Abstract—Device-to-Device (D2D) communication has gained attention due to its potential to reduce data traffic in mobile operator networks. Several models and algorithms for efficient D2D communication have been proposed recently. However, despite the availability of D2D communication technologies in most current devices, there are few real-world performance evaluations using such communication model. Aiming to fill this gap, this paper presents an experimental evaluation of D2D communication using off-the-shelf devices. To achieve this goal, we propose ShareFile, a tool to measure the performance of content sharing through Wi-Fi Direct in Android devices. We deployed a testbed to compare the performance of D2D communication against centralized or non-direct solutions. The results demonstrate that even small distances degrade D2D communication performance. The time to find nearby devices ranges from 400ms to 1.5s, while time to establish a connection can reach 6s and the flow rate reaches up to 6.5MBps, which is close to the 7.9MBps achieved by cloud solutions.

I. INTRODUCTION

With the improvement of wireless capabilities of mobile devices, as well as the increasing of digital content production, exchanging information has becoming a challenge for the mobile Internet service providers. Indeed, global mobile data traffic grows exponentially and it is expected to be seven times higher in 2021 than in 2016 [1].

The exchange of multimedia content among mobile devices is a routine task. Traditionally, the transmission of content occurs using the infrastructured network. In such case, a device sends content to a server in the cloud, which forwards it to Clients. This results in redundancy of content transmission in the carrier’s infrastructure and consumption of costumers data allowance.

Since direct communication between nearby devices can avoid redundant transmissions, 3GPP announced the Device-to-Device Proximity Service (D2D ProSe) as an integral part of future 5G networks [2]. D2D ProSe uses Long Term Evolution-Advanced (LTE-Â) as radio technology for ad-hoc communication (inband communication). However, D2D ProSe may also exploit the unlicensed spectrum, such as Wi-Fi Direct, for ad-hoc communication (outband communication) [3].

Wi-Fi Alliance defined Wi-Fi Direct as a certification for devices that support ad-hoc communication [4]. In Wi-Fi Direct, a device assumes the role of Group Owner (P2P GO) and other devices can connect to it, creating a group.

This work aims to evaluate the performance of D2D communication by using devices already available in the market. To achieve this goal, we developed ShareFile, an architecture for content sharing via D2D and infrastructural communication. ShareFile uses Wi-Fi Direct for D2D communication in Android devices without modifications in the embedded operating system. Therefore, ShareFile enables group creation and content sharing between nearby devices. Additionally, ShareFile records all actions performed by users and communication protocols.

Based on these records, we have analyzed the delays for group formation, reachability and data transfer rate in relation to the size of the files and the distance between the devices. To allow comparisons with centralized approaches, ShareFile also share content using local and cloud servers.

We built a testbed, composed of mobile devices, access points and servers, to evaluate the performance of D2D communication in off-the-shelf devices. The main contributions of this work are:

• a proposition of a public available architecture for content sharing via Wi-Fi Direct on native Android devices;
• a performance evaluation of the communication D2D in a controlled scenario (testbed);
• a discussion the current limitations and challenges to implement D2D communication in off-the-shelf devices, with no OS modifications.

The remainder of this article is organized as follows: Section II discusses background and related work. Section III presents the ShareFile architecture for content sharing. Performance evaluation is presented in Section IV. Challenges and limitations about the off-the-shelf Wi-Fi Direct radios are described in Section V. Final considerations are presented in Section VI.
II. BACKGROUND

A. Wi-Fi Direct

Given the wide use of Wi-Fi technology in many types of devices, a natural way for communication to progress is by device-to-device connectivity, i.e., without intermediary elements, like access points. Therefore, Wi-Fi could be used to exchange information among nearby devices. Figure 1 illustrates two modes of communication between mobile devices. In infrastructured network, a central entity manages the connection (Figure 1a), while in D2D communication, the connection occurs in an ad-hoc fashion (Figure 1b).

Wi-Fi Direct is a wireless technology that allows direct communication between two or more devices using standard Wi-Fi. In Wi-Fi Direct, a device must take the lead role, called P2P Group Owner (GO). The other participants are called P2P Client, as shown in Fig 1b.

![Fig. 1. Transmission of content using infrastructured network versus Content transmission via D2D communication.](image)

A device declares itself as GO and other devices must meet and connect with the GO to join the network and become Clients. Briefly, exchanging information between devices using Wi-Fi Direct in Android Devices works as follows:

- A Device requests group creation and becomes GO
- Other devices perform a search for GO devices
- After finding a GO, a device selects the GO device and requests connection
- GO device receives an invitation from the proponent Client
- If GO device accepts the Client invitation, a communication flow is established;
- At any time, devices can exit the group. If the GO goes out of the group, the group is destroyed.

