Performance Enhancement in LTE Cellular Networks through Direct Communication

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ABSTRACT

Direct or Device-to-Device (D2D) communication underlaying cellular infrastructure has recently gained tremendous interest by the researchers, cellular operators and device manufacturers due to its benefits in terms of increased spectral efficiency, low delay and transmission power. These days, commercialization of D2D communication is the major focus of the operators, especially for the Indian telecom operators due to their stiff competition, capacity constraints and increased operational and capital expenditure. In this direction recently we have proposed a novel D2D communication scheme [1] along with D2D discovery and scheduling for Long Term Evolution (LTE) networks. This uses resource sharing and can be used by the telecom operators for commercial use for better network performance at low cost. However, However, this requires extensive evaluation through simulations and emulations in order to gain more acceptance by the operators, academia, device manufacturers and the research community. In this direction, we have designed and implemented an emulated platform using WiFi Access Point (AP) to serve as an LTE eNB and Android and Java Applications for D2D transmission and reception in a laboratory environment, which we have discussed in this paper. We further explain the experiments conducted using our emulated platform and demonstrate the performance enhancement in terms of spectral efficiency, end-to-end delay and transmission power through the use of D2D communication.

1. INTRODUCTION

In today's wireless network world whether it is 2G/3G/4G, mobile users use high data rate services such as multimedia content sharing, gaming, proximity-aware-social-networking, emergency services, etc. However, the existing cellular communication system does not allow direct communication between mobile users, even though the mobile users communicating are in close proximity as in a stadium, club, office, homes, restaurant, etc. Under the existing cellular communication system, all the file or data sharing between mobile users happen via the eNB (eNodeB or eNB is the LTE Base Station (BS)) – uplink from the transmitter mobile to eNB and downlink from the eNB to the receiver mobile. This is a complex and resource consuming procedure.

To avoid this complexity in case of close proximity users and to improve the spectral efficiency, Device-to-Device (D2D) communication has been proposed [1-4]. In D2D communication mobiles can directly communicate between themselves using the cellular resources (sub-carrier/channel/Resource Blocks) as peer-to-peer communication, with or without the guidance of the eNB. This helps in direct transfer of data between two close-by mobiles at a higher rate with less transmission power. Although, there are other methods for direct communication between devices such as WiFi Direct, Bluetooth, InfraRed, etc., D2D is more efficient as it works under same network (as the cellular) and on same cellular spectrum. D2D architecture has been envisioned to be implemented in two ways; one for emergency services like disaster, fire spreading situations, etc., and second for commercial uses. Although, both the application scenarios are under study item of 3rd Generation Partnership Project (3GPP) [5], our focus in this paper is to develop a proximal service architecture for commercial use with network assistance or eNB guidance.

In our recent paper [1], we have introduced a novel D2D communication scheme which can be realized by D2D discovery mechanism along with a two-phase interference aware optimal D2D uplink scheduling scheme for Long Term Evolution (LTE) networks. Further, our scheme differs from the existing 3GPP proposal in terms of (i) reuse of Resource Blocks (RBs) and (ii) network assisted D2D communication. Due to this commercial use of the proposed scheme can be made possible. However, to gain wider acceptance for our proposed scheme at standards body, operators, manufacturers, academia and research community, we observe that extensive evaluation of such scheme is very essential. Though we have evaluated the proposed scheme mostly through Matlab simulation [1], evaluation through an emulated platform was at its preliminary stage. Therefore, in this paper our focus is to evaluate D2D communication model proposed in [1] through an emulated platform. In this direction, we discuss the design of an emulated platform in which WiFi is being used to emulate cellular LTE networks; WiFi Access Point (AP) is being used as an LTE eNB. We further explain the various Applications (Android and Java APPs) designed and implemented in smartphones and at WiFi AP for the signaling, power control, data transmission etc., in detail through this paper.

The rest of the paper is organized as follows. In Section 2, we provide the literature survey related to D2D communication. Section 3 explains the system model used for the evaluation. In Section 4, we discuss the design and implementation of the emulated platform, emulation scenario and analyze the performance of the emulated D2D communications. We then conclude the paper Section 5.

