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Orchestration and Reconfiguration Control Architecture

D7.1: Summary of results of first Open Call for experiments

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Authors	Kai Zhang (MARTEL), Joao F. Santos (TCD), Jonathan van de Belt (TCD), Wei Liu (IMEC), Ingrid Moerman (IMEC)
Reviewers	Xianjun Jiao (IMEC)

Abstract	D7.1 will collect the summaries and conclusions of the first Open Call for Experiments. It introduces the Call, the winners, as well as

	provides an overview of the problem addressed, the main challenges, the proposed solution, the results obtained and the main findings with respect to the use of the ORCA testbed and SDR platforms for each of the projects. This deliverable will be used for promotion of the ORCA facility in WP8.
Keywords	Open Call, testbed, SDR

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Nature of the deliverable:	R	
Dissemination Level		
PU	Public, fully open, e.g. web	✓
CI	Classified, information as referred to in Commission Decision 2001/844/EC	
CO	Confidential to ORCA project and Commission Services	

EXECUTIVE SUMMARY

This report summarises the organisation and operation of the ORCA 1st Open Call for Experiment (OC1 EXP).

The open call organisational process, led by Partner Martel Innovate, has given the following indications for future open call management:

1. Better / more hands-on tutorials will be needed
2. "Feasibility" and "Relevance" can be separate selection criteria
3. "At least one ORCA function must be used" shall be clearly shown in the Call text to avoid misunderstandings
4. It helps increase relevance of the proposals by providing guidelines on the subject of the EXP

There are six winners for OC1 EXP, three fall under the category "Scientific Excellence", and the other three "Industry". as listed below. The main results and conclusions are:

- Scientific Excellence (3)
    - **FastFlow5G**: dInstantaneous end-to-end flow latency optimization in a cellular 4G/5G based network. Submitted by: Universidade de Vigo (Spain)

      Main results:
      It is possible to replicate Gateway Network Functions at the Edge and dynamically move flows to the replicated functions in a completely transparent way to the whole network in less than two seconds.

      Conclusions:
      FastFlow5G was completed successfully. The IRIS testbed was able to support complex experiments. The existence of testbeds like ORCA simplifies the creation of innovative experiments without requiring an investment in hardware and time to build an infrastructure.

    - **ACROSS**: Autonomic CRoss layer prOtocol stack for SDR Systems. Submitted by: ICCS – Institute of Communications and Computer Systems (Greece)

      Main results:
      i) the framework adapts transparently to the behavior of the primary network, ii) most collisions occur in multi-hop flow involved transmissions, rather than in point-to-point transmissions, iii) convergence of the Gibbs sampler takes place rather fast, i.e., within approximately 20-50 sweeps, iv) the more the channels assigned to secondary nodes, the less the collisions detected, as expected.

      Conclusions:
      ACROSS allowed a first realistic evaluation of our resource allocation framework in real wireless conditions. Experiments showed the feasibility of the framework and adaptation to primary network activity, paving way for further improvement.
      ORCA was a major enabler for ACROSS. Despite the steep learning curve, the experiment has been concluded. Several improvements could make ORCA better.

    - **WilDCAT**: Waveform Design and benChmArking Tool. Submitted by: UPRC – University of Piraeus Research Center (Greece)

Main results:
The main results of the experiments consists of frequency synchronization error and reception reliability (BER) experiments. The results showed that the FBMC system outperformed GFDM using prototype pulse Beaulieu in both measurements. Since the pulse shape was not optimized for GFDM, there is margin for improvement, thus it should be studied furtherly.

Conclusions:
Generally, the idea of having unlimited access in both software resources and hardware components of the TUD's testbed at any time through remote access, seemed extremely useful and promising towards further future experimentation. Regarding the experimentation tools, jFed Experimentation toolkit was used. The experience with jFed was rather satisfactory and the final results proved to be in line with our initial expectations.

- Industry (3)
    - **CiLANTRO:** Cross LAyer NeTwork monitoRing in Orca
      Submitted by: NM2 srl (Italy)

      Main results:
      The product monitoring capabilities with SDR-based sender-side inter-packet-time (IPT) tracing at LTE MAC layer, in addition to the sender- and receiver-side at UDP Transport layer. The ECDF shows that alterations of IPT pattern when traveling the Internet are actually mostly imposed transmitting, at the first (LTE) hop.
      Conclusion / lessons learned:
      As a result, monitoring capabilities of the products was extended adding new LTE MAC and PHY layer metrics.
      The ORCA facility has proved of very high value in exploring a sizeable number of different setups, thanks to the different types and models of devices.

    - **CLUE:** Coexistence of LTE-Unlicensed & Wi-Fi
      Submitted by: EIGHT BELLS LTD (Cyprus)

      Main results:
      LTE-U and WIFI in ISM bands are proved to be able to only co-exist by deploying the concept of "Duty Cycle" on LTE eNB and by assigning a high number of sub-carriers (PRBs). LTE transmissions interfere with LTE deployment and significantly deteriorate WIFI channel performance.

      Conclusions:
      ORCA framework and IRIS infrastructure were critical for the successful execution of the experiment. SDR nodes with pre-configured GNU-Radio and SRSLTE software modules were mandatory of the timely completion of the project.

    - **E2EWebRTC:** Proof of Concept of an 5G End to End Computationally Intelligent WebRTC service leveraging ORCA's combined SDR/SDN approach
      Submitted by: Modio Computing (Greece)

      Main results:
      The optimal receiver gain and sensitivity to ensure high-throughput and low latency traffic under interference of Wi-Fi.

Conclusions:

The clustering models implemented in Qiqbus are effective in finding best possible GNU Radio and OpenFlow configurations.

Thanks to the ORCA facility, specifically hardware and software resources of the IRIS testbed, a Qiqbus-based processing pipeline with suitable clustering models were defined and implemented.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The Deliverable 7.1 aims to provide an overview of the results, key outcomes and findings from the First Open Call for Experiments (OC1 EXP).

It will include an overview of the OC1 for Experiments (OC1 EXP), including call information and the winners (Chapter 2); and then dig deeper into each individual winner project, to analyse its results and implications on ORCA project, the testbed and the SDR platforms (Chapter 3)

Chapter 2 will include the following sub chapters:

2.1 Call Information

2.2 Winners

Chapter 3 will include the following sub chapters, for each of the projects:

1 Problem description

2 Main challenges

3 Proposed solution

4 Results

5 Main findings

2 FIRST OPEN CALL FOR EXPERIMENTS

2.1 Call Information

The OC1 EXP solicits for Experiments for rapid validation of innovative software defined radio (SDR) solutions using the facilities, SDR hardware platforms and software toolsets supported by the ORCA Consortium.

The following Table 1 demonstrates basic Call information

Project full name	ORCA - Orchestration and Reconfiguration Control Architecture
Project grant agreement No.	732174
Call identifier	ORCA-OC1-EXP
Call title	First ORCA Open Call for Experiments
Submission deadline	Wednesday the 28th February 2018, at 17:00 Brussels local time
Feasibility & relevance check deadline	Sunday the 18th February 2018, at 17:00 Brussels local time

Table 1: ORCA OC1 EXP Basic Call Information

The SDR functionalities that are used in the OC1 EXP include:

- SDR data plane functionality
- SDR control plane functionality
- SDR management plane functionality
  - Over the testbed control backbone
  - Over the air

Within the context of ORCA, six testbeds were made available for experimentation by ORCA partners or by Third Parties selected via the OCs:

- IMEC w-iLab.t testbed for heterogeneous environments
- IMEC Portable testbed
- RUTGERS ORBIT heterogeneous multi-node testbed
- TCD IRIS network virtualization testbed
- TUD OWL scale testbed
- KUL dense multi-node networks testbed

In terms of financial information, the total budget for OC1 EXP: 350,000€. Maximum budget per Experiment: 50,000€. It is defined that each project will have guaranteed support of 28,000€, with an extra budget of typically €4000 per Experiment will be allocated to the ORCA consortium partner acting as Patron for guaranteed support.