B. Related Work

The evaluation of D2D communication algorithms, such as GO selection, cluster formation, and applications are commonly performed by theoretical analysis or simulations [6][7]. However, there are still few prototype development and evaluation initiatives, highlighting [5], [8], [9], [10], and [11].

D2D communication using Wi-Fi Direct was evaluated in [5]. The authors measured the delay for detection and formation of groups. This delay can achieve up to 5 seconds and the discovery phase of neighbors has a great impact on energy consumption.

A data routing protocol using multi-hop D2D communication is proposed in [8]. The protocol clusters devices based on their topology and delay tolerance. The authors implemented a proof of concept on Android devices without presenting a performance evaluation.

A hybrid architecture, in which the network infrastructure is responsible for creating devices groups and devices of each group communicate directly through Wi-Fi Direct, is proposed in [9]. The authors show that small groups reach higher data rate and smaller delays.

A framework for D2D communication based on Wi-Fi Direct in Android devices, called Oil, is presented in [10]. The authors focus on presenting a demo and proof of concept, without presenting evaluations.

An assessment of Wi-Fi Direct between mobile devices appears in [11]. The authors propose a mobile social network for Android devices and deployed a testbed consisting of three mobile devices. The results show that Wi-Fi Direct can achieve a data rate up to 4MB/s on average.

The mentioned work tackle the still existing gap regarding the necessity of evaluating communication D2D in mobile networks, especially in real scenarios. In common, the aforementioned articles present experimentation on testbeds that is unavailable for the general public.

This paper proposes a content sharing tool, called ShareFile, for off-the-shelf devices, which can be used by the general public. ShareFile allows D2D or infrastructure communication mode and gathers metadata about communication process. In this way, we evaluated the performance of D2D communication in a real environment.

III. SHAREFILE: CONTENT SHARING

Content sharing can occur through the infrastructure network or through D2D communication. In this section, we present ShareFile, a tool for content sharing through an infrastructure network or via communication D2D. Sharing content using network infrastructures allows us to compare with the D2D communication approach.

A. Overview

ShareFile allows users to share content in three modes: D2D communication; local server; and cloud server. Figure 2 illustrates these communications models, respectively.

D2D: Devices exchange content directly. A device represents the group leader GO and several Clients can connect to it.

Local: Devices exchange data using a local server as intermediate node. ShareFile sends a broadcast beacon on the network to find the server that offers the service. Upon receiving it, the server responds to the Client and the device connects to the server to send/receive files.

Cloud: Devices exchange data using a cloud server. ShareFile sends a broadcast beacon on the network to find the cloud server that offers the service. Upon receiving it, the server responds to the Client and the device connects to the cloud server to send/receive files.
using the local network. This communication mode does not require Internet connection.

Cloud: Devices exchange content using an external server as intermediate node. An external server, Figure 2c, was used to send/receive files from the cloud. The operation is similar to the local server.

B. Event log

ShareFile records all device operations, such as searching, connection, disconnection, sending and receiving of data, using Comma Separated Values (CSV) format. Afterward, log files are transmitted to a server for analysis. The main information gathered in each action is:

- Action - (REQUEST, CONNECT, DISCONNECT, SEARCH, SEND/RECEIVED);
- Device type - (GO, CLIENT), address and name;
- Initial and final event timestamp;
- Number of devices found in the search;
- Size of the file being transmitted.

C. Implementation

ShareFile has been deployed for Android mobile devices (version ≥ 5.0) using Android API P2P, SDK minimum version 14, for D2D communication. We developed a friendly GUI to allow general public usage. Figure 3 shows the main menu and the three communication modes mentioned.

For D2D communication, this implementation of ShareFile is one-sided, that is, only Clients devices send files to the GO. Figure 4 presents the discovery phase, where the devices meet. A warning informs that traditional Wi-Fi will be turned off to allow Wi-Fi Direct to create groups. After establishing a connection, group participants can choose to share one file, a set of files, or all directory.

IV. Performance Evaluation

We evaluate the three ShareFile communication modes, which allow us to compare D2D communication on off-the-shelf devices with devices to local server and devices to server in the cloud. We considered the following metrics for D2D communication mode: i) Search time for nearby GO devices and ii) Time to establish a connection (pairing). In common to all communication models, we evaluate the network throughput by sharing a set of contents. The setup and test methodology are described below.

