Cognitive Radio and Networks in coalition deployments through the dual use of IEEE 802.11h

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Outline

- Introduction to the project
- Scenarios and vignettes
- Routing protocol model
- Implementation Details
- Testbed setup
- Conclusions

Introduction

- Interest from the Spanish Ministry of Defense to investigate cognitive radio and networking paradigms.

- The project started in 2016.

- The project funds us during 2 years.

- The objectives of the project are aligned with NATO RTG IST140 (previous IST 077).

Motivation

- In military environments
  - The different nations rely on a fixed frequency assignement.
  - The fixed frequency assignment in many cases is not efficient and not operative.
  - Coalition deployments:
    - Platoons from different nations operate in the same band often without interoperational capabilities.
    - Are characterized by a high variability of the theatre of operations
- A dynamic management of frequencies may be very useful.
- This has already been proven via simulation studies in IST077.

Requirements from the client

- Dual use of civil technology.
- If possible, rely on COTS (Commercial off-the shelf) products.
- Experimental approach
- Study of both cognitive radio and cognitive networking solutions.
- Particular interest in cognitive routing solutions and effective distributions of information.
- Not interested in more traditional routing solutions based on routing tables, due to
  - difficulty to maintain these tables in very dynamic tactical environements
  - need to avoid as much as possible exchange of control information
- Assessment of scalability

Methodology

- We take advantage of COTS, like IEEE 802.11 h to coexist in 5 GHz bandwidth between WiFi and radar technology.
- IEEE 802.11h includes
  - Dynamic frequency selection
  - Transmission power control
- We build a IEEE802.11ac wireless multi-hop testbed where we exploit those functionalities at two levels of cognition:
  - cognitive radio
  - cognitive networking, load aware routing.

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Methodology

- ns-3 emulation capabilities are exploited for rapid prototyping
- The same code will be used in simulations and in the testbed.
- This enables cross-validation of simulated and experimental scenarios, hence offering the best of both worlds:
  - Model validation for the simulator based on experimental evaluations
  - Scalability assessment of the scheme in the simulator once models have been validated.

Technical problems we aim to solve

- *Problem 1:* Configuration of the cognitive ad-hoc network and distribution of the control information.
- *Problem 2:* Intra-platoon interference control by means of transmission power control.
- *Problema 3:* Detection of transmissions coming from other foreign platoons and consequent channel re-selection (inter-platoon interference control).
- *Problema 4:* Routing algorithm for a cognitive network.
- *Problema 5:* Scalability.

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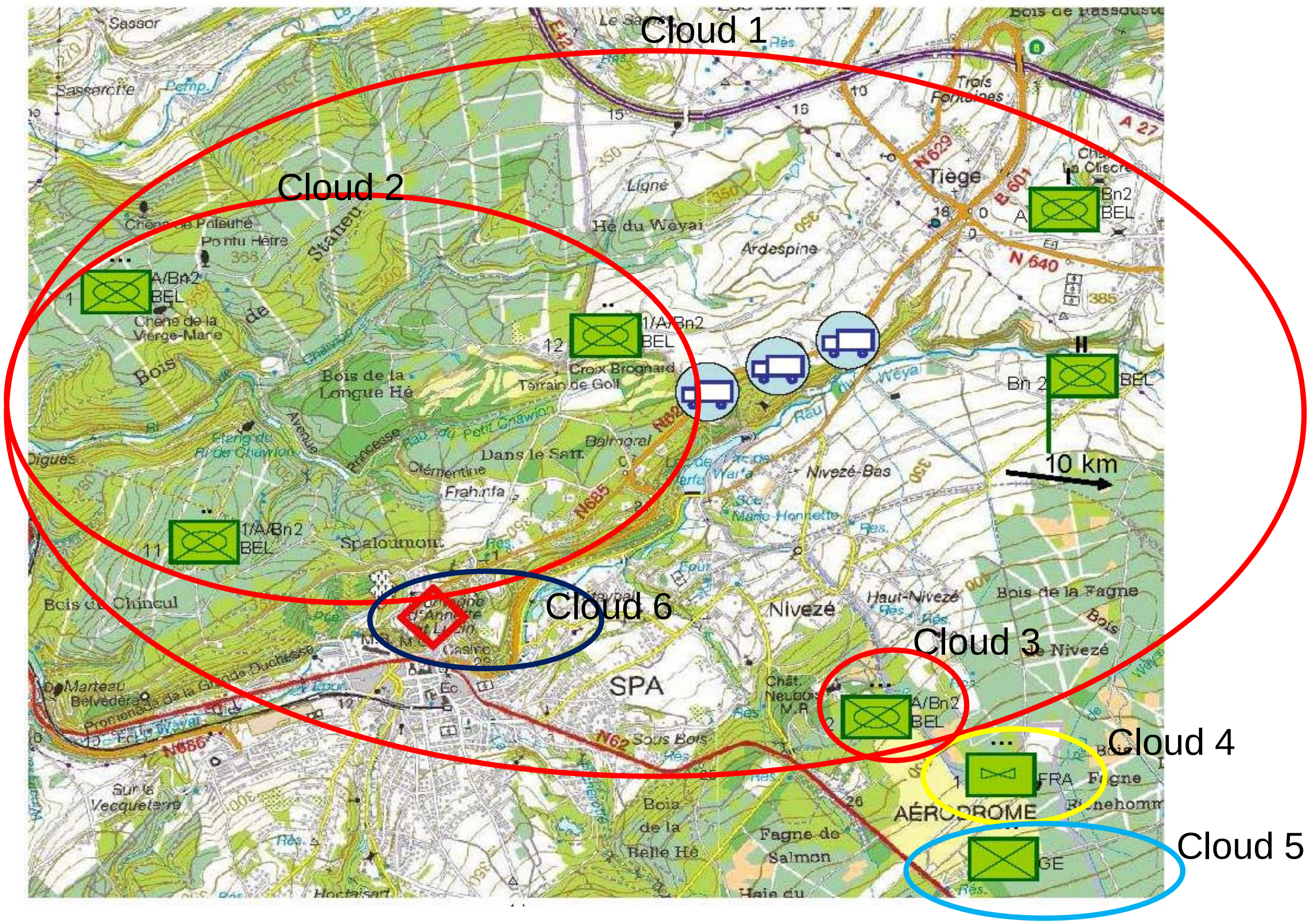
Simulation methodologies and vignettes in IST077