Two categories of projects are planned to be funded, in total seven projects:

- Scientific Excellence (3 projects)

- Industry (4 projects)

2.2 Winners

An established, independent and impartial evaluation process, of confidential nature has been applied to filter and select the winning proposals. A brief summary of the process is as follows:

- Feasibility check
  - Candidates provide a first submission
  - Patrons evaluate the feasibility and relevance of the proposals and provide feedback
- Final submission and evaluation
  - Based on the feedback, the proposals passed the feasibility check will submit the final applications
  - External evaluators receive and review the final applications based on a set of criteria and give scores
  - Consensus meetings between evaluators were held when necessary to agree on the winners

The following projects have won the ORCA OC1 EXP, six in total:

- Scientific Excellence (3)
  - **FastFlow5G**:Instantaneous end-to-end flow latency optimization in a cellular 4G/5G based network. Submitted by: Universidade de Vigo (Spain)
  - **ACROSS**: Autonomic CRoss layer prOtocol stack for SDR Systems. Submitted by: ICCS – Institute of Communications and Computer Systems (Greece)
  - **WilDCAT**: Waveform Design and benChmArking Tool. Submitted by: UPRC – University of Piraeus Research Center (Greece)
- Industry (3)
  - **CiLANTRO:** Cross LAyer NeTwork monitoRing in Orca Submitted by: NM2 srl (Italy)
  - **CLUE:** Coexistence of LTE-Unlicensed & Wi-Fi Submitted by: EIGHT BELLS LTD (Cyprus)
  - **E2EWebRTC:** Proof of Concept of an 5G End to End Computationally Intelligent WebRTC service leveraging ORCA's combined SDR/SDN approach Submitted by: Modio Computing (Greece)

2.3 Observations / Lessons Learned

The consortium, through the organisation process of the OC1 EXP, has the following observations that would like to take into consideration for future OC EXPs:

1. Better / more hands-on tutorials will be needed on the functionalities and the platforms
2. "Feasibility" and "Relevance" can be divided into two selection criteria
3. "At least one ORCA function must be used" shall be clearly shown in the Call text to avoid misunderstandings
4. It helps increase relevance of the proposals by providing guidelines on the subject of the EXP

3 SUMMARY OF RESULTS OF EACH PROJECT

3.1 Scientific Excellence

3.1.1 FastFlow5G

3.1.1.1 Goal of the Experiment

FastFlow5G seeks to prove that it is possible to adapt an end-to-end network in real time to new traffic requirements transparently to the session layer, by exploiting technologies such as SDN, SDR, RAN-Sharing and new paradigms such as Network Slicing, RAN Slicing, Edge Computing, Network Function Virtualization (NFV), service orchestration and virtualization.

3.1.1.2 Main Challenges

FastFlow5G requires a complex setup that involves User Equipment, Radio Access Network, a Core Network and different technologies: SDN switches and controller, Docker containers, GTP tunnels, etc. They conform a challenging complex architecture. Furthermore, we have to deploy OpenAirInterface implementations in the testbed.

3.1.1.3 Description of Experiment Setup

We have performed six different experiments to gain insight into solutions for flexible and dynamically reconfigurable 5G networks. The different experiments allowed us to deploy several LTE operators in the IRIS infrastructure and move Network Functions from the core to the edge without disrupting ongoing communications. The combined setup is shown in the figure below.

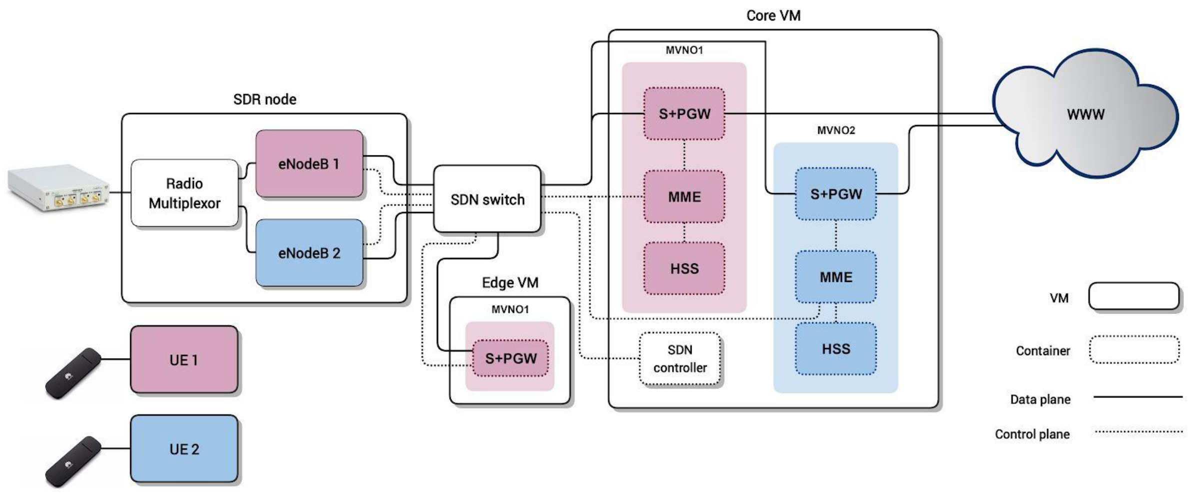

Figure 1: FastFlow experiment setup.

Two LTE dongles (UEs) were connected to two laptops installed in the IRIS testbed. Each UE was connected to its corresponding LTE network, generated by an eNB. The two eNBs could even share a single SDR device (although the experiment revealed some limitations of existing hardware). The core of the LTE networks was virtualized in a testbed VM. It was possible to relocate Network Functions from the Core to the Edge in order to reduce communication latency.

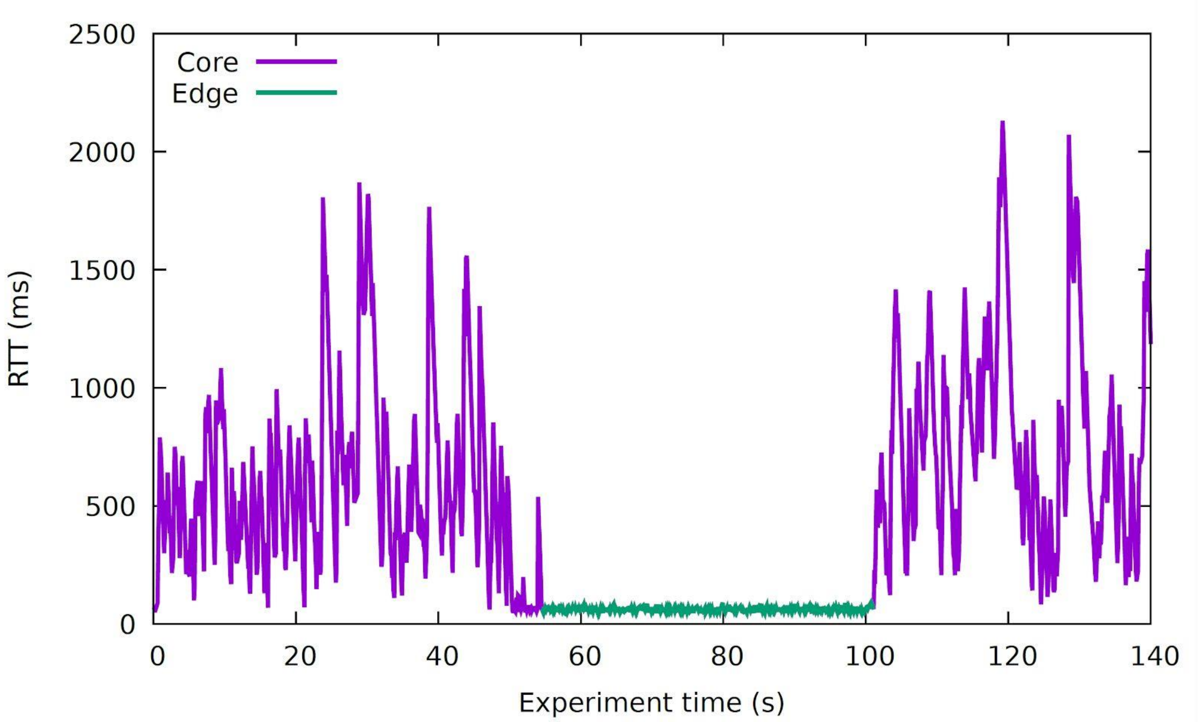

Figure 2: Round-trip time when moving a flow to the edge.

3.1.1.4 Main Results

The results of FastFlow5G experiments demonstrate that it is possible to replicate Gateway Network Functions at the Edge and dynamically move flows to the replicated functions in a completely transparent way to the whole network in less than two seconds. As shown in Figure 2, when the Core Gateway was congested, latency improved an order of magnitude by moving a flow to the Edge.

Moreover, we managed to deploy two independent RAN slices sharing the same SDR device. Using our frequency multiplexing scheme, both slices could operate simultaneously, independently and without interfering with each other as shown in Figure 3.

