Content-centric routing in Wi-Fi direct multi-group networks

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Abstract: D2D communication was largely transferred to cable-replacement use cases. Device-to-Device (and Wi-Fi Direct in particular) has the potentiality to play a crucial role in future LTE offloading strategies. The aim of this paper is to implement the content-centric routing in a D2D architecture for Android devices based. Proposed method is based on a protocol called WiFi Direct. We implement a novel approach including intra- and inter-group bidirectional communication. We proposed a solution to overcome the limitations of the physical Wi-Fi Direct network topology and of its addressing plan, and we built a logical topology that enables bidirectional inter-group data transfers. In this paper, we focus on the potentiality of Wi-Fi Direct as D2D communication technology in medium and large-scale scenarios, using open-source, non-rooted Android devices. We also compare the results against the ones achievable exploiting Bluetooth technologies.

Key Words: D2D communication, Wi-Fi, Bluetooth, Internet.

INTRODUCTION:

In today's world, vast majority of wireless communicating devices uses an Access Point (AP)-based mechanism. Mobile networks, Wi-Fi hotspots requires user devices to connect to a common base station before they can operate. Use of Device to Device (D2D) connectivity is so beneficial and is at the forefront of standardisation and research efforts. Some commonly scenarios for D2D are Internet of Things mechanism, machine to- machine communication, device replacement (in case of failure), social data sharing. Device-to-Device has the potentiality to play a vital role in future LTE offloading strategies. However, many of the promises in store for D2D communication lay bare what is arguably its biggest flaw: no "static" infrastructure, the availability of content is spotty and unreliable. Even if requested content is cached by a nearby node, reachable through a multi-hop D2D path, a robust content discovery and retrieval mechanism is needed. In this paper, we focus on the potentiality of Wi-Fi Direct as D2D communication technology in medium and large-scale scenarios, using open-source, non-rooted Android devices. [3] – [5].

We try to overcome above limitations by implementing a multi-group, interconnected logical topology by exploiting transport-layer tunneling. This can allows us bidirectional and inter-group content transmission. We implement a content-centric routing architecture to overcome the content availability issue.

METHOD:

- Multi-group Communication with Android Devices
    - A multi-group topology could be implemented by letting a device have two virtual P2P network interfaces: in this way, it could act as a bridge using a different MAC entity in each group.
    - In non-rooted Android devices, however, the programmer cannot create a custom virtual network interface.
    - Our experiments revealed that none of the following scenarios are feasible in Android:
        - a device plays the role of P2P client in one group and GO in another,
        - a device behaves as the GO of two or more groups,
        - a device behaves as client in two or more groups.
    - Thus, in order to create a multi-group physical topology (i.e., bridge nodes), we let a GO be a legacy client in another group. Consider Figure 1.
    - In each peer, we enable two network interfaces, one of which is the conventional Wi-Fi interface and the other (P2P) is used for Wi-Fi Direct connection.