- Scenarios based on the vignettes defined in IST-077 group.
- Prevention of an aid convoy attack.
- NATO troops are involved in peacekeeping operations.
- They only can operate in case of self-defense.
- NGOs provide food and medical equipments through aid convoys.
- A group of rebels has been recently atacking the zone.
- A coalition deployment supervises the route of the humanitarian convoy from a distance
- The objective of the tactical vignette is to prevent the hijack of such an humanitarian convoy.

Preventing the hijack of an aid convoy vignette



Vignette IST 077

- Cloud 1: Company BEL
  - Platoon 1 and plantoon 2 BEL
  - Voice/data
- Cloud 2: Platoon 1 BEL
  - Voice/data
- Cloud 3: Pelotón 2 BEL
  - Voice/data
- Cloud 4: Company FR
  - Platoon FR
  - Voice/data
- Cloud 5:
  - Platoon GE
  - Voice/data
- Cloud 6:
  - Convoy
- Cloud 7
  - Rebels

Possible frequency conflicts that we aim to reproduce and deal with

- Clouds 3, 4 and 5 operate in the same frequency channel in uncoordinated fashion.

- The rebels try to attack the frequency of operation of clouds 3, 4 and 5.

- The helicopter of cloud 4 has a counter-RCIED (Radio Controlled Improvised Explosive Device) which affects the frequency of operation of clouds 3 and 5

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Cognitive networking

- We need cognitve routing approach which:
  - reduces to the minimum the control information exchange
  - takes decisions based on local information
  - quickly adapts to dynamic tactical environments

- We propose backpressure (BP) routing approach due to:
  - scalability,
  - low overhead,
  - maximization of resource usage in high mobility and dynamic wireless contexts,
  - low requirements in terms of state stored at nodes.

Cognitive networking

- *Neighbour Discovery*: BP does it, each node maintains neighbour tables.

- *Route dissemination*: BP does not need it, and this reduces significantly the overhead.

- *Route calculation*: BP does it, but at packet level.

- *Route recovery/maintainence*: not needed it.

