

D2D Communications for Mobile Devices: Technology Overview and Prototype Implementation

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Abstract—The mobile devices of today evolve towards offering uninterrupted connectivity while attempting to achieve untethered mobility of their users. Further technological advances in hardware often lead to an increased data consumption. Combining these two factors, we notice that the data rates on the current Internet connections are starting to lag behind. Ultimately, we observe a mismatch between the data transfer rate requirements and the actual throughput availability. In this paper, we utilize direct links between proximate devices to help offload the large amounts of user-originated data from the conventional cellular links. The paper explores the implementation possibilities of this technology on the consumer Android devices, as well as substantiates our application development choices. The proposed approach employs the infrastructure-based connections for coordination, while most data transfers happen over the device-to-device links. This allows the developers to utilize our data offloading platform for other proximate applications.

I. INTRODUCTION

Direct communications between devices is currently being extensively supported by all mobile platforms [1]. It provides user equipment with several possibilities to connect to other mobile devices in its local surroundings. Today, WiFi Direct [2], [3] (WFD) technology delivers high-throughput connections to locally bound groups as compared to e.g., Bluetooth, both conventional and Low Energy (BLE). However, with regards to such device-to-device (D2D) communications, we notice a lack of services provisioned for this specific type of connectivity. With the recent influx of wearables in the consumer markets [4], [5], researchers recognize the boost of direct communications between such devices and their hosts.

Developers are able to utilize powerful mobile platforms that are capable of advanced photo and video capture, thus leading to increasingly large data files. Direct communications are currently not ready to handle this abundant data in a comprehensive manner, which is confirmed by the state-of-the-art technological implementations. Direct links between two mobile devices are still rather exotic and the connection between wearables and their hosts is almost exclusively BLE with the notable example here being smart watches [6]. Presently, WFD is a popular technology utilized for file transfer, but it also has excellent capabilities to accommodate a variety of direct data exchange applications. For example, Apple has coined an implementation of WFD named “Airdrop”¹ that is applied solely to support interaction of two devices.

Furthermore, most of the WFD applications for Android are focused purely on facilitating the data transfer applications [7]. Therefore, the developer community has access to improved capabilities for acquisition of large amounts of data, but few meaningful ways to efficiently transfer it between nearby peers are known. Our approach aims to provide a collection of services facilitating the direct data transfer between devices by utilizing the D2D links without data or user restrictions and taking into account the corresponding security questions [8], [9]. The main goal here is to determine the peers in advance and to handle the transmission of data transparently without requiring any unnecessary user input. The key requirement for the proposed method is to provide a simple and elegant D2D connectivity solution, allowing to transfer all of the data types between peers residing in proximity. This paper specifically offers a closer look at the issues encountered during the development process of a characteristic example application.

The rest of this text is organized as follows. First, we determine the input requirements and review specific implementation options. Further, we overview the state-of-the-art communication capabilities of mobile devices, tailored to our implementation demands. The following section is dedicated to our D2D application, details how exactly the proposed solution is used, and describes the operation of the resulting setup. The subsequent section continues with outlining the actual application by focusing on the issues encountered and solutions proposed. A numerical analysis of the developed approach is provided in the next section. The last section summarizes the directions of future work as well as concludes the discussion.

II. IMPLEMENTATION AND REQUIREMENTS

The existing mobile operating systems enable D2D communications, but they do so in a non-unified manner [10]. Comprehensive data connections are only available for the conventional Internet access, but D2D connectivity is not yet widely implemented for direct links between local users [11]. Our approach aims to further increase the usability of direct communications, thus providing a unified data transfer mechanism between locally bound peers. Such connections are based on the state-of-the-art technological implementation within today’s mobile devices. Since this research is focused on an application that is to be run in a public environment, we consider the same capabilities as modern consumer applications. Any modifications, such as root access or customization of the operating system, are assumed to be not available.

