Analysis of Device-to-Device Discovery and Link Setup in LTE Networks

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Abstract—Device-to-Device (D2D) communications allow devices to communicate directly without going through infrastructure. It is considered a promising solution to improve communication performance and network capacity of LTE-Advanced system. From the perspective of User Equipment (UE), additional energy consumption is required to support D2D communications. In addition, recent device supports multiple Radio Access Technologies (RATs) with high energy consumption. For an energy efficient D2D communication, the most significant problem is how to detect proximal devices and to establish a D2D link in a timely manner. In this paper, we propose a D2D discovery and link setup procedure, and analyze its performance in terms of energy consumption and delay by utilizing the measurement results with real LTE smartphones. Based on the analysis results, we conclude that there is a trade-off relation between energy consumption and delay performance.

Index Terms—D2D discovery, D2D link setup, Radio Resource Control (RRC), Discontinuous Reception (DRX)

I. INTRODUCTION

Recently, cellular traffic amount has tremendously increased due to the popularity of smartphones and tablet PCs. As one of decent solutions to cope with such heavy traffic demand, Device-to-Device (D2D) communication has received much attention. D2D communication is direct communication between User Equipments (UEs) without going through infrastructure. Different from D2D communication without any external help, which had been mostly considered in the past, D2D communication with the help of external source (i.e., cellular infrastructure) has been considered recently. When D2D UEs are allowed to reuse cellular resources, D2D communication in cellular network has a potential advantage of increasing the system capacity. In addition, D2D communication may reduce the energy consumption because of the reduced number of hops and shorter communication distance [1]. Fig. 1 shows an example of D2D communication in LTE networks.

Long Term Evolution (LTE) technology brings cellular communication to the fourth generation (4G) era. LTE standard specification has been proposed by the 3rd Generation Partnership Project (3GPP). The aim of LTE is to support reduced latency, higher user data rate, improved system capacity and increased spectral efficiency [2]. Currently, LTE is studied and labeled as LTE-Advanced (LTE-A) technology. LTE-A technology includes Proximity Service (ProSe) which is the same concept of D2D communication as a new study item in Release 12. It is expected to be a promising technology that serves future services or needs, e.g., public safety, social networking, and proximity-based advertising in various use cases and scenarios [3].

Even though the demand for D2D communication has increased, energy consumption is a growing concern. A device has to support both cellular and D2D communication, meaning that additional energy is required. Meanwhile, recent device supports multiple Radio Access Technologies (RATs), i.e., multiple modems, RF chains and antennas are implemented in one device. Furthermore, LTE shows the highest UE energy consumption compared with Wi-Fi or WCDMA (3G) [4].

There is a growing interest in D2D communication underlaying cellular networks. However, most of the previous D2D works have focused on the D2D communication issues assuming discovery procedure is completed, and as a result, few have investigated on the D2D discovery [5]. The contributions of this paper are summarized as follows. We first propose the D2D discovery and link setup model working in an LTE network. Second, we comparatively analyze the performance of the D2D discovery and link setup in RRC_CONNECTED and RRC_IDLE state by utilizing the real measurement results with LTE smartphones.

The rest of the paper is organized as follows. We first introduce background in Section II, and present our system model in Section III. After that, we describe the analysis model in Section IV, and evaluate the performance in Section V. Finally, we conclude the paper in Section VI.

II. BACKGROUND

A. Radio Resource Control (RRC)

The main function of the RRC protocol is to manage the connection between UE and network. The RRC state in
LTE system is simplified to only two states: RRC_IDLE and RRC_CONNECTED. There is no connection between UE and evolved NodeB (eNB) in RRC_IDLE state, i.e., the location of UE is not known at the eNB level. In this case, it can be traced by an Mobile Management Entity (MME). We define the UE in RRC_IDLE as an idle-UE and the UE in RRC_CONNECTED state as a connected-UE, respectively [6].