2. LITERATURE SURVEY

D2D communications using cellular spectrum resources simultaneously with ongoing cellular traffic is a relatively new concept [4]. The non-orthogonal resource sharing between the cellular and D2D layers has the benefits like reuse gain, higher throughput, hop gain, and increase in resource utilization [6]. The impact of power control and resource (e.g., OFDM resource block) allocation in a single cell scenario has been studied in [7]. The multi-cell problem scenario is considered in [8] which assumes that the Channel State Information (CSI) is available at the eNB to select the optimal resource sharing modes. The concept of allowing local D2D communication to (re)use cellular spectrum resources simultaneously with uplink/downlink in cellular traffic is mentioned initially by [1], [9] and has gained much interest since then. The impact of power control and resource allocation in a single cell scenario has been studied in [10-11]. The authors in [10] have analyzed different resource allocation methods for D2D, where D2D link can use dedicated resources or use resources of one or more cellular link.

3. SYSTEM MODEL

In this paper we consider a single cell scenario in which the eNB and the users are located in a single cell. The eNB is capable of obtaining the locations of the users, the wireless channel conditions between the users, users and self, the activity information of the users (whether busy or idle), etc. As explained in [1], the eNB can classify the requested communication into either D2D or cellular, undertake interference aware uplink scheduling and decide the transmission power to be used by the users for successful communications.

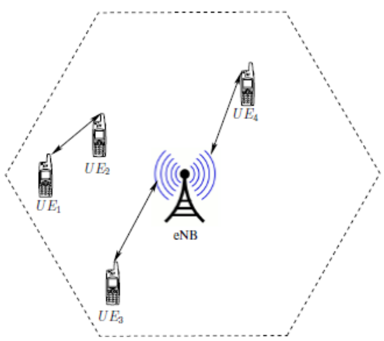

Fig. 1: Single Cell LTE Networks

Through Fig. 2, we explain the different modes of communication that is possible in LTE Networks. Note that, in both regular/cellular and the D2D communications control path is always through the eNB (network assisted) whereas the data path is either via eNB or direct depending upon the modes of communications.

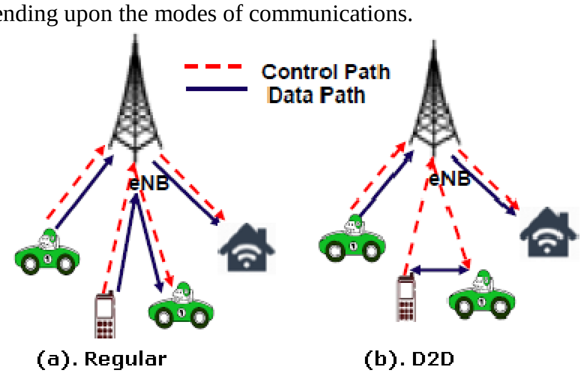

Fig. 2: Communication Modes under LTE Networks

We now explain the control flow used in our emulation environment as in Fig. 3. Let U_x and U_y be two active users – U_x is the transmitter and U_y is the receiver. The transmitter U_x initiates communication requests through REQ message containing the receiver address and the amount of data to be communicated. Upon receiving the Request (REQ) message (similar to the Logical Channels of LTE), the eNB classifies the modes of communication (D2D or cellular) and informs U_x through the Response (RES) message (similar to the Transport Channels of LTE) carrying communication parameters such as mode (D2D or cellular), transmission power and scheduled channel or Resource Block (RB). Post that, the transmitter U_x sets the transmission power and starts data transmission in the scheduled RB; direct transmission to U_y if the mode selected is D2D or transmission via the eNB otherwise (similar to the data transmission using Transport and Data Channels in LTE). However, note that the control communications (Logical and Transport Channel combination) such as future frame by frame scheduling, wireless channel information, etc., are being communicated to the eNB irrespective of the mode of operations.