¹See: How to use Airdrop with your iPhone, iPad, or iPod touch, 2016. <https://support.apple.com/en-us/HT204144>

Proposals have been made to implement this new D2D technology directly within the operating system [12], but these have not been explored on the consumer scale. Other choices are limited, and our envisioned approach offers possibilities for a meaningful trial that provides impact with implications beyond the communications research field, such as software engineering and human-centered technology. In addition to aiding the network by offloading data [13] from the conventional cellular links [14], we focus on facilitating the data exchange between the local users. This strongly binds users to their proximate peers and allows for reducing the infrastructure communications to a minimum. The conventional interaction over the Internet links, through cellular network or WiFi infrastructure, is used to maintain the state-machine for all the involved devices and to exchange metadata aiding the direct communications.

Current implementations of D2D connectivity on the major mobile operating systems require regular user input before any information could be exchanged. Furthermore, these connections often have no relation to peer locality or geographical proximity. A user attempting to initialize a link is required to execute a search for other open connections. This varies from sporadic to permanent depending on the user’s preferences; an increased battery consumption is the direct consequence of this action. Considering these limitations, we outline several specific suggestions that have been made for the D2D connections. These are mostly theoretical models with little real-life implementation relevance.

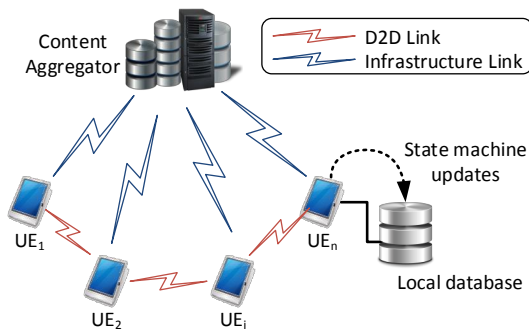


Fig. 1. Considered system topology

The known applications and platforms for D2D links often suggest to offload voice communications onto the direct connections [15]. Issues with this approach include the implementation complications beyond theoretical speculation. The spectrum of voice services is heavily dominated by popular messaging applications and cellular providers are already offering the readily available VoIP. An alternative scenario for direct communications is the file transfer functionality. Apple’s Airdrop and Android Beam are just a few examples of these applications, which often require considerable user input to enable a relatively simple data transfer. The proposed method leverages the proximate relations to facilitate communications between local peers by using data transfer as a background activity.

Given the absence of a unified data transfer Application Program Interface (API), we aim to provide a model for adopt-

ing the D2D connections to facilitate localized information exchange. The system topology of our proposed framework can be observed in Fig. 1. Here, proximate connections are utilized to analyze which data is to be exchanged and to decide on the concrete data transfer mode. The main management system, named “Content Aggregator” (CA), serves as the central authority for all the devices. The CA keeps metadata about the successful D2D transfers and has knowledge of all the data associated with the model on the consumer devices.

The connection to the CA is maintained through the conventional Internet access. The specific implementation of the CA is customized by the application designer. The purpose of the CA is to provide users with an authoritative means to control which peers are to be connected with which, and what data is to be requested for transfer.

Whenever a new device joins the system, it acquires the most recent information from the CA and selects which data it wishes to acquire. The server then provides the requester with a list of users possessing these particular subsets of data. Now this new user has the knowledge on which other users to contact for any specific data. The data transfer employs the direct links between the users individually over a pair-based scheme. Following this, the device that has acquired its needed data informs the CA of the completed transfer. The CA is now aware of the new bearer associated with this distinct data set.

The corresponding state-machine is presented in Fig. 2 and its detailed description is as follows. Initially, a user is required to login into the system by contacting the CA. This step provides the security and authentication to the user and the server alike. Given that the user device has proven its credentials, it is now capable of acquiring the corresponding metadata. This data can be tailored to the user needs by the CA or be a general summary of all the available information: locality-bound info, user specific data, different levels of user access are all possible within our model.

The CA should be setup such that it only provides the users with the relevant metadata that they are authorized to access. The user continues its interaction with the CA by indicating interest in a specific subset of data, if any at all. Further details about these interests are acquired from the server and stored in an internal database. The data includes information that other users keep: size, name-scheme, and other relevant properties. The knowledge acquired from the server is to be refreshed at the application-specific intervals, upon a user input, or subject to other applicable triggers.