B. Discontinuous Reception (DRX)

In DRX mode, the UE powers down when there is no packet activity. In LTE system, DRX mode can be enabled in both RRC_IDLE and RRC_CONNECTED states. DRX operation in RRC_CONNECTED state is defined as connected mode DRX (cDRX). When no data is sent or received during a specified time, the connected-UE performs DRX operation with a short DRX cycle, where the UE wakes up only periodically and sleeps for the remaining time to save energy. If there is no data activity until the short DRX cycle timer is expired, the connected-UE switches to long DRX mode which operates with a longer DRX cycle. All the parameter values related to DRX are defined by RRC configuration [7]–[9].

C. Motivation

Fig. 2 shows the power trace of User Datagram Protocol (UDP) packet received at 6 Mbps for 30 seconds by iperf.1 It is measured with Samsung Galaxy Note 2 LTE phone (SHV-E250L). Our experiment is conducted with Monsoon power monitor.2 Because the UE screen is off, most of the energy is consumed by the radio connection and interface.

The procedures for packet reception are as follows. First, an idle-UE has to perform the promotion procedure for initial random access [7]. After the promotion procedure is completed, the connected-UE can receive packets. After completing the reception of packets, there is some amount of energy consumption although there is no packet activity during tail duration (which is the RRC inactivity time). Then, the connected-UE releases the RRC connection to switch to RRC_IDLE state.

1Iperf is a network testing tool that can create TCP and UDP data streams.
2http://www.msoon.com/LabEquipment/PowerMonitor.

Through the measurement results, we observe that there is some amount of base power in RRC_CONNECTED state. However, if cDRX is activated in LTE system, energy consumption will be reduced in tail duration [10].

In this paper, we introduce the chip-on-duration, $T_c$, which depends on the modem chipset implementation. When the UE wakes up according to the DRX cycle, it has to remain in active state during $T_c$. In Fig. 2, if cDRX cycle is long enough when cDRX is enabled, the connected-UE may reduce tail energy. However, if $T_c$ is longer than the cDRX cycle when cDRX is activated, energy consumption is not reduced in tail duration as shown in Fig. 2.

Based on these observations, the motivation of our study is to reduce the energy consumption in the D2D discovery and D2D link setup. In order to verify the relationship between energy and delay, we analyze energy consumption of the D2D discovery and delay of the D2D link setup in RRC_CONNECTED (cDRX) and RRC_IDLE state respectively. If the D2D discovery occurs only in RRC_CONNECTED state, the idle-UE always has to switch to RRC_CONNECTED state regardless of cellular communication. This will increase energy consumption due to the promotion procedure.

III. SYSTEM MODEL

A. D2D Beacon

D2D discovery is a procedure that UEs find each other periodically before the communication link is set up. For the purpose, UEs have to exchange predefined signals, referred to as beacons. By checking beacons periodically, a UE maintains a list of proximity UEs in order to establish communication link when it is needed. Beacons should be detected reliably, even in low Signal-to-Noise Ratio (SNR) environments [5]. To allow beacons transmitted periodically, resources for beacons should be assigned. For guaranteeing the performance of cellular UEs, we assign some dedicated resources for beacons. The minimum unit of beacon is Resource Block (RB) which carries 72 OFDM symbols [11]. Therefore, we can fill the beacon with some useful information such as UE identity and offered/required service list.

B. D2D Discovery

Table I summarizes a list of important parameters for the D2D discovery and LTE system. Fig. 3 shows the D2D discovery operation by using LTE uplink resources [12]. It
Beacon transmission time
Number of paging cycles
Power during promotion
eNB
Promotion time
Number of beacon transmissions
D2D discovery time in a Paging cycle
Beacon transmission time
Beacon reception time
On duration time
Promotion time
Chip on duration time
Number of D2D discovery cycles
Number of beacon transmissions
Number of beacon receptions
Number of paging cycles
Number of long DRX cycles
Beacon transmission power
Power during promotion
Power during on duration time
CONNECTED state
D2D discovery cycle
Number of D2D discovery cycles
Beacon reception time
Beacon transmission power
IDLE state, the UE2 has to switch to CONNECTED state through the promotion procedure.
Total period time
checks whether a paging message is delivered. A connected-UE monitors Physical Downlink Control Channel (PDCCH) and an idle-UE wakes up periodically during T_{I, on} according to paging cycle, T_{pa}. Within each periodic interval, the idle-UE monitors Physical Downlink Control Channel (PDCCH) and checks whether a paging message is delivered. A connected-UE also monitors a PDCCH during T_{C, on} according to T_{ld} cycle.

