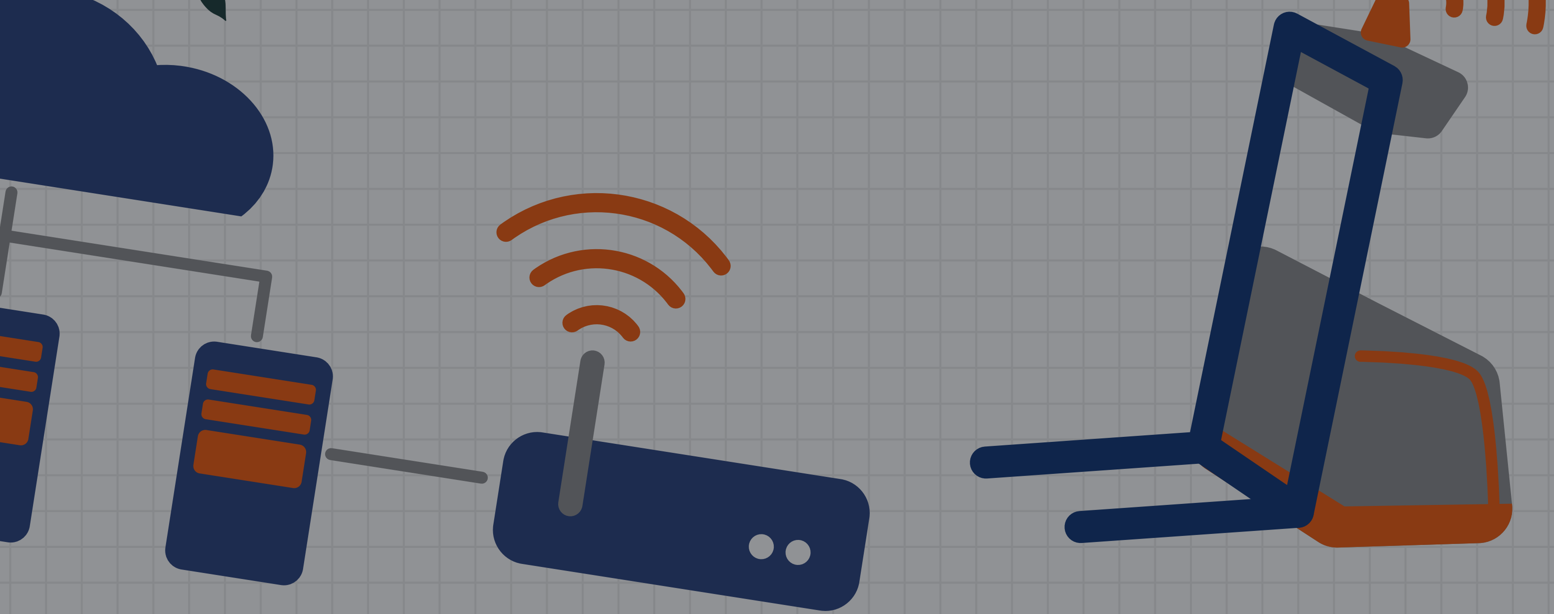
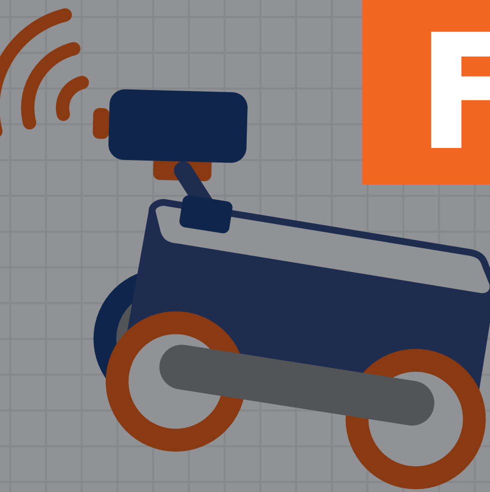
Orca