After a login, the user enables its peer discovery module to acquire the information about the proximate peers with the D2D-ready connections. A list of all appropriate D2D neighbors is constructed/refreshed. The list of the available user equipment (UE) is compared with the table of the data to be acquired. If there is a match, a direct data connection is established. Both peers exchange the needed information on the data transfer session and initialize a secure transmission. The data is transferred over a direct link, which is finalized by sending a message containing the metadata about the transfer to the CA. The CA is updated with the actual information and the user triggers the entry removal in the database.

The discussed model has the potential to accommodate a wide range of applications and/or to become a valuable

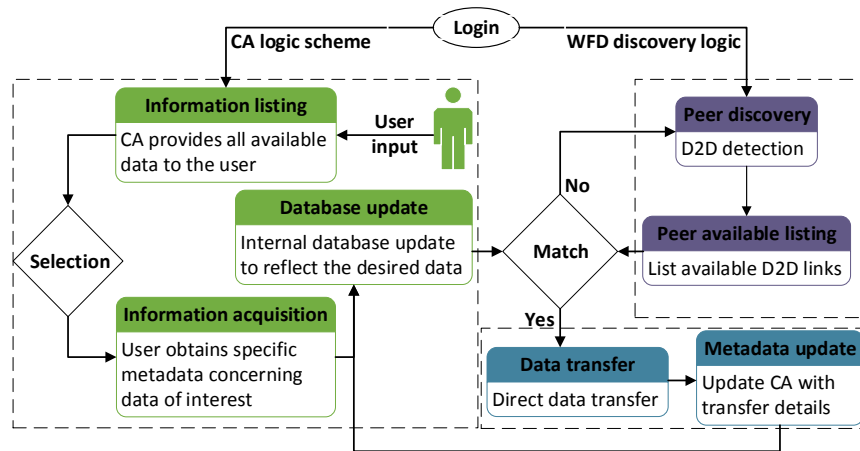


Fig. 2. D2D demo application state machine

addition to the existing applications. More specifically, several popular messaging applications enable media transfer over the conventional Internet (e.g., Facebook, Whatsapp, Telegram, Snapchat, etc.). Utilizing the local connectivity and transferring a file over direct links would save cellular data usage, battery charge, as well as increase the user perceived throughput [10]. Finally, the envisioned model can be employed in remote areas or locations where the conventional Internet access is limited or unavailable [16].

III. STATE-OF-THE-ART MODEL ENABLERS

To achieve the objective of a feasible model implementation, we review the current direct transmission schemes. The goal of our model is to facilitate D2D data transfer between mobile handheld user devices in proximity without modifying the operating system. Historically, D2D communications have been proposed to relieve the loading on the conventional Internet connections [13], [14], [17]. We differentiate between two main types of D2D communications: in-band and out-band [13]. In-band communications assume D2D interaction within the licensed operator spectrum, while out-band flavor is targeted to utilize the unlicensed frequencies [18].

Using in-band D2D connections produces an overlap between the conventional cellular communications and may lead to unpredictable interference that causes channel degradation or link interruption. Out-band connections occur in the unlicensed spectrum, which could be regulated through adequate interference management and resource allocation [19], [20]. Some works recommend the utilization of in-band technology, but considering that it is currently not implemented on any major mobile operating system provider, we focus on the out-band mechanisms in the remainder of this paper.

Accounting for the market share of mobile operating systems, we are limited to Android and iOS. Both of these mobile platforms offer D2D communication possibilities. Given the effective market penetration, we prefer to work with the An-

droid platform, as it currently shows strong popularity². It also follows an open-source approach to the code distribution, including different D2D communications possibilities: (i) NFC, (ii) Bluetooth (BT) supplemented with the BT-based schemes, and (iii) WFD. First, NFC technology is deemed not applicable for our purposes due to its very low data rates and transmit ranges [21]. The second available option is BT and BLE. According to the specifications³, we are severely limited in the data transfer capabilities with any existing implementation of Bluetooth. The maximum communication rate of 2.1 Mbit/s theoretically does not justify the use of direct links when equivalent rates can be readily achieved on the conventional cellular connections.