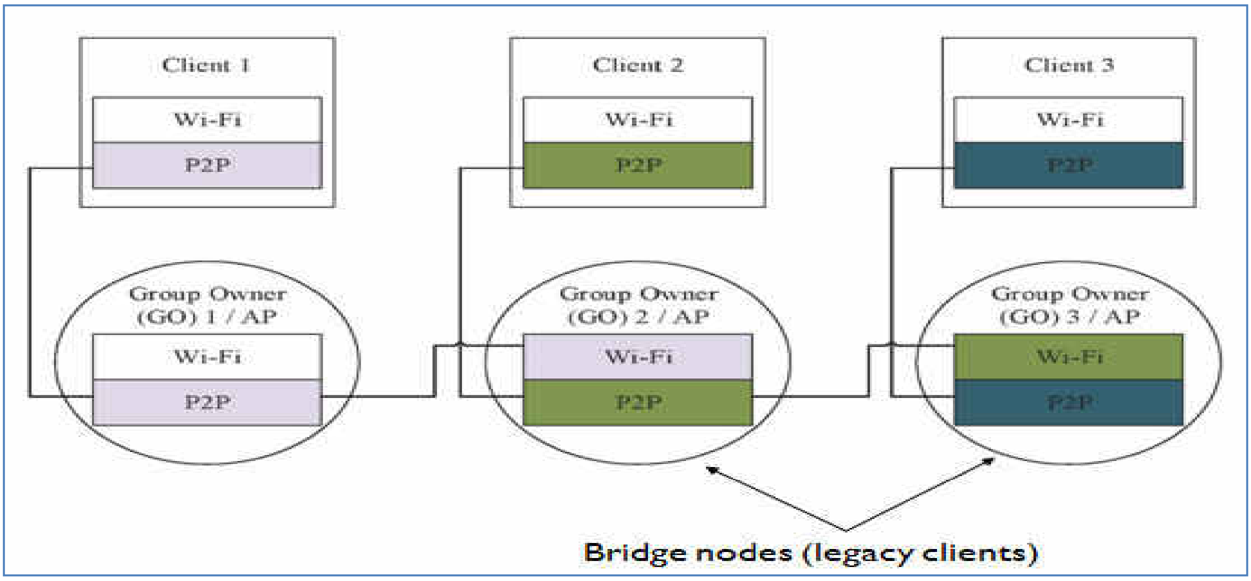

Figure 1: Multi-group physical topology with six devices (three clients and three GOs). G02 and G03 are bridge nodes, i.e., they are legacy clients of GO 1 and G02, respectively.

- IP address assignment:
    - Once a Wi-Fi Direct connection is established, the GO automatically runs the DHCP to assign IP addresses to itself (192.168.49.1/24) as well as to the P2P clients or legacy clients in its own group (192.168.49.x/24 where x is a random number ∈ [2, 254] to minimize the chance of address conflicts).
    - Therefore, the P2P interfaces of all GOs have the same IP address, namely 192.168.49.1.
    - The Wi-Fi interfaces of the GOs that act as legacy clients in another group are assigned an IP address in the format 192. 168.49.x/24.
    - Similarly, P2P interfaces of clients are assigned different IP addresses in the format 192.168.49.x/24. Consider figure 2.

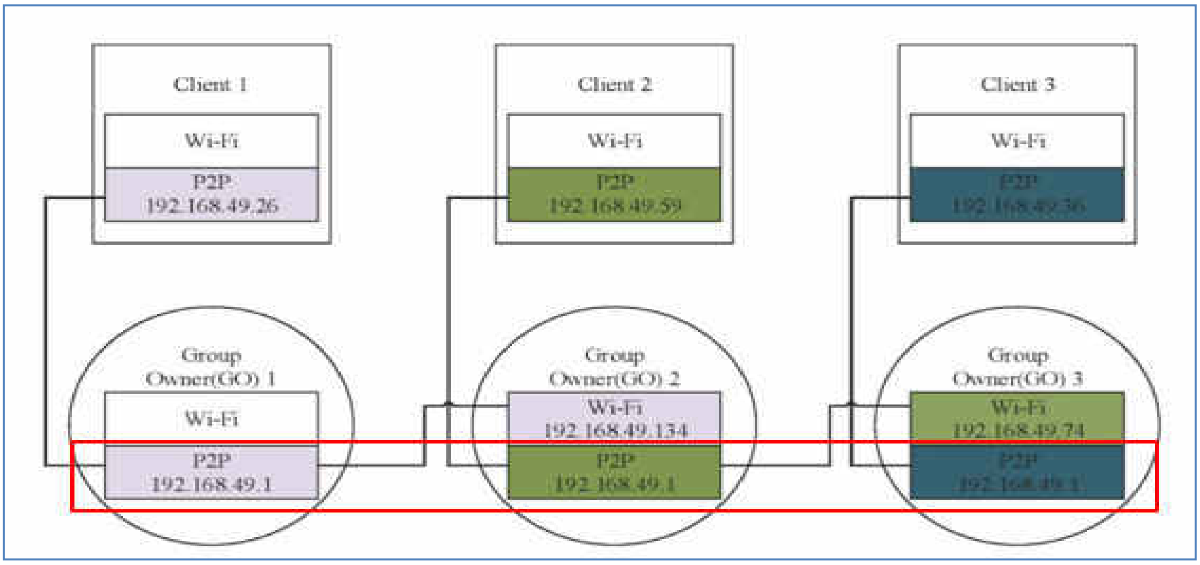

Figure 2: Example of IP addresses (124) for multi-group configuration.

- Design of the logical topology :
    - Two cases of intra-group communication:
        - the GO is not connected to any other group as legacy client:
            - Any pair of devices (GO, P2P clients and legacy clients) can exchange data at the IP layer.