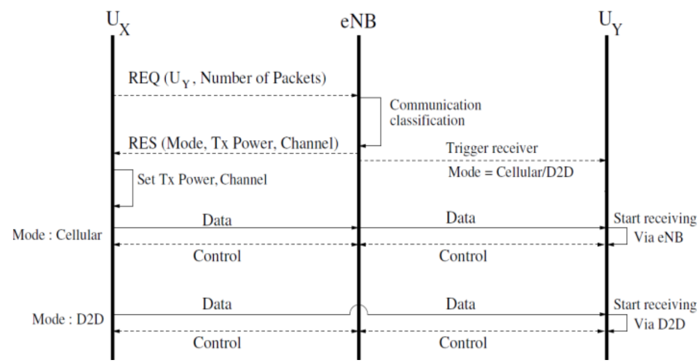

Fig. 3: Control Flow Diagram

4. PERFORMANCE EVALUATION

To evaluate the performance through emulation, we use 10 different users; assume max 30% of which can communicate using D2D. We consider static mode of operation. We analyze bandwidth utilization, latency, and overall power consumption through emulation. We now discuss the details of the emulated platform and emulation methods being conducted through the following subsections.

4.1 Emulated Platform

In our emulation design, we have implemented the eNB using a desktop computer that is capable of acting as wireless Access Point (AP). This capability to act as an AP is provided using WiFi adapters that can provide wireless connectivity to the users. We have not changed any hardware configurations in the WiFi AP, instead we have used plug and play WiFi adapter that plugs into the USB port of the desktop computer. In our platform we have used a Live Tech WiFi adapter [12] to provide wireless connectivity so that users can connect and interact with eNB. We have developed various software modules that are capable of handling the control information required for scheduling and communication to undertake, which we discuss in detail in the next section.

We have also developed Android based applications for both transmitter and receiver to emulate the proposed scheme. These applications are deployed in LG Nexus 5 and LG Nexus 4 mobile phones, running Android Operating System KitKat 4.4.4 [13]. Though we have developed these applications for LG Nexus phones having Android KitKat 4.4.4 O.S, these applications can be deployed on any Android O.S based phones.

Once the eNB classifies the communication as D2D, the transmitter should be able to reduce its transmission power for communication as proposed by the D2D scheme [1]. To address this requirement, we have added a capability in the transmitter application module to acquire the root permissions so that it can access the WLAN characteristics of the device and change the transmission power. However, by default Android devices do not have root permissions and also there is no facility available to check the WLAN characteristics even with root permissions.

4.1.1 Emulation Scenario

We consider a single cell scenario in which one LTE Base Station (eNB_1) and multiple users (U_1, U_2, U_3, U_4, U_5, etc.) as in Fig. 4. Note that both the transmitter and the receiver belong to the same cell. Other users such as XU_1 and XU_2 are part of other cells (eNB_2 and eNB_3); these cells are not considered in our emulations and are shown for a realistic network scenario only. Though we have described a single scenario, with multiple WiFi APs and handoff mechanism, D2D communication can be extended to multi-cell scenario with mobility.

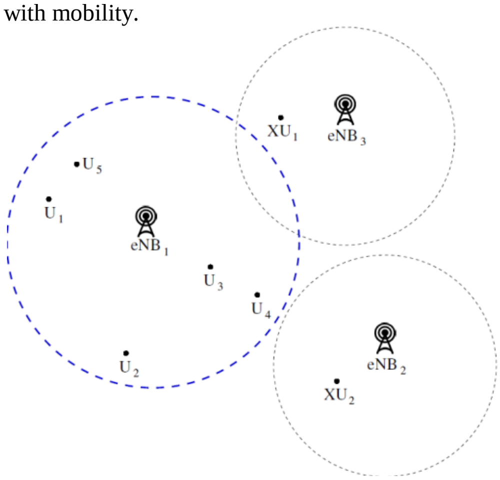

Fig. 4: LTE Networks

4.1.2 Software Modules

There are three modules that are developed in order to evaluate the proposed scheme mentioned above. A module is developed and deployed at the network operator's end (eNB) to perform communication classification and scheduling, i.e., classification of call requests and uplink scheduling of cellular and D2D calls. Two other modules are deployed at the user end (smartphones) to interact with the eNB in order to establish communication and transfer data accordingly.