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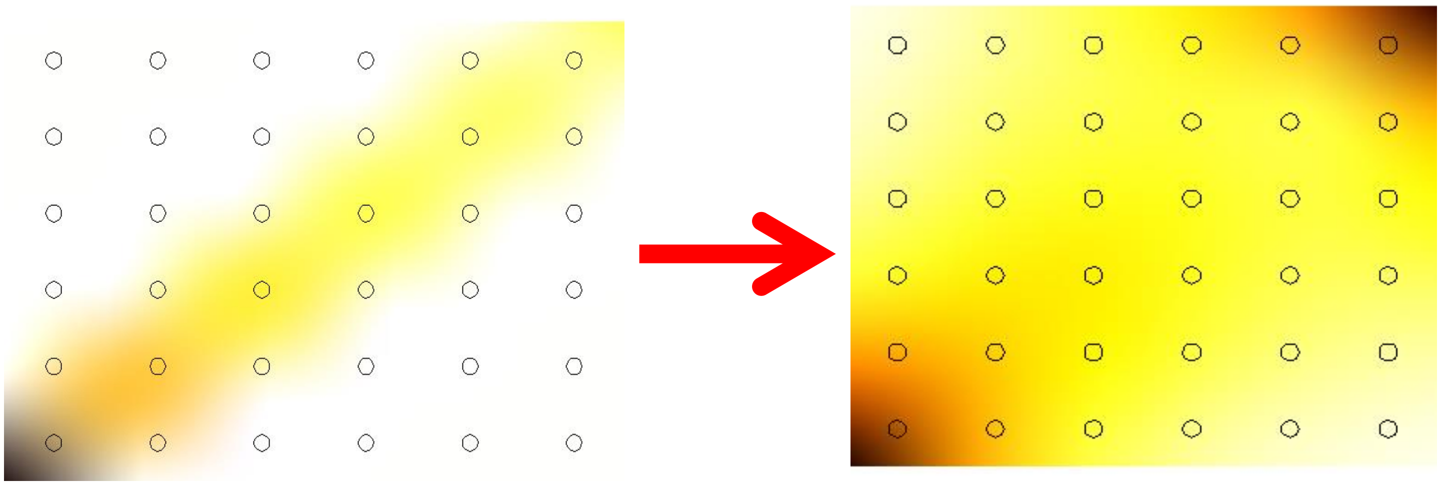
The Backpressure idea

Shortest Path Routing | **Backpressure Routing**



$$\Delta(t) + V p(t)$$

- Minimize a drift-plus-penalty function
    - Lyapunov drift Δ(t) $\Delta(t)=L(t+1)-L(t)$
        - L(t) function that measures network congestion
    - Penalty p(t) quantifies the cost of performing routing decisions satisfying Δ(t) minimization
    - Control Parameter V allows for appropriate trade-off between backlog reduction and penalty minimization

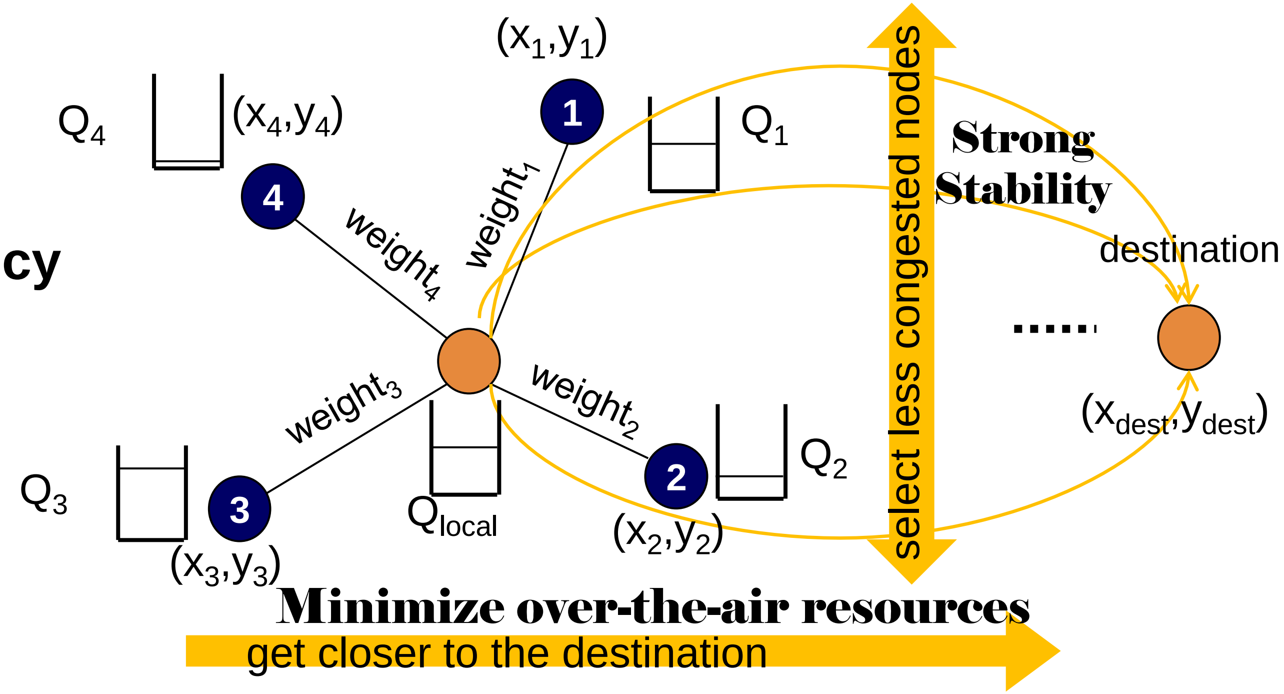
Distributed Max-Weight Policy

The weight of a link (*i,j*) with a data packet to transmit to reach *d* is calculated as follows:

$$w_{ij} = \Delta Q_{ij} - Vp(i,j,d)$$

Distributed

Max-Weight Policy



V

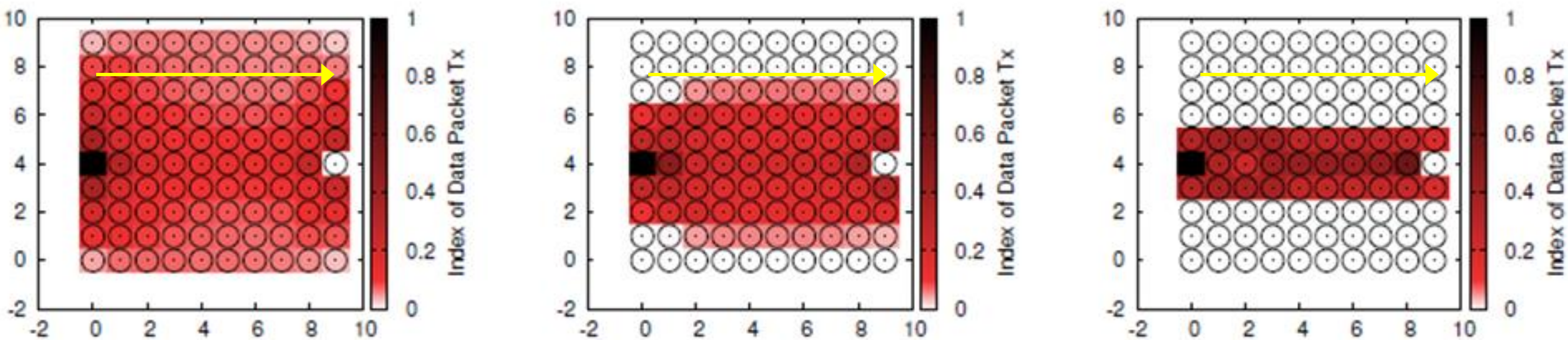
V Parameter Illustration

Distributed Weight computation:

$$w_{ij} = \Delta Q_{ij} - V p(i, j, d)$$

backpressure reach destination

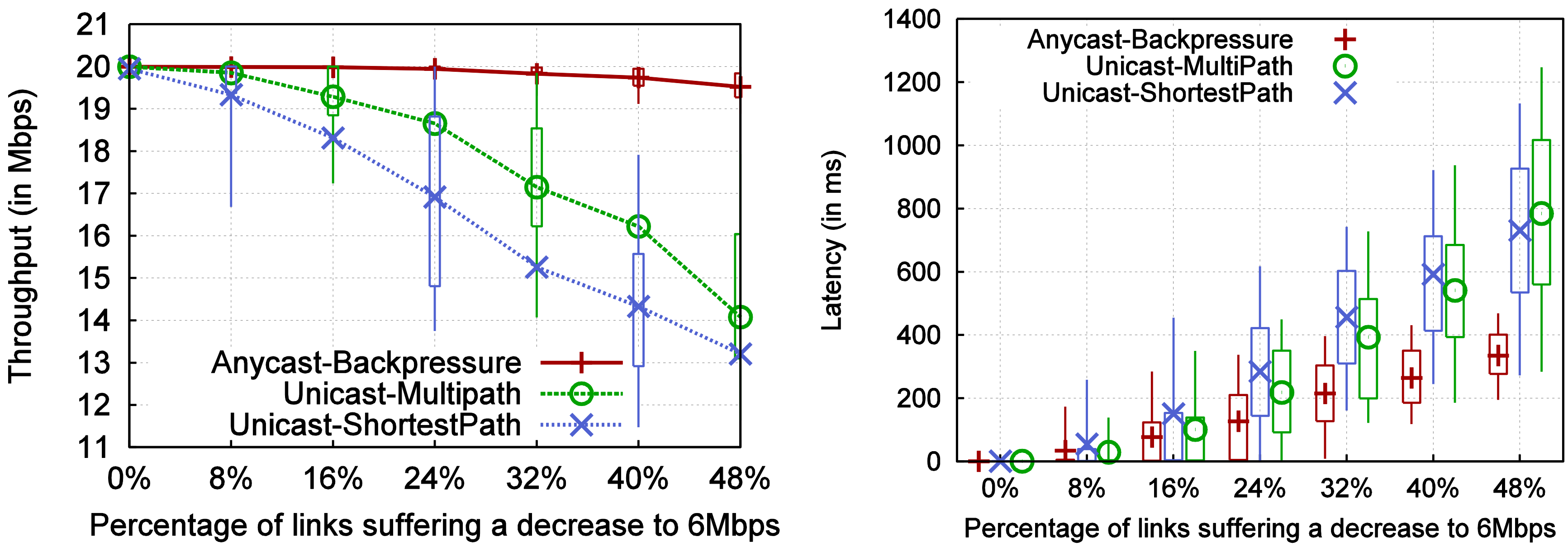
What is the role of the V parameter in practice?



