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P2P Group formation enhancement for opportunistic networks with Wi-Fi Direct

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***Abstract*—The Wi-Fi Direct technology was proposed by Wi-Fi Alliance in order to facilitate device-to-device communications in Wi-Fi. The Wi-Fi Direct technology offers new possibilities to deploy opportunistic and cooperative networks. The actual state of the Wi-Fi Direct specification lacks optimization for P2P grouping and creating opportunistic networks. In this paper, we present a new P2P group formation method for opportunistic networks and we introduce the concept of nominating a backup group owner that can replace the group owner of a broken P2P group. In addition, we investigate required times to form a P2P group of variable number of nodes and evaluate the efficiency of the backup group owner. Results show that our proposed P2P group formation method, in addition to the introduction of the backup group owner, can facilitate and accelerate opportunistic P2P grouping.**

***Index Terms*—Wi-Fi Direct, Cooperative Networks, Opportunistic Networks**

I. Introduction

In opportunistic networks and collaborative networking, wireless peers have to discover each other in a short time and then discover what kind of services are provided by each peer. If peers are interested in a published service by a discovered peer, then they can be aggregated into groups, and share/consume the advertised service (video streaming, software updates, etc.). Several technologies and standards were published by hardware manufacturers and working groups in order to simplify the device to device wireless connectivity and collaborative networking. 802.11 Ad-hoc mode (also named infrastructure-less mode) already offers device to device wireless connectivity. But the Ad-hoc mode lacks of efficient power saving support and setting-up the Ad-hoc mode is a complex procedure. In addition, Ad-hoc networks can cause a lot of interference because each device has to have a separate connection with other devices [1]. To overcome the drawbacks of the Ad-hoc technology, Wi-Fi Alliance has proposed a device-to-device wireless connectivity technology, called Wi-Fi Direct (named also Wi-Fi P2P) [2]. Using the Wi-Fi Direct technology, devices can dynamically organize themselves to form a P2P group. In order to establish the P2P group, P2P devices have to firstly discover each other and then negotiate the role that each device shall assume. Two roles are possible for P2P devices in a P2P group: Client and Group Owner (GO). The Group Owner device acts as a Wi-Fi access point (AP). P2P devices acting as clients connect to the GO using the same AP association mechanism as connecting to a conventional Wi-Fi infrastructure AP. The election of the GO is based on a P2P attribute, named GO Intent value. Devices exchange their GO Intent in a GO negotiation procedure and then decide which one will act as a GO. In the Wi-Fi Direct specification [2], the GO Intent attribute is left to P2P Device's implementation policy. In this paper, we propose and evaluate a new method to set a GO Intent that best describes the P2P device capabilities. In this paper, we first provide an overview of the Wi-Fi Direct technology and we describe in details its GO negotiation and group formation procedures. In addition, we propose a new approach to accelerate the group formation procedure in the Wi-Fi Direct technology. This paper is organized as follows. An overview of Wi-Fi Direct technology is provided in Section II, which details the main Wi-Di Direct functionalities: device discovery procedure, service discovery procedure and the P2P group formation. Section III introduces related work. The proposed P2P group formation method and the backup GO are presented in Section IV. Section V presents an experimental evaluation of Wi-Fi Direct that analyses the performance of its device discovery and group formation procedures, and compares it to our proposed method for opportunistic P2P grouping. Conclusions and future works are then outlined in Section VI.

II. Overview of Wi-Fi Direct (P2P)

The Wi-Fi Direct [2], named also Wi-Fi P2P, is a device to device technology proposed by Wi-Fi Alliance. The Wi-Fi Direct technology is based on the Wi-Fi infrastructure mode. Wi-Fi Direct devices are able to connect to each other and form P2P groups in order to exchange and share content quickly and easily, without having to go through the wireless access point (AP), as it is traditionally the case. In order to form a P2P group, Wi-Fi Direct devices have to run an optional phase called Service Discovery and two mandatory procedures: Device Discovery and Group Formation.

