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WiFi-Direct InterNetworking

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PhD state: planner …

Research area: Networking

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PhD: WiFi-Direct Internetworking

- Problem: **why not WiFi-Direct multi-hop networks?**
  - without any supportive communication infrastructure
- Importance: enable communication with **WiFi speed and range with off-the-shelf devices**
- **Phase 1: efficient communication in WiFi-Direct multi-hop networks**
  - Statement: using WiFi and WiFi-Direct **interfaces** of **Android 5 Compliant** devices and addressing to the **address in WiFi** interface
  - Consequence: **communication (TCP and UDP) topologies that only use unicasts**
- **Phase 2: algorithms to create WiFi-Direct multi-hop networks**
  - Statement: BSF algorithms prefer nodes with **limited number of slaves** (ODL); **WiFi-Direct needs that**, and **also, limited number of masters** (IDL)
  - Consequence: **WiFi-Direct network formation algorithms** to support autonomous mobile systems (edge-clouds)

ODL: Out-Degree Limited
IDL: In-Degree Limited

Current challenges

- Network formation algorithms
  - for tree like networks, using only GOGO:
    - BlueTrees BSF: can't be used directly; but can be adapted to use information from the election algorithm
  - for mesh networks, using GOCRGO (and GOGO):
    - We need: out-degree limited to 8 and in-degree of 1; or, in-degree of 2 and out-degree of 0
    - Several BSF algorithms considered to be adapted
- WiFi-Direct simulator
  - WiDiSi (PeerSim) or WFD-INET-OMNeT++ (OMNeT++)

Context / Motivation

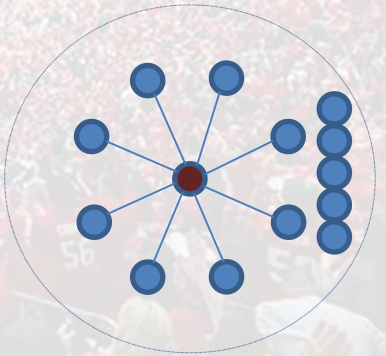
- Mobile autonomous edge-clouds
- Using out of the box devices

- Use cases:
  - **Facial recognition** services to search for missing persons in **large crowds**
  - **Videos or photos** services to share data in **large events**
  - **Messaging and data** services in **catastrophe** situations

WiFi Direct (WFD)

- General context:
  - Non-rooted Android device communication with WFD
  - To enable data and computing services in case of no network infra-structure

- WFD specification enable communication inside groups, and allows:
  - Node discovery;
  - Group Owner (GO) selection;
    - Node that acts as soft AP for the group,
    - controls group membership,
    - provides DHCP and routing for the others
  - Node authentication
    - Accepts WFD or WiFi (WF) (should know SSID and PSK) clients

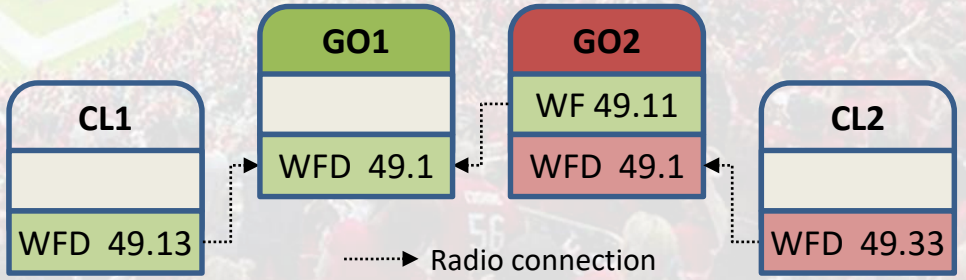


- But each GO supports only 8 clients
- Wi-Fi Direct does not tackle intergroup communication

Wi-Fi Direct inter-group comm. limitations

- WFD Group bridging:
  - Using only WFD, one device can only belong to a single WFD group
  - But can participate in another WFD group using its WiFi interface as a legacy device
- Problems:
  - All GOs have the same IP address (and network address): 192.168.49.1/24
  - A device connected with both, WFD and WiFi interfaces, will route all unicast traffic to one interface, the priority interface (*priInt*)
- Communication problems example:
  - With WFD as *priInt* and using UDP:
    - CL1 → GO2, GO2 → CL2
    - CL2 → GO2, GO2 ✗→ GO1 or GO2 ✗→ CL1