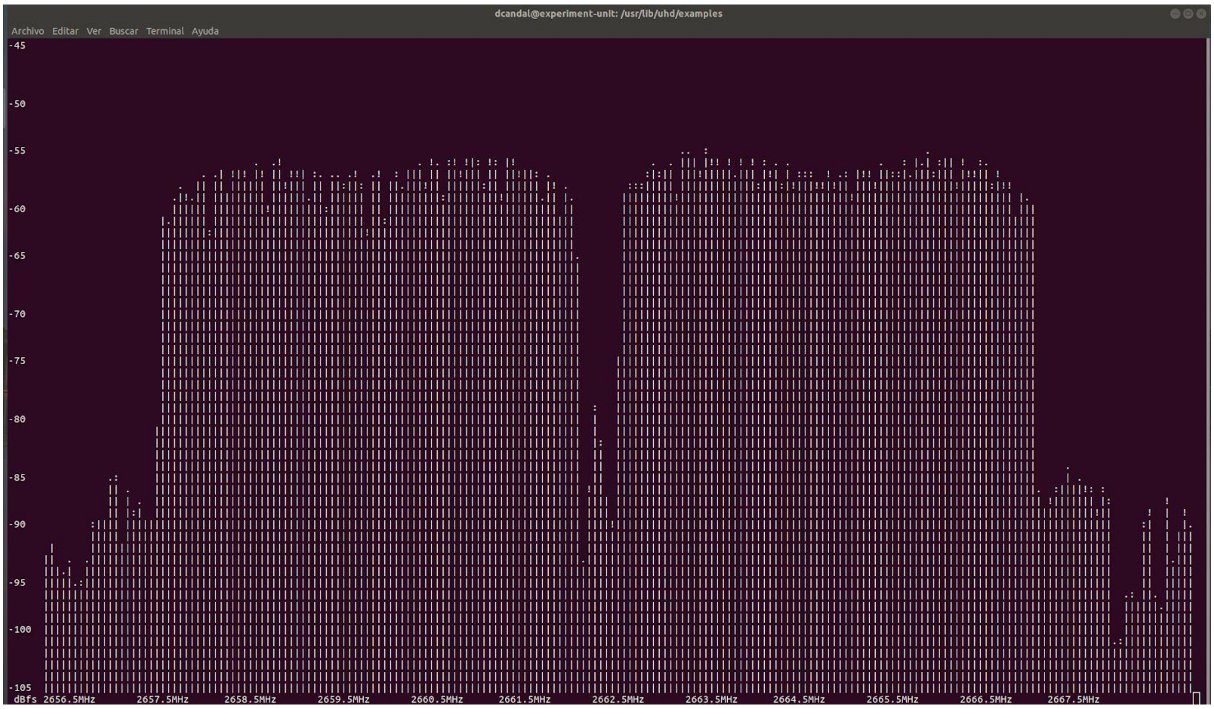

Figure 3: Spectrum analysis after deploying the eNodeBs for MVNOs 1 and 2.

3.1.1.5 Conclusions and Feedback (with respect to the use of the ORCA testbed and SDR platforms)

FastFlow5G, an elaborated set of experiments to study how to create dynamic environments for 5G networks and analyze their performance, was completed successfully. The IRIS testbed, in combination with the excellent support provided by its staff, proved to be able to support complex experiments.

The existence of testbeds like ORCA simplifies the creation of innovative experiments without requiring an investment in hardware and time to build an infrastructure. The support provided by the Iris Testbed Manager was outstanding. He even provided ad-hoc solutions for complex FastFlow5G experiments .

3.1.2 ACROSS

3.1.2.1 Goal of the Experiment

ACROSS experiment aimed at demonstrating the feasibility of a resource allocation framework based on Markov Random Fields for the first time in real cognitive radio topologies implemented via SDR. It also aimed at providing usable software components (e.g., spectrum sensing) and feedback on the use & development, contributing towards a more attractive ORCA for cross-layer design in SDR networks.

3.1.2.2 Main Challenges

The main challenge in ACROSS was the implementation and demonstration of operation of a complete, distributed and autonomic protocol stack in GNU radio. This needed to be achieved from scratch over two different ORCA testbeds that had not been used before for similar developments. ACROSS achieved these goals, providing a multitude of results and considerable directions for future research.

3.1.2.3 Description of Experiment Setup

Our experiment involved setting up a secondary cognitive radio network consisting of 4, 7, 8 or 10 secondary users, with USRP devices running our cross-layered resource allocation approach, based on Markov Random Fields. Different types of topologies, such as line, triangle, square, partial mesh and mesh were defined and the operation of our approach was demonstrated. The impact of various radio parameters, e.g., background noise, existence or no existence of primary spectrum users, etc., was investigated and quantified over the performance of the system, e.g., by accounting for the collisions taking place, the achieved throughput and demonstrating the adaptive features on primary user activity.

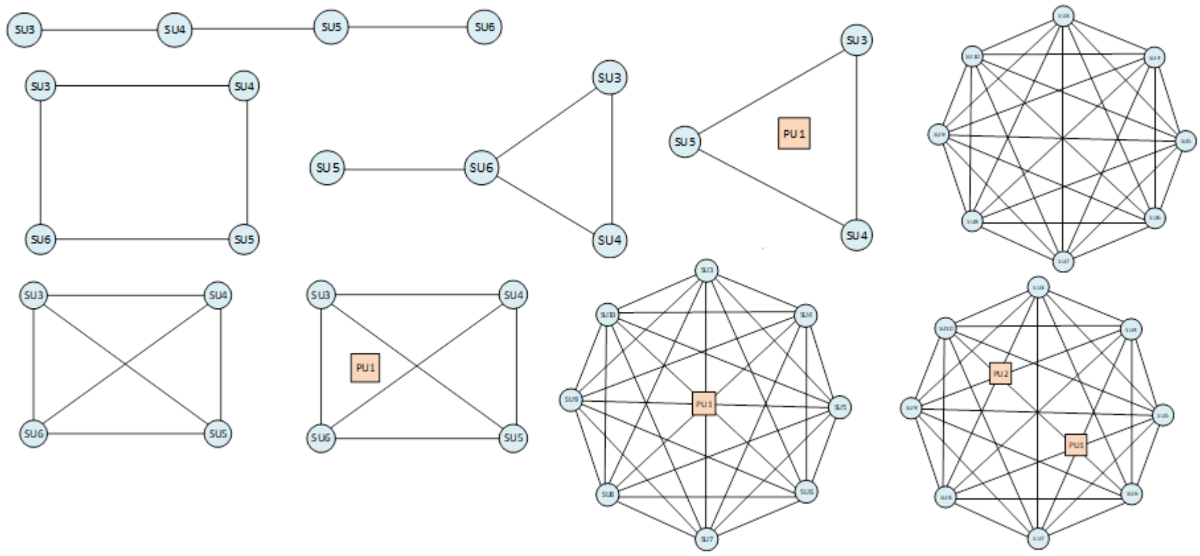

Figure 4: Network topologies implemented in IRIS and ORBIT testbeds.

3.1.2.4 Main Results

ACROSS enabled making several observations on the implementation, performance and potential extensions of our framework. Among them, the most important ones are the following: i) our framework adapts transparently to the behavior of the primary network, ii) most collisions occur in multi-hop flow involved transmissions, rather than in point-to-point transmissions, iii) convergence of the Gibbs sampler takes place rather fast, i.e., within approximately 20-50 sweeps, iv) the more the channels assigned to secondary nodes, the less the collisions detected, as expected. Some highlights from the obtained results, are the following:

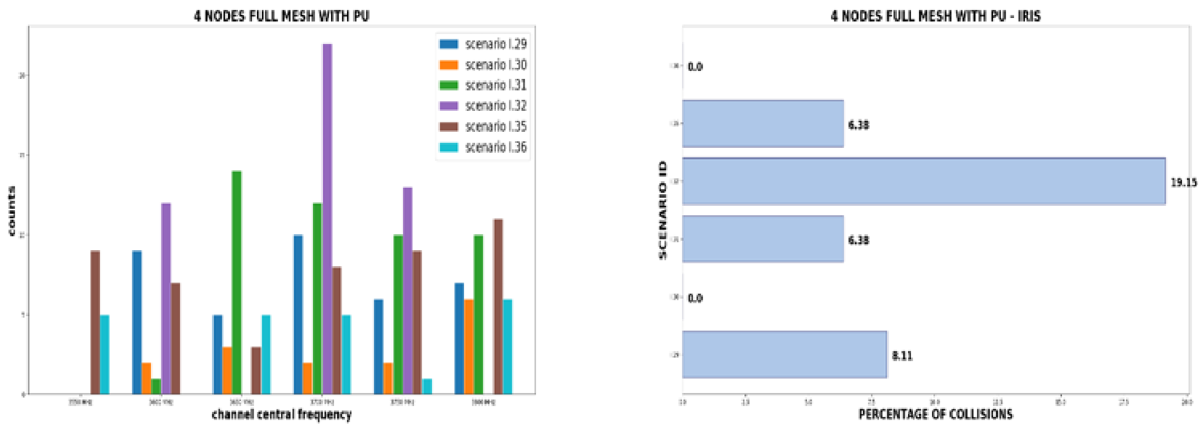

Figure 5: Number of channels used in 4-node full mesh topology scenarios with PU in IRIS testbed and the corresponding percentage of collisions.

