WiFi Direct Internetworking

António Teófilo[*] [†]
ADEETC, Instituto Superior de Engenharia de Lisboa,
Instituto Politécnico de Lisboa
Portugal
ateofilo@deetc.isel.ipl.pt

Hervé Paulino
NOVA LINCS, DI,
Faculdade de Ciências e Tecnologia,
Universidade NOVA de Lisboa
Portugal
herve.paulino@fct.unl.pt

João M. Lourenço
NOVA LINCS, DI,
Faculdade de Ciências e Tecnologia,
Universidade NOVA de Lisboa
Portugal
joao.lourenco@fct.unl.pt

ABSTRACT

We propose to interconnect mobile devices using WiFi-Direct. Having that, it will be possible to interconnect multiple off-the-shelf mobile devices, via WiFi, but without any supportive infrastructure. This will pave the way for mobile autonomous collaborative systems that can operate in any conditions, like in disaster situations, in very crowded scenarios or in isolated areas. This work is relevant since the WiFi-Direct specification, that works on groups of devices, does not tackle inter-group communication and existing research solutions have strong limitations.

We have a two phase work plan. Our first goal is to achieve inter-group communication, i.e., enable the efficient interconnection of WiFi-Direct groups and be able to transmit data on top of these connections. We will then proceed to automatic network formation, i.e., to the development of algorithms for group formation by electing group heads, members and gateways nodes, taking into consideration the topologies previously proposed.

We already developed three inter-group communication topologies, named GO2CR, GOGO and GOCRGO, and we are just starting the definition of the network formation algorithms.

KEYWORDS

Wi-Fi Direct, Mobile Networking, Device-to-Device Communication, Autonomous Networks, Android.

1 INTRODUCTION

The processing and storage capabilities of today's mobile devices makes them increasingly suitable to play the role of small mobile servers, providing services to nearby devices. Besides that, they now have multiple communications technologies, such as WiFi , WiFi-Direct (WFD), Bluetooth (BLT), GSM / UMTS / LTE, allowing them to communicate in a wide scope of situations. Of these, WFD distinguishes itself by enabling direct Device-to-Device (D2D) WiFi communication without requiring an external infrastructure. BLT, Mobile Ad Hoc Networks (MANETs) and LTE D2D also offer D2D communication, but they have some handicap: BLT have small radio range and slow data transfers, compared to WiFi ; MANETs require access to radio functionalities that are locked with current off-the-shelf mobile devices; and LTE D2D standard restricts discovery and communication services (Proximity-based Services - ProSe), outside LTE network coverage, only for Public Safety [1]. Consequently, if built, a WFD multi-group communication network will enable WiFi communication range and speed even in cases of: network infrastructure congestion, which may happen in highly crowded venues (such as sports and cultural events); or temporary, or permanent, absence of infrastructure, as may happen in remote locations or disaster situations.

WFD allows devices to form groups, with one of them, called Group Owner (GO), acting as a soft access point for remaining group members. WFD offers node discovery, authentication, group formation and message routing between nodes in the same group. However, WFD communication is very constrained, current implementations restrict group size 9 devices and none of these devices may be a member of more than one WFD group. Furthermore, the WFD specification does not tackle inter-group communication. But it does not discard it.

To circumvent these limitations, nodes can use their WFD interface to connect to one WFD group and use their WiFi interface to connect to another one, as a legacy client. There are currently several proposals for inter-WFD-group communication, that use both (WFD and WiFi) interfaces to connect two WFD groups. These, however, present several limitations, of which we highlight: the use of *broadcasts* or *multicasts* [2, 5], or the need to switch connections between nodes, breaking and re-establishing links [3].

This thesis aims to contribute in this context, enabling WFD inter-group communication with permanent connections. The main goal will be achieved in two phases: first, enabling inter-group communication; and second, enabling automatic group formation and interconnection.

2 WIFI-DIRECT INTER-GROUP COMMUNICATION

As already stated, to enable communication between two WFD groups, one device must act as a gateway connecting its WFD interface to one group and its WiFi interface to the other. However, in Android, all GO nodes have the same address (192.168.49.1/24), which prevents the gateway node to directly address both groups. Usually, devices direct all traffic to address 192.168.49.1/24 out by one interface, that is called the *priority interface* (*priInt*). So, usually, gateway nodes cannot initiate *unicast* communications in their *non-priority interface* (*non-priInt*).