A. Device Discovery procedure

Device Discovery procedure in Wi-Fi Direct consists of two phases: Scan and Find. In the Scan phase, the device looks for existent P2P Groups and Wi-Fi networks, by scanning all the supported wireless channels as in a traditional Wi-Fi scan (active or passive). During the Find phase, the P2P device alternates between Search and Listen states, for randomized time periods, on the Social channels, namely channels 1, 6 or 11 in the 2.4 GHz band. In the Search state, the P2P device performs active scanning by sending Probe Request frames in each of the social channels in order to discover other devices, which are in the Listen state on the same channel. In the Listen state, the P2P device stands in its listen channel, and listens for Probe Request frames. When it receives a Probe Request frame, the device responds with a Probe Response frame. The time spent in each state is randomly distributed and it can depend on the implementation policy. The Probe Request and Probe Response frames can be transmitted by any P2P Device. These frames include one or more P2P Information Element (IEs) and the Wi-Fi Simple Configuration Information Element.

A user may also use out-of-band device discovery if the P2P device supports Near Field Communication (NFC) similar to legacy Wi-Fi.

After the peer discovery, the P2P device can proceed to a Service Discovery before starting the group formation with discovered peers.

B. Service Discovery procedure

The Service Discovery procedure is an optional frame exchange that may be performed at any time to any discovered P2P Device, for example following a successful Device Discovery procedure and prior to group formation. This Wi-Fi Direct feature provides the ability to support Service Discovery at the link layer. Based on discovered services, a P2P device decides whether to continue the group formation or not. Service Discovery queries are generated by a higher layer protocol, e.g. Bonjour [3] or UPnP [4] and transported at the link layer leveraging the Generic Advertisement Service (GAS) protocol/frame exchange as defined in IEEE Standard 802.11-2012 [5]. The P2P group formation in Wi-Fi Direct can be based on the available services on each device, i.e. the device that offers a service can have the role of a GO, and the device requesting the advertised service can simply act as a client.

C. Group Formation procedure

After a successful P2P device discovery and a service discovery (optional) procedure, the P2P group formation procedure starts. Wi-Fi Direct defines three methods of group formation: standard, autonomous and persistent. In standard group formation, roles of P2P devices are defined during the P2P group formation: one P2P device is elected as group owner, and the other device will act as a P2P client. In autonomous group formation, a P2P device announces itself as GO without any GO negotiation phase and starts sending beacons (as a conventional Wi-Fi AP). In persistent group formation, the P2P devices that were part of a previous P2P group can quickly re-instantiate the group by using an invitation procedure.

The GO negotiation in the standard P2P group formation is a three-way handshake (request/response/confirmation) whereby two devices agree on which device will act as P2P GO and on the channel where the group will operate (the operating channel can be in the 2.4 GHz or 5 GHz bands). In order to agree on the device that will act as P2P GO, P2P devices exchange a numerical parameter, named the GO Intent value, within the three-way hand-shake. The device declaring the highest Intent value becomes the P2P GO. After deciding which device will act as Group Owner, both devices move to the negotiated operating channel. The elected GO starts to operate in the Access Point mode, and broadcasts beacons with the negotiated SSID. The GO negotiation request/response frames contain P2P attributes similar to those of the Probe Request/Response frames: P2P Device info, Channel list, Listen Channel, Operating Channel, etc.

D. Intent value computation

In the standard group formation procedure, each P2P device sends its GO Intent value. The Intent value reflects the willingness of a P2P device to become a GO in the P2P group. According to the specification, the Intent value can vary from 0 to 15. The device with the larger Intent value becomes GO. A random Tie breaker bit is included in the GO negotiation request, and its complement is sent in the GO negotiation response. If the Intent values of both P2P devices are equal, then the device sending the Tie breaker bit equal to 1 becomes the GO. In the Wi-Fi Direct specification, the GO Intent attribute is left to P2P Device's implementation policy. In the Android implementation, the GO Intent is chosen randomly, without taking into account any characteristics of the device. We believe that the Intent value shall be carefully chosen as detailed in our previous work in [6]. Most probably, the more useful approach to choose Intent value is based on the device capabilities to serve as GO. Once selected, the GO shall serve all associated P2P client devices for communication. For example, in the case of video content distribution, all the data is first received by the AP and then forwarded to the GO which in turn forwards it to the destination P2P client in the group. Therefore, there is a need to select very carefully the GO in order to achieve better performance and enhance the overall Quality of Service. The capabilities of a P2P device when acting as GO depend on the application. Different device parameters can be considered in the computation of the Intent value: battery power level, processing capability, signal quality to an AP, number of neighbor devices, etc.

