Review Open Call 6 Experiments "Cooperative Proactive resource management for 5G in the unlicensed spectrum"

Fotis Foukalas

Cognitive Innovations

Review OC6

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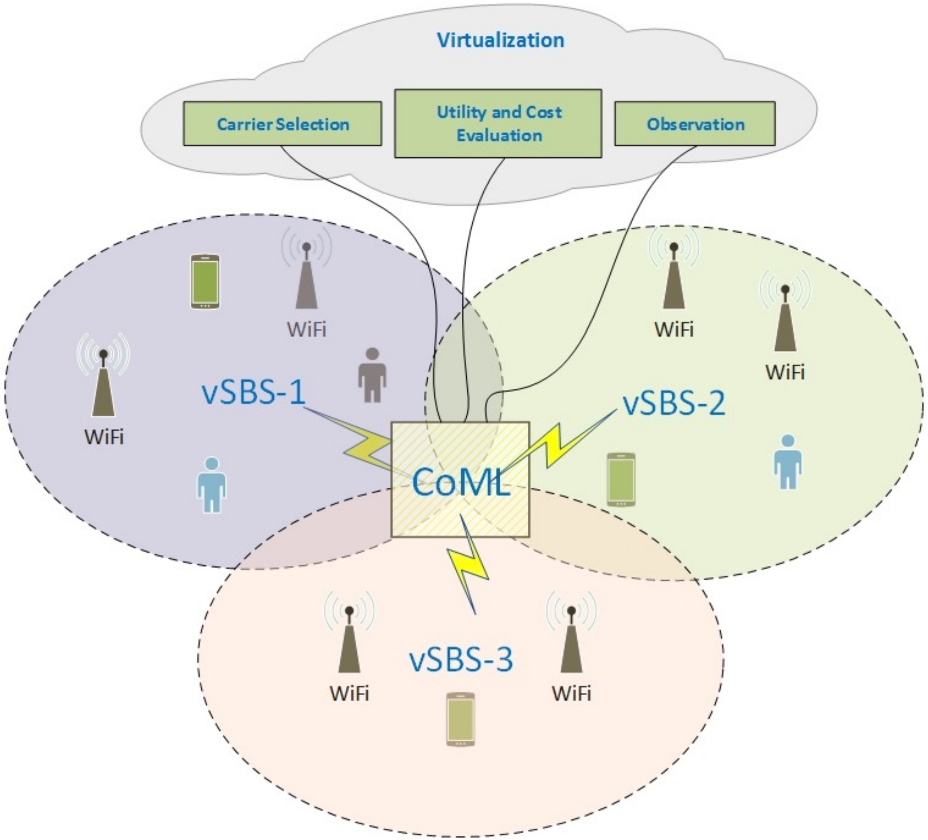


CoPro5G

COOPERATIVE PROACTIVE RESOURCE MANAGEMENT FOR 5G IN THE UNLICENSED SPECTRUM

Outline

- **Experiment description (max. 4 slides)**
  - Concept and objectives
  - Background and motivation
  - Experiment set-up
- **Project results (max. 3 slides)**
  - Measurements
  - Lessons learned
- **Business impact (min. 4 slides)**
  - Impact on your business, .. how did Fed4FIRE helped you ?
  - Value perceived, .. why did you come to Fed4FIRE ?
- **Feedback (min. 4 slides)**
  - Used resources and tools
  - Added value of Fed4FIRE