\[ T_{pr} = N_{dc} T_{dc} \]
\[ T_{dt} = N_{bt} T_{bt} + N_{br} T_{br} \]
\[ N_{dc} = \frac{T_{pr}}{T_{dc}} , N_{pa} = \frac{T_{pr}}{T_{pa}} , N_{ld} = \frac{T_{pr}}{T_{ld}} \]

C. Synchronization

In our work, we limit our scope to synchronous discovery, which means that all UEs are synchronized with external timing information. Compared to asynchronous discovery, synchronous discovery has many advantages over asynchronous discovery such as fast detection, low energy consumption, and the large number of discoverable UEs [13]. D2D UEs are able to synchronize using signals from an eNB which are transmitted in downlink. Those are broadcasted periodically by an eNB through dedicated channel [11], [14]. Even though D2D UEs are synchronized with external source, the exact synchronization between UEs cannot be achieved. However, we assume that the maximum range of D2D communication is shorter than the range of cellular communication. Thus, we assume that propagation delay is negligible and delay spread is smaller than the normal cyclic prefix duration in 3GPP [5].

D. D2D Link Setup

In this section, we illustrate a call flow for the D2D discovery and link setup in Fig. 4. The D2D link setup procedure is composed of three parts: D2D link setup request/response, resource allocation and D2D link establishment. Dtx is the UE which transmits a beacon and Drx is the UE which receives a beacon. After a device is detected, the D2D devices perform the D2D link setup procedure. We assume that UE1 and UE2 are already registered so that their eNB is aware of D2D candidates (UE1 and UE2) when a D2D link setup request is received.

1) D2D link setup request/response: After receiving a beacon, UE2 (Drx) transmits (in RRC_CONNECTED state), a D2D link setup request message to its eNB. If the UE2 is in RRC_IDLE state, the UE2 has to switch to RRC_CONNECTED state through the promotion procedure. Then, the eNB sends a request to UE1 (Dtx) for a D2D link setup. After that, UE1 responds (in RRC_CONNECTED state) to its eNB for a D2D link setup. If the UE1 is in RRC_IDLE state, UE1 also has to switch to RRC_CONNECTED state through a promotion procedure.

2) Resource allocation: The eNB allocates the temporal link setup resources to both UE1 and UE2 through RRC connections. The resources are appropriately allocated in a centralized manner.

3) D2D link establishment: After each UE is assigned to a dedicated resource, they can transmit and receive messages each other. After a D2D link is established, UE2 will notify eNB that the D2D link setup is completed.
IV. NUMERICAL ANALYSIS

A. Average Power Model

In this section, we analyze the average power. The average power of the connected-UE is the sum of uplink $E[P_{C,ul}]$, downlink $E[P_{C,dl}]$, base $E[P_{C,base}]$ and promotion $E[P_{C,pri}]$:

$$E[P_C] = E[P_{C,ul}] + E[P_{C,dl}] + E[P_{C,base}] + E[P_{C,pri}]$$

where

$$E[P_{C,ul}] = \frac{N_{dc} (P_{bt} N_d T_{bt} + P_{br} (T_{dt} - N_d T_{bt}))}{T_{pr}}$$

$$E[P_{C,dl}] = \frac{P_{C,on} T_{C,on}}{T_{ld}}, \quad E[P_{C,pt}] = \frac{P_{p,t} T_{pt}}{T_{pr}}$$

and $E[P_{C,base}]$ is derived below. Similarly, the average power of the idle-UE is the sum of uplink $E[P_{I,ul}]$, downlink $E[P_{I,dl}]$ and $E[P_{I,pri}]$:

$$E[P_I] = E[P_{I,ul}] + E[P_{I,dl}] + E[P_{I,pri}]$$

where

$$E[P_{I,ul}] = \frac{N_{dc} (P_{bt} N_d T_{bt} + P_{br} (T_{dt} - N_d T_{bt}))}{T_{pr}}$$

$$E[P_{I,dl}] = \frac{P_{I,on} T_{I,on}}{T_{pa}}$$

and $E[P_{I,pri}]$ is derived below.