Based on the above observation, we believe that the Intent value which defines the desire or the capability of a P2P device to become a GO shall be computed by considering the combined effect of all these parameters. A simple approach to compute the Intent value is described in [6].

III. Related work

Authors in [7] have made preliminary experimental results that portray the performance of the group formation delays (standard, persistent and autonomous) and energy efficiency in Wi-Fi Direct. Their experimental test-bed consisted of two nodes by using laptops with a customized implementation of Wi-Fi Direct framework. Other researchers have studied how the use of Wi-Fi Direct can be useful for example: in creating opportunistic networks ([8] and [9]), in collaborative data loading [10] and in the LTE traffic offloading ([11] and [12]). In our work, we provide an enhancement to the Wi-Fi Direct group formation by improving the selection of the GO and allowing multiple devices to form a P2P group in an optimized delay. Authors in [13] have presented a similar approach to our method. They used the RSSI measure to reflect the willingness of a device to take the role of a Group Owner. In our case, devices were assigned random Intent values for the sake of simplicity. In addition, contrary to our work, the method proposed in [13] only uses the Probe Request frame to exchange GO Intent value and does not mention how to handle the discovery of a new device that has a better GO Intent than the actual GO. Our work can be considered as an enhancement to the method proposed in [13].

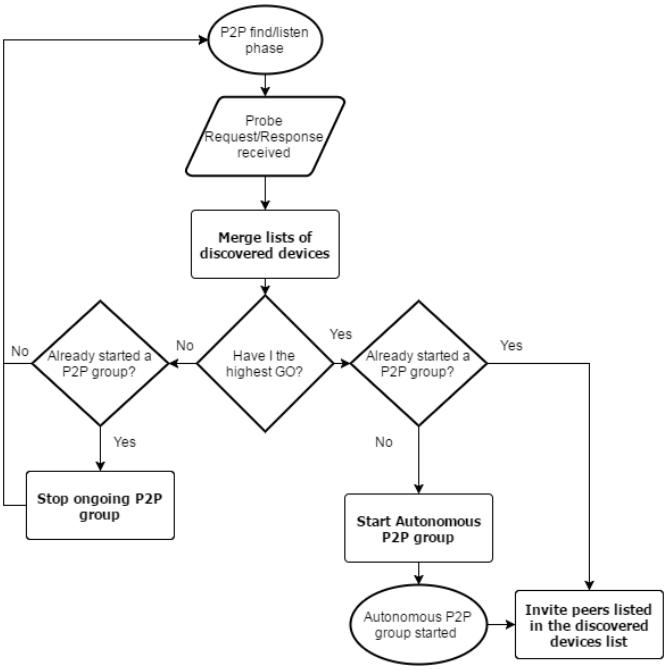

Fig. 1. Devices state diagram with the proposed P2P group formation method

IV. Description of our proposed method

As described in Section II-C, the standard group formation procedure requires a 3-way handshake for the GO negotiation and other messages exchanges in order to form a group within two devices discovering each other. In addition, the GO negotiation is limited to two devices, which can lead to the election of a GO that is not necessarily the best candidate within its neighbors. To overcome these limitations, we propose a new group formation procedure.