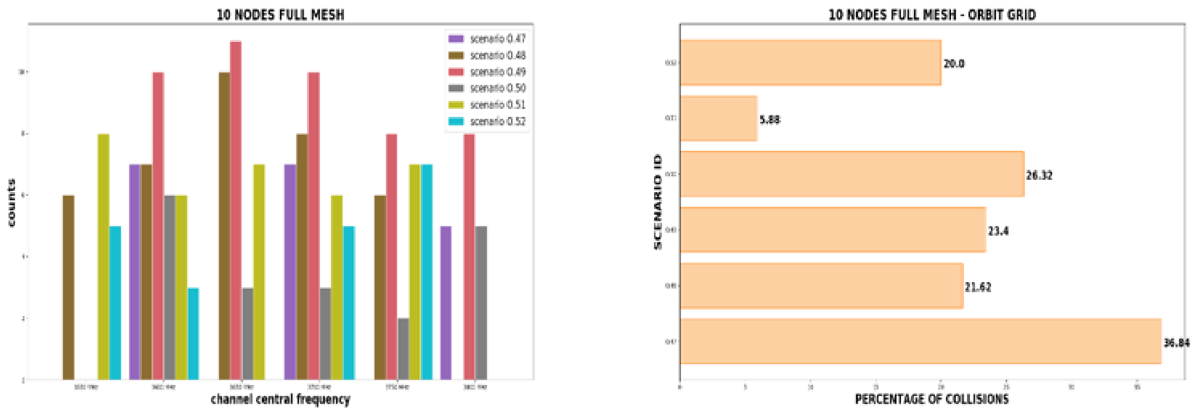

Figure 6: Number of channels used in a 10-node full mesh topology scenario in ORBIT Grid and the corresponding percentage of collisions.

3.1.2.5 Conclusions and feedback (with respect to the use of the ORCA testbed and SDR platforms)

ACROSS allowed a first realistic evaluation of our resource allocation framework in real wireless conditions. Experiments showed the feasibility of the framework and adaptation to primary network activity, while allowing performance quantification in terms of throughput, channel reuse, etc. Further improvements of implementation and design have been identified and can be attained in the future.

ORCA was a major enabler for ACROSS. Despite the steep learning curve, eventually we were able to complete our experiments and demonstration in very short time, with more than expected results. To fully exploit ORCA, prior familiarity with GNU radio seems necessary. Several improvements, like more devices, defining arbitrary topologies and spectrum band isolation, could make ORCA more lucrative.

3.1.3 WildCAT

3.1.3.1 Goal of the Experiment

The Waveform Design and benChmArking Tool (WilDCAT) project aims at the design, development, validation and exploitation of a Software Defined Radio (SDR) tool for waveform design, analysis and evaluation of multicarrier modulations, starting from conventional OFDM and extending to combinatory schemes that use filterbanks, windows, cyclic extensions and other relevant signal processing tricks and features. The WilDCAT objective is achieved with the development of a generic modulator – demodulator that is able to implement through parametric reconfiguration all known multicarrier modulations, as well as respective single-carrier extensions.

3.1.3.2 Main Challenges

During the Experimentation phase, challenges occurred. A major problem, which led to delay of the experiments, was the USRP connection. Once connected remotely to Windows desktop, the plugged USRP was identified as an unknown device. During this stage, communication with Patron was necessary in order to the USPR cable be unplugged and plugged again. Therefore, we had to wait for Patron's intervention. Fortunately, in most times, it was immediate.

3.1.3.3 Description of Experiment Setup

WilDCAT experimentation was performed in three phases:

Phase 1: It includes all preparatory activities and experiment design procedures. Initially effort was spent in order to learn, understand and familiarize with the resources and services provided by ORCA and the TUD testbed. More specifically, during Phase 1:

Phase 2: The specific Phase included the main implementation activities. It also included the theoretical design of the receiver model for the generic scheme, as well as the following technical work:

- Implementation of the generic modulator and demodulator in MATLAB.
- Implementation of the generic modulator and demodulator in C++/UHD.
- Implementation of the generic modulator and demodulator in Labview.
- Execution of experiments in order to validate reception.

Phase 3: this phase included the main experimentation activities. An overview of the experimentation procedure is presented in Figure 7. The experimental setup procedure can be summarized by the following steps:

- The user opens the "jFed Experiment Tool Set" locally on his/her PC, and chooses "Login withFed4FIRE-credentials". (it is required to install jFed on the local PC).
- The user logins using his/her Fed4FIRE credentials. (it is required to obtain Fed4FIRE credentials).
- A new experiment is created through the jFed tool.
- With the creation of the experiment, the jFed topology editor opens.
- The user selects two "Wireless Node" blocks and drags them into the topology editor.
- No connection between blocks in the topology editor is required.

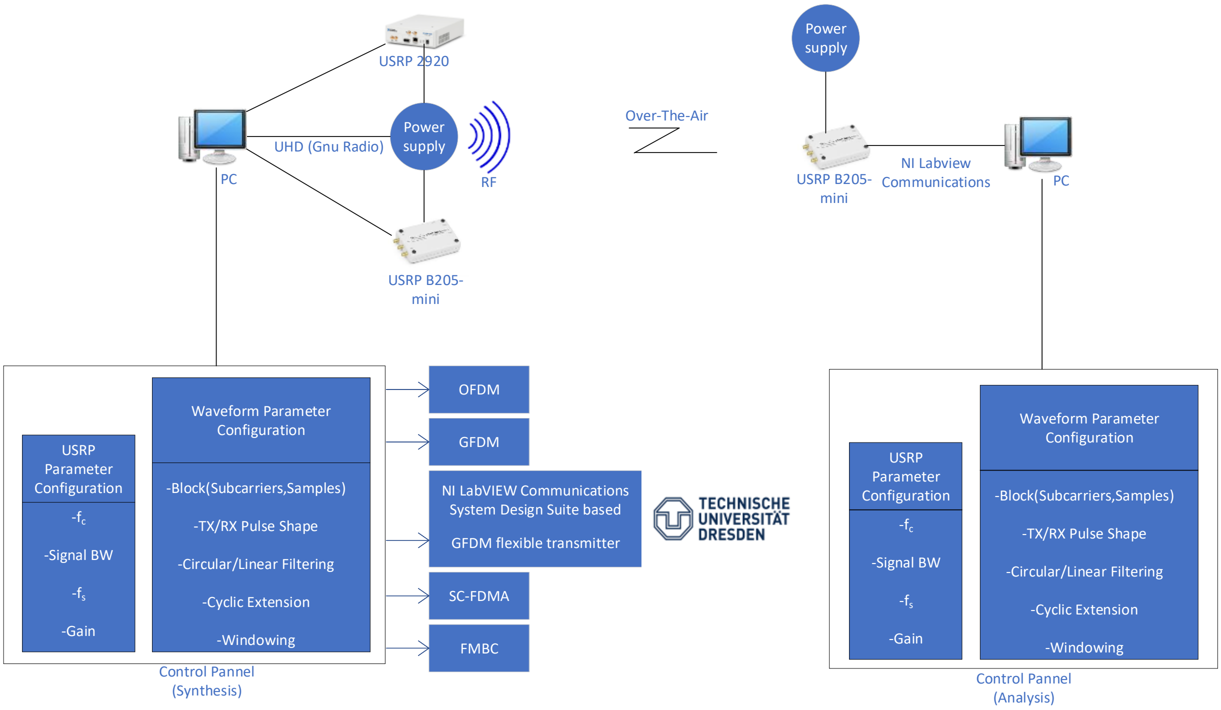

Figure 7: Experimentation procedure in WilDCAT.

- The user sets OWL TUD as the active selected testbed.
- The user opens the properties of each block and selects the resource per block. More specifically, for WilDCAT experiments, two hosts are available: 192-168-1-50 and 192-168-1-51. The user specifies the respective resource on each “Wireless Node”.
- In the open property window, the user also specifies the desired image. Two options are provided: an Ubuntu image and a Windows image.
- After setting up the nodes, the experiment starts. Through a dialog box, the project name is set to WilDCAT and the experiment name is defined. Finally, the experiment duration is set. Typically, the duration of WilDCAT experiments was 4 hours.
- The testbed initializes the WilDCAT hosts and the selected image is loaded on the remote nodes. The initialization is completed when nodes turn green (after approximately 20 minutes).
- A Remote Desktop configuration file (RDP), together with login credentials were sent to TSL by the TUD testbed administrator. The RDP file allows the connection to the main experimentation server in the remote TUD network (for WilDCAT the LAN IP of the TUD server was 192.168.192.12).
- Then, through the experimentation server, and with the use of VNC, RDP or SSH connections, the user can connect to the experiment nodes. Each node IP is given by the node name in the jFed tool (192.168.1.50 and 192.168.1.51).
- Before using the toolbox, it is needed to check, if the USRP devices are accessible to each node. If not, communication with the TUD team is required in order to re-plug the USRPs.
- Then, the user is able to open the WilDCAT toolbox in each node (C++ executable, MATLAB or Labview). The waveform configuration and the setup of the SDR equipment are performed through scripts, blocks, or configuration files depending on the toolbox instantiation.
- One node is set as Transmitter and one is set as Receiver. Identical waveform configuration on both nodes is necessary in order to achieve connectivity.