At the same time, current technology allows for utilizing BLE while simultaneously maintaining Internet connections without causing significant interference [22]. An example here is wearable technology, where the host remains connected to the Internet while a wearable is communicating only with its host that runs two simultaneous connections. Despite said advantage of Bluetooth, we also note its limiting factors, such as constrained data transfer rates and coverage, altogether making the BLE technology unsuitable for a broad range of practical applications.

Therefore, the primary D2D technology for the purposes of this paper is WiFi Direct, also known as WiFi peer-to-peer (P2P⁴). WFD offers significant throughputs and extensive transfer ranges [23]. Considering these benefits, we see it frequently utilized for applications providing direct file transfer. Under typical circumstances, it may be possible to simultaneously connect to the Internet with the use of a cellular link since a different physical radio part is utilized then. Similarly, other connections, such as those over BLE or NFC, may remain active during WFD operation. Specifically,

²See: iOS and Android Capture Combined 98.4% Share of Smartphone Market, 2016. <http://www.macrumors.com/2016/02/18/ios-android-market-share-q4-15-gartner/>

³See: BT Core Specification 4.2, 2016. <https://www.bluetooth.com/specifications/adopted-specifications>

⁴See: WiFi peer-to-peer (P2P) technical specification, 2016. www.wi-fi.org/Wi-Fi_Direct.php

WFD supports link lengths of up to 70 m as well as transfer rates of up to 300 Mbps [24]. Comparing the three discussed technologies, we identify WFD to be the most suitable option for our envisioned approach.

In a nutshell, WFD provides an out-band solution for localized data transfer between a group of peers. It is built on top of the WiFi infrastructure, with the main difference being that one of the user devices assumes the role of an access point (AP) for the purposes of the channel utilization management. The user acting as the AP is referred to as the “Group Owner” (GO). Other users connected to the GO are the corresponding group peers. A direct connection may only be established between the GO and a peer. Due to the fact that the connection between the peers and the GO should always operate via a single point of failure, groups of larger sizes are considered inefficient since the GO becomes quickly overloaded with data.

In order to test the proposed model, the authors have developed a prototype application that employs WFD technology to exchange video information. It is detailed in what follows.

IV. OUR VIDEO-SHARING APPLICATION

A. Application concept

To prototype the proposed model, we developed a video sharing application targeted at multi-purpose video distribution. As stated in the previous section, our approach utilizes WFD technology to facilitate the direct connections between neighboring devices. Our test application specifically implements the model to transfer the video files between users in proximity. The video is captured and compressed locally at the devices, thus following a unified media standard for the video fragments. The application supplies the user with a platform for recording short video clips and sharing these with people in the user’s proximity range. The videos can be individual clips and/or groups of clips that form a concatenated story [25].

The main purpose of our application is to socially encourage people to share their video clips with each other thus creating a complete story. The users interact with our application by indicating their interest in several collaborative challenges containing a certain number of clips. Being in the vicinity of other D2D-ready users that prompt an interaction in the background to acquire the requested clips, this functionality does not require any user input. The user has an option to actually partake in the challenge by requesting a token which grants a temporary reservation to add a new clip, or simply help distribute the video files to other users. The CA is updated correspondingly whenever the users interact with their internal data. This can include acquisition, modification, or deletion of video clips. Ultimately, the CA is aware of the metadata ownership and provides this information to users interested in these particular video clips.

B. Implementation-specific features of the application

The developed application has three separate cycles that run semi-continuously depending on several specific triggers. These cycles are: (i) the internal application logic, (ii) the CA service, and (iii) the D2D data transfer. The triggers for these cycles include, but are not limited to, user input,

timer expiration, and neighboring device detection. To prevent from excessive battery consumption, we employ an ORMLite database that stores the data when no active connections are in effect. The internal database is updated with the simple @GET methods, being a part of the Representational State Transfer (RESTful) design [26]. This database only accepts updates that come through the CA and cannot receive queries from other sources, hence attributing the central data authority to the CA. The updates are performed periodically based on an internal timer or user input.