A. Setup

The experiments were done in a 15.6m x 6.5m cover located in the city of João Monlevade. These were performed in a barrier-free environment where the devices were placed on top of a bench and spaced apart as mentioned later. In the tests with the local and/or external server, the Wi-Fi Modem was at a distance of 1.5m from notebook and smartphone. The testbed is composed by the following equipments:

- two smartphones Motorola XT1069 16gb;
- one notebook Lenovo G400S Core i3 with 8GB of DDR3 RAM (Local Server) - Wireless Atheros Ar5b125;
- one modem Wi-Fi ZTE F660.
A 15Mbps speed Internet access was utilized by means of fiber optic links offered by the Valenet. It should be noted that at the time of testing, no other device was connected to the local network.

In each of the three scenarios a set of 37 files of varying sizes (total = 942.3MB) were transmitted, each experiment being repeated 10 times. Therefore, 2200 submissions were made in D2D (total = 55.21GB), that is, 370 submissions to [0, 1, 3, 5, 10, 15] meters. Using the local server were 370 submissions (total = 9.2GB) and 370 submissions on the external server (total = 9.2GB). Total, we have 73.61GB of information exchanged. Table I summarizes the metadata of transmitted content.

### TABLE I. CONTENT TRANSMITTED DURING EACH EXPERIMENT.

<table>
<thead>
<tr>
<th>Type (Extension)</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image (png)</td>
<td>42.0KB; 59.2KB; 60.8KB; 60.9KB; 76.3KB; 79.8KB; 84.5KB; 121.2KB; 828.9KB</td>
</tr>
<tr>
<td>Music (mp3)</td>
<td>3.2MB; 3.6MB; 4.7MB; 4.9MB; 5.7MB; 8.6MB; 7.2MB; 7.3MB; 7.6MB; 9.5MB</td>
</tr>
<tr>
<td>Document (pdf)</td>
<td>104.5KB; 314.2KB; 396.2KB; 452.8KB; 560.4KB; 985.4KB; 1MB; 2.3MB; 3.3MB; 6.6MB</td>
</tr>
<tr>
<td>Video (mp4)</td>
<td>467.7KB; 589.4KB; 2.1MB; 7.6MB; 7.9MB</td>
</tr>
<tr>
<td>Disk (iso)</td>
<td>227MB; 617.8MB</td>
</tr>
</tbody>
</table>

To assess the influence of distance between devices in D2D communication, a pair of devices were placed at [0, 1, 3, 5, 10, 15] meters from each other in each test.

The local server was connected by cable to a wireless router. An external server has fixed IP and is hosted at Locaweb3. Before each experiment for local and cloud server, the network Round-Trip-Time (RTT) was measured during 30 seconds.

### B. RESULTS

The searching time and pairing time represent an overhead to D2D communication. Figure 5 presents the Cumulative Distribution Function (CDF) for these metrics considering several distances.

Figure 5a shows the searching time. In 90% of the tests with closer devices (distance = 0), the time for a Client to find the GO was less than 450ms. Until a distance of 10m between devices, the searching time is similar, taking 477ms in average for the Client to find the GO. However, when the distance increase to 15m, the Client took at least 500ms to find the GO and in 90% of the experiments this time was greater than 1050ms.

Once devices meet each other, they must pair and establish a connection. Figure 5b shows the CDF of the pairing timing among Client and GO. Pairing time increases with the distance between devices. At distances shorter than 3m, Client and GO devices connected in less than 1.5s. The pairing time was less than 2s for 70% of the tests for devices 5 and 10m apart from each other. For devices far away 15m from each other, only 20% of the connections took less than 2s. The averages and standard deviations for all distances analyzed are summarized in Table II.

![Image](https://via.placeholder.com/150)

### TABLE II. AVERAGE PAIRING TIME AND STANDARD DEVIATION.

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Average (ms)</th>
<th>Standard Deviation (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1203.5</td>
<td>48.1</td>
</tr>
<tr>
<td>1</td>
<td>1342.7</td>
<td>37.5</td>
</tr>
<tr>
<td>3</td>
<td>1375.3</td>
<td>19.7</td>
</tr>
<tr>
<td>5</td>
<td>1375.3</td>
<td>19.7</td>
</tr>
<tr>
<td>10</td>
<td>2847</td>
<td>523</td>
</tr>
<tr>
<td>Aggregate</td>
<td>1932</td>
<td>131</td>
</tr>
</tbody>
</table>

Figure 6 depicts the influence of file size and distance on data rate and transmission time metrics. As shown in Figure 6a, the average data rate between nearby devices was 5,700KB/s, with peaks of up to 8,710KB/s. On the other hand, for 15 m distance, the average flow rate was 4,266KB/s. Indeed, processing time has an impact on the measurement of transfer time in smaller files. In general, the transmission rate between devices was on average 5,000KB/s, with a standard deviation of 1,448KB/s.