- Radio experiments are performed and result files are saved into the Receiver node. Result files may include Key Performance Indicators (e.g. BER, OOB etc.) or even a waveform segment.
- It is necessary to terminate the experiment before expiring (15-minute interval is required), otherwise files will not be saved on the node image. It is highly recommended to use scp or ftp in order to download the result files on the user local PC.

Phase 4: this phase included the preparation of the final report. The final report includes WilDCAT description, description of implantation activities, description of experimental procedures, experimentation results in terms of performance evaluation, presentation of waveform reconfiguration examples, and toolbox function description. Moreover, the report includes an extended feedback report on lessons learned from the use of the ORCA platforms and a list of recommendations for improvements for the provided hardware/software platforms.

3.1.3.4 Main Results

In this deliverable, the results related to **frequency synchronization error** and **reception reliability (BER)** will be reported.

1. **Frequency synchronization error:**

   With the specific experiments, our goal was to measure the sensitivity of the waveform to CFO, that was not compensated, e.g. due to estimation error. The measurement procedure for the specific set of experiments was the following:

   - The receiver captures the signal and uses the OFDM preamble to synchronize.
   - The CFO is estimated.
   - The distorted waveform is fed to the receiver for demodulation. The SNR at the output of the receiver (from the Error Vector Magnitude of the constellation) is extracted.
   - The experiment is repeated for high-SNR with compensation of the complete CFO. This was used in order to define the reference used for the calculation of the SNR degradation due to frequency synchronization error.
   - The measurement procedure was repeated multiple times. The measurements were collected and the results of were extracted.
   - Two lengths of Beaulieu pulses, which were proved to be efficient in the previously described set of experiments, were used for FBMC-OQAM and GFDM.

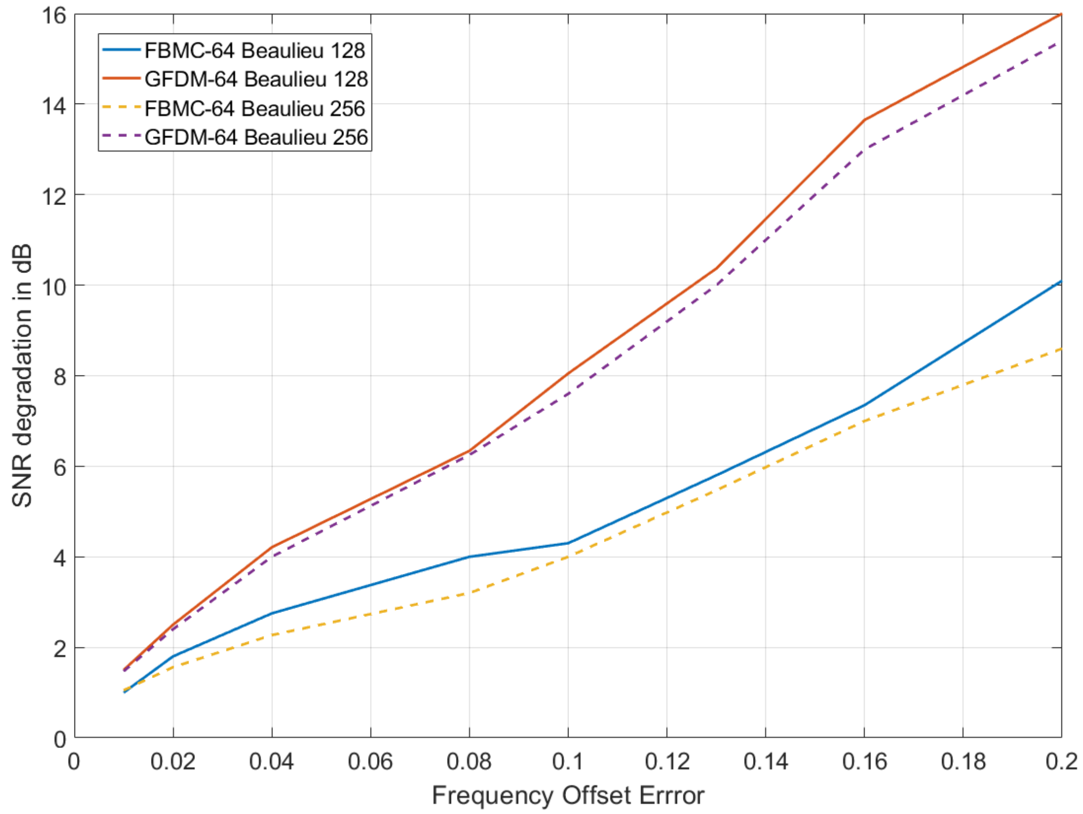

Figure 8: Effect of the Frequency Synchronization Error in terms of SNR degradation.

Comments:

- Analysis results are quite worse than simulation and theoretical studies in the field. This can be a result of:
    - The estimation error of the OFDM preamble synchronizer adds up to the reference error considered in the experiment.
    - CFO subsequently affects the channel estimator and the channel equalizer. Error propagation is usually not considered in theoretical or simulation studies.
    - FBMC is more robust than GFDM with significantly lower rate of SNR degradation increase as CFO increases.
- The measurements showed that GFDM has similar sensitivity to CFO with OFDM, despite the claims of other relevant research studies. This may be caused by the fact that the use of the specific receiver design (with matched filter) amplify the effects of CFO on the waveform. Further optimization of the GFDM receiver design is required.
- FBMC is more robust than GFDM with significantly lower rate of SNR degradation increase as FCO increases.
- Filter rank increase improves performance but it does not provide the expected benefits.

2. Reception reliability (BER)

In order to evaluate the receiver design as a whole, a set of experiments was performed where:

- Frequency offset was estimated by the OFDM preamble and compensated.
- Synchronization was performed using jointly the estimate of the OFDM preamble and the filter-based multicarrier waveform to minimize the probability of an error.
- MMSE channel estimator and channel equalizer were applied.
- 64 subchannels for the multicarrier modulation is considered.
- The bandwidth was set to 1MHz and 2MHz.
- The target SNR value was achieved with configuration of the Gain values for the transmitter and the receiver and measuring the received signal power.

The following figures are extracted from the conducted experiments in order to investigate the receiver performance if Bit Error Rate (BER) vs. SNR input. The experimentation results presented in the figures below concern FBMC-OQAM for Figure 9 and GFDM for Figure 10 with number of subchannels M=64. Prototype pulse Beaulieu is used with 128 coefficients. Symbol modulation was QPSK with Gray Coding. No channel coding was employed.

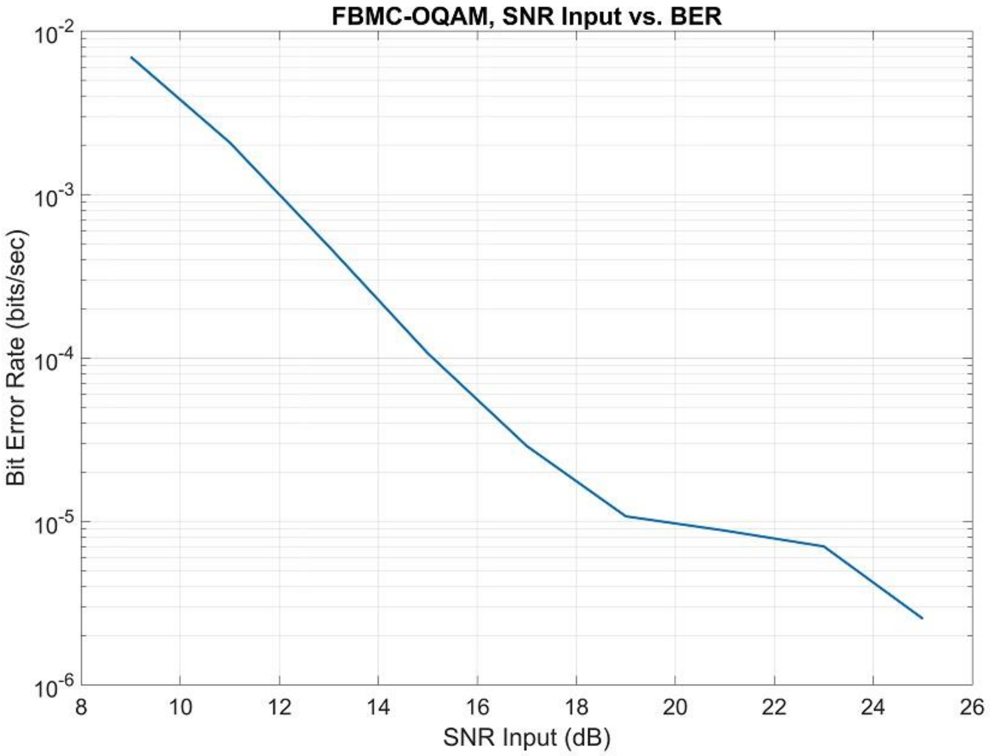

Figure 9: Bit Error Rate (BER) vs. SNR input for FBMC-OQAM M=64. Prototype pulse Beaulieu is used with 128 coefficients.