Orchestration and Reconfiguration Control Architecture



FINAL PROJECT BROCHURE



Showcases and Open Calls Results

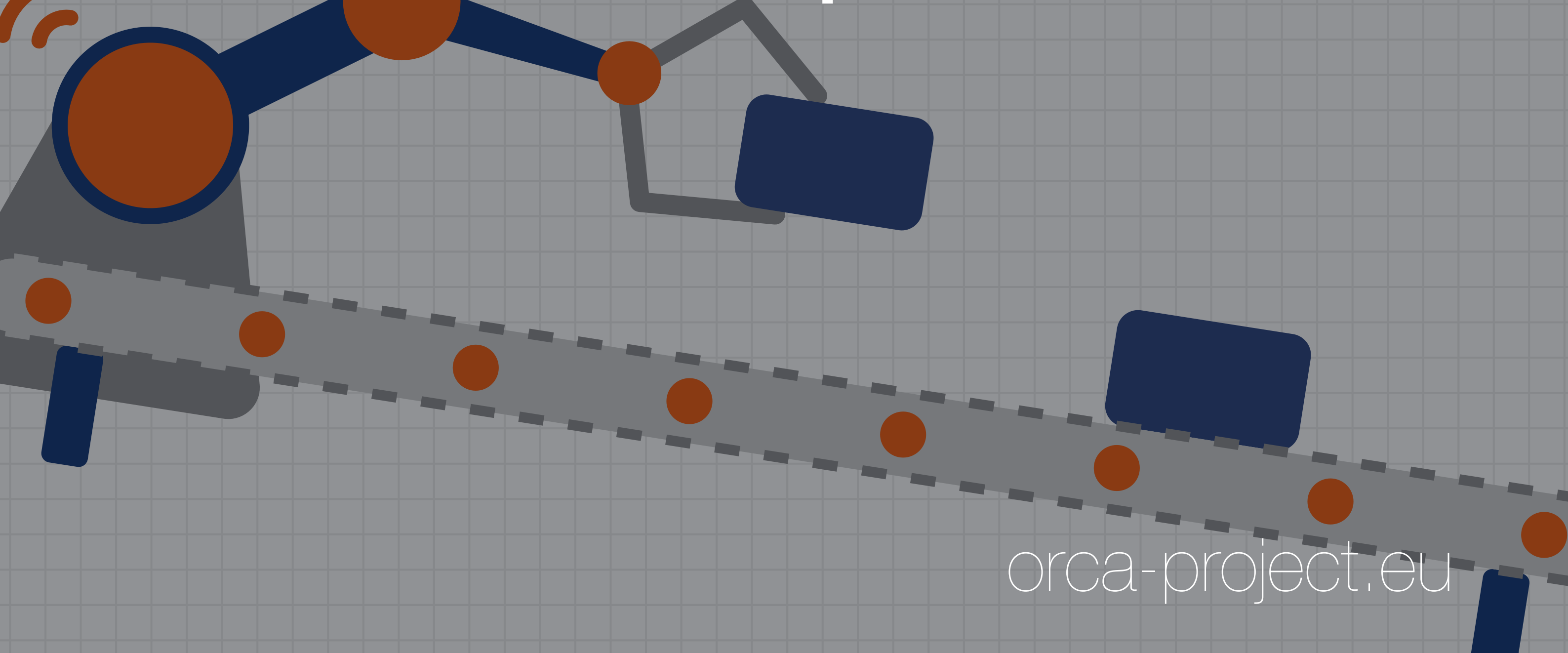


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Table of contents

OPEN CALLS RESULTS

PREFACE

The ORCA project situates its main innovations in Software-Defined Radio, driven by Industrial 4.0 usage case scenarios.

The project ran from January 2017 to June 2020: during this time span, the ORCA consortium has completed 5 major achievements embedded in 4 showcases. The showcases were designed in the context of a future factory, covering the requirements of reliability and low latency (showcase 2), network slicing (showcase 3) and aggregation (showcase 4), and the need of throughput via pioneer mmWave technology (showcase 1). The functionalities demonstrated in the showcases were made available via the ORCA website: https://www.orca-project.eu/orca-functionalities/.
The 5 main achievements are listed in the Golden Nuggets section of this brochure.