A. Proposed P2P group formation procedure

The new procedure consists of eliminating the 3-way handshake of the GO negotiation, and including all required information, to form a group, in the already defined Wi-Fi Direct frames: Probe Request and Probe Response frames. Our method consists in inserting the device GO Intent and the list of already discovered devices (and their corresponding GO Intent) in the P2P Information Element (IE) attributes available in the Probe Request and Probe Response frames. Therefore, when a device receives the Probe Request or the Probe Response frame from a second device, it can easily determine which of the device is more capable of being a GO without a need for a GO negotiation. The device with the highest GO Intent can start an autonomous group formation and invite all discovered devices to join its group. Figure 1 is a state diagram that describes the proposed P2P group procedure. This method offers P2P devices the ability to have an idea about discovered neighbors' capabilities. In addition, by using the Probe Request and Probe Response frames, the proposed method will be **backward compatible** with P2P devices that do not implement the proposed method. By eliminating the GO negotiation, the group formation between two devices can be accelerated. One of the most interesting features provided by the proposed method is the ability to elect the best GO from more than two neighbor devices, which is not possible with the current state of the Wi-Fi Direct specification. Another important feature of the proposed method is that each device can build a list of neighbor devices with their corresponding Intent. In such way, when the actual GO leaves the group or do not have the highest Intent anymore, all peers have already a prior knowledge of which device will be elected as a replacement of the actual GO. The description of this backup GO is detailed in Section IV-B.

B. Backup Group Owner

In the current Wi-Fi Direct specification, when a GO device leaves a P2P group, then the P2P formation is broken, and a new P2P GO negotiation has to be made. There two cases where the actual GO of a P2P group have to be replaced by another device: i) the GO leaves the P2P group or ii) the GO's Intent value is no more the highest within its neighbors (due to the joining of a device, with a higher GO Intent, to the created P2P group). Making a new (conventional) P2P group formation is time consuming and does not necessarily elect the device with the highest Intent value.

Our proposed P2P group formation method addresses this issue. In fact, all devices have a list of all discovered devices and their Intent values. Thus, all devices have already a knowledge about the device with the second highest Intent value within their neighbors. We call the second highest Intent value device as a backup GO.

When clients of a P2P group notice that the actual GO is no more reachable or does not have the highest GO Intent value any more, they update their discovered list, and start a new

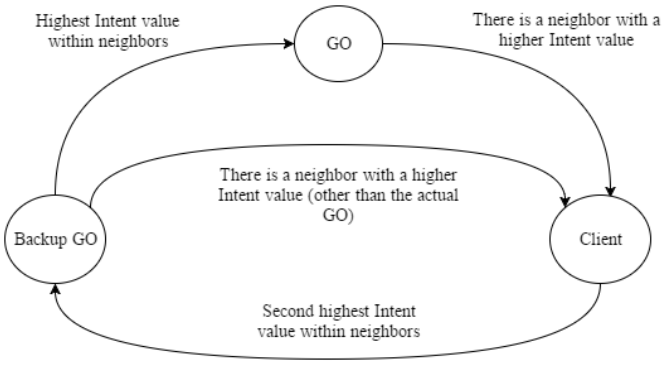

Fig. 2. Device state machine

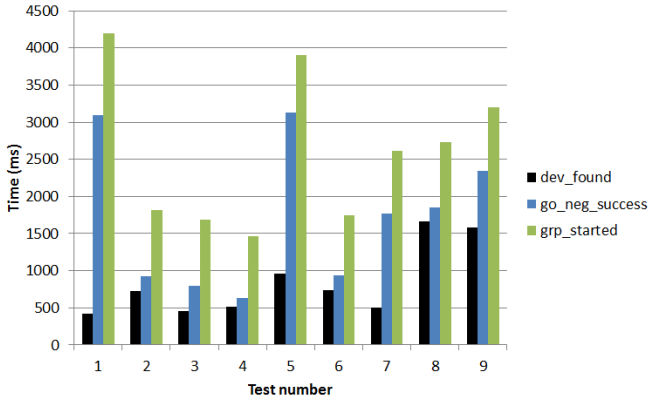

Fig. 3. Discovery and group formation examples

P2P group formation procedure. The backup GO becomes the device with the highest Intent value and thus elected as new GO, as described in Figure 2. The newly elected GO starts a new (autonomous) P2P group and invites all peers in its discovered devices list.