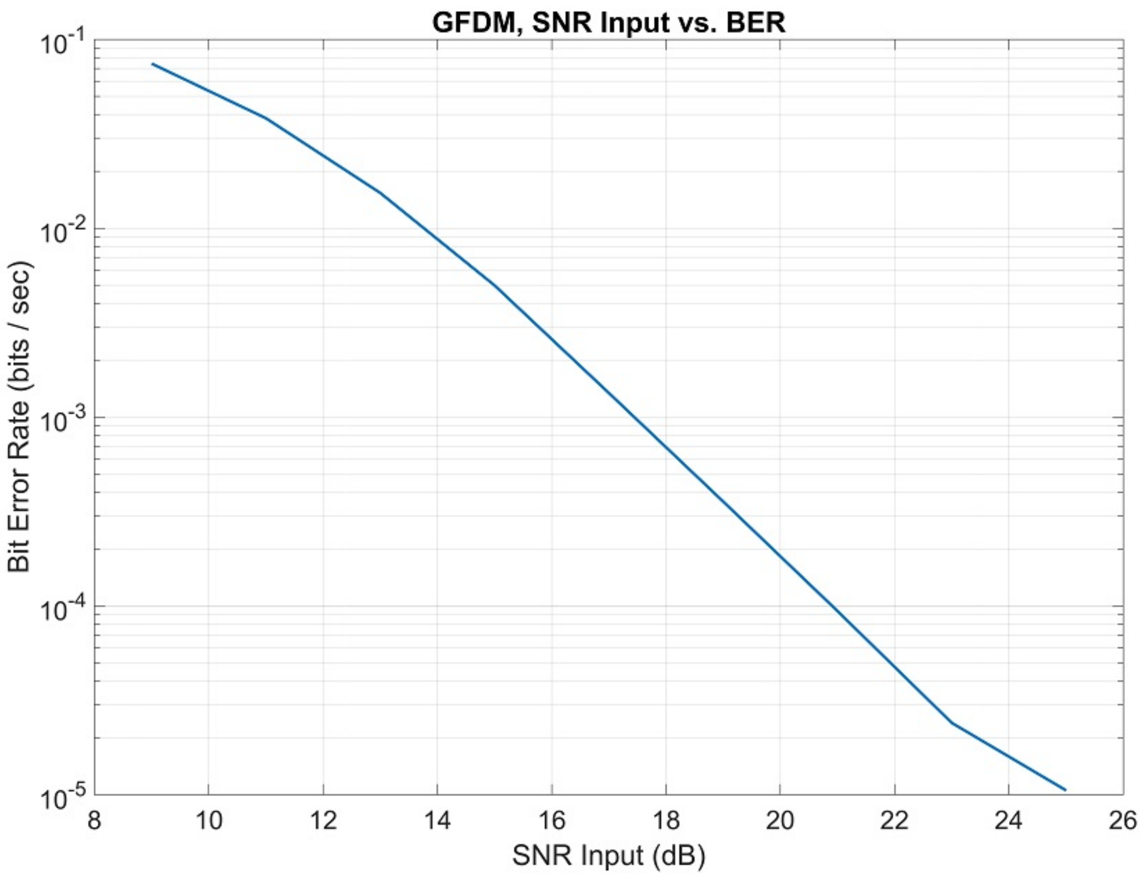

Figure 10: Bit Error Rate (BER) vs. SNR input for GFDM M=64. Prototype pulse Beaulieu is used with 128 coefficients.

Comments:

- The developed scheme seems to favour FBMC, since the receiver outperforms GFDM, however, no filter selection or design optimization for GFDM was performed. This means that there is a large improvement margin.
- The GFDM equalization process seems to introduce big distortion and it should be studied furtherly.
- Symbol Errors – even at high SNRs are observed. This is normal for a real-world system since it can be the result of an instantaneous phenomenon, a host stall, the effect of an erroneous impairment compensation etc.

3.1.3.5 Conclusions and Feedback (with respect to the use of the ORCA testbed and SDR platforms)

The experience of using the ORCA facility followed a learning curve for WilDCAT's members all this time. The associated documentation provided for the testbed used, which in WilDCAT's case was TUD macro scale testbed, is rated with 5. The instructions were quite detailed and analytical and it provided a clear guideline for the testbed usage so that WilDCAT's members could easily get familiarized. It also provided a detailed overview of both software and hardware components of the testbed. Regarding the TUD testbed, it was found to be fully equipped with the initial required hardware infrastructure. All components of testbed hardware were functional, too. The GFDM software resources of the testbed were also explanatory, detailed and provided great guidance. Generally, the idea of having unlimited access in both software resources and hardware components of the TUD's testbed at any time through remote access, seemed extremely useful and promising towards further future Experimentation.

3.2 Industry

3.2.1 CiLANTRO

3.2.1.1 Goal of the Experiment

The CiLANTRO experiment explored the monitoring features provided by Software-Defined Radio (SDR) devices, used in conjunction with controlled application traffic generation. A set of experimental scenarios have been explored, monitoring operating conditions of the wireless channel while measuring the performance as experienced at Network Layer and above.

3.2.1.2 Main Challenges

The flexibility in configuring SDR devices, the variation of available devices models with the related different hardware features, and the experimental and research-oriented nature of both the hardware and software (with varying degrees of documentation and feature support): all contribute to an extremely challenging scenario for an enterprise exploring novel products and services enabled by SDR.

3.2.1.3 Description of Experiment Setup

We explored several setups, looking for the best (and cost-effective) combination of SDR-based devices or Commercial off-the-shelf (COTS) LTE devices that could provide useful lower-layer monitoring capabilities. We performed measurements also on a path originating with an LTE link and traversing the Internet towards an external measurement server, to emulate a smartphone streaming content towards a cloud server.

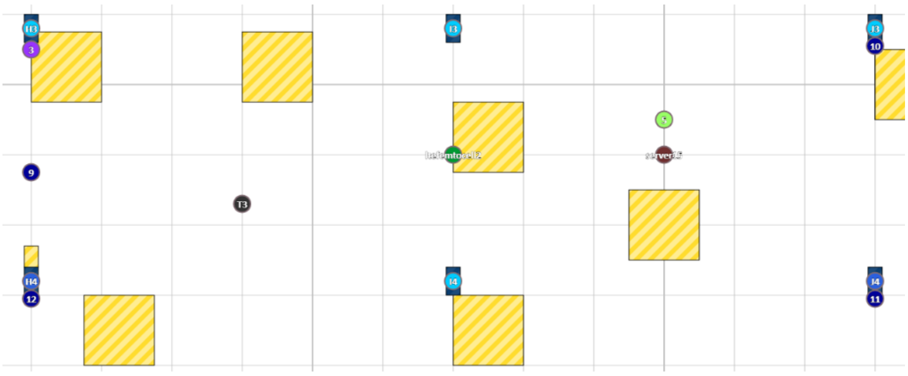

Figure 11: We explored more than 20 different setups, varying the models, the number, and the role of the devices establishing a radio connection, also mixing SDR and standard LTE equipment and including Internet-traversing paths.

3.2.1.4 Main Results

We extended our product monitoring capabilities with SDR-based sender-side inter-packet-time (IPT) tracing at LTE MAC layer, in addition to the sender- and receiver-side at UDP Transport layer. The ECDF shows that alterations of IPT pattern when traveling the Internet are actually mostly imposed transmitting, at the first (LTE) hop.

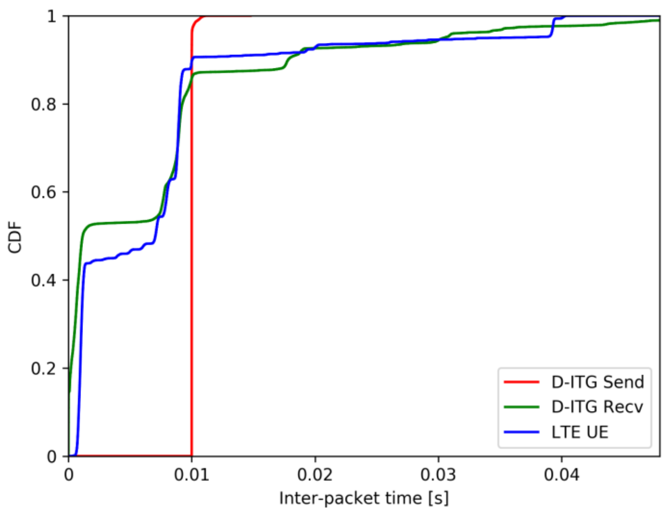

Figure 12: Alterations of IPT pattern at the first (LTE) hop.

We extended our product monitoring capabilities with SDR-based tracing of sender-side throughput at LTE MAC layer, and PHY layer signal metrics (RSRP RetX). The time series graphs show all these metrics together with Transport layer throughput, providing a cross-layer picture of transmission conditions.