In addition, 2 Open Call for Extensions and 3 Open Call for experiments wereare carried out. The 3rd Open Call was originally planned to run in the first half of 2020. The COVID-19 pandemic interrupted some measurements campaigns and caused some institutes to temporarily shut down experimental facilities. The Open Call was therefore delayed by 2 months. Despite the impact of the COVID-19 pandemic, most Open Call experiments were carried out successfully. The remote access of ORCA testbed facilities was greatly appreciated in this special period of time.

This brochure provides an overview of the main achievements and showcases of the ORCA consortium, as well as the results of the Open Call activities.

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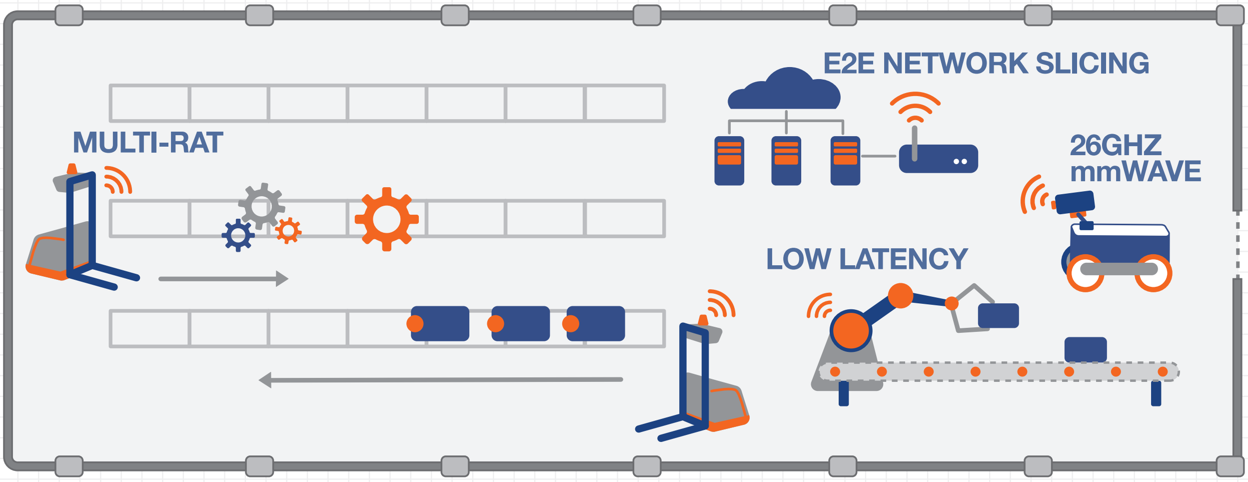
THE ORCA FACTORY



FEATURE COMPARISON

	PHY/MAC RAT selection	Dynamic deployment of intelligent control	Hierarchical orchestration	Hybrid SDR/SDN
26GHz mmWave	√	√	√	
Low latency	√	√		
E2E network slicing	√	√	√	√
Multi-RAT	√		√	

mmWAVE BACKBONE FOR VIDEO INSPECTION IN THE ORCA FACTORY

A camera is installed on a mobile robot for live inspection of the factory, it leverages on mmWave uplink with moderate throughput, a low-latency and reliable transmission at the downlink for the beam control, providing the capability of dynamic control on the physical layer (PHY).

MULTI-CHANNEL GATEWAY AND RADAR-COMMUNICATION SYSTEM TO CONTROL ROBOTIC ARMS ON THE ORCA ASSEMBLY LINE

Robots on the assembly line are simultaneously controlled via an SDR based multi-channel IoT gateway offering user-controlled service on each channel, while a Doppler radar senses the environment (e.g., speed of moving parts in nearby machines) to provide context-awareness.