Experiment description

FED4FIRE

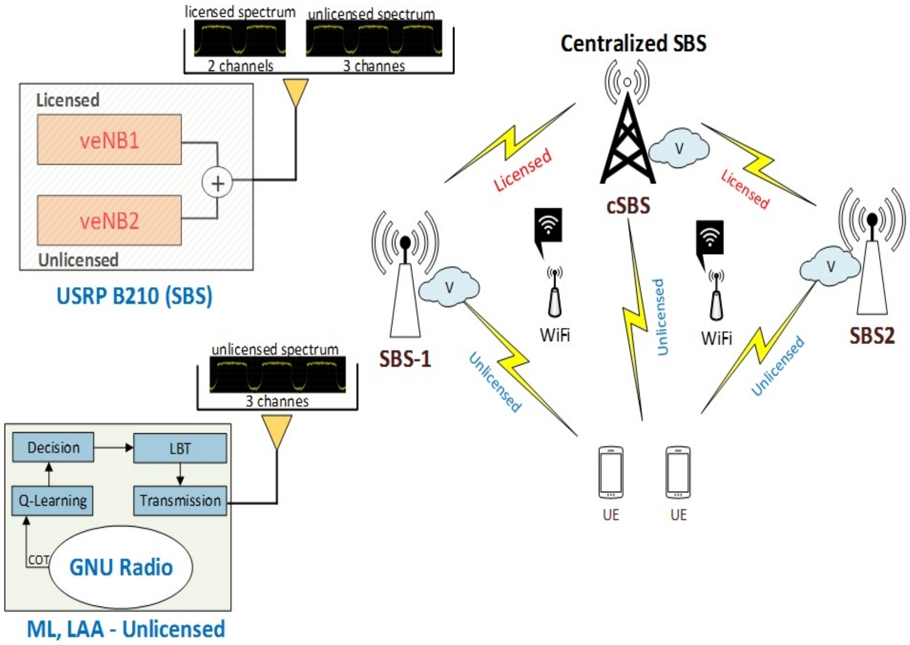
Concept & objectives

- Learn the availability of the unlicensed spectrum.
- Provide proactive resource allocation.
- Efficient spectrum utilization for both licensed and unlicensed spectrum bands.
- Carrier aggregation (CA) concept through LAA.

Bckground and motivation

- ML progress enables us to rethink the way of learning the wireless medium.
- Incorporate intelligence to wireless medium that could not exist with the current channel estimation techniques.
- Foster cooperation instead of competition for the available channel resource.
- The concept of cloud enabled small cells has been recently proposed and multiple separate experiments could be carried out to deploy such a solution.

Experiment description



Experiment setup 1/2

- 3 B210 USRPs configured as SBS.
- Each USRP trnasmits and receives LTE frames in licensed and unlicensed spectrum.
- Small cell virtualization by deploying both the licensed (veNB1) and the unlicensed (veNB2) baseband on the same USRP while sharing a common RF front end.
- Deploy Q-Learning for proactive channel resource allocation.
- Centralized SBS for coordination of the cooperative resource management.
- 1 B210 USRP configured as Wi-Fi traffic generator.

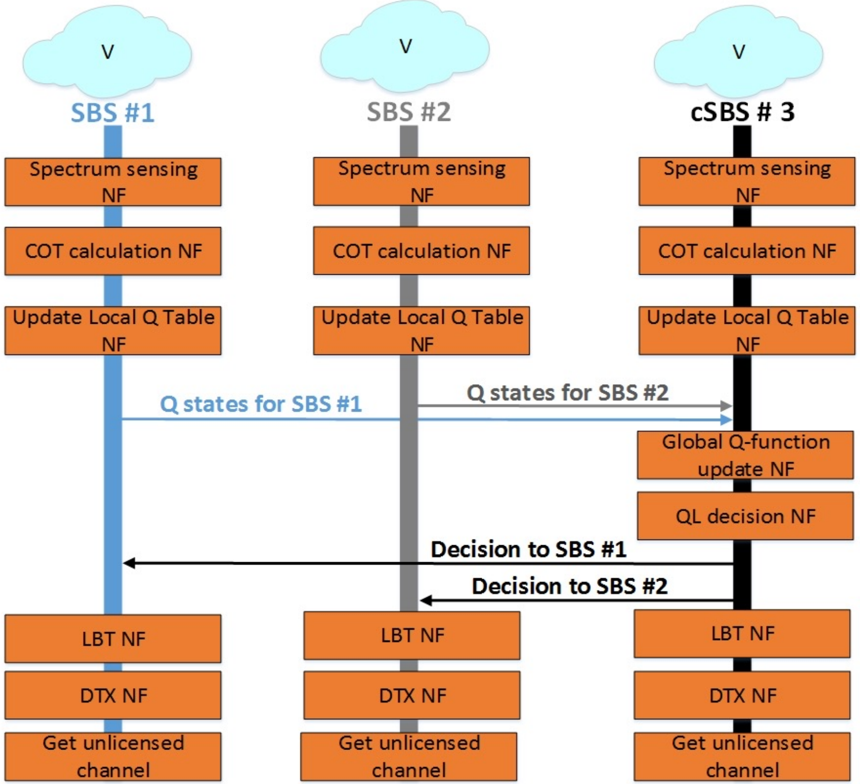
Experiment description

Channel	Central frequency	Bandwidth
Licensed 1	2446932000 Hz	1.4 MHz
Licensed 2	2448464000 Hz	1.4 MHz
Unlicensed 1	2.45 GHz	1.4 MHz
Unlicensed 2	2451536000 Hz	1.4 MHz
Unlicensed 3	2453068000 Hz	1.4 MHz
Total	-	7.68 MHz

Experiment setup 2/2

- Three channels are located on the unlicensed spectrum and 2 channels are located on the licensed spectrum bands
- Licensed channel for in-band communication between the veNBs.
- The veNBs dedicated to the unlicensed channel transmission is LAA-enabled, with listen before talk (LBT) and discontinuous transmission (DTX) capabilities. It also features a spectrum sensing mechanism which can scan the unlicensed spectrum and detect any on-going traffic.
- 1.4 MHz BW for each channel.
- Channel spacing for avoiding possible interference.
- Traffic generation in unlicesed spectrum.