V. Experimental evaluation

This sections portrays the performance of our proposed P2P group formation procedure, and the efficiency of the introduction of the backup GO.

A. Test-bed description

The test-bed consists of an Ubuntu-server virtual machine with several virtual wireless interfaces. Each virtual wireless interface is attached to a different P2P node. We created the virtual network interfaces using mac80211_hwsim [14]. The mac80211_hwsim driver is a Linux kernel module and is used for testing MAC functionality and user space tools such as wpa_supplicant/hostapd. The wpa_supplicant module is an implementation of the WPA Supplicant component. It is used for controlling the wireless connection and it allows the use of Wi-Fi Direct [15]. Throughout our experiments, we assume that all devices have identical capabilities (but different Intent values) and we do not take into account the improvement/drop of the per-device throughput/battery. In addition, we presume that all devices are discoverable by each other. Furthermore ,in order to automatize the test execution, we always pre-provision devices with a Wi-Fi Protected Setup (WPS) PIN .

B. P2P group formation

As described previously, the Wi-Fi Direct specification defines three types of P2P group formation: standard, autonomous, and persistent. The difference between the standard and persistent P2P group formation is the absence of the GO negotiation phase in the persistent P2P group formation. In fact, the persistent mode setups a previously created group, and thus, each device has already a knowledge about its role in the P2P group. The device discovery algorithm in the persistent mode is the same as in the standard mode. In the autonomous mode, a device claims itself as a GO and starts acting as an AP, without waiting for the discovery of any device in its neighborhood. In this section, we analyze the required time to establish a P2P group in the standard mode. The group formation procedure consists of several steps. First of all, devices (A and B) need to discover each other. The device discovery time is random as specified by the Wi-Fi Direct specification. Once device A discovers device B, they start a GO negotiation. Device A sends a GO negotiation request to device B, and device B replies with a GO negotiation response (with success status). Device A replies with a GO negotiation confirmation with a success status. The device with the highest GO Intent (device A for example) starts the group formation by activating the AP-mode. Device B tries then to connect to device A (the GO). Figure 3 shows examples of delays when two devices try to form a group and connect.

Figure 3 depicts the elapsed time in each phase (discovery/negotiation) of a device (elected as client). Time zero is the start of the finding phase. dev_found bars represents the moment when it discovers another device (during the finding phase). $go\_neg\_success$ is the moment when the device receives a GO negotiation response, and the negotiation is successful. $grp\_started$ represents the moment when the group is successfully formed and the client is connected to the GO. The Cumulative Distribution Function (CDF) of the P2P group formation is depicted in Figure 4. A total of 70 tests