(a) V=1 (b) V=50 (c) V=100

Some curves to test backpressure

Workload 20Mbps



Backpressure offers robustness under heterogeneous wireless link rates choosing higher rate links over low-rate links

Backpressure shows lower latencies since 1) longer paths only used under congestion 2) lower queuing latencies

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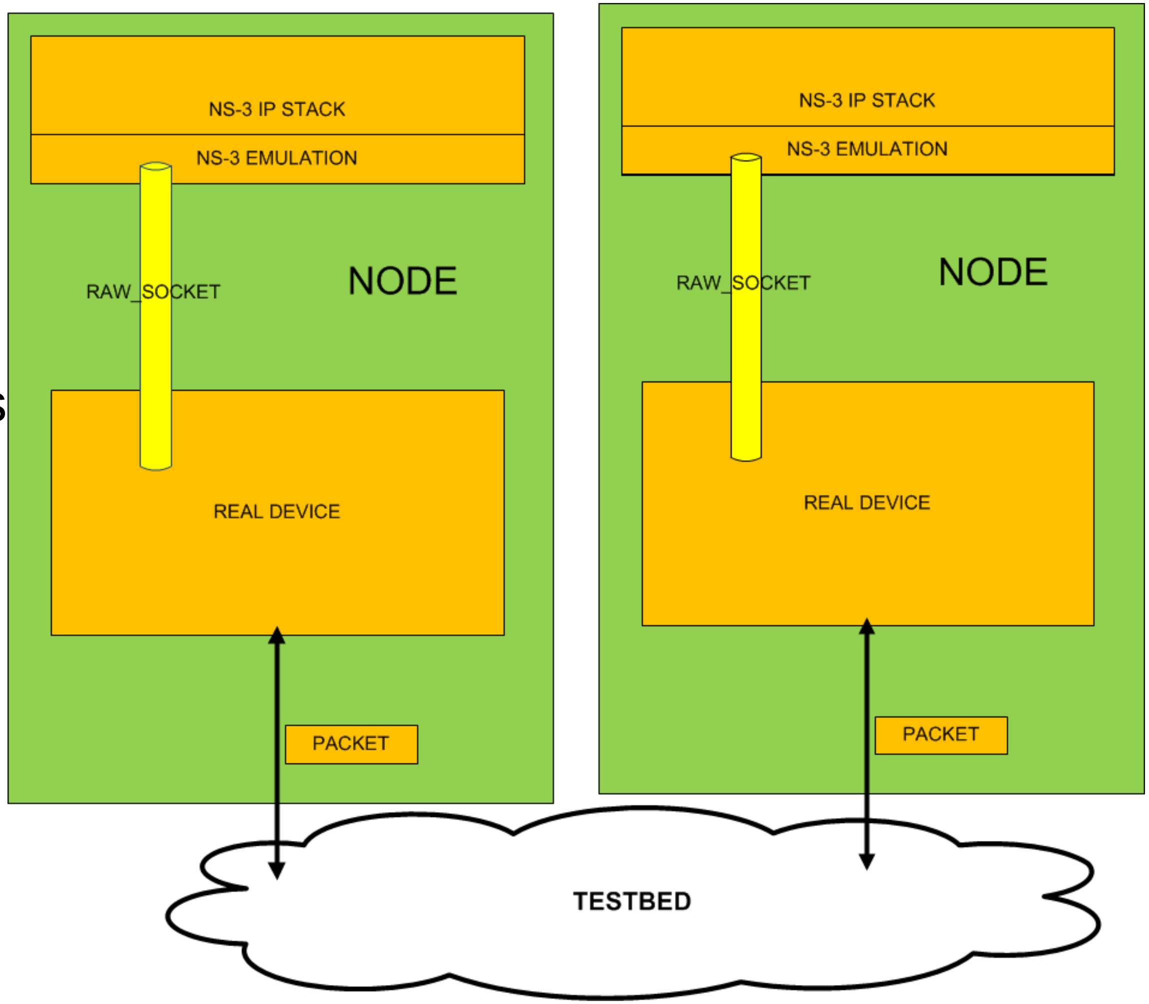
From simulation to rapid prototyping

- Protocol Implemented in Ns-3 simulator
  - Ns-3 is a quite accurate network simulator but still a simulator

- Ns-3 asset: Emulation Mode
  - You do not need to make double effort to test your schemes in simulations and in testbeds.
  - It allows the ns-3 simulator to send ns-3 packets to real physical devices, and to receive real (and ns-3) packets from physical devices.
  - The protocol requires to manage data queues to take routing decisions and there are various implementation issues.