- *Operator End – eNB*

  This is a Java based module deployed at the eNB as shown in Fig. 5 in order to provide following additional capabilities:

  - eNB waits for the communication requests initiated by users.
  - eNB processes the user communication requests by classifying them as either cellular or D2D communication depending upon the distance between the transmitter and receiver. This requires location and identity information of the users. Note that in reality under LTE, location information of the users is not available by default, though using Global Positioning System (GPS), location of users can be obtained. Further the GPS accuracy differs from device to device. Therefore, accurate information on location of users is still under standardization through 3GPP. However, in this paper, location information is obtained using physical grids/markings in the lab. Lab area is divided into grids physically and is shared with the eNB. Based on the position of the user, grid numbers are communicated to the eNB which further get resolved to particular locations.
  - In our implementation, distance of 30 meters is considered as the threshold for D2D communication, i.e., D2D communication is possible only if the distance between the transmitter and the receiver smartphones is less than or equal to 30 meters. If the distance is more than the specified threshold value then cellular mode of communication is considered.
  - After classifying the mode of communication, the eNB informs the receiver about the communication request initiated by the transmitter, so that the receiver can take necessary actions for further communication.

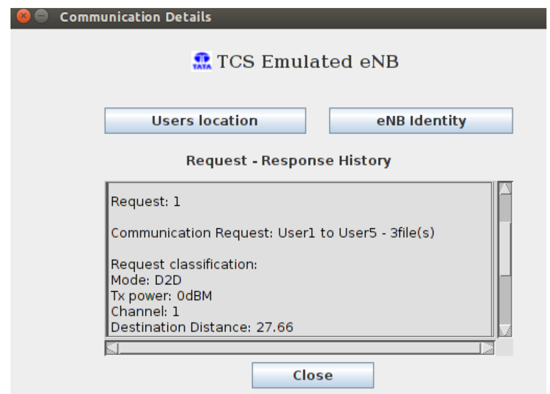

Fig. 5: eNB Controller and Scheduler

- *User End: Transmitter*
  - This module is implemented as an application in Android platform using Android API's such as Network Manager, WiFi Manager, etc.

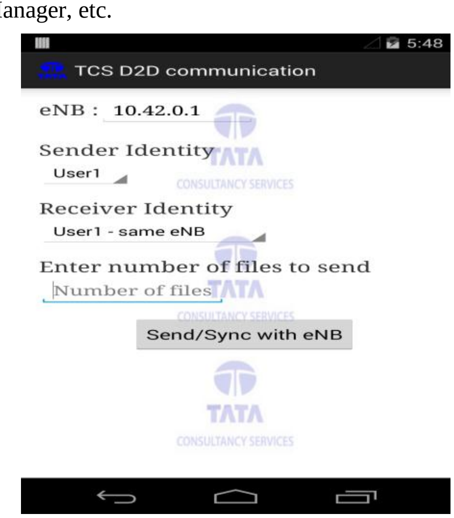

Fig. 6: Communication Request

- This module is responsible for initiating the communication requests to the eNB and also to process the response returned from the eNB about the communication parameters.
- For communication requests, REQ (receiver_identity, Number of packets) message is being sent to the eNB using cellular infrastructure.

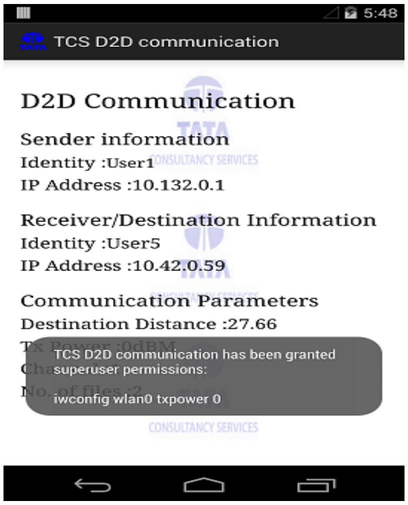

Fig. 7: Transmitter Module with D2D Mode

- Once eNB classifies the communication requests (either D2D or cellular), it sends the response packet RES (Mode, Tx power, Channel) back to the transmitter. This response packet includes information related to mode of transmissions, transmission power, and channel or Resource Block (RB) in LTE Networks to be used. Simultaneously, it will alert the receiver about this direct communication and the channels on which to expect the data.
- After receiving the response packet from the eNB, transmitter changes its transmission mode and power according to the response and initiates data transfer with the receiver or the eNB based on the mode of communication, i.e, D2D or Cellular (Fig. 7 and Fig. 8).