Addresses shortened to last two octets: 192.168.49.1 ≡ 49.1

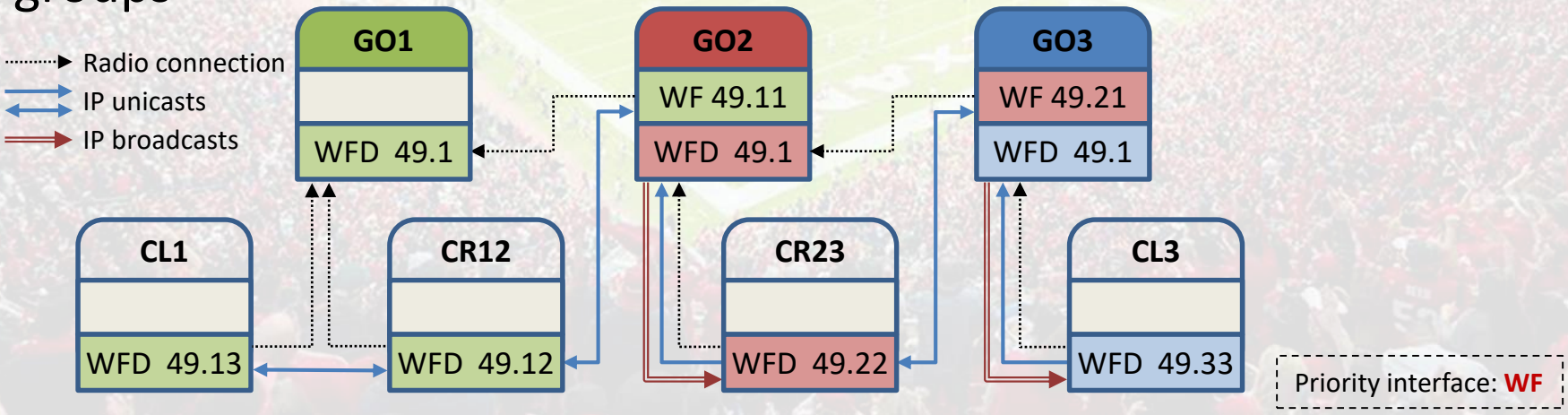


Current inter-group communication topologies with WFD

- GOCR – Casetti, et al.
- GO2CR – Teófilo, et al.

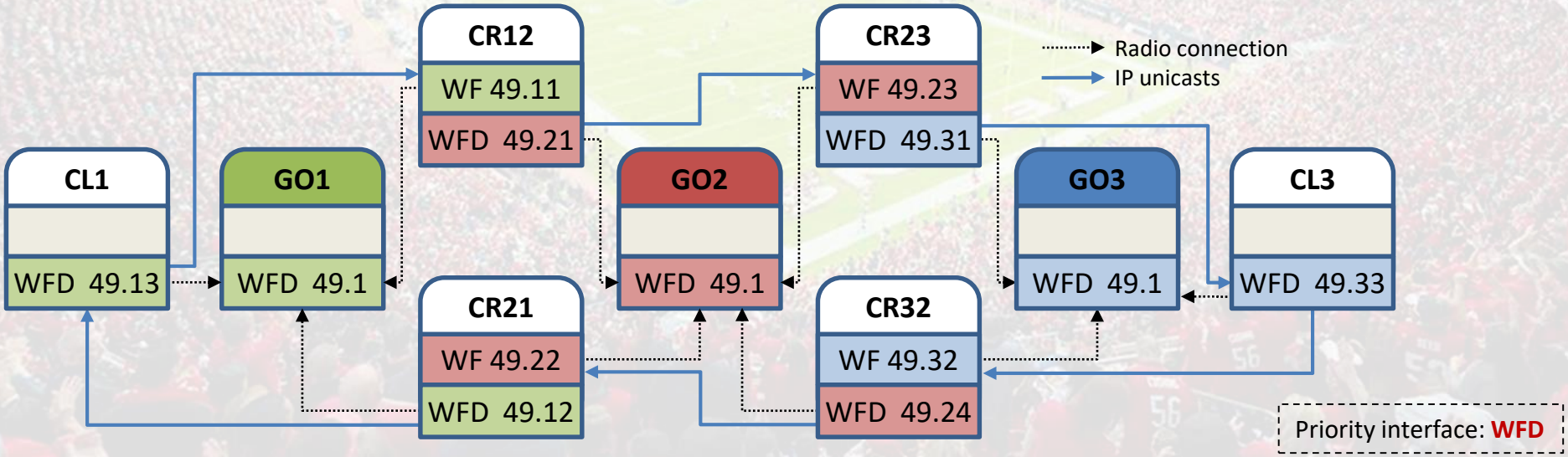
GOCR (Casetti, et al.)