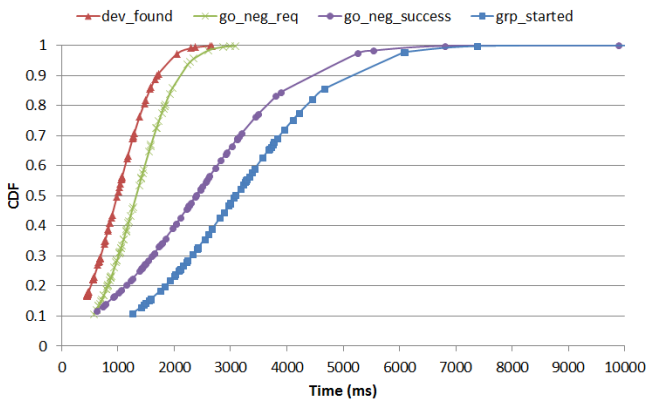

Fig. 4. CDF of P2P group formation phases

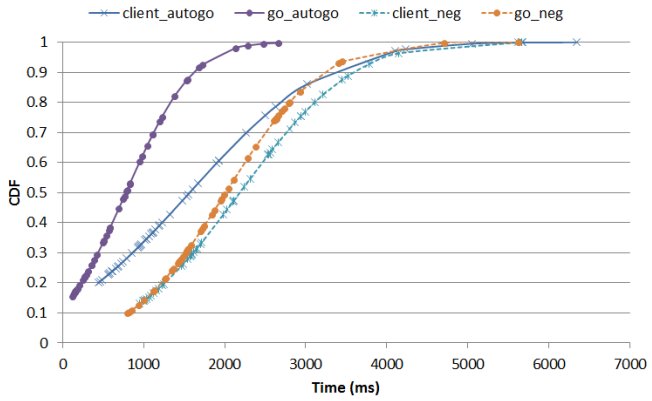

Fig. 5. Two devices P2P group formation time comparison

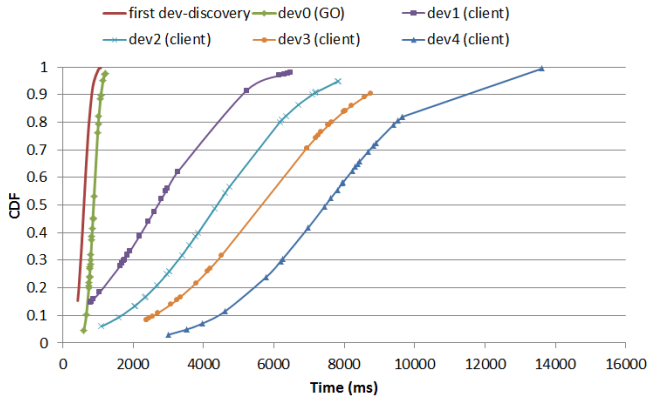

Fig. 6. Five devices P2P group formation time comparison

were performed to measure the discovery/group formation procedures. For sake of clarity, only 9 of these tests are shown in Figure 3. Figure 3 and Figure 4 show the randomness resulted from the Wi-Fi Direct discovery algorithm. In average, the device discovery time requires $1070ms$. The time elapsed to negotiate the GO and form a group can vary from $850ms$ to $9000ms$ and is in average equal to $2198ms$ (the median is equal to $1958ms$). The time required to form a group once the GO negotiation is finished successfully, is in average equal to $903ms$ (the median is equal to $873ms$).

As depicted in Figure 3 and Figure 4, devices spent more than 50% of the time during the GO negotiation phase once they discovered another device. The evaluation shows that there is room for an improvement if the procedure of the GO negotiation is combined with the device discovery phase as described in Section IV. The next section is an evaluation of the proposed method for the P2P group formation.

C. Evaluation of the proposed P2P group formation

As explained in the studies [8] and [13], with the current state of Wi-Fi Direct specification, it is hard to manage a variable number of nodes joining the same group. The P2P group formation delays can increase rapidly when the number of neighbor devices increases. In the next sections, we evaluate our proposed P2P group formation for the following number of devices: two devices, and five devices.

1) Two devices: To evaluate the proposed P2P group formation procedure, we start by measuring the delay performance of P2P group formation between two devices. Figure 5 shows the CDF of the required time to form a P2P group between two devices. Dashed-lines represent the conventional P2P group formation (using a P2P GO negotiation). Solid lines represent our proposed P2P group formation. The results confirm the fact that the proposed method is faster than the conventional P2P group formation between two devices. The median P2P grouping time is improved by 20% when the proposed P2P group formation procedure is used.