Experiment description



QL learning

- Perform spectrum sensing in the unlicesend channels and obtain channel occupancy time (COT).
- Update QL tables according to QL. Ql decides the channel selection for the next transmission, the amount of subframes to be transmitted and performs transmit power control.
- LBT and DTX for transmission in the unlicesed channel.
- We have deployed 4 different QL configurations.

Project results

QL learning implementations

- Non cooperative Q-Learning **(NC-QL)**. The QL algorithm runs individually on each SBS. In this setup the SBSs compete for the available network resources.
- Non cooperative Double Q-Learning **(NC-DQL)**. The QL runs individually on each SBS, also taking decisions for transmit power control under the double Q-Learning paradigm.
- Cooperative Q-Learning **(C-QL)**. The QL runs in a distributed way on each SBS with the cSBS acting as the centralized controller which is responsible for cooperation between SBSs. In this sense, SBSs do not compete for network resources; instead they cooperate in order to maximize the resource utilization of the whole network.
- Cooperative Double Q-Learning **(C-DQL)**. The QL runs on each SBS in a distributed way as in C-QL, while also taking decisions for transmit power control by employing the double Q-Learning algorithm.

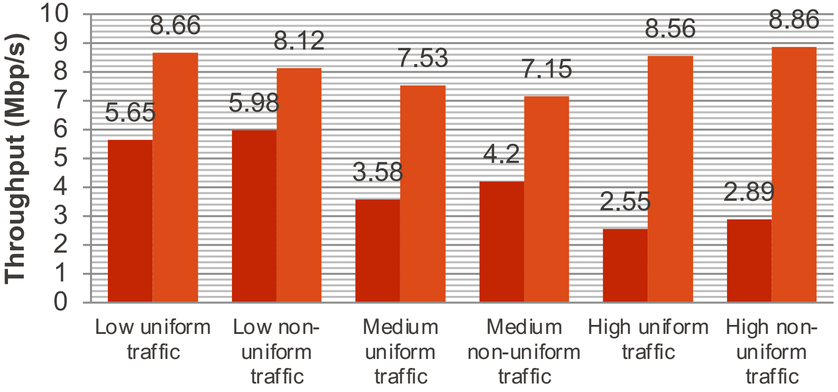
Measurements

- **SBS throughput** is depicted with red colour and measures the throughput achieved by the three SBSs collectively. This metric gives information on how the SBS compete or coordinate for network resources and can be used to describe the success of QL paradigm in proactive resource allocation.
- **Network throughput** is depicted with orange colour and measures the throughput achieved by the network as a whole, i.e. the Wi-Fi and SBS throughput combined. This measurement displays the coexistence levels of Wi-Fi and SBS as they compete for network resources. The higher the network throughput, the more efficient the QL algorithm is in managing the coexistence levels between those two entities.
- **Power consumption** on the transmitter side on each SBS under three different QL configurations.

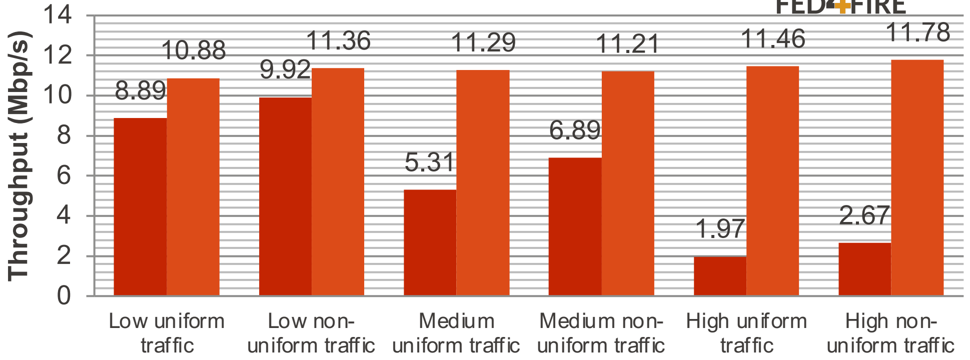
Traffic conditions

- **Uniform traffic**. The Wi-Fi traffic is equally distributed across the available channels.
- **Non-uniform traffic**. The Wi-Fi traffic is randomly distributed across the available channels.
- **Low traffic**. The Wi-Fi traffic occupies 25% of the channels.
- **Medium traffic**. The Wi-Fi traffic occupies 50% of the channels.
- **High traffic**. The Wi-Fi traffic occupies 75% of the channels.