Ns-3 emulation mode

- Physical Nodes have one ns-3 process running
  - routing intelligence
- It allows executing ns-3 IP stack over physical devices implementing L2 functionalities
- ns-3 provides the interface with the real physical device
  - RAW sockets
  - to generate/receive/send packets from/to the real device
  - real devices on PROMISCUOUS mode



Ns-3 Emulation: Characteristics

- ns-3 emulation is based on MAC spoofing
  - FdNetDevice avoids this way conflicts between virtual ns-3 IP stack (virtual MAC address) and real IP stack (real MAC address)
- SOCKET RAW captures all Ethernet packets
  - FdNetDevice sends to ns-3 stack the packets that have the specified ns-3 MAC address
  - Packets generated with ns-3 are sent with a source, and destination MAC addresses different than the real physical MAC address
  - Packets with the real source and destination MAC address are sent to the real node stack

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Testbed setup

- The testbed consists of 15 nodes emulating soldiers of platoons.
- Each node accounts with 2 IEEE802.11ac cards for control and data communications, intra- and inter-platoon.
  - chipset Atheros AR10XX
- An Agilent signal generator is used to generate jamming and other kind of co-channel signals.
- Nodes have installed Linux/GNU (Ubuntu 14.04 Desktop 64 bits).
- Network Time Protocol for node synchronization

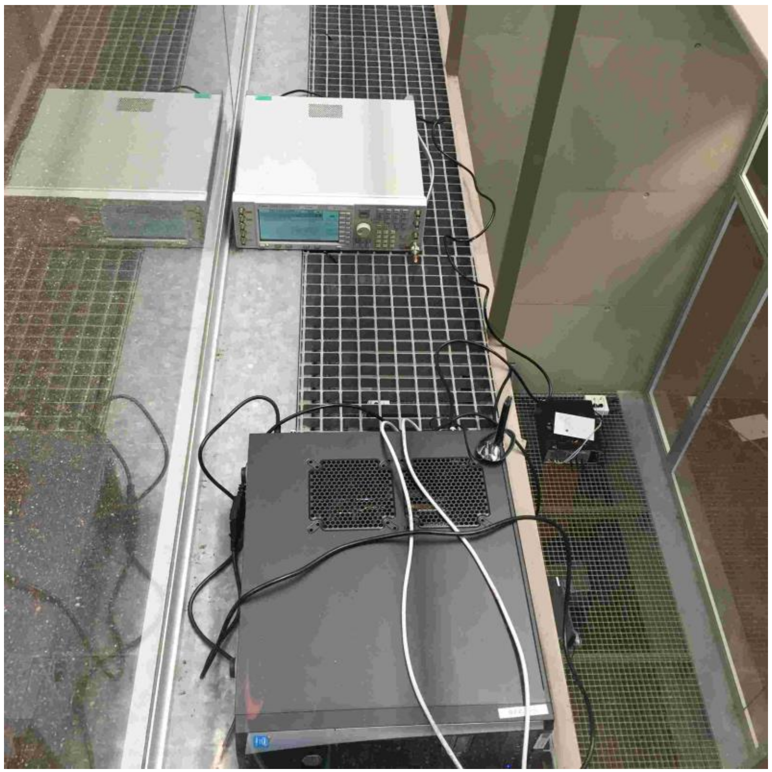
Testbed setup

- Driver and firmware of the cards is ath10k
- We substitute the original firmware with the one provided by Candela Technologies
  - It allows "ad-hoc" mode, which is fundamental to allow every node in the platoon network to be able to talk to all the other nodes
  - It allows for channels of 20 MHz, and also of 40 and 80 MHz.
  - It allows direct access to firmware source code.
  - With commands *iw* or *iwconfig,* we can easily change the channel, the bandwidth, the transmission power.

Testbed setup

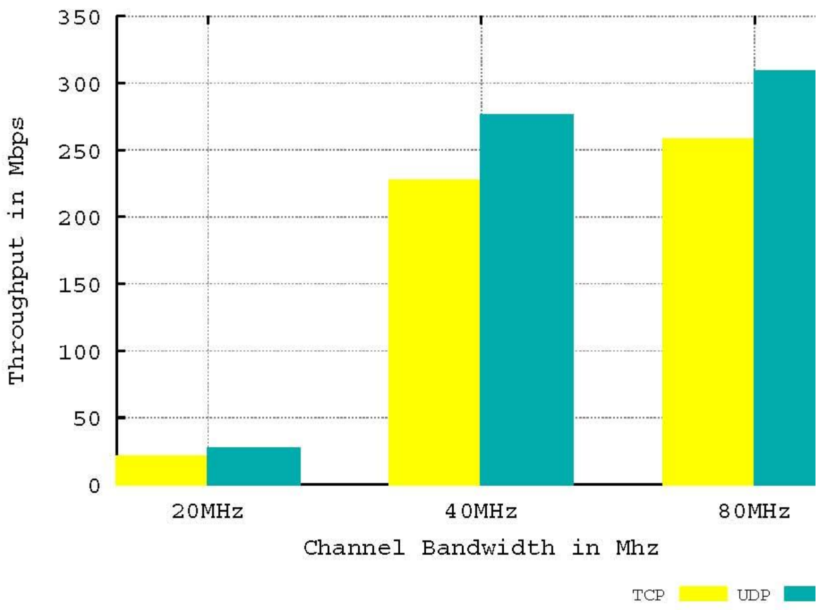
- TPC: We have tested that transmission power can be properly changed, by measuring the received power in a receiving node
- To activate DFS and TCP functionalities we need:
  - IEEE 802.11d: it is an amendment approved in 2001 to 802.11, which allows clients to automatically configure themselves to their local regulatory domain.
  - IEEE 802.11k: it is an amendment approved in 2007 to 802.11, to facilitate radio resource management and maintainance

