ShareFile: Sharing Content Through Device-to-Device Communication

Daniel M. Reis*, Theo S. Lins*, José Marcos S. Nogueira†, Vinícius F. S. Mota*‡

*Universidade Federal de Ouro Preto, Department of Computing and Systems, João Monlevade, Brazil
†Universidade Federal de Minas Gerais, Department of Computer Science, Belo Horizonte, Brazil
‡Universidade Federal do Espírito Santo, Department of Informatics, Vitória, Brazil
danielmartinsreis@gmail.com,theo@decsi.ufop.br,jmarcos@dcc.ufmg.br,vinicius.mota@inf.ufes.br,

***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-A)* 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 infrastructure communication. *ShareFile* uses *Wi-Fi Direct* for *D2D* communication in Android devices[1] 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.

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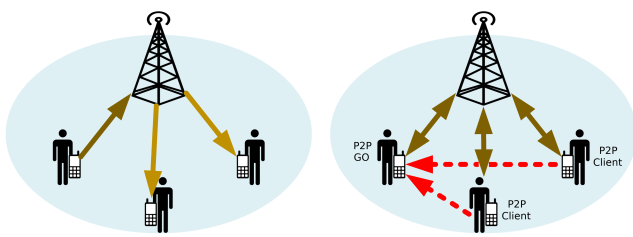
[1] *ShareFile* is available for Android devices in *Google PlayStore* in *<goo.gl/gwEC3d>*

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, ie., 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.



(a) Transmission of content using infrastructured network. (b) Submission of content using *Wi-Fi Direct*.

Fig. 1. Transmission of content using infrastructured network versus Content transmission via *D2D* communication.

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 [2]:

- 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].

[2]Readers interested in *Wi-Fi Direct* details can refer to [5].

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 *Oi!*, 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

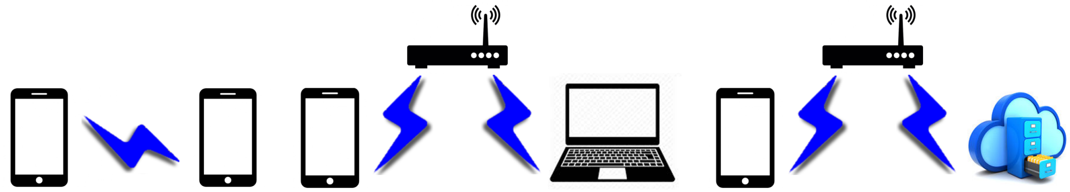
Content sharing can occur through the infrastructure network or through *D2D* communication. In this section, we present *ShareFile*, a tool for content sharing through an infrastructure network or via communication *D2D*. Sharing content using network infrastructures allows us to compare with the *D2D*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



(a) Transmission of content via communication *D2D*.
(b) Content streaming via local server.
(c) Transmission of content via external server.

Fig. 2. *ShareFile* - Content Transmission

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, 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 $\geq$ 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.

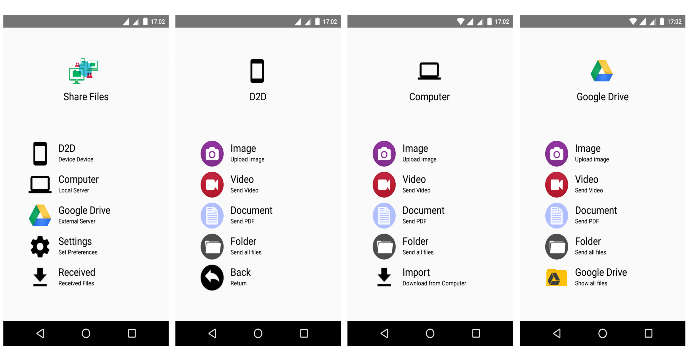


Fig. 3. *ShareFile*: Main menu and communication models.

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.

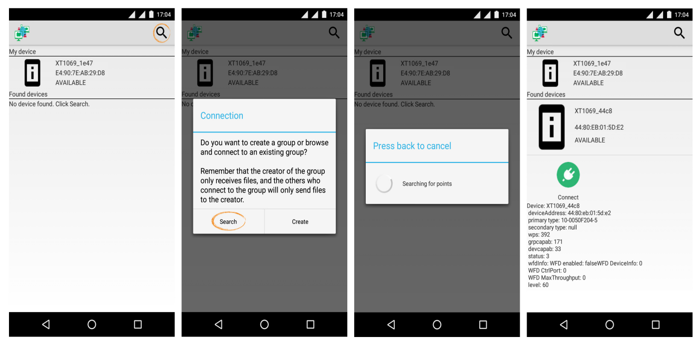


Fig. 4. *ShareFile*: *Wi-Fi Direct* Group searching phase.