These results are critical for solutions where the infrastructure only initializes the D2D network and Wi-Fi communication in ad-hoc mode, such as Wi-Fi Direct. These solutions consider that devices connected to the same base station are close enough to communicate in an ad-hoc manner. However, for devices available in the market, the distance between them is determinant for the user experience, as shown in the results above.

The bandwidth CDFs in the local server and cloud executions are shown in Figure 8. Using a local server, Figure 8a, the bandwidth averaged 14,900KB/s against 7,900KB/s using the server in the cloud, Figure 8b. It is important to note that in up to 70% of the tests, the download flow is less than 2,600KB/s in both scenarios, which can be explained by the signal quality of the local network in which the tests were performed.

Prior to the execution of each test, the RTT was recorded for 30s. The average RTT for all tests in the local network was 4.59ms (standard deviation 16.76ms) versus 29.28ms of the server in the cloud (standard deviation 15.10).

On average, the local network and cloud throughput is 3x and 1.57x the Wi-Fi Direct throughput, respectively. In fact, local network presented the higher throughput for content sharing, as expected. However, it requires an extra effort to implement and configure the server, which makes this solution unfeasible for most cases.

On the other hand, the traditional solution for content sharing, using cloud servers, has 57% higher data rate than Wi-Fi Direct. It is important to note that sharing content

3Locaweb is a private web hosting service in Brazil - http://www.locaweb.com.br
Privacy, security and incentive mechanisms are complex issues in ad hoc network research. The main challenge to implement D2D communication in off-the-shelf devices is related to group creation and the establishment of a pairwise connection. Due to safety issues, groups should be established manually (users must accept the creation of group explicitly). Autonomous grouping creation, the basis for several algorithms in ad-hoc networks, requires low-level access to mobile operating systems, which most of users do not have. Therefore, there is still a lack of secure protocols to establish connection between devices.

In addition, as discussed in the previous section, the total time to establish a connection (searching plus pairing time) can be considered high, especially when compared to centralized solutions. In such a case, users must support the delay caused by the communication overhead. Furthermore, Wi-Fi Direct data rate is also lower than centralized solutions data rate.

In some cases, just saving data allowance and device energy can compensate for the delay introduced by the D2D communication. In other situations, mobile Internet operators may apply techniques to incentive users to adopt D2D communication and save their resources. For instance, decreasing redundant transmissions in their infrastructure. However, incentive techniques for D2D communication are still an open challenge.
With the emergence of new paradigms of wireless networks, Device-to-Device communication is a promising approach to enable data offloading from the cellular network. In particular, content sharing between nearby devices can occur directly through the D2D communication, without making use of the infrastructured network.

Although there are several works proposing algorithms and protocols and there exist some testbeds, in this work we present an evaluation of off-the-shelf devices content sharing using D2D communication. We developed ShareFile, a tool for content sharing, that uses either Wi-Fi Direct, local servers or cloud servers. With ShareFile, no modifications is need in the mobile device operating system for D2D communication; the software is available in the repository PlayStore.

ShareFile can be used as a D2D content sharing app, as well as a tool to measure the quality of this communication mode, The developed tool is already available for general use (devices with Android) and has been prepared to be an open source tool.

From a systematic analysis, we have observed that the time to locate devices in the neighborhood and the time to establish connection grow with the distance, while the data rate decreases. For the success of the D2D paradigm, the quality of user experience is directly related to these metrics. The delay caused by searching and pairing devices can impact the quality of experience of the users.

As future work, we intend to analyze the massive use of ShareFile. In this way, we can evaluate the efficiency of D2D communication for different vendors and hardwares.

Furthermore, the application of intrinsic incentive techniques, such as gamification or rewards, certainly will promote the adoption of D2D communication paradigm as the technology for content sharing. Therefore, we plan to incorporate such incentive techniques in ShareFile to study up to what extent they can improve the usage of D2D communication.

References