The only existing communication topology for inter-WFD-group communication, with permanent connections, is the one proposed in [2], that we call Group-Owner Client-Relay (GOCR) topology. However, it uses *broadcasts* to enable data to go out by the *non-priInt*, and requires one extra node per group, besides the GO. In [5]

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[*] And NOVA LINCS, DI, FCT, Universidade Nova de Lisboa, Portugal

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the same topology is presented, but with the use of even more broadcasts than GOCR.

In [6] and [7], we proposed three topologies, that only require *unicast* communication, and improve over the GOCR topology. The first one, named Group-Owner 2 Client-Relay (GO2CR) topology, requires two gateway nodes to interconnect two WFD groups. Considering WiFi Range (WFR), as the generic distance of WiFi coverage range, the GO2CR needs an average of 1.5 nodes per additional WFR. The second one, named Group-Owner Client-Relay Group-Owner (GOCRGO) topology, requires only one gateway node to cross groups and needs an average of 1 node per additional WFR. The third one is the Group-Owner Group-Owner (GOGO) topology, and allows direct communication between GOs. This topology, requires Android 5 Compliant (A5C) devices as GOs and requires 1 node per additional WFR.

In [7] we presented an extensive comparison of the characteristics of these topologies, focusing on metrics such as maximum communication speed, routing operations, type of network, and redundancy. We were able to conclude that GOGO surpasses GOCR and GOCRGO surpasses GO2CR. With regard to GOGO and GOCRGO: GOGO presents better potential in cases of low and high density of nodes; while GOCRGO showed better potential for middle case scenarios. The handicap of GOGO is that it forms tree like networks, while GOCRGO can form mesh networks and benefits from possible redundancy. On the other hand, GOGO warrants connectivity, if the underlying visibility network is connected, and GOCRGO does not.

3 WIFI-DIRECT NETWORK FORMATION

Having the first goal addressed, that is, to know how to communicate between WFD groups, the next challenge is algorithms to select groups, group heads (GOs), groups members and gateway nodes.

For this task we set up three sub-goals: algorithm requirements; best existing candidates; and finally the algorithms.

We identify three general algorithm requirements, and one extra for each topologies (GOGO and GOCRGO). The first requirement is that WFD networks can't have unlimited Arbitrary Graph (AG) as the underlying network, as one WFD node is limited to 8 client connections plus one more by the WiFi interface. So WFD can only operate with AGs with a maximum degree of 9, or operate with Unit-Disk Graphs (UDGs). An UDG is a graph where nodes at radio coverage distance are always radio visible. Meanwhile, in AG nodes in radio coverage may be visible, enable to model obstacles like walls. An UDG graph have the property that we can split the set of neighbours of one node in a set of a maximum 5 independent sets of neighbours, i.e, neighbours that are not neighbours of any other neighbour from any other set.

The second requirement is that: GOs are Out-Degree Limited (ODL), that is, they are limited to connect to 8 clients (in graph theory, one arrow from node A to node B, means that A is master (GO) of B). They can also connect by WiFi to an additional node. Non-GO nodes can connect to only one node by WFD and another one by WiFi . Expressing this requirement in a different way: nodes are In-Degree Limited (IDL) of 2 connection, i.e., nodes can only be slaves of a maximum of 2 GOs, if they are not GOs. If they are GOs they are IDL of 1 connection.

The third requirement is that each node should be Two Groups Limited (TGL), that is, a node can only participate in two groups, as each node only have two interfaces, and each one can connect to only one group.

The GOGO topology also requires that the resulting network be Slave-Slave bridge Free (SSF), that is, all the gateways should be Master-Slave gateways. They can't be slaves of two GOs.

Because the GOCRGO topology can't guarantee connectivity, we can't have WFD networks only using this topology. But as this topology can build mesh networks, we want to use it together with GOGO to have mesh connected networks.

The second task is to identify existing network formation algorithms that can be used with the identified requirements. The closest field that can provide algorithms with similar requirements is the Bluetooth Scatternet Formation (BSF). However, BLT differs from WFD, as it enables one node to be slaved by several masters (GOs), that is, BSF do not produce TGL networks.

Consequently, for GOGO, we need ODL, TGL and SSF, and we found BlueTrees-ODL [8] as the only candidate. As this algorithm needs to elect a root node, before start, we want to develop a more efficient algorithm without that requirement. This algorithm forms a tree like network, starting at the root node. To build a GOCRGO-GOGO mesh network, the network must be ODL, TGL and to be able to form mesh networks, and we didn't found any direct candidate.