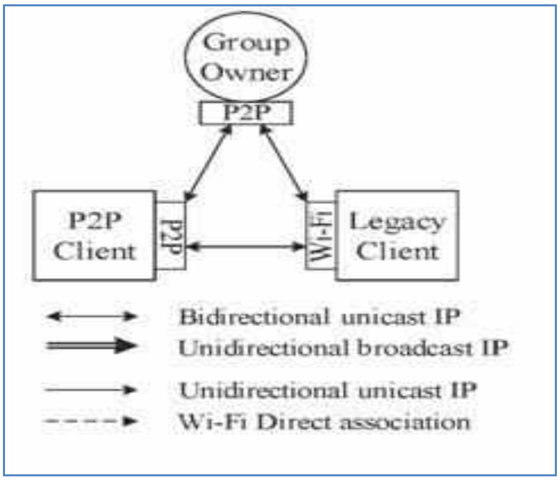

Figure 3 : D2D intra-group communications in an isolated group

The GO is also connected to another group as a legacy client

All D2D unicast data transfers among clients (P2P or legacy clients) are allowed, thus TCP connections and/or UDP flows between clients are supported.

Instead, between two GOs, or between a GO and its clients, only a subset of D2D data transfers is allowed.

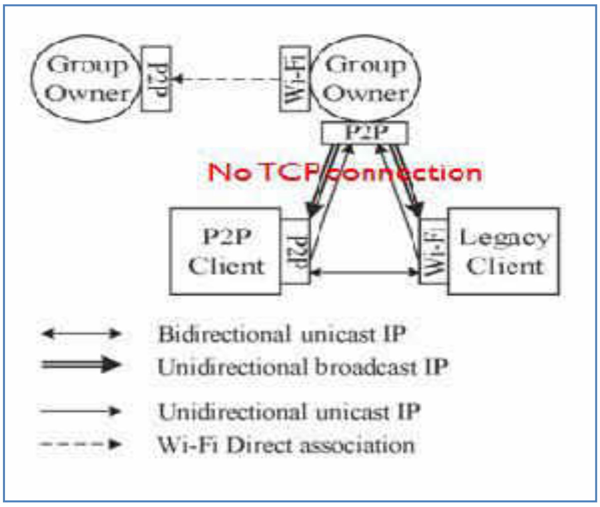

Figure 4 : D2D intra-group communications in in a group whose GO is a legacy client in another group.

- GO's connection with another legacy clients:
    1. GO2 to GO1

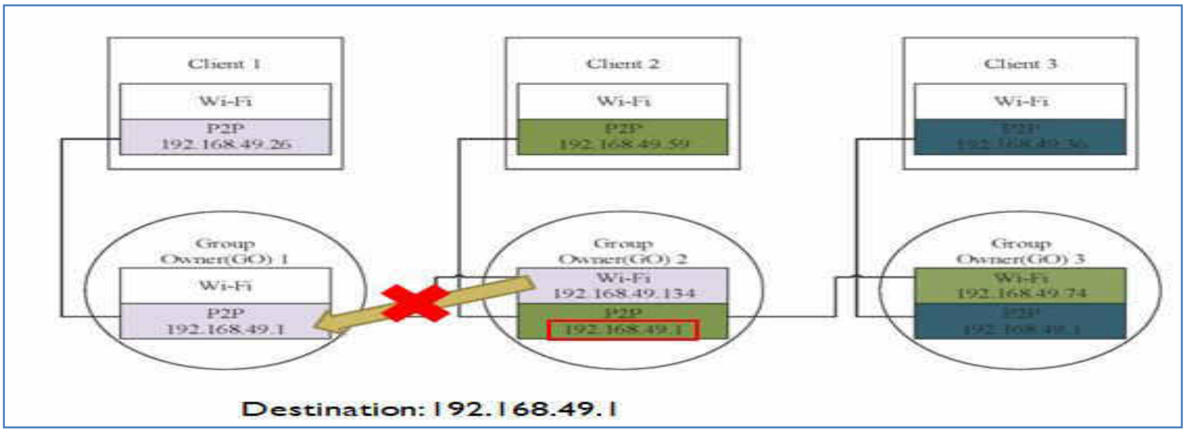

Figure 5: GO2 to GO1 connection could not be

Established as message sent for address 192.168.49.1 from will be received to itself at GO2 instead of GO1