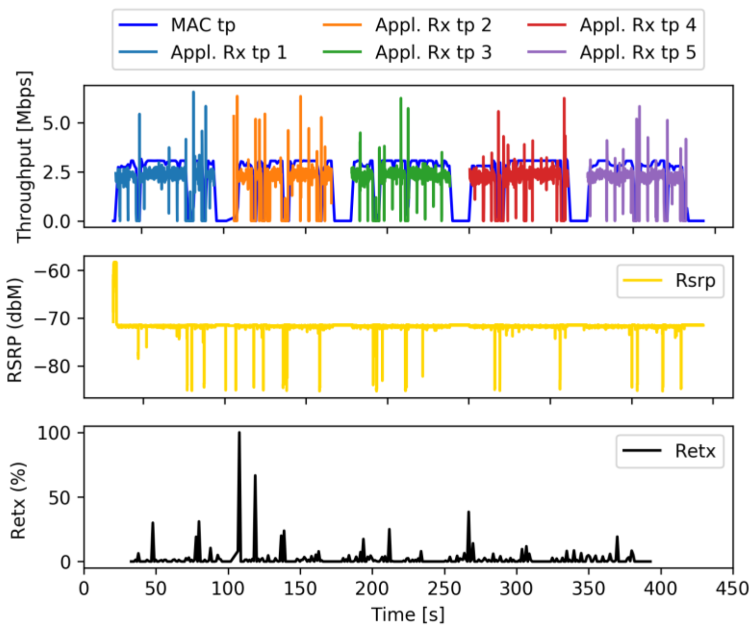

Figure 13: The time-serie graphs show all these metrics together with Transport layer throughput, providing a cross-layer picture of transmission conditions.

3.2.1.5 Conclusions and Feedback (with respect to the use of the ORCA testbed and SDR platforms)

As a results of our extensive experiments, we were able to extend the monitoring capabilities of our products adding new LTE MAC and PHY layer metrics. In our experiments we faced a (partially expected) high complexity in having SDR and COTS LTE devices interoperate: this will be of high value in the industrialization phase of our novel products involving SDR.

The ORCA facility has proved of very high value in exploring a sizeable number of different setups, thanks to the different types and models of devices. We did run in several issues ranging from hardware incompatibilities, hardware instability, lack of fully baked setups for some scenarios, and minor documentation issues. The support team from ORCA has been quick in responding and assisting in all these cases.

3.2.2 CLUE

3.2.2.1 Goal of the Experiment

CLUE project experiments on unlicensed LTE and Wi-Fi interference scenarios using the ORCA open platform, paving the way for optimal LTE-U and Wi-Fi coexistence and for avoiding service quality degradation when allowing LTE transmissions in the unlicensed bands.

3.2.2.2 Main Challenges

The main challenge in CLUE experiment was the implementation of sleep period and sleep period length in srsLTE libraries in a way that can facilitate the execution of a number of repetitive experiments. In parallel, the implementation must have been compatible with X310 SDRs that were available only in the testbed and couldn't been verified before the experiment.

3.2.2.3 Description of Experiment Setup

The topology of the experiment consisted of the following building blocks: an SDR node acting as eNB (srsLTE), a SDR node acting as UE (srsLTE), a Commercial WIFI access Point, a and a node accessible from IRIS testbed connected to AP via wired connection, as iperf server.

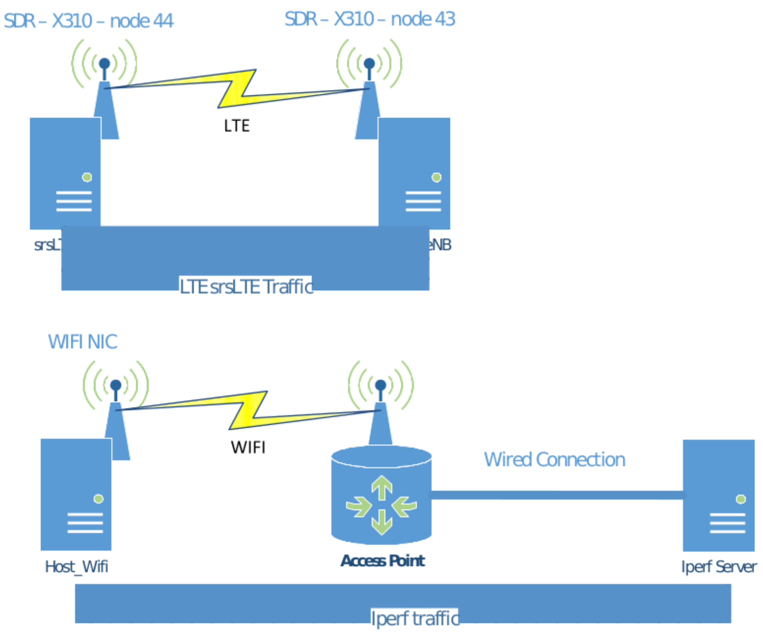

Figure 14: CLUE experiment setup.

3.2.2.4 Main Results

After the successful implementation of CLUE project, we prove that LTE-U and WIFI in ISM bands can only co-exist by deploying the concept of "Duty Cycle" on LTE eNB and by assigning a high number of sub-carriers (PRBs). LTE transmissions interfere with LTE deployment and significantly deteriorate WIFI channel performance.

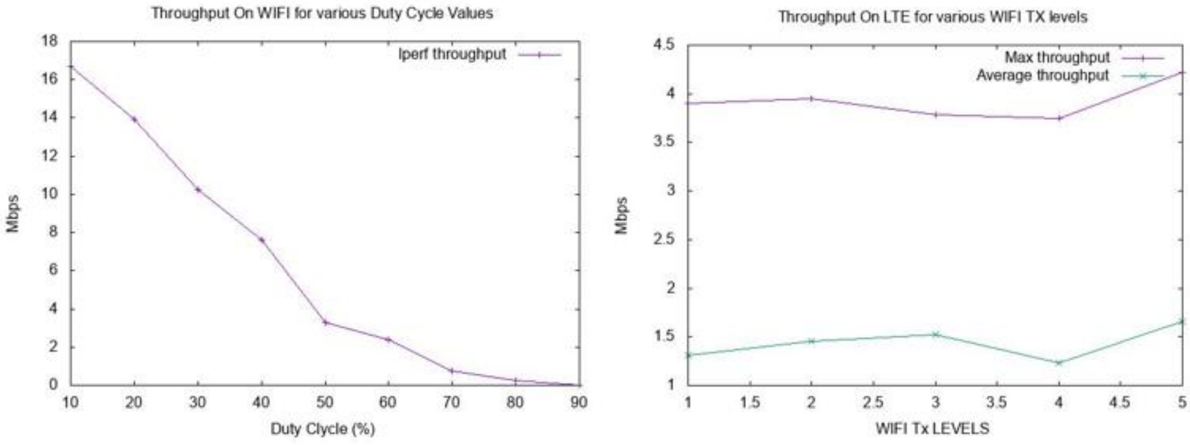

Figure 15: CLUE results.

3.2.2.5 Conclusions and Feedback (with respect to the use of the ORCA testbed and SDR platforms)

ORCA framework and IRIS infrastructure were critical for the successful execution of the experiment. SDR nodes with pre-configured GNU-Radio and SRSLTE software modules were mandatory of the timely completion of the project. Reservation modules and prompt integration of jFed framework was also very important for the final result.

3.2.3 E2EWebRTC

3.2.3.1 Goal of the Experiment

The main goal is to apply machine learning methods and validate them within IRIS to improve the performance of a combined wireless (GNU radio controlled) and wired (OpenFlow controlled) network by a) deciding how parameters of the Traffic Class 3 (TC3) Rx (e.g. gain) should be set to achieve best possible QoS; and, b) deciding appropriate OpenFlow actions (e.g. path splitting) for the TC3 traffic.

3.2.3.2 Main Challenges

The main technical challenges encompassed: a) identifying appropriate machine learning models for various network setups, b) applying the selected models to choose the best possible GNU radio and OpenFlow configurations; and, c) enforcing (through use of GNU Radio / XMLRC and OpenFlow respectively) the selected configuration(s) within the related IRIS wireless (N210) and wired (VM) nodes.

Figure 16: Steps of the experimentation methodology

3.2.3.3 Description of Experiment Setup

We used the topology shown in Figure 17 to firstly obtain a training dataset which is the prerequisite to construct and secondly train the cluster model implemented within Qiqbus, our decision making engine.

More specifically, this experiment focused on how to find the optimal configuration of the gain parameter of node Rx 1 depicted in Figure 17. Together with node Rx 2, Rx 1 receives from Tx a sequence of WiFi 802.11 frames (each of size 1500bytes). Our experiment has the goal to treat Rx 1 as a client of an ORCA Traffic Class 3, thus our technical objective is to maximize the number of frames that will be received by Rx 1. This shall be achieved with our clustering model deciding which is the optimal value of parameter gain for Rx 1. Note that we initialized the live experiment with both Rx 1 and Rx 2 to be configured with a gain of 0.3.