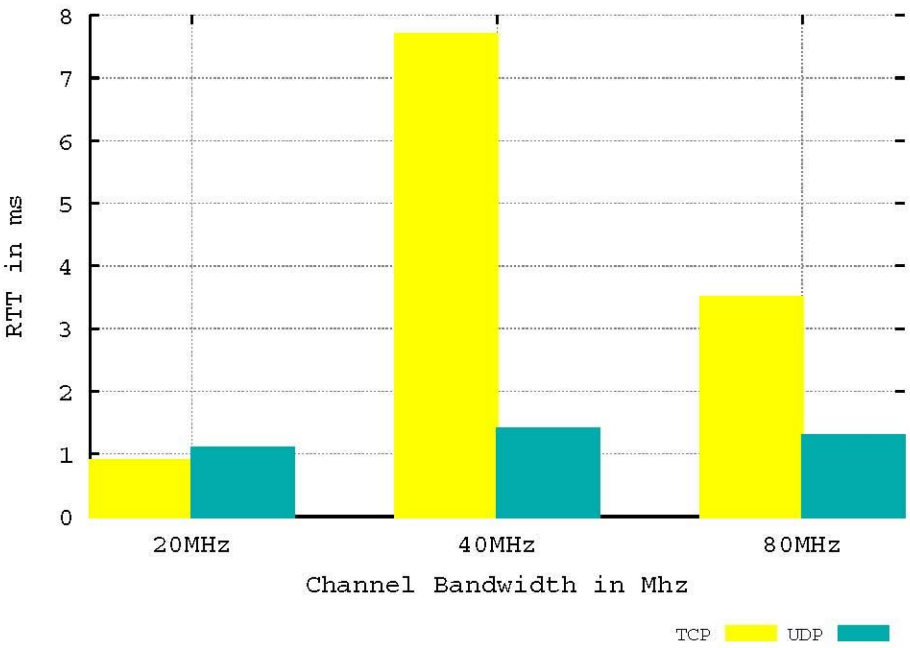
DFS Test



```
root@sc228:/home/monet# hostapd /etc/hostapd/hostapd-ac.conf
Configuration file: /etc/hostapd/hostapd-ac.conf
wlan2: interface state UNINITIALIZED->COUNTRY_UPDATE
wlan2: interface state COUNTRY_UPDATE->HT_SCAN
wlan2: interface state HT_SCAN->DFS
wlan2: DFS-CAC-START freq=5640 chan=128 sec_chan=-1, width=1, seg0=122, seg1=0, cac_time=60s
wlan2: DFS-CAC-COMPLETED success=1 freq=5640 ht_enabled=0 chan_offset=0 chan_width=3 cf1=5610 cf2=0
Using interface wlan2 with hwaddr 04:f0:21:18:26:af and ssid "ATH10K"
wlan2: interface state DFS->ENABLED
wlan2: AP-ENABLED
wlan2: DFS-RADAR-DETECTED freq=5640 ht_enabled=0 chan_offset=0 chan_width=3 cf1=5610 cf2=0
wlan2: DFS-NEW-CHANNEL freq=5180 chan=36 sec_chan=1
wlan2: DFS-RADAR-DETECTED freq=5640 ht_enabled=0 chan_offset=0 chan_width=3 cf1=5610 cf2=0
wlan2: DFS-RADAR-DETECTED freq=5640 ht_enabled=0 chan_offset=0 chan_width=3 cf1=5610 cf2=0
wlan2: DFS-RADAR-DETECTED freq=5640 ht_enabled=0 chan_offset=0 chan_width=3 cf1=5610 cf2=0
wlan2: DFS-RADAR-DETECTED freq=5640 ht_enabled=0 chan_offset=0 chan_width=3 cf1=5610 cf2=0
wlan2: IEEE 802.11 driver had channel switch: freq=5180, ht=1, offset=1, width=3 (80 MHz), cf1=5210, cf2=0
wlan2: AP-CSA-FINISHED freq=5180 dfs=0
```

