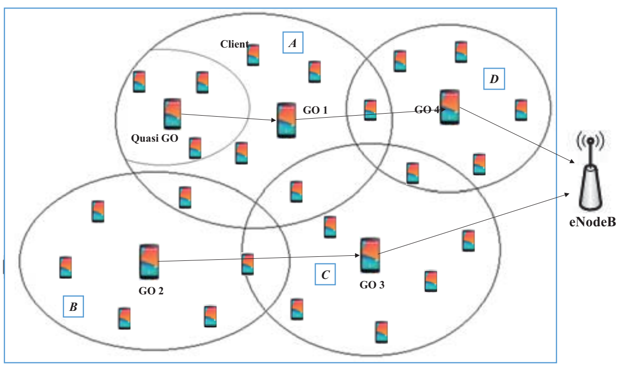

Fig. 5. Quasi Group Formation.

The case considered here is the case of intra-cluster communication. As proposed in [4], let $MinPwr_i$ denote the minimum power level required by a node $v_i, 1 \leq i \leq N$ to communicate with a group owner H, where N is the number of devices in the group range. All group members send their $MinPwr_i$ to the GO. GO now computes average minimum reachability power ($AMRP$) with $MinPwr_i$ values of all the smartphone devices. $AMRP$ can be defined as the mean of the minimum power levels required by all N devices within the cluster range to reach H, i.e., $AMRP = \sum MinPwr_i/N$.

The $AMRP$, defined in the HEED protocol, is used as the estimate of the communication cost. The $AMRP$ of a node is basically a measure of the expected intra-cluster communication energy consumption for communication to the GO. Using $AMRP$ as communication cost, the QG members can be found out. The device power levels below the $AMRP$ are considered to be in the quasi group.

When the QG is formed, any member of the group can be selected as the quasi-GO (qGO) in pure random basis for that round (may be one with the highest energy). The qGO creates a TDMA schedule as LEACH and assign time slots to zone members to transmit the data to the qGO. qGO then transmit data to the GO of that group. In this way one round is completed. Fig. 6 shows the flowchart for the QG formation algorithm.

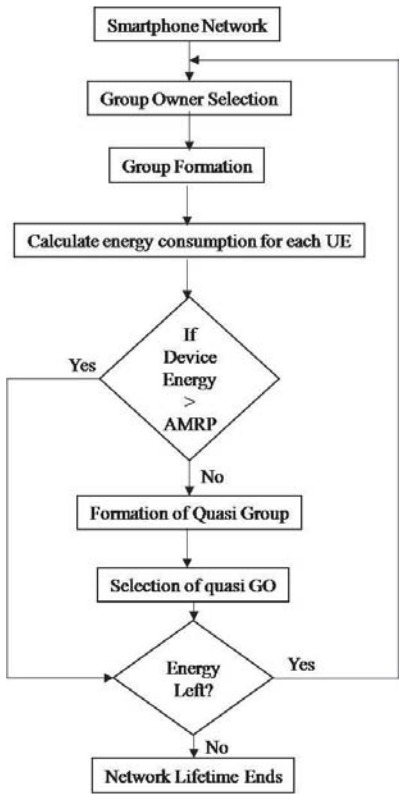

Fig. 6. Flowchart of Quasi Group Formation.

C. Analysis of Energy Efficiency

Quasi group within a group can be considered as a virtual hierarchical level-2 group. In this section we analyzed the energy consumption for the proposed model. The energy analysis presented in this section is based upon analysis presented in the LEACH paper [3] and by F. Comeau et al. [1].

We consider a smartphone network with M devices which are divided into m groups and n quasi groups in the first round of operation. N will be the number of devices in each group assuming equal distribution.

For the data transmission within the groups by WiFi-Direct we consider the free space path loss model (d^2 power loss). The clients in a group transmit data to their respective group owners which in turn send the accumulated data to the eNodeB. We have assumed that the cellular (LTE) transmission between the GOs and the eNodeB, along with background processes of each of the devices in the network follow the Power Model for Data transfer as described in [12].

The power level for uplink is defined as $P_u = \alpha_u t_u + \beta$, where t_u is the uplink throughput in Mbps and β is the base power when throughput is 0. In our scenario, we are just concerned about the uplink transmission of data.

The devices in a quasi group send data to the n qGOs. They collect data, aggregate it and transmit to the m GOs. Energy consumption at each level can be calculated as follows. Expected energy expended to process l-bits of data at zone level includes the energy of sending data by devices and receiving data by n qGOs.

$$E_1 = l \cdot \left[2 \cdot (N-n) \cdot E_{elec} + (\epsilon_{fs} \cdot \frac{M^2}{\pi})(\frac{N}{n} - 1) + N \cdot E_{DA} \right]$$

Where E_{elec} is the energy dissipation for transmission and reception, ϵ_{fs} is the free space amplifier energy E_{DA} is the energy of data fusion.

Selection of qGOs is done randomly depends upon the energies transmitted to the m GOs. To compute the energy consumption, only $(n \times m)$ nodes will participate. Expected energy expended by GOs, includes the energy of receiving data from n qGOs, energy expended in aggregation and transmission to m GOs.

$$E_2 = l \cdot \left[2 \cdot (n-m) \cdot E_{elec} + (\epsilon_{fs} \cdot \frac{M^2}{\pi})(\frac{n}{m} - 1) + n \cdot E_{DA} \right]$$

Also the energy dissipated by each GO while transferring its duties to the next round of group owners is:

$$E_3 = m \cdot l \cdot \epsilon_{fs} \cdot d^2$$

Where d is the distance between two such GOs.