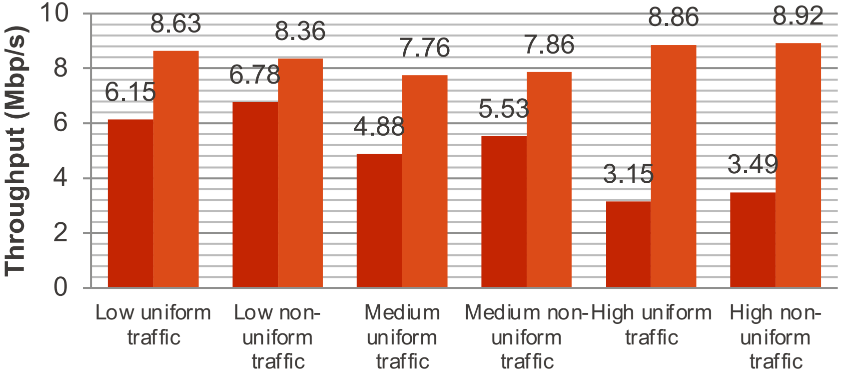
Project results



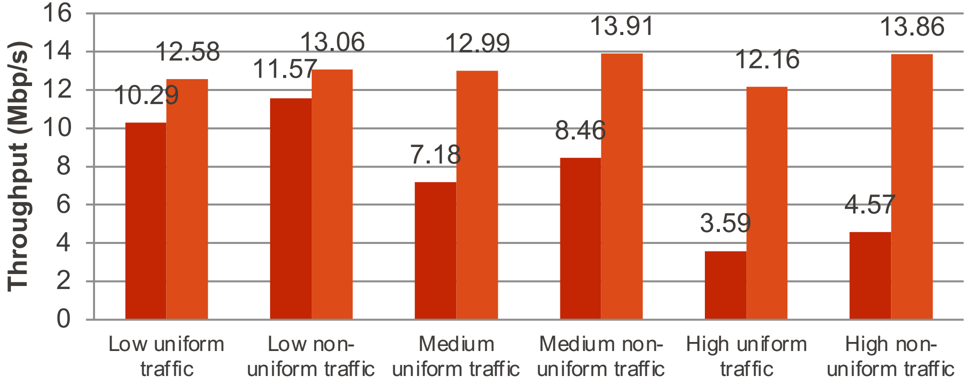
NC-QL



C-QL

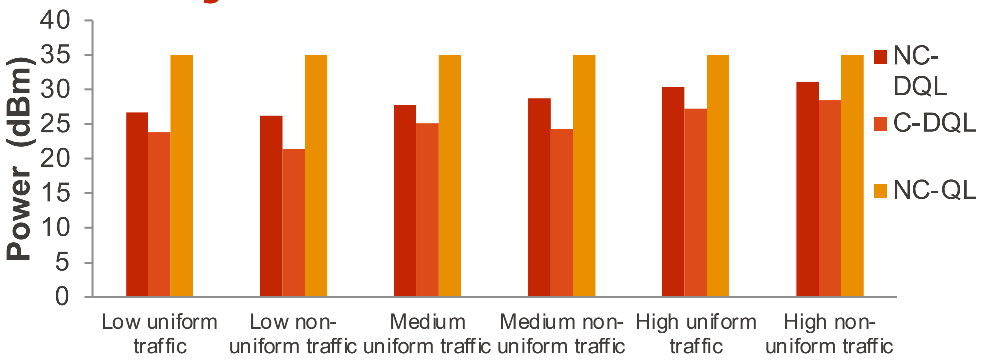


NC-DQL



C-DQL

Project results



- C-DQL achieves the best SBS and network throughput. Distributed learning takes into account the inputs from every SBS and thus, it fosters cooperation instead of letting the SBSs compete with each other. The result is an efficient coexistence scheme that maximizes the SBS and Wi-Fi.
- The non-cooperative versions of QL display lower throughput levels with NC-DQL achieving 8.9 Mbps, and NC-QL achieving 8.8 Mbps. Thus a cooperative QL scheme significantly boosts the achievable network throughput when compared with a non-cooperative algorithm.
- C-DQL manages to lower the transmit power consumption to a minimum of 21 dBm, while NC-QDL achieves only a 26 dBm minimum.