- Each GO uses a Client Relay, to enable inter-group data forwarding using UDP and UDP broadcasts
- Communication between GO2 and GO3:
  - GO2 → CR23 (1 broadcast), CR23 → GO3 (1 IP unicast msg , using 2 MAC msgs)
  - GO3 → CR23 (1 IP unicast msg, 2 MAC msgs), CR23 → GO2 (1 IP unicast)
- Main problems: require broadcasts; 3 data transmissions to traverse WFD groups

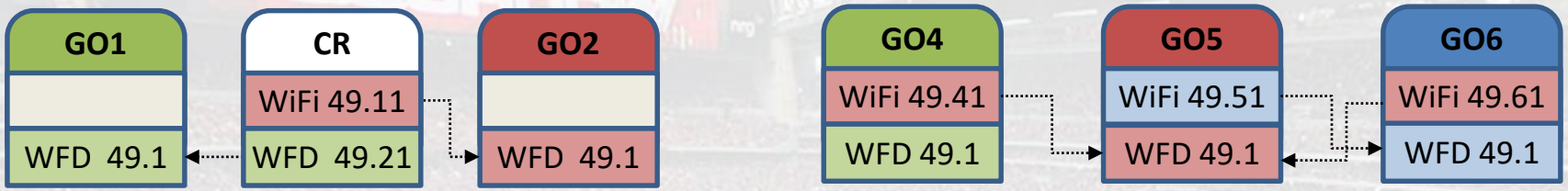


GO2CR (Teófilo, et al.)

- Pairs of GOs interconnected by 2 CRs
  - CRs connected in a symmetric way, each one forwarding data in just one direction, from WF to WFD interfaces; supports UDP and/or TCP
- Data forwarding: CRs at IP level; GOs at MAC level
- Main problem: 2 auxiliary (CR) nodes between GOs



Communication assessment



$GO1 - {}_{WFD}CR_{WiFi} - GO2$				$GO4_{WiFi_{.41}} - GO5_{WiFi_{.51}} - {}_{.61}WiFi\,GO6$					
$GO1 \leftrightarrow CR$ $\rightarrow$	$\leftarrow$	$CR \leftrightarrow GO2$ $\rightarrow$	$\leftarrow$	$GO4 \leftrightarrow GO5$ $\rightarrow$	$\leftarrow$	$GO5 \leftrightarrow GO6$ $\rightarrow$	$\leftarrow$	$GO4 \leftrightarrow GO6$ $\rightarrow$	$\leftarrow$
TCP $\checkmark_a$	$\checkmark_a$	$\times_j$	$\checkmark_c$	$\times$	$\times$	$\times$	$\times$	$\times$	$\times$
UDP $\checkmark_a$	$\checkmark_a$	$\times_j$	$\checkmark_d$	$\times$	$.41_f$	$.61_g$	$.51_g$	$\times$	$\times$
T/U-WF –	$\times$	$\checkmark_b$	–	$.51_e$	$\times$	$.61_h$	$.51_h$	$.61_i$	$.41_i$