The total energy expended in each round to transmit l-bits for such system is sum of E_1, E_2, E_3 and the energy per bit as defined by the LTE power model. Lifetime of the network in terms of number of rounds can be calculated from the above discussion. Number of rounds can be calculated by dividing total network energy by energy expended in one round.

IV. Simulation Results

The simulation is performed using ns-2, a discrete event network simulator, and MATLAB. We have compared the performance of the network with normal WiFi-Direct specifications (fixed GOs) and the QGRP proposed in this paper.

TABLE I
Simulation Parameters

Parameter	Values
device number	100
network grid	$100m \times 100m$
base station position	$50m \times 175m$
size of data packet	500 bytes
initial power level	1J
E_{elec}	$50nJ/bit$
ϵ_{fs}	$10pJ/bit/m^2$
ϵ_{mp}	$0.0013p/bit/m^2$
α_u	$438.39mW/Mbps$
β	$1288.04mW$
t_u	$1Mbps$

Please note, that a smartphone can typically store around 15-20000 Joules of energy, however, for the simplicity of our simulation process, we have considered considerably smaller levels of energy (Smartphones with 1-2% battery left, which is a feasible case) for the devices and smaller network grid. Our motive is just to show that we can actually implement an energy efficient routing protocol for the smartphone devices involved in WiFi-Direct. So, the basic parameters used are listed in table 1. Fig. 7 illustrates the performance comparison of QGRP and WiFi-Direct in terms of energy dissipation. As shown in Figure 7, energy consumption of QGRP is less than the regular WiFi-Direct protocol in all cases thus it is energy-efficient and has optimum performance. The reason is clear that the devices within the quasi group do not have to transmit for long distances that save a significant amount of energy.

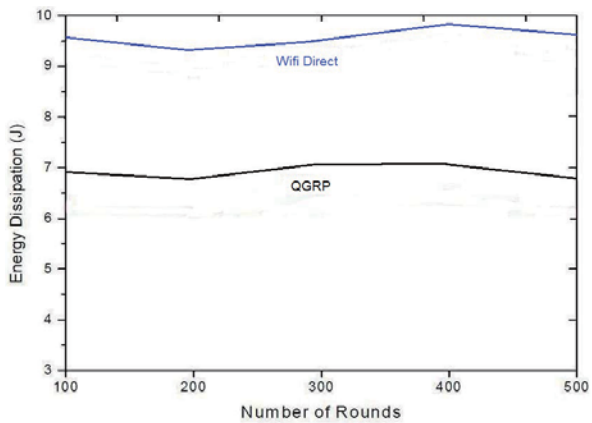

Fig. 7. Energy Dissipation.

Fig. 8 illustrates the performance of proposed algorithm comparing to the static WiFi-Direct GO structure in terms of network lifetime. As it is clear from the following figure that the smartphone network performs longer with QGRP in comparison to WiFi-Direct.

It is pretty much evident from Fig. 8 that the WiFi-Direct performs poorly in comparison to the proposed QGRP protocol, because of its static GO strategy, as a result of which the energy of the GOs reduces rapidly. QGRP utilizes the

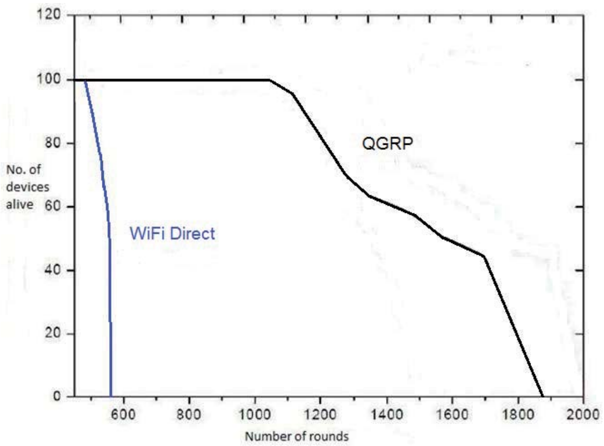

Fig. 8. Network Lifetime.

rotating GO strategy as in LEACH and the residual energy as in HEED, which makes it a significantly better choice in smartphone networks.

V. Conclusion

In this research work, we have proposed an improvement in the network lifetime and the energy efficiency of smartphone networks, involved in D2D communications. We have proposed a quasi group routing protocol (QGRP), which is based on the LEACH and HEED protocols for wireless sensor networks and considers a quasi group inside a large group of smartphone devices. Simulation results prove the improvement in the performance in the original WiFi-Direct protocol in terms of the network lifetime. However, this research is in a very nascent stage in terms of the real time parameters involved in smartphone networks. Future work will include experiments by forming test beds with real smartphone devices and studying the energy dissipation behavior in such cases.

Acknowledgement

This work was supported in part by NSF under grant CNS-1117687. Xiaohua Tian's work was supported by NSF China (No. 61202373); National Mobile Communications Research Laboratory, Southeast University (No. 2014D07) and Shanghai Basic Research Key Project (12JC1405200, 11JC1405100).

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