2) Five devices: The evaluation of the P2P group formation in the case of five devices is a complex task due to the randomness of the device discovery algorithm. Several combinations can be obtained when devices have to make a GO negotiation with the first discovered device. Most of the time, two P2P groups are formed. The formed group that contains three (or more) devices has a high probability that its GO isn't actually the device with the highest GO Intent. As an example, if we consider three devices A, B and C, with respective GO Intent equal to 1, 2 and 3. If devices A and B discover each other and form a P2P group before discovering device C, then the GO will be device B (with an Intent equal to 2). Device C will join later the created P2P group. In this case, device C will have a higher GO Intent (equal to 3) than the GO (device B with a GO Intent equal to 2). The complexity of Wi-Fi Direct to manage a variable number of nodes is well-detailed in [8]. In our proposed P2P group formation, discovered devices (and their GO Intent) are shared between neighbors during each Probe Request/Response frames exchange. If a device within an already created P2P group discovers another device (out of the group) with a higher GO Intent than the current GO, then it will notify all other peers of the group and switch to the new P2P group created by the discovered device. To test the proposed method, each device will proceed as described in Figure 1. Once the GO is elected, the latter has to invite all discovered devices to join him. For this purpose, in our experiments, the GO will sequentially invite discovered devices so that it doesn't cause any joining failure, i.e. the next device will be invited just when the already invited device have successfully joined the P2P group. Figure 6 shows the CDF of the elapsed time of each device trying to associate with the created P2P group. The solid line with no marker represents the moment when a first device is discovered. Device $dev0$ was selected as a group owner (with the highest GO Intent equal to 7). The other devices have a smaller GO Intent than $dev0$. Obtained results show how the proposed P2P group formation method can be very efficient to accelerate the grouping of multiple devices. The elapsed time to form a P2P group with 5 devices is equal in average to $8000ms$. $8s$ to form a P2P group, using our proposed method with 5 devices, is almost three times faster than the conventional Wi-Fi Direct P2P group formation procedure, as measured in [8] and [13].

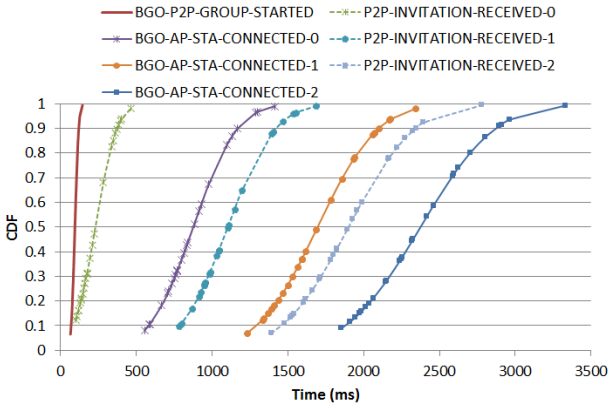

Fig. 7. Backup GO becoming a GO and inviting peers

D. Evaluation of the Backup GO

In this section, we evaluate the latency of re-grouping a broken P2P group. We assume that the GO of a P2P group formation has left (or turned off). The backup GO takes the lead, becomes a GO (autonomous P2P group formation) and invites all other peers to join him. Figure 7 shows the CDF of the elapsed time regrouping all devices. The red solid line, with no marker is the time elapsed creating a new P2P group since the backup GO has been disconnected from the former GO. Dashed lines represents the moment when a device has received an invitation from the GO (former backup GO) to join the new formed P2P group. The experiment shows that having a backup GO is very useful when the P2P group is broken. Short times are required to regroup the devices of a broken P2P group. Contrary to the conventional P2P group formation of Wi-Fi Direct, regrouping devices of a broken P2P group requires a new GO negotiation, and the newly elected GO is not necessarily the best amongst its neighbors.

VI. Conclusion and Future Works

The current status of Wi-Fi Direct specification makes the deployment of opportunistic networks a complex task. Dynamic nodes' characteristics and the randomness of the Wi-Fi Direct device discovery algorithm have a high influence on the smooth functioning of the P2P group formation. We analyzed the several steps of the P2P group formation procedure, and we found out that the GO negotiation can cause delays and bad devices' roles assignment. In addition, the P2P group formation in Wi-Fi Direct is not efficient when the number of devices is more than two.

Our evaluation showed that the conventional P2P group formation (within two devices) can take from 2 to 3 seconds. To enhance the P2P group formation delays, we have proposed a new P2P group formation procedure (compatible with the conventional P2P group formation) for opportunistic networks. Results show that the proposed P2P grouping method offers a real gain of time and an efficient role assignment when the number of devices is more than two. Furthermore, the introduction of a backup GO simplified the regrouping of a broken P2P group, and most importantly, it helped avoiding a considerable delay and a bad device's role assignment that would otherwise occur due to the conventional P2P GO renegotiation.

Future work will consist in implementing the proposed method on android smartphones and studying its impact on devices' throughtput and lifetime.

VII. Acknowledgment

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