2. GO1 to GO2

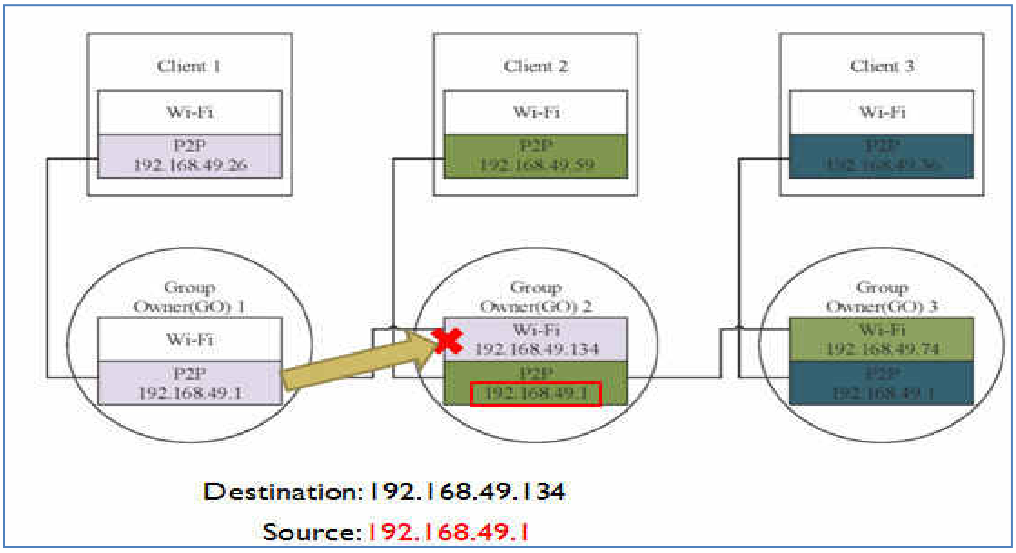

Figure 6: GO1 to GO2 connection could not be

Established as message sent for address 192.168.49.1 from GO1 will be received to itself at GO1 instead of GO2

1. GO2 to Client 2

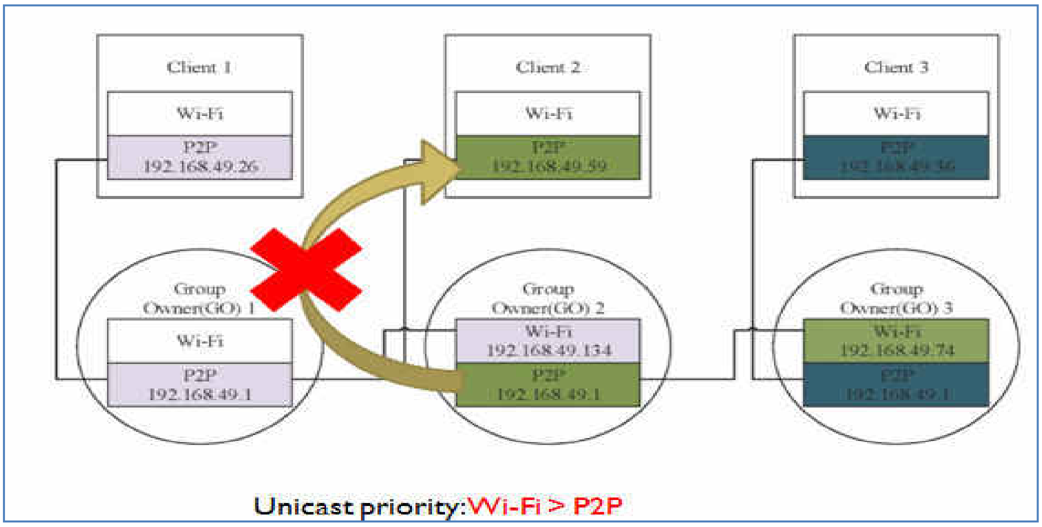

Figure 7: GO2 to Client 2 connection could not be established due to unicast priority WIFI>P2P