If the user device has acquired new data through a D2D link or is interested in adding its own clip/challenge – it contacts the CA with the @POST or @PUT methods. This triggers the corresponding CA update, which the user can contact later on to acquire the most up-to-date information. Our application utilizes two internal databases to keep track of the required clips together with a database containing all the current users posting a particular clip. If a proximate user that matches the two aforementioned databases is detected, a connection is setup and the data is transferred. This completes the construction of our video-sharing application.

The following section addresses the issues encountered with the WFD, Android, and other design elements.

V. MAIN LESSONS LEARNED

In the course of the development process, several complications were encountered that are summarized below in the form of four main issues. Upon inspecting the sample code provided by the Android SDK, and later by reassembling the code, the most significant challenges were identified as follows:

- First, there are difficulties with user attempts to form a WiFi P2P group: the WFD requires a constant connection to the GO, which always has to be one specific device. In an automated environment, the application thus has to make a differentiation between two devices and (pseudo-)randomly assign one device to be the GO. This issue was solved by lexicographically comparing the MAC-addresses of both devices.
- The creation of a single large group for all the users utilizing the application is not possible, as the randomly-assigned GO might not be present. In this case, no communication may occur. The solution to this challenge was found by constructing a full mesh and performing a pair-wise grouping. For example, in case of 100 users, each of them requires a total of 99 groups to be able to communicate with every peer. This puts a strain on the user device due to the obscurity of the maximum number of groups per an Android device.
- Third, and by far the largest challenge, is in the requirements set by the Android platform. The client (not a GO) has to confirm the connections with all the users that are encountered in proximity every time the connection is being initialized. This issue was brought up by Google⁵, but was deemed obsolete. We explored different ways of how to overcome this challenge. Our first solution was to rewrite the part of the kernel causing the visual pop-up by simply returning the “true” value instead of displaying the pop-up.

⁵See: Issue 30880 Wi-Fi Direct API for connection acceptance, 2012. <https://code.google.com/p/android/issues/detail?id=30880>

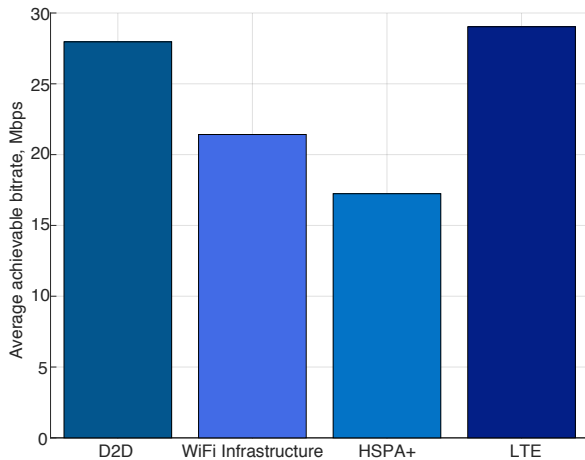


Fig. 3. Comparison of WFD and infrastructure connectivity

Another option was to acquire the root access privileges by installing a root kit and making this particular pop-up to follow an always-accept logic. Both of these solutions are not readily available for users, who do not wish to tamper with their devices. Therefore, *initialDiscovery* method was developed, which scans the environment for the WFD-enabled devices, connects to them, exchanges the *HELLO* messages, stores the user id and the MAC-address, and disconnects immediately. This creates a pair-wise group between all the users currently present in proximity after running this method.

- The last challenge is due to the fact that a group is uniquely defined by its GO and thus a connection has to be always controlled by the same GO. After this phase is completed, the first data exchange can only occur from the client to the GO, as the GO has no knowledge of the IP address of the client in advance. For instance, the GO still has to initiate the connection, even though there may be another client that is interested in content sharing. To resolve this issue, the GO attempts to connect to all of its groups and request files or offer its own files to the client. Any constrains on the system are mitigated by sporadically scanning with a period of 30 minutes.