T/U-WF: TCP and UDP sockets bound to WiFi interface *

* Requires Android 5 Compliant devices

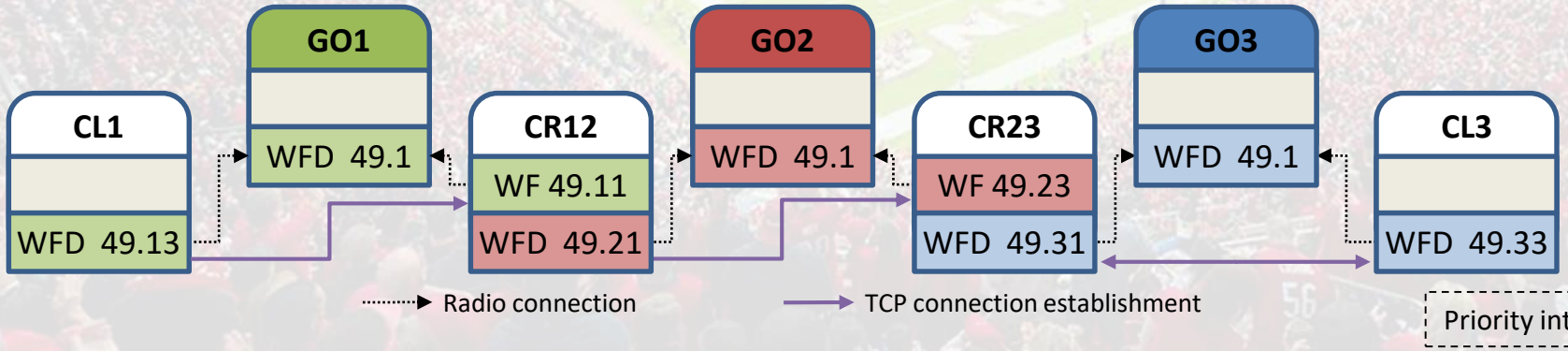
Priority interface: **WFD**

Proposed inter-group communication topologies with WFD

- GOCRGO – uses one CR between GOs
- GOGO – direct GO to GO communication

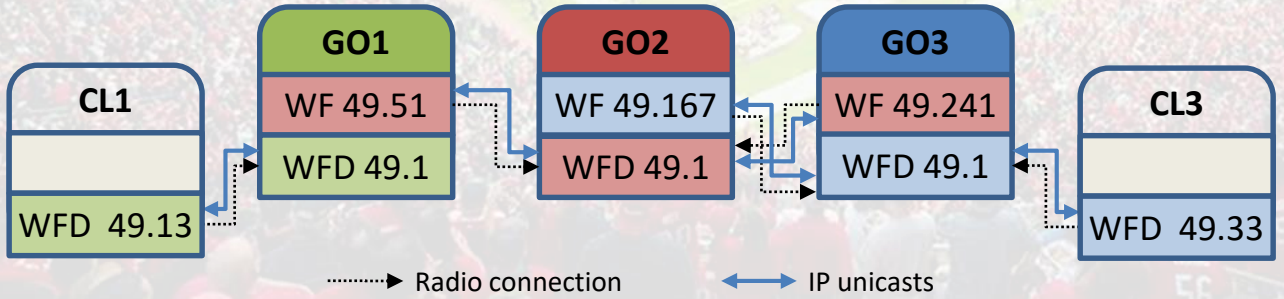
GOCRGO topology

- Requires 1 relay node between GOs and TCP connections
  - The use of UDP datagrams requires Android 5 compliant devices
    - To enable sockets bound to WF interface (ex: $CR23_{WF} \rightarrow CR12_{.21}$)
  - The relay node can extend radio range between GOs
- CRs should create a TCP connection to the next CR, using their priority interface, and they can use it bidirectionally
- Data forwarding: CRs at IP level; GOs at MAC level



GOGO topology

- Direct GO-GO communication, requires Android 5 compliant devices
  - all GOs must have their WF interface connected
- Each GO can create TCP connections in its WF interface to the GO^{τ} connected in that interface, but to the address in the WF interface of that GO^{τ} - that connection is used bidirectionally
  - Ex: $GO1_{WF} \rightarrow GO2_{.167}$
- In UDP: $GO1_{WF} \rightarrow GO2_{.167}$; and $GO2 \rightarrow GO1_{.51}$