2. GO2 broadcast to Clients

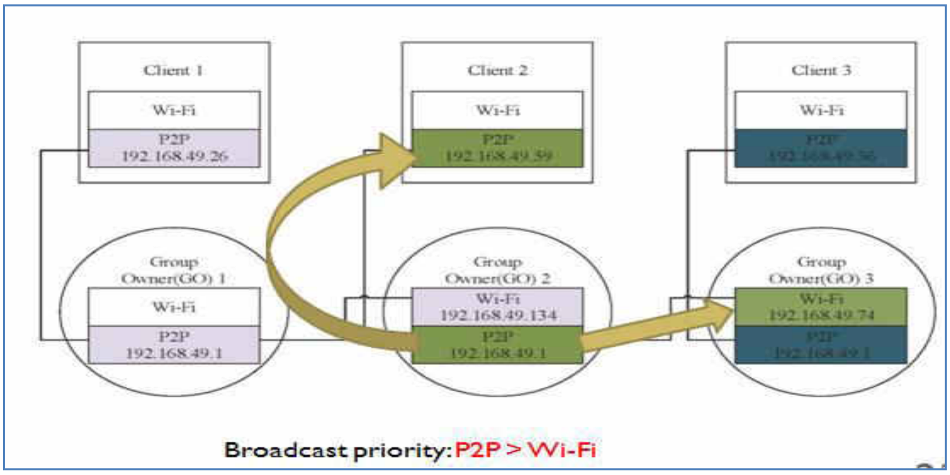

Figure 8: GO2 to Clients communication using broadcast priority P2P>WIFI

3. Client 2 to GO2:

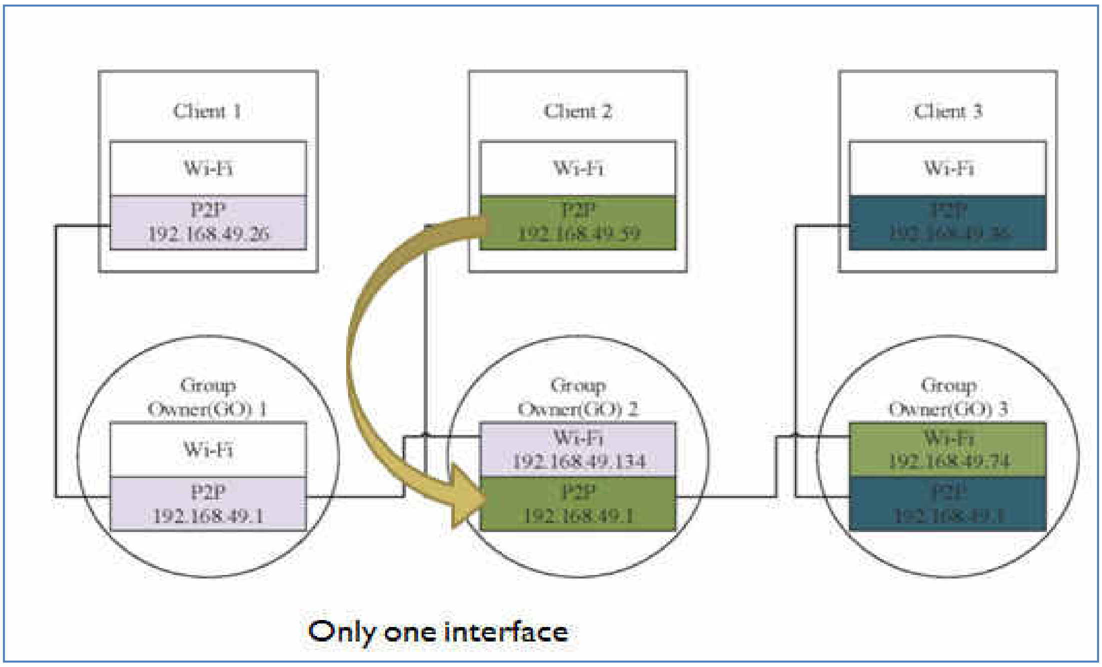

Figure 9: Client 2 to GO2 communication in one interface

- Design of the logical topology:

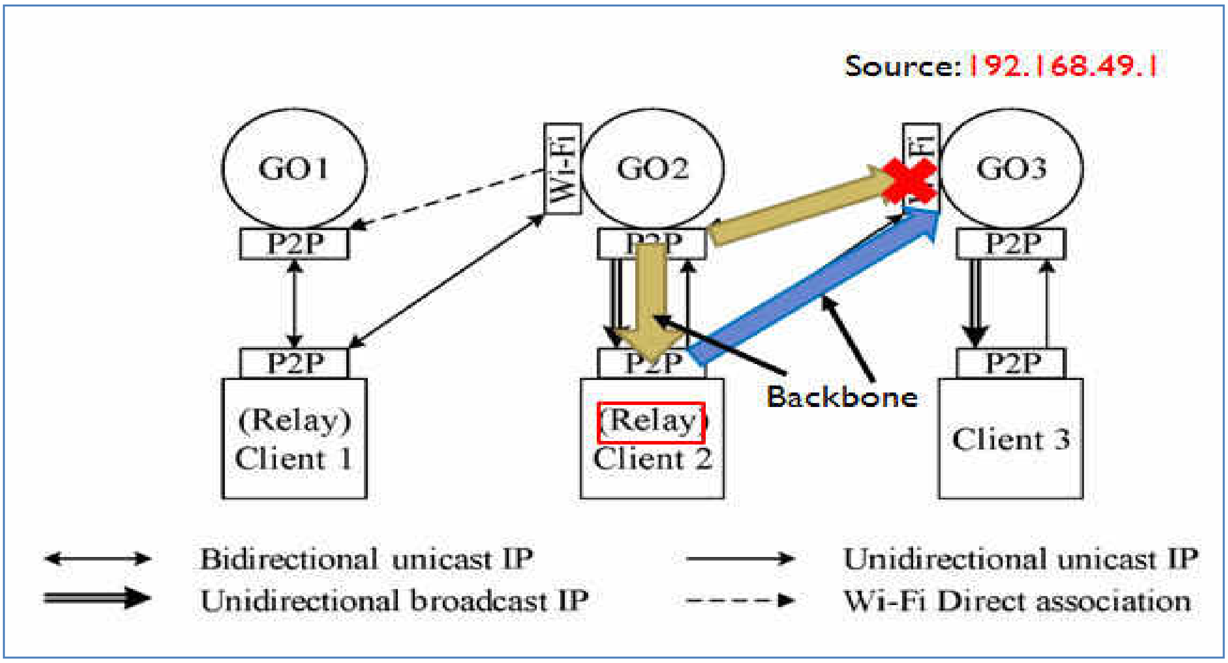

Figure 10: D2D inter-group communication.

The picture refers to the example network with three groups and a linear topology. The P2P clients in Groups 1 and 2 are used as relays to reach the right side group (Group 2 and 3 respectively). G02 and G03 are used as relays to reach their left side group (Group 1 and 2, respectively).

- Content-centric Routing:
    - We assume that each node knows the neighboring node (next hop) to which it has to send the request for a specific content.
    - Content Routing Table (CRT)
        - provides the routing information to reach content items
    - Pending Interest Table (PIT) [7]
        - provides the information to route a content to the requester

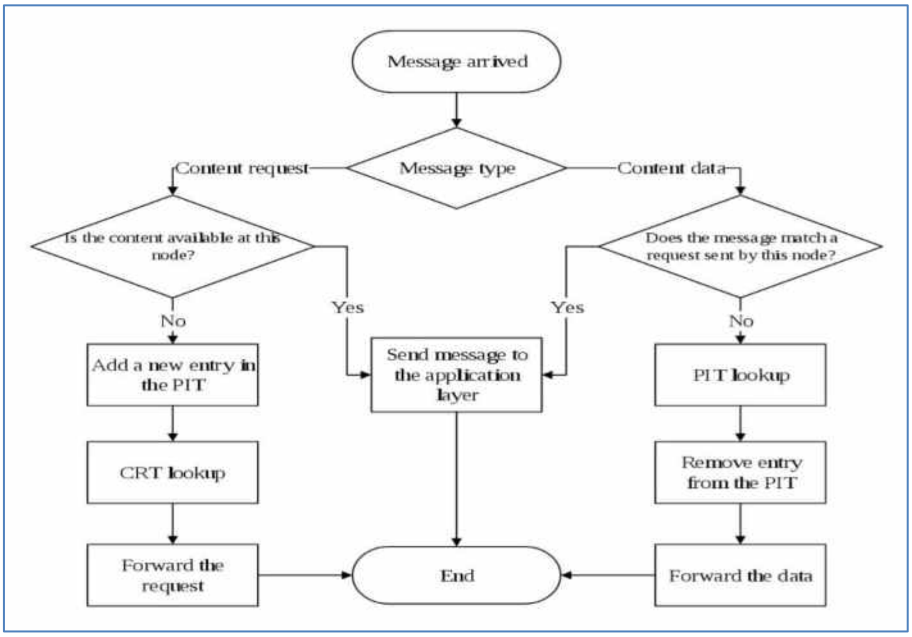

Figure 11: Content-centric Routing

ANALYSIS:

- 5 devices and 2 Wi-Fi Direct groups
    - Group 1: GO1, Client 1A, Client 1B(relay client), GO2(legacy client)
    - Group 2: GO2, Client 2A(relay client)
- Content delivery performance
- Content registration and advertisement performance

FINDINGS:

- We manually configured the CRT and PIT tables to avoid any protocol overhead due to content requests and table updating.
- Each content is divided into chunks of fixed size equal to 1400 bytes, to avoid IP fragmentation.
- We validated the data delivery mechanism by picking different pairs of devices among the possible ones, and letting them act as source-destination nodes

RESULT:

We mainly focus on 5 scenarios:

1. "2 devices - 1 group" (2d1g), in which the source is Client 1A and the destination is GO1.
2. "3 devices - 1 group" (3d1g), in which the source is Client 1A and the destination is Client 1B.
3. "4 devices - 2 groups" (4d2g), in which the source is Client 2A and the destination is Client 1B.
4. "2 devices - 1 group - broadcast" (2d1g-B), in which the source is GO2 and the destination is Client 2A.