DISTRIBUTED END-TO-END NETWORK SLICING AND ORCHESTRATION IN A NUTSHELL

Industrial applications with diverging service requirement can coexist on top of a shared infrastructure, leveraging end-to-end network slicing, enabled through a distributed orchestration of resources across multiple network segments.

AGV NAVIGATION IN A MULTI-RAT ENABLED ORCA FACTORY WAREHOUSE

AGVs in the ORCA warehouse rely on multiple radio access technologies and a centralized control in the cloud to transfer parts between the assembly and the storage. The joint usage of 5G, LTE and WIFI provides high reliability and reduced latency links for remote control.

CONSORTIUM

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SHOWCASES
YEAR 1

Orchestration and Reconfiguration Control Architecture

SHOWCASE 1

HIGH THROUGHPUT - MMWAVE

GOALS

- Facilitate the development of alignment/tracking algorithms by offering a remote, easy, configurable and reproducible HALO setup with antenna mobility, in order to measure the mmWave channel that can be further processed offline.
- Offer two different channel measurement setups
  - graphic user interface based
  - command line based.

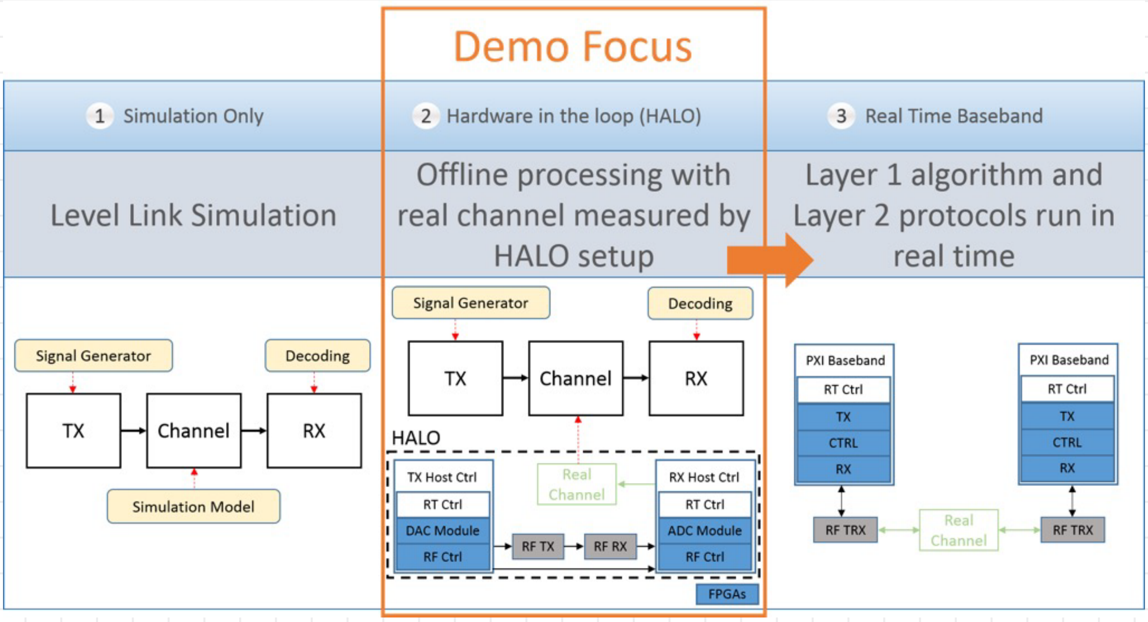
CHALLENGES

- Integrate PHY and MAC layers in a real-time system, where parameters such as antenna beam or MCS can be set from a higher layer during run-time
- Implementation of remote control and monitoring interfaces in order to connect the LabVIEW controlled baseband systems (PXI) to other platforms such as MatLab or Python
- Design a device where the mmWave antenna movement can be controlled remotely in order to test mobility scenarios

CONCEPT

In order to reduce system complexity, the deployment of an beam alignment/tracking algorithm for a real-time system can be divided in three steps