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.

Content	
Type (Extension)	**Size**
Image (png)	42.6KB; 59.2KB; 60.8KB; 60.9KB; 68KB; 76.5KB; 79.8KB; 84.5KB; 121.2KB; 828.9KB
Music (mp3)	3.2MB; 4.6MB; 4.7MB; 4.9MB; 5.7MB; 6.6MB; 7.2MB; 7.3MB; 7.6MB; 9.5MB
Document (pdf)	104.5KB; 314.2KB; 396.2KB; 452.8KB; 560.4KB; 985.4KB; 1MB; 2.3MB; 3.3MB; 6.6MB
Vídeo (mp4)	467.7KB; 589.4KB; 2.1MB; 7.6MB; 7.9MB
Disk (iso)	227MB; 617.8MB

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 Locaweb[3]. 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 paring 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.

[3]Locaweb is a private web hosting service in Brazil - http://www.locaweb.com.br

TABLE II. AVERAGE PAIRING TIME AND STANDARD DEVIATION.

Distance (m)	Average (ms)	Standard Deviation (ms)
0	1203.5	48.1
1	1342.7	37.5
3	1375.3	19.7
5	1375.3	19.7
10	2847	523
15	2708	212
Aggregate	1932	131

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 5,008KB/s, with a standard deviation of 1,448KB/s. Although the influence of the distance is small for files smaller than 200MB, for larger files the difference can reach more than 100s, as occurred in files larger than 600MB, as shown in Figure 6b.

Figure 7 presents the CDF for the data rate for each of the considered distances. In 75% of the experiments, third quartile (Q3), content transfers at distances up to 3m have obtained up to 6,591KB/s of rate. For distances greater than 5m, the third quartile was less than 5,900KB/s, that is, 10.4% lower.

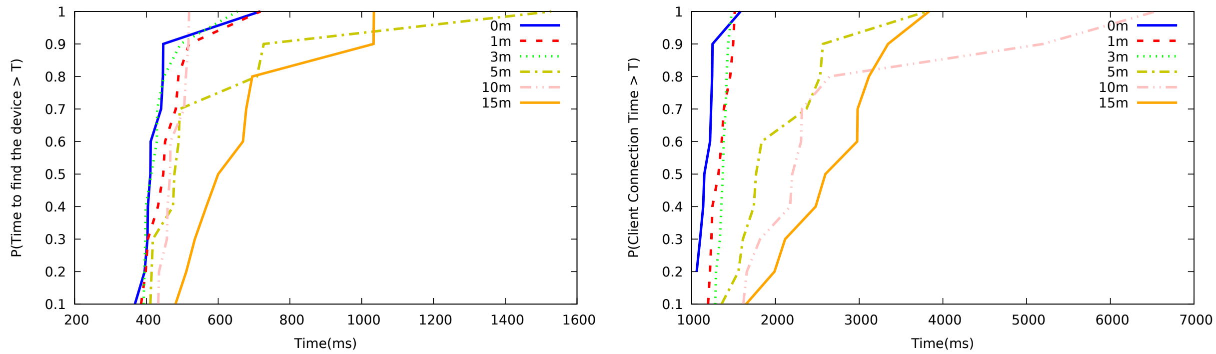
These results are critical for solutions where the infrastructure only initializes the *D2D* network and *Wi-Fi* communication in *ad-hoc* mode, such as *Wi-Fi Direct*. These solutions consider that devices connected to the same base station are close enough to communicate in an *ad-hoc* manner. However, 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.