5. "4 devices - 2 groups - broadcast" (4d2g-B), in which the source is Client 1B and the destination is Client 2A.

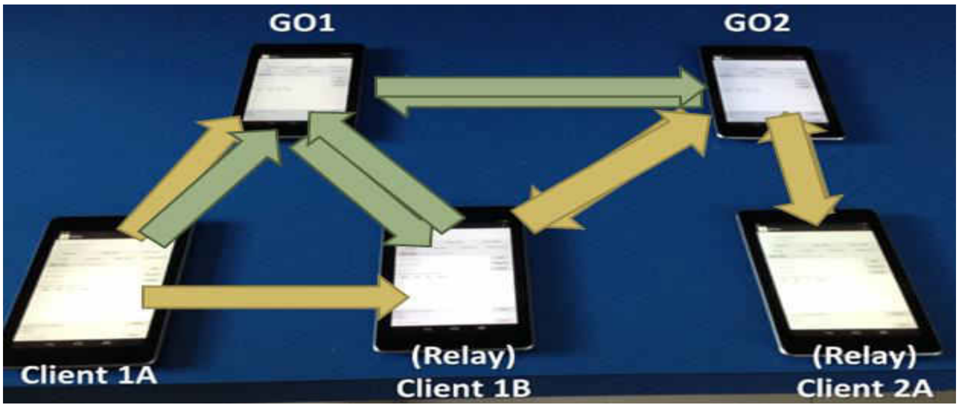

Figure 12: Communication among devices

Figure 13 shows the application-layer throughput vs. the offered load. As expected, the throughput increases with the load, and reaches a maximum value of about 19 Mbitls (2d Ig scenario), 8.4 Mbitls (3d1g scenario) and 5.0 Mbitls (4d2g). Figure 14 depicts the throughput for the last two scenarios,
2dlg-B and 4d2g-B, both implying one broadcast transmission by G02. The maximum throughput is 4.6 Mbitls for 2dld-B and 2.5 Mbitls for 4d2g-B.

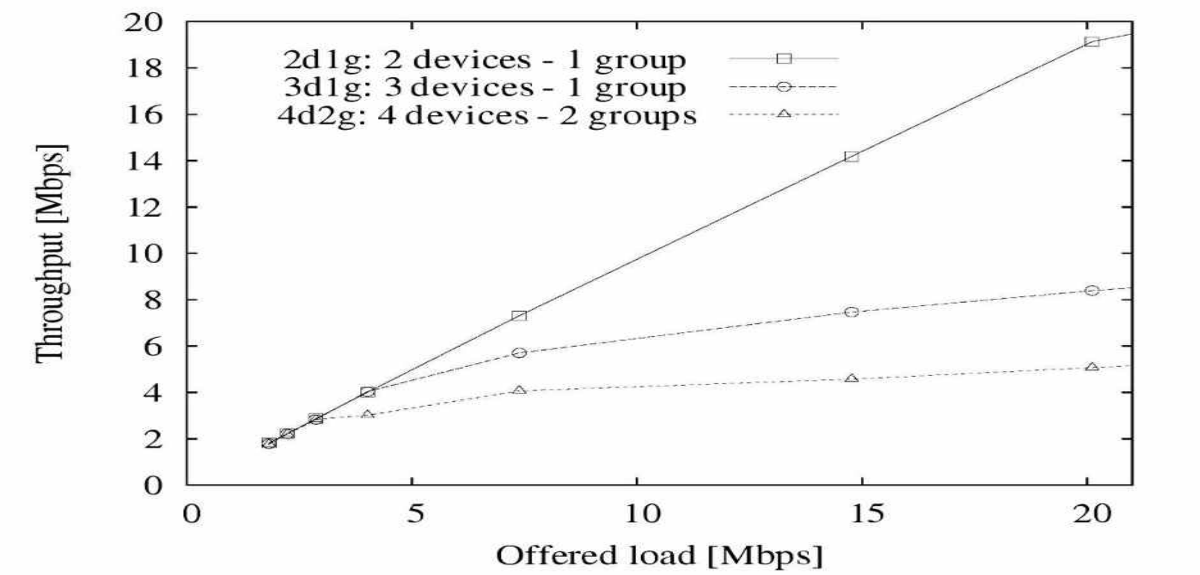

Figure 13: Throughput at application layer as a function of the offered traffic load. for packet transfers involving only unicast transmissions.

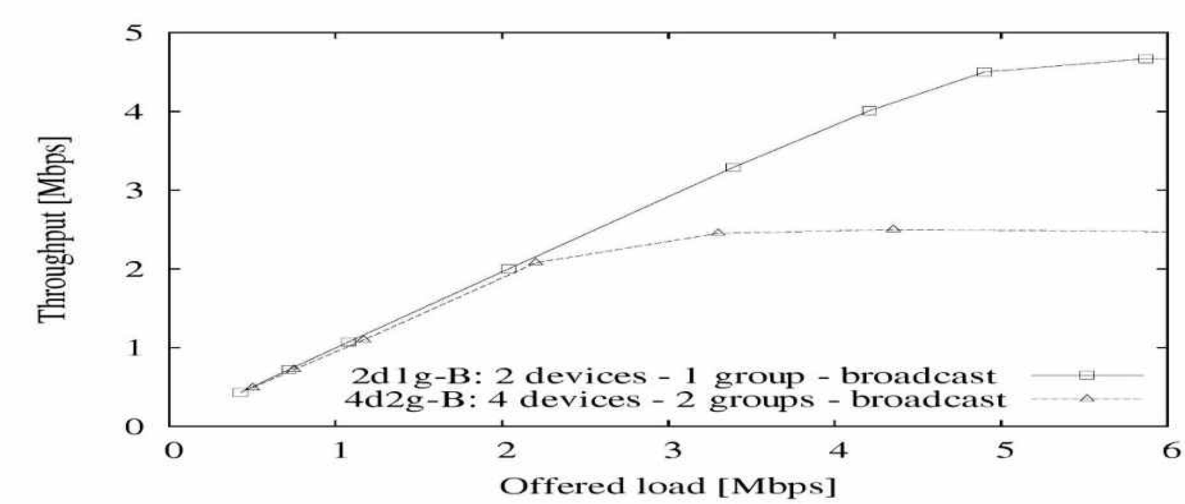

Figure 14: Throughput at application layer as a function of the offered traffic load. for packet transfers involving also broadcast transmissions.

We focus on the scenario in Figure 15 where, every second, Client I A registers one new content item with GO I, through the two messages 1 & 2 reported in the figure. The experiment lasted I minute, with a total of 60 new registered items. The sequence of the advertisement messages that are generated and transmitted is represented by messages 3 to 8; all of them are processed at the application layer. Table 1 reports the latency measured at each hop, as well as the end-to-end latency in the 4d2g scenario, obtained by logging the time at which each device processes the incoming advertisement message.

Table 1: LATENCY TO ADVERTISE A NEW CONTENT ITEM IN THE TWO-GROUP SCENARIO

Transfer	Incoming Messages	Average[ms]	95% confidence interval [ms]
GO1-> Client 1B	3	250	206-294
Client 1B -> GO2	5	304	219-390
GO2 -> Client 2A	7	226	199-252
GO1 -> Client 2A	3	780	688-872

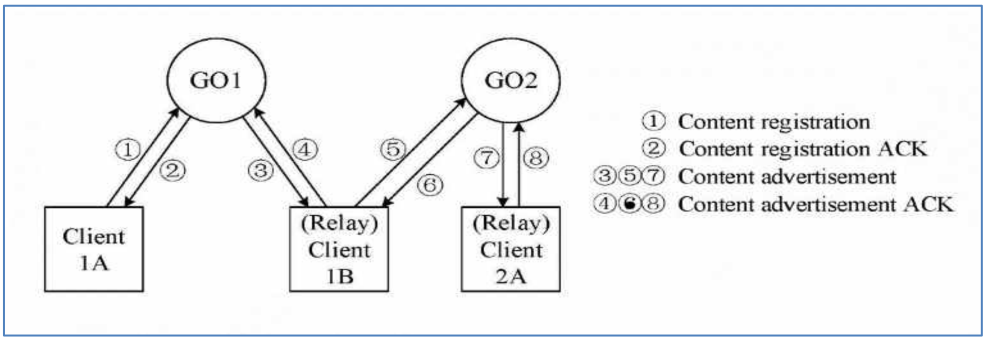

Figure 15: Message exchange triggered by a new content available in Client l A.

RECOMMENDATIONS:

The performance of the communication backbone is strongly affected by the traffic flow direction. The two different relay schemes, adopted within a group to work around the constraints imposed by Wi-Fi Direct, show significantly different performance. The main bottleneck is represented by broadcast communications from the GOs to their relay clients.

CONCLUSION:

We proposed a solution to overcome the limitations of the physical Wi-Fi Direct network topology and of its addressing plan, and we built a logical topology that enables bidirectional inter-group data transfers. We also devised a content-centric routing scheme, which properly exploits the above backbone and allows content advertisement, discovery and retrieval in arbitrary D2D network topologies.

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