B. Base Power Model

$E[P_{C,base}]$ and $E[P_{I,base}]$ are the average base power in UE. We define $P_{active}$ as base power when the UE is active and $P_{idle}$ as base power when the UE is idle. Fig. 5 shows the base energy consumption according to the DRX cycle. Before cDRX is enabled, the connected-UE has to operate a promotion procedure to switch to RRC_CONNECTED state. While the connected-UE enters cDRX mode, optionally a short DRX cycle is applied before enabling a long DRX cycle. In this paper, short DRX mode (e.g., 40 msec) energy consumption is added up to the energy consumption of promotion. If $T_{ld}$ is longer than $T_c$, energy consumption will be reduced to $P_{idle}$ with cDRX operation. However, if $T_{ld}$ is shorter (e.g., 32 msec) than $T_c$, high power level $P_{active}$ is maintained. $u(t)$ is the unit step function.

$$E[P_{C,base}] = P_{active} \min \left( \frac{T_c}{T_{ld}}, 1 \right) + P_{idle} \frac{u(T_{ld} - T_c)}{T_{ld}}$$

$$E[P_{I,base}] = P_{active} \min \left( \frac{T_c}{T_{pa}}, 1 \right) + P_{idle} \frac{u(T_{pa} - T_c)}{T_{pa}}$$

C. D2D Link Setup Delay

We analyze the D2D link setup delay based on our proposed D2D link setup procedure in Fig. 4. $T_{pa}$ indicates the average of paging time which depends on the paging cycle. $T_{sc}$ represents the scheduling time for D2D link setup. $T_{ue}$ is the time for signal transmission from UE to eNB and $T_{link}$ represents the time for D2D link setup between UEs. In addition, processing delays in both eNB and UE are also considered [15]. The average delay of D2D link setup can be given as follows:

$$E[T_{C,link}] = E[T_{ld}] + E[T_{sc}] + 2E[T_{link}] + 3E[T_{ue}]$$

$$E[T_{I,link}] = E[T_{pa}] + 2E[T_{pr}] + E[T_{sc}] + 2E[T_{link}] + 3E[T_{ue}]$$

V. PERFORMANCE EVALUATION

In this section, we compare the performance of RRC_CONNECTED and RRC_IDLE through numerical analysis. Detailed parameters are shown in Table II. We utilize D2D parameters which are based on our power measurement with Samsung Galaxy Note 2 LTE smartphone. Fig. 6 shows that the average power as a function of $T_c$. As $T_c$ increases, the average power also increases due to the
time that a UE is active. RRC_CONNECTED state shows more average power because of the promotion procedure and short DRX mode operation. Fig. 7 represents that the average power is varied according to $T_{ld}$ and $T_{pa}$. If $T_{ld}$ is longer than $T_c$, the energy consumption is decreased because the UE can reduce $P_{idle}$ after $T_c$ duration. The average delay of D2D link setup is shown in Fig. 8. The D2D link setup delay in RRC_IDLE state is longer than that in RRC_CONNECTED state because of the promotion procedure. The delay increases according to the length of $T_{ld}$ and $T_{pa}$, which are related with how frequently the UE wakes up.

VI. CONCLUSION

In this paper, we have analyzed the energy consumption of D2D discovery in RRC_CONNECTED and RRC_IDLE state, and have proposed a novel D2D link setup procedure for delay comparison. Using the analytic evaluation, we prove that there is a trade-off relationship between energy consumption and delay. That is, the energy consumption of D2D discovery in RRC_IDLE state is smaller than that in RRC_CONNECTED (cDRX), but after the device is detected, the D2D link setup delay in RRC_IDLE state is longer than that in RRC_CONNECTED.

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