Priority interface: **WFD**

Topologies analysis

- Spatial node requirements
- Communication speed
- Routing requirements
- Network frequency usage
- Network path redundancy
- Network flexibility
- Extreme situations: sparse and crowded networks

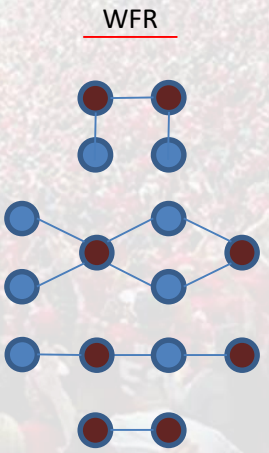
Topologies analysis

WFR – WiFi Range

- Spatial node requirements
  - Number of nodes per WFR
- Communication Speed
  - S_{MAX} max speed in one direction, SBD_{MAX} max speed in bidirectional comm.

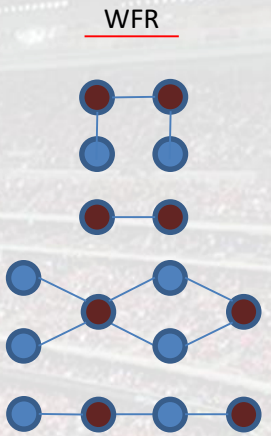
    WiFi Unicast Speed (WFS) = 54 Mbps, Broadcast Speed (BCS) = 6 Mbps, BCF = WFS / BCS = 9
- Routing
  - Number of Routing Operation per WFR

	#Nodes / WFR	S_{MAX}	SBD_{Max} Mbps*	#RO / WFR
GOCR	2	WFS / 3, WFS / (2 + BCF)	WFS / (5 + BCF) = 3.86	3
GO2CR	1.5	WFS / 2	WFS / 4 = 13.5	1
GOCRGO	1	WFS / 2	WFS / 4 = 13.5	1
GOGO	**1**	**WFS / 1**	**WFS / 2 = 27**	**1**



Topologies analysis

	Freqs per 2 WFRs	Freqs needed 1D / 2D	RC	RP TS SP BEM ECS NF	ES S/C	AD	Net. Struct.
GOCR	2	4 / 6	+	✘	✘ / –	ANY	Tree
GOGO	2	4 / 6	+	✘	+ / +	A5C	Tree
GO2CR	1	2 / 3	-	✓	✘ / –	ANY	Mesh
GOCRGO	**1**	**2 / 3**	**-**	✓	– / –	ANY	Mesh



RC = Radio coverage;

RP = Redundant Paths; TS = Traffic Splitting; SP = Short Paths; BEM = Better Energy Management and Efficiency; ECS = Extended Communication Speed; NF = Network Flexibility;

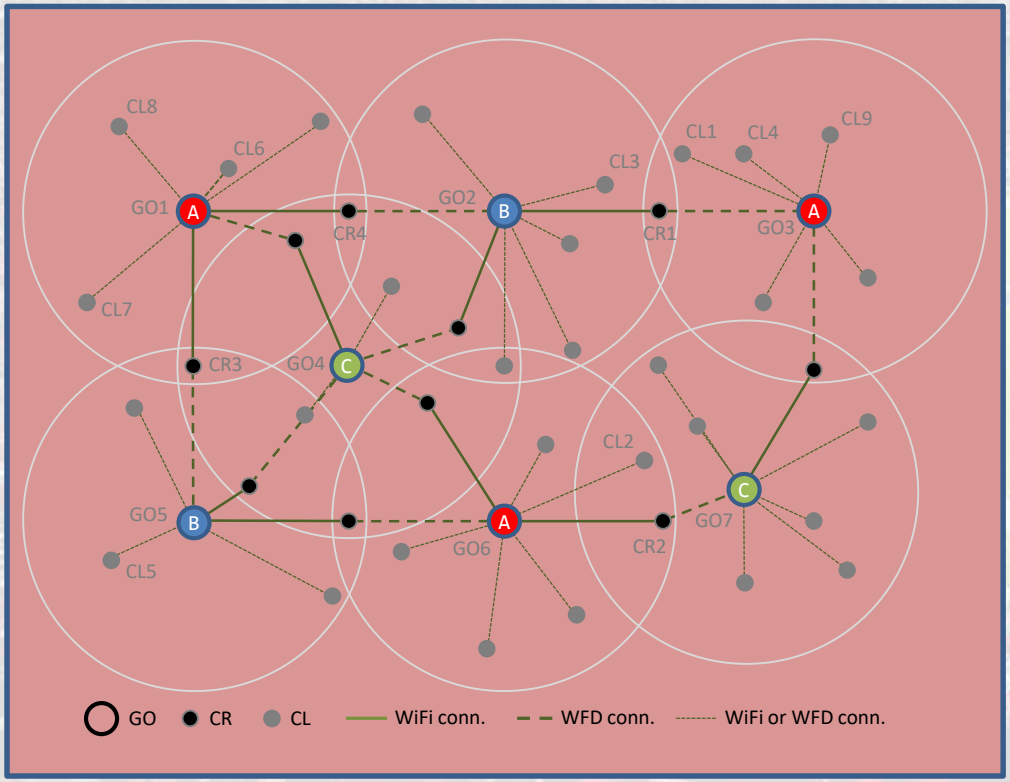
ES S/C = Extreme Situations: Sparse / Crowded scenarios;