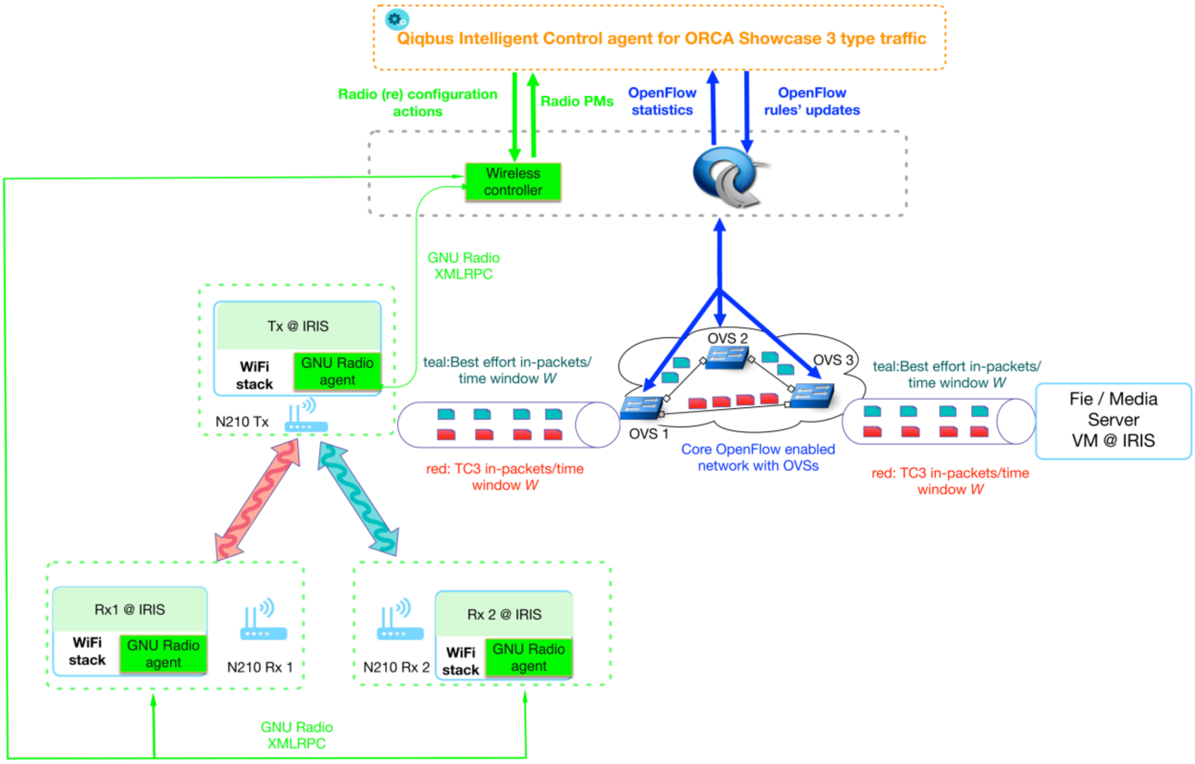

Figure 17: Configuration and deployment of Modio's slice within the IRIS testbed

To explain how our clustering model works, we firstly extracted the configurable variables and the invariants from the training data we received from the components and we constructed the feature set. That is, we conducted a set of experiments in order to gather experimental monitoring data in order to train our model. Next, we employed these offline data to train our clustering algorithm, in this experiment KMeans, and we proceeded in saving the trained model within Qiqbus, as a binary format. Following the processing pipeline after training the model, we classified the training data to one top performing cluster, that is the one that maximises the **received_frames** metric.

3.2.3.4 Main Results

Upon execution of the live experiment, we used network monitoring information which we gathered according to the architecture in Figure 17. In one of our experiments, we received the following tuple which contains all Performance Monitoring metrics, from the client side, the Wireless network and the Wired network:

{"id": 30, "client": "client", "received_frames": 16, "of": "of", "paths": 1, "TC6": 0, "QE": 0, "gnu-radio": "gnu-radio", "nodes": 2, "tx_gain": 0.1, "rx1_gain": 0.3, "rx1_sens": 0.56}

The Qiqbus provisioner then extracted the features of the tuple and employed the trained model to classify the tuple received to the according cluster and returned the top configuration for that cluster. The message returned can be seen in the following snippet:

{"QE": 0, "TC6": 0, "rx1_gain": 0.1, "rx1_sens": 0.56, "tx_gain": 0.1}

This effectively means that our clustering model decided that the gain of Rx 1 should be set to 0.1 in order to achieve the maximum number of frames received (remember that the live experiment has been configured with both nodes Rx1 and Rx 2 having a gain value of 0.3). Upon that decision, our provisioner executed an XMLRPC call to Rx 1 (see Figure 1) in order to change the gain from 0.3 to 0.1. This decision was taken after the end of the 1st minute of the live experiment, as we can observe in the where the y axis is in log10 scale.

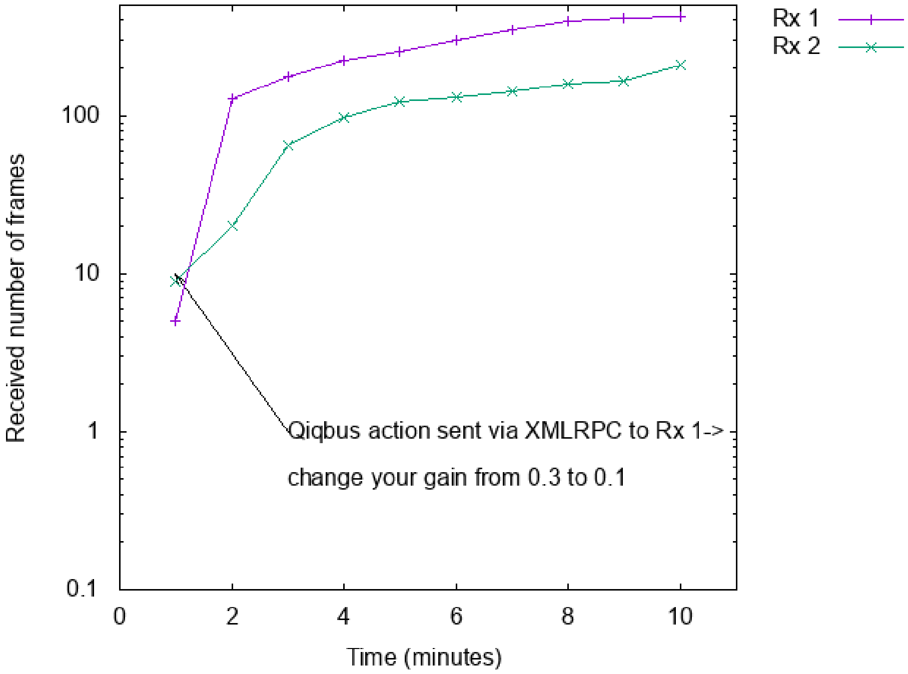

Figure 18: Effect of Modio's provisioner in increasing the received number of frames for TC3 client Rx 1, by setting its gain to 0.1 during runtime as output of the clustering model, whilst the node was initially configured with gain 0.3, as was Rx 2.

Clearly, Figure 18 demonstrates that although initially Rx2 was receiving more frames than Rx 1 in the first minute of our experiment (9 vs 5 frames) as shown in Figure 2, the situation changed upon execution of our provisioning action. As it is shown in the figure, after execution of our provisioning action to change the gain of Rx1 from value 0.3 to 0.1, the N210 node Rx 1 started performing better in terms of being able to receive more frames than Rx2. This better frame rate reception was kept until the 10th minute which was set as the end time of our experiment. Therefore, it can be concluded that our clustering model (having been trained as we earlier discussed) correctly advised the network to switch Rx 1 to its optimal gain value.

3.2.3.5 Conclusions and Feedback (with respect to the use of the ORCA testbed and SDR platforms)

The clustering models implemented in Qiqbus are effective in finding best possible GNU Radio and OpenFlow configurations to ensure that the SLA requirements of an ORCA Traffic Class 3 service are always met, independently of the recourse demands of other slices or upon changing network conditions, answering questions like which should be the gain of an IRIS Rx N210 belonging of the TC3 slice.

Thanks to the ORCA facility, specifically hardware and software resources of the IRIS testbed, we were able to define and implement a Qiqbus-based processing pipeline with suitable clustering models which Modio will use during the prototype implementation of a new product tailored for 5G network operators, catering for intelligent network configuration in their combined SDR/SDN substrate environments.

4 CONCLUSIONS

The OC1 EXP of ORCA has been successfully concluded by December 2018. Six projects, three from "Scientific Excellence" and three other from "Industry", reported their overall-positive experiment process, results, feedback and indication on ORCA. Almost all projects have reported the efficiency and high relevance of the ORCA functionality in facilitating the experiments, as well as help from the support and interaction with testbed patrons respectively.

This will serve as a source of good reference in implementing future open calls for experiment (two additional ones in ORCA project), and open calls in general.