<u>Leesons learned</u>

- We learned to employ the small cell virtualization concept in order to deploy two virtual eNBs on the same small cell.
- We learnt to deploy a traffic generator, which is capable of generating traffic on the unlicensed spectrum.
- We managed to develop four different QL algorithms for pro-active spectrum allocation. We deployed the QL schemes over the existing infrastructure and we utilized GNU radio and SrsLTE to manage the communication between SBS and QL modules.
- We obtained measurements for each QL configuration under different network traffic conditions and we utilize such knowledge to deduce the effectiveness of each algorithm

Business impact

VALUE PERCEIVED

- The scalability and size of the testbed provided by Fed4Fire enables the deployment complex experiments.
- Gain knowledge on deploying our innovative solutions to large experimental networks.
- Results enhance Cogninn's position on giving consulting services to mobile operators in collaboration with big vendors.

DIRECT / INDIRECT VALUE TO COGNINN

- Direct value: Deployment and testing of our solution.
- Indirect value: Enforcing our capabilities to deal with large-scale networks providing our clients the necessary insights of the corresponding technologies.
- Both: Our solution is transparent of 4G or 5G given that most of the features are main components of any radio access network even Wi-Fi. In this way, we are ennabled to apply the proposed solution to other scenarios and products.

Business impact

FED4FIRE

FED4FIRE+ IMPACT ON SOLUTION DEVELOPMENT

- We need Fed4FIRE+ testbed infrastructure to benchmark wireless networking solutions.
- Without such an infrastructure, our solution can not be tested with all the required components.
- For example: very high cost of 3 small base stations and 2 more devices to produce traffics plus any other device playing the role of end device.
- The deployment in a large geographical area is also important in some use cases.

Business impact

IMPACT ON PRODUCT DEVELOPMENT

- We used Fed4FIRE+ funding to further develop, tune and refine and our product.
- We identified the strengths and weaknesses of solution and thus we are now be able to steer the development process towards the right direction.
- We conducted extensive testing so that to verify the functionality of our product.

Business impact

FED4FIRE

PRODUCT DEVELOPMENT CYCLE AND FUTURE COLABORATIONS

- CoPro5G is a continuation of an experiment within the WishFul experiments provided by their open calls.
- We are constantly enhancing our solution in order to maintain a competitive edge of our products.
- In the same context, we could imagine our participation to future experiments either within open calls or other kind of collaborations.
- We are always looking for opportunities to collaborate with such infrastructure based partnerships so that to benchmark our solutions.

Feedback to Fed4FIRE+

RESOURCES USED

- Testbed : w-iLab.t (imec)
- 4x USRP B200/B210 devices .
- We made full use of all the testbed infrastructure resources requested at the Open Call proposal.

TOOLS USED

- Jfed
- Gnuradio
- srsLTE
- Python programming framework

Feedback to Fed4FIRE+

DESIGN/SET-UP/RUNNING OUR EXPERIMENT ON FED4FIRE+

- The administration, feedback and conference attendance work was excellent and very helpful.
- The documentation provided for the software examples was very good.
- No additional drivers or utilities had to be installed in order to setup the experiment.
- The communication between the user and the service was acting as an abstraction layer between the programmer and the infrastructure. As a result the overall experience was excellent.

Feedback to Fed4FIRE+

EXPERIMENT EXECUTION AND RESULTS

- The amount of time was adequate for us to setup and run the experiment. We also had enough time to rerun it several times, changing some configuration options.
- The results we obtained were in line with our initial goals.
- A major bottleneck was the resource managing of the USRP's resources in order to meet the computation intensive requirements of our experiment.
- The experiment replication is an easy process due to the stable nature of the testbed environment.
- Fed4FIRE+ environment was completely trustworthy for the deployment of our experiment.

Feedback to Fed4FIRE+

ADDED VALUE OF FED4FIRE+

Fed4FIRE+ components in order of importance according to our experience:

- The abstraction layer between the USRPs and the software. The user is not required to directly program the USRPs.
- The software support of Gnuradio and srslte tools.
- The ease of access to the testbed infrastructure. The resource reservation system was simple and no ssh commands were necessary for the user to log in. Instead, the JFed tool was hiding the underlying complexity of such actions.
- The detailed and thorough documentation provided.
- The diversity of the resources provided.
- The USRP utilization which offer high configurability.

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THANK YOU!

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