1. Simulation Only: the transmission chain incorporates a simulated channel model. Transmission and reception are done offline and no FPGAs are involved
2. Hardware in the loop: a real channel is included to the transmission chain. Because the channel impairments are generated from the real equipment, the algorithm evaluation is done in a much more realistic manner
3. Real Time Baseband: in this case the TX and RX signals are generated by the real-time system implemented on FPGA with real-time CPU, which includes layer 1 algorithm and layer 2 protocols



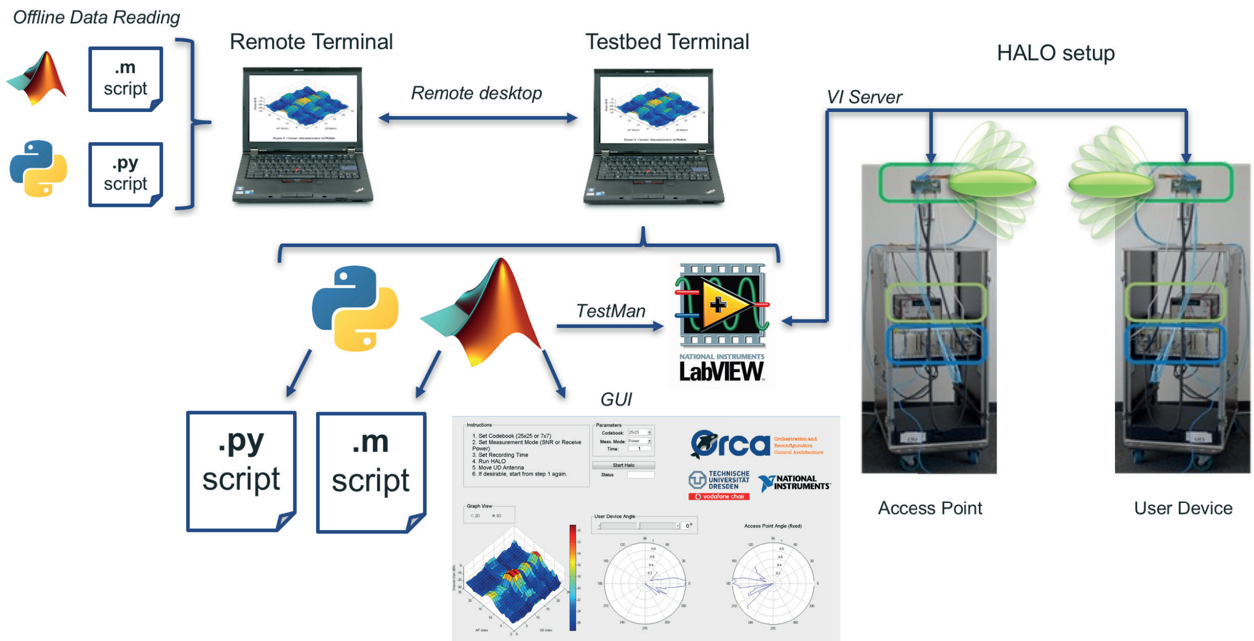
It is a very challenging task to program a functional and real-time capable algorithm on the mmWave system, which makes step 2 of the development process to be indispensable in the reduction of system complexity

Orchestration and Reconfiguration Control Architecture

SHOWCASE 1

HIGH THROUGHPUT - MMWAVE

DEMO SET UP

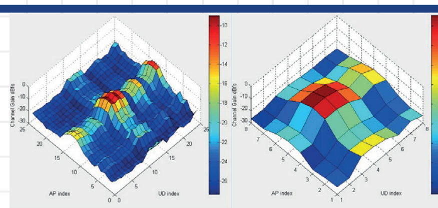


GUI:
1. Open the GUI
2. Set Codebook (25x25 or 7x7)
3. Set Measurement Mode (SNR or Receive Power)
4. Set Recording Time
5. Run HALO
6. Move UD Antenna
7. Read data offline

Script:
1. Open main.m file
2. Set Codebook (25x25 or 7x7)
3. Set Measurement Mode (SNR