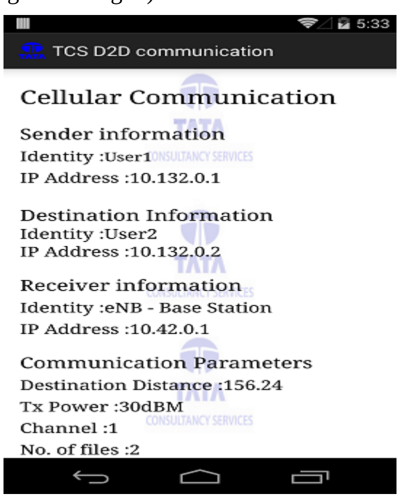

Fig. 8: Transmitter Module with Cellular Mode

- *User End: Receiver*
  - This module is implemented in both Java and Android platform as standalone applications using appropriate platform specific API's.
  - This module is responsible for receiving data from the transmitter or eNB based on the mode of communication.
  - After eNB classifies the communication mode, it triggers the receiver about the communication that is going to happen, so that the receiver can take necessary actions before the start of the communication (Fig. 9).
  - Once the transfer is successfully completed, receiver again starts listening for eNB triggers for communication.

Fig. 9: Receiver Module

4.2 Performance Enhancement of LTE - Results

In this section we discuss how and why the performance of LTE networks with D2D is enhanced. We observe that the average per-user throughput is substantially improved with D2D. Average per-user throughput is improved mainly due to (i) re-use of the RBs – which are the physical channels under LTE and (ii) interference minimization due to the interference aware scheduling and power control of our proposal [1]. Improvement in average throughput leads to improvement in capacity and spectral efficiency. Further, we also observe that this improvement is substantial as the number of simultaneous active users increase as shown in Fig. 10.

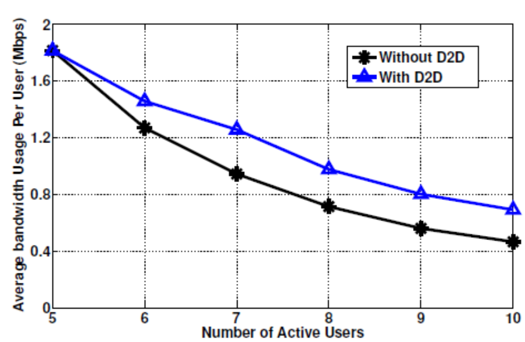

Fig. 10: Throughput: with and without D2D

Therefore, in a capacity constraint or highly congested network, D2D can bring more value as compared to a capacity rich network. Moreover, as the number of active users increase, D2D can bring down the average end-to-end delay to a large extent as the downlink sub-frame is unused during D2D communication as in Fig. 11 (almost seven times drop in the delay as the number of users is doubled).

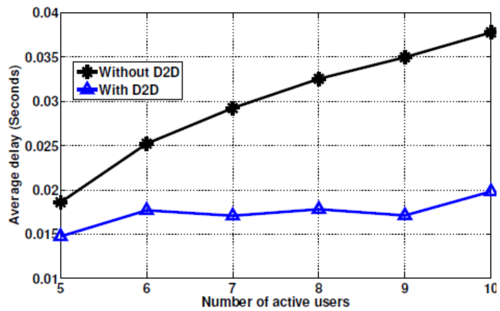

Fig. 11: Transmission Delay: with and without D2D

Hence we argue that by incorporating D2D, telecom operators can not only improve the Quality of Experience (QoE) of the existing users in terms of low end-to-end delay and capacity improvement but also can even add more users to the network without compromising the QoE at same cost. Further, we also observe that the transmission power used by the users is substantially low during D2D communications (low power is required to transmit at a high rate due to the low distance communication: 1 dBm vs. 30 dBm). Therefore, with D2D enabled, the lifetime of the mobile users can be improved substantially.

5. CONCLUSIONS

In this paper, we have proposed, implemented and evaluated the network assisted D2D communication that can be extended for commercial applications for an LTE networks. Further, a single cell scenario using WiFi based eNB and Android based transmitters and receivers is implemented. We have also implemented/configured appropriate software/hardware modules in order to emulate the proposed scheme. Extensive emulations are also conducted for studying the performance of the proposed scheme. From the emulation studies, we infer that spectral efficiency is improved significantly and overall transmission power and transmission delay is reduced for D2D communication.

As a part of the future work, we are planning to extend the proposed scheme for a multi cell scenario and incorporate the user mobility. We have also planned to extend this to an LTE based test bed with the network operators' assistance.

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