VI. NUMERICAL INVESTIGATION

In order to demonstrate possible benefits for the users and operators, we conducted a set of experiments aiming to evaluate the key metrics of interest from the networking side: the average and the maximum achievable throughput for the connections between a pair of D2D users, as well as between a user and the server. For our evaluation, we utilized two Nexus 5 smart phones running Android 6.0. We evaluated the operation of our application by distributing compressed video files of 100 MB size⁶ for 100 times. The interference environment for all the measurements was kept similar. The adopted Wi-Fi technology was the following: 802.11n in 2.4 GHz range.

⁶See: Information On Data Sizes: U.S. Cellular report, 2015. <https://www.uscellular.com/uscellular/cell-phones/informationOnDataSizes.html>

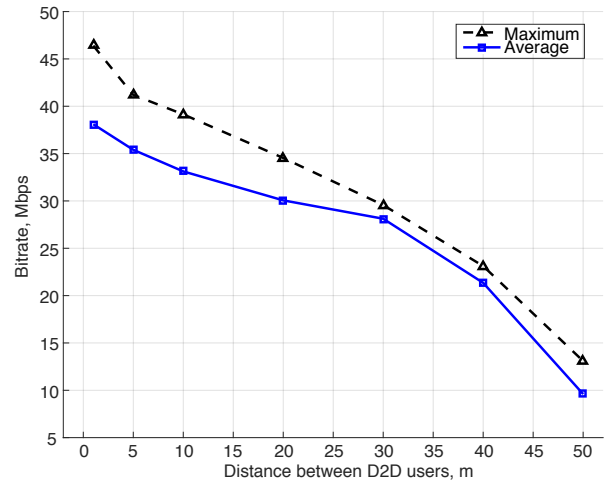


Fig. 4. Achievable D2D rate based on distance between nodes

First, we compared the results that may be achieved by the WFD D2D links in contrast to the WiFi infrastructure and cellular links. The resulting bars are given in Fig. 3. As we can conclude from our measurements, the utilization of WFD may improve the file acquisition rate by up to 30% for a given set of users. Importantly, utilizing D2D connectivity not only provides higher data rates but also “frees” the expensive licensed cellular spectrum.

To further evaluate the results, we assessed the maximum D2D link distance as summarized by Fig. 4. Indeed, the longest achievable operating distance for a WFD link is around 50–60 meters. After this threshold, the average bitrate tends to zero and the session interruption probability is over 50% for all of our measurements. Based on these sets of results, we can conclude that the utilization of WFD is feasible whenever the devices are within 40 meters from the service consumer point of view.

VII. CONCLUSION AND FUTURE OPPORTUNITIES

The proposed approach is just the first step in optimizing the process of utilizing the D2D connections between proximate mobile devices. Many improvements can be made across various extensions that can later be incorporated into this model. In conclusion, we are in a position to state that the practical level of usability of the D2D links between users remains considerably far from what is envisioned theoretically in the 5G literature. In an attempt to increase the usability of already possible links, we created a model and constructed an example application which employs D2D connections to offload user-originated data from the conventional cellular network. The technology utilized for establishing direct communications in our work is WiFi Direct, while the model itself is implemented on Android platform.

Given the many complications and issues related to the current implementation of WFD for Android (6.0), the resulting applications may be not immediately usable for people in day-to-day situations. This is due to the physical user input requirements that need to precede any group setup. The model

for the background data transfer might thus be suboptimal, but appropriate changes to the Android platform may make it highly relevant for further usage.

In the future, we plan to utilize the proposed model in the Social Devices (SD) concept [27], where the devices proactively augment people in their daily activities as well as support collaboration in heterogeneous multi-device environments [28], [29]. Previously, with the SD concept, we studied the possibilities of using BLE for coordinating the devices [30]. Despite the fact that BLE fits well with more lightweight communication required for the coordinations flow, it does not fulfill the requirements of transferring massive data.

In many SD use cases, the digital content is an essential part of the user experience. The D2D links in SD could become the key to efficient sharing and accessing data on all the co-located devices. With SD, the interactions between the devices are proactively triggered based on social relationships of the device owners. This information – that we name the social proximity graph – could then be utilized for establishing the links between the devices. While the D2D links in Android 6.0 still require direct human input, this type of filtering could help avoid unnecessary user interventions.

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