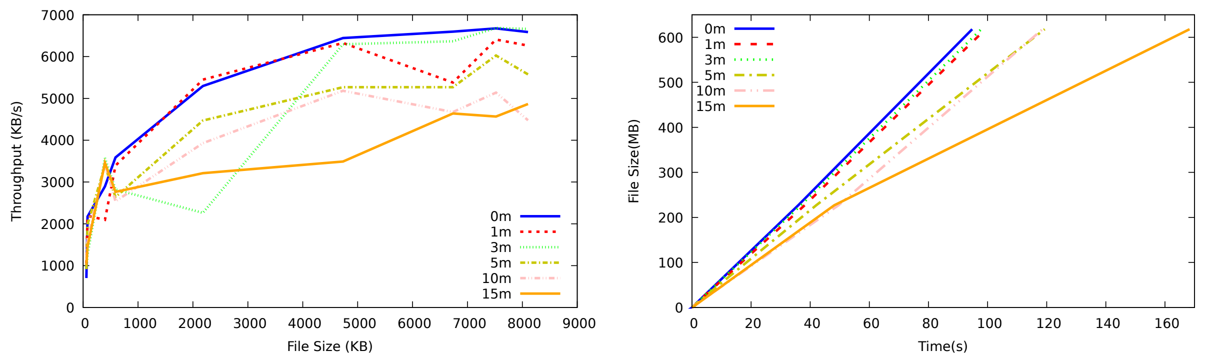
On the other hand, the traditional solution for content sharing, using cloud servers, has 57% higher data rate than *Wi-Fi Direct*. It is important to note that sharing content



(a) Time to find *GO*.

(b) Connection establishment time.

Fig. 5. *Wi-Fi Direct* time to search and pair *GO* and *Client*.



(a) *Average data rate - D2D Communication.*

(b) *Transmission time.*

Fig. 6. Influence of file size and distance on the *D2D* transmission.

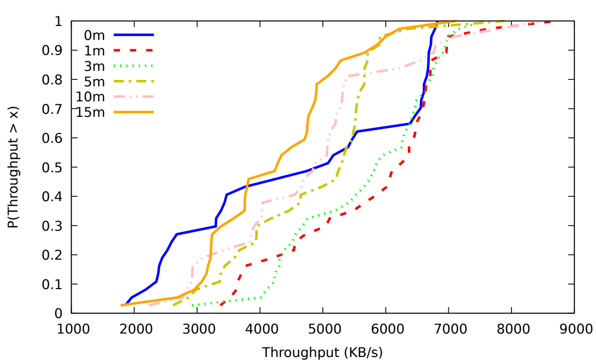


Fig. 7. Bandwidth over distance - *D2D* communication.

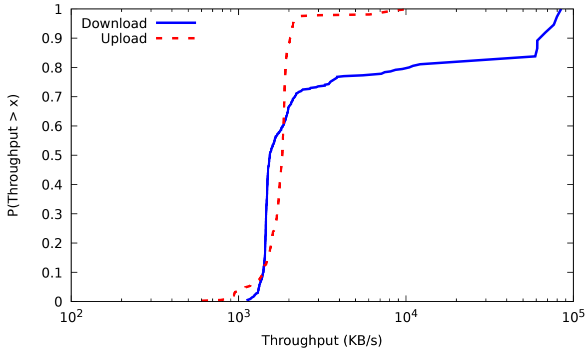
through clouds implies in more users devices resources consumption. For instance, to send and receive content, users may spend their monthly data allowance. Also, LTE communication consumes more battery than *Wi-Fi* [12]. Resource savings can compensate for lower quality of experience of the *Wi-Fi Direct* communication.

V. Challenges and Limitations

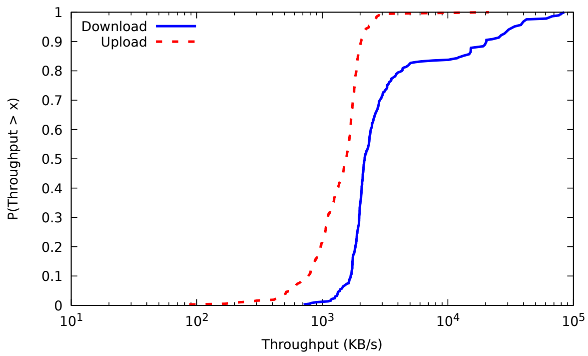
Privacy, security and incentive mechanisms are complex issues in ad hoc network research. The main challenge to implement *D2D* communication in off-the-shelf devices is related to group creation and the establishment of a pairwise connection. Due to safety issues, groups should be established manually (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.



(a) Local server bandwidth.



(b) Server bandwidth in the cloud.

Fig. 8. Bandwidth centralized solutions.

VI. Conclusion

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.

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