1 Hop Test





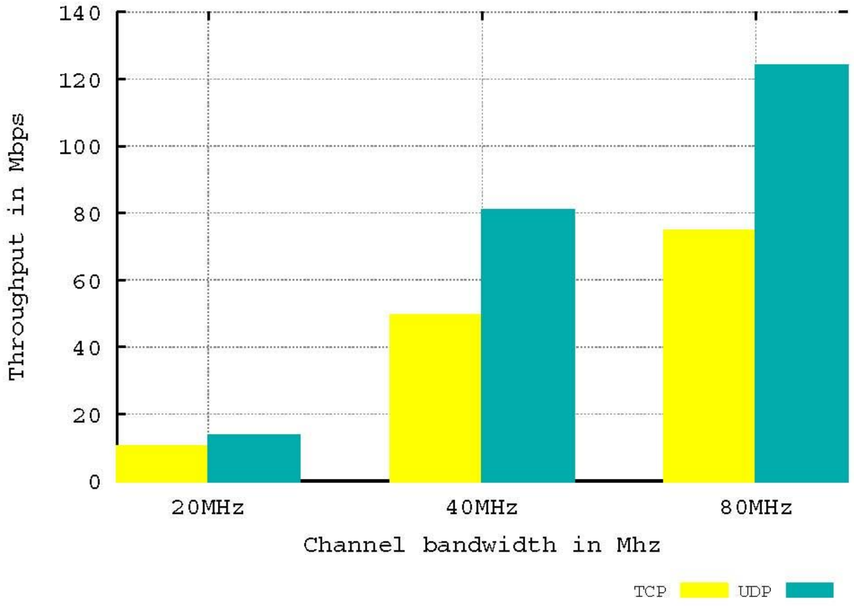
Traffic generated by *netperf*, *iperf* .
Packets of 1500 bytes
Latency is measured by *hping3*
There are unexpected results

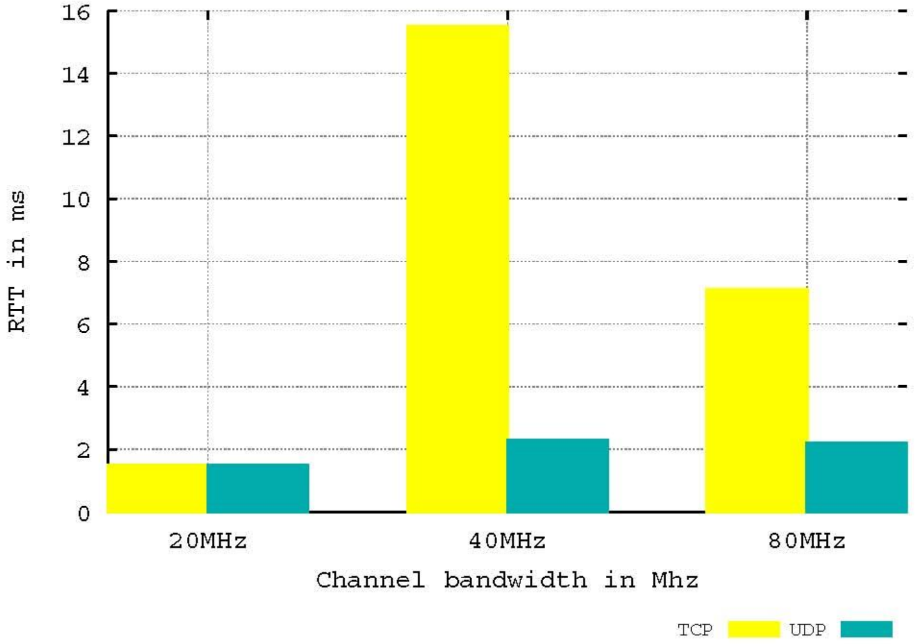
1 Hop Test

- T1: Packet P is received at PHY
- T2: Packet P has been processed by firmware and driver ath10k
- T3: ACK received at PHY
- T4: ACK has been processed by firmware and driver ath10k
  - Original firmware does not present this problem at 40 MHz.
  - At 20 MHz the behaviour is correct in both firmwares.

Time	msec
T1	0
T2	0,003
T3	0,027
T4	3,303

2 Hop Test


140
120
100
80
60
40
20
0
Throughput in Mbps
20MHz
40MHz
80MHz
Channel bandwidth in Mhz
TCP
UDP


16
14
12
10
8
6
4
2
0
RTT in ms
20MHz
40MHz
80MHz
Channel bandwidth in Mhz
TCP
UDP

Conclusion

- We are studying the dual use of WiFi technology for cognitive radio/networks technology in coalition deployments
- We have proposed to take advantage of rapid prototyping capabilities of ns-3
- We have shown some initial simulation results based on a backpressure routing approach
- We have setup the testbed and we are dealing with some implementation issues to move to prototyping