As BLT doesn't imposes ODL, allowing masters to have more than 7 slaves. However, only 7 slaves can communicate inside a cluster, and the remaining ones must be in a state called parked, i.e., waiting for a free slot to be one of the 7 active slaves. Consequently, there are some BSF algorithms that are ODL and some that aren't. In WFD, all network formation algorithms must be ODL and TGL. Consequently, this situation invalidates all, except one (BlueTrees-ODL), BSF algorithms, from being used. The new requirement (TGL) invalidates gateway nodes from connecting more than two clusters, forcing a new approach to this kind of nodes.

The third task is to develop the algorithms and is our current work. As mentioned, we are working in a more efficient algorithm to form tree networks exclusively based on GOGO topology, and we are working to develop another one (or two) to produce mesh networks, supported mainly by GOCRGO, but using GOGO where it needs to unsure connectivity. From all the BSF algorithms analysed we identified BSF-UED [4] as the best BSF algorithm and it is our current target to adapt and improve.

The algorithms for MANET formation were analysed, but as they assume that communication is connection-less (i.e., based on broadcasts), many of them consider that clusters (groups), using inter-cluster relaying, can have nodes at more than 1-hop distance from cluster head (GO). From the literature review done, we did not found one single MANET formation algorithm that is simultaneously ODL (Out-Degree Limited), TGL (Two Groups Limited) and only forms 1HCs (1-Hop Clusters - clusters with all the nodes at 1 hop from the cluster head). However, we plan to make a deep analyse of these algorithms when we approach node mobility, but that is delegated to a second goal. First we want to have working algorithms good for stationary cases, then we will introduce mobility and improve the algorithms, or conceive new ones, that should be efficient when nodes move around.

WFD network algorithm correctnesses and evaluation

To show the correctnesses of developed algorithms we plan to make theoretic analysis, with proofs of connectivity and to know the message and time complexity.

Having that, we want to have extensive simulations with all node distributions possible, from sparse networks to highly crowded ones. In those simulations, we are interested to know the number of masters, average of slaves per master, number of messages to build the network, number of gateways (Slave-Slave and Master-Slave), time needed to build the network and the average path length. We plan to make adaptations of some BSF algorithms to enable relevant comparisons. We need to adapt these algorithms due to the restrictions of WFD.

We are considering two possibilities for the WFD simulator to use: WiDiSi; and WFD-INET-OMNeT++. WiDiSi is a (Java) PeerSim based simulator that only offers high level message exchange, with message and WFD operations delay and drop rate based on distance. It does not consider any type of radio interference. It, also, provides WFD discovery, group formation and communication services (but no security issues). WFD-INET-OMNeT++, is a WFD extension for INET framework of OMNeT++ (C++) simulator. It provides full stack WFD simulation (without security issues). The big problem with this simulator is that it is single-threaded (the multi-thread version is a commercial product). NS3 would be our preference, but, until now, we don't know any WFD extension for it, and to develop one is out of our plans.

Currently, we are working with WiDiSi. We decide to used it as a first approach to unsure that we can test scenarios with at least 1000 nodes. It will provide high level simulation that will enable to collect node and data communication statistic information and to check if algorithm terminate and do not incur in faults like surpassing 8 WFD clients per GO. It will only provide a lower bound of algorithm execution time, as it only consider the basic delays (message and operations), but not radio interference, message loss and retransmission. We are currently using only reliable message transfer, to make base tests of the algorithms being developed.

We plan to use WFD-INET-OMNeT++, in a second phase, to offer a complete evaluation with rigorous time and communication analyses.

Meanwhile, if there is available a WFD simulator based on NS3, it will be very welcomed.

4 FINAL CONSIDERATIONS

This thesis aims to enable internetworking with WiFi-Direct (WFD). For that it is needed: WFD inter-group communication; and WFD network formation. For WFD inter-group communication, we already proposed three new topologies that surpasses existing ones. With respect to WFD network formation we expect to contribute with some algorithms for automatic network formation using the developed topologies.

When finished these topologies and algorithms will support mobile cloud/collaborative systems, where nodes can contribute with local resources to provide and use the services available by all the nodes in the network.

We are considering to have an end-to-end system with one application scenario, to show that contributions are effective. But that is still an open issue.

This kind of system, when build, and using off-the-shelf devices having communication hardware that should effectively support both interfaces (WiFi and WFD) in simultaneous use, will offer a platform with bigger range and communication speed than with Bluetooth.

Our initial scenario was to develop a system to enable photo, and video, searching and acquisition, from all the fans present in a big sportive event (like Super Bowl). That system would require a storage and a computational layer, on top of a communication layer. The communication layer should include the network formation service, and also a message routing service. But all of that seems now a huge task, far bigger than our available time.

Consequently, ideas and discussion for a more simple mobile autonomous system and application scenario are very welcomed.

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