AD = Android Device; A5C = Android 5 Compliant device.

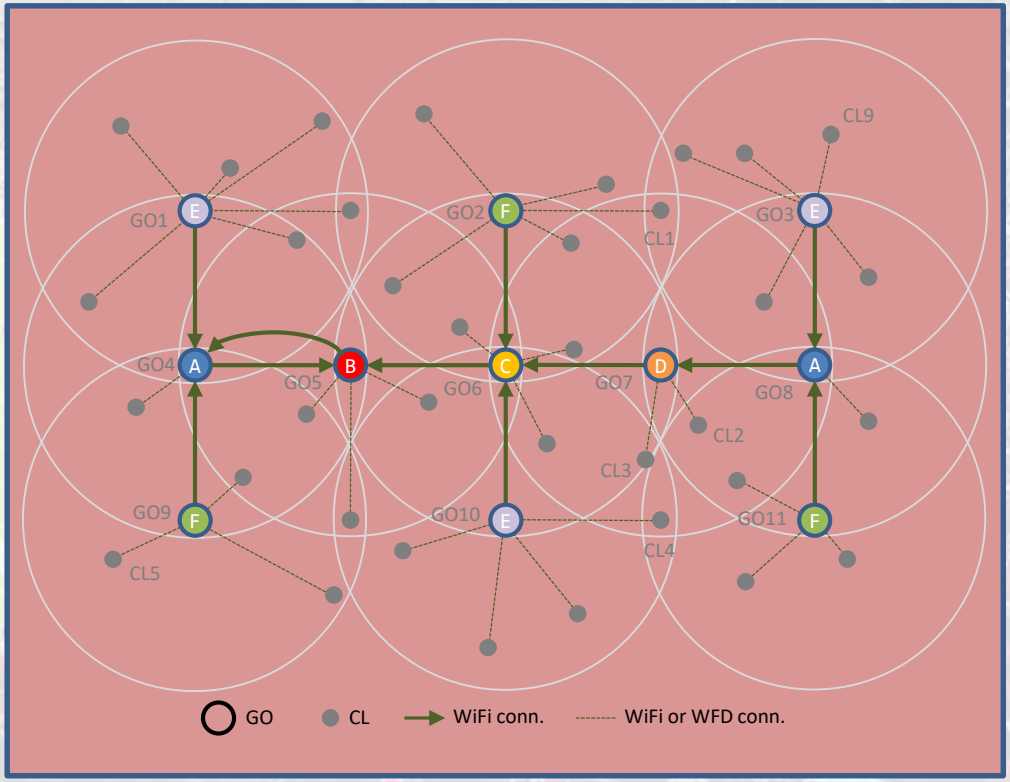
Net. Struct. = Network Structure

Topologies analysis

GOCRGO Topology - Mesh

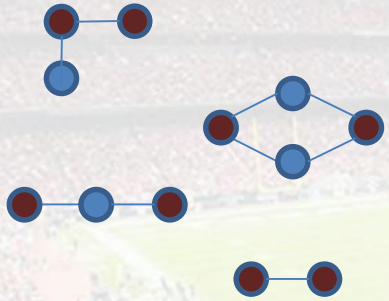


GOGO Topology - Tree



Experimental results

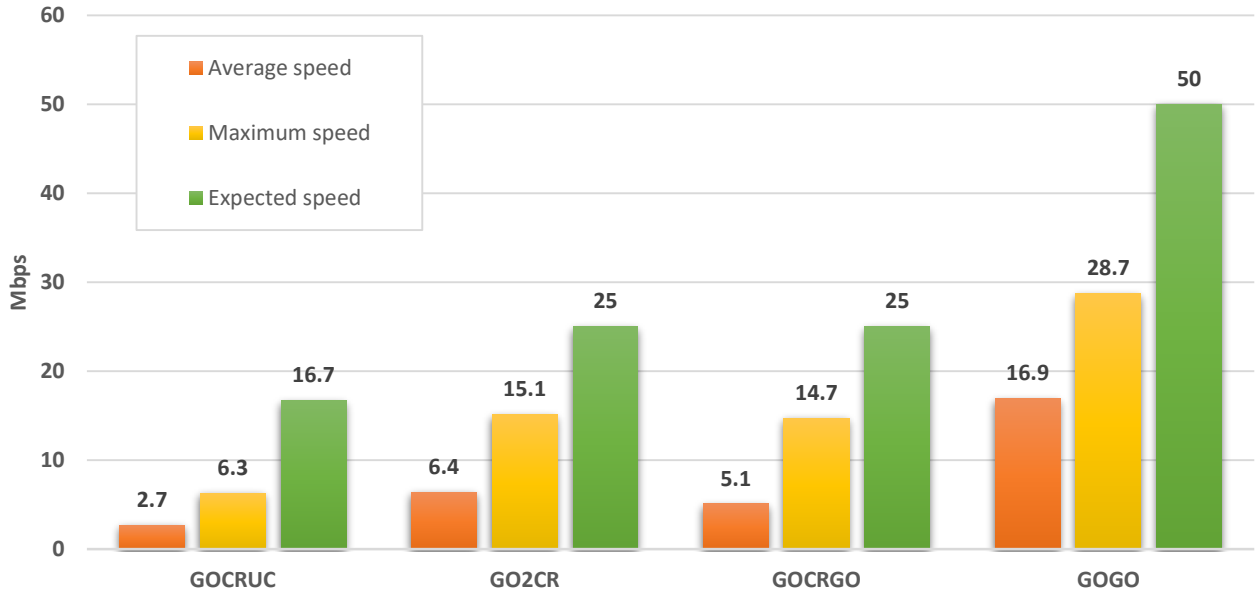
- Nexus 6, Nexus 9: WFS = 100 Mbps, priInt = WFD
- 100MB of data exchange between GOs, with data echo:
  - $GOCR_{UC}$: 6 MAC msgs
  - GO2CR: 4 MAC msgs
  - GOCRGO: 4 MAC msgs
  - GOGO: 2 MAC msgs



GO

CR

$GOCR_{UC}$: GOCR adaptation, using only TCP connections and priInt



	Energy (J/MB)
$GOCR_{UC}$	4.8
GO2CR	2.9
GOCRGO	2.6
GOGO	1.3

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Conclusions

- We propose 2 new WFD inter-group topologies, requiring only unicasts
  - GOCRGO, that only needs one relay node between GOs:
    - offers shorter and alternative communication paths, traffic splitting, better energy management and efficiency, extended communication speed, network flexibility and better frequency usage
  - GOGO, that connects GOs directly, but needs Android 5 compliant devices:
    - offers better radio coverage and communication speed in sparse and crowded scenarios
- These topologies contribute for WFD mobile autonomous networks, for data and computing services
  - However, to make it real, devices should decently handle simultaneous communications in both interfaces (WiFi and WFD)
- Future work:
  - Explore internal changes in Android to improve simultaneously communication in both interfaces
  - Automatic network formation that should take into account node churn, topology, devices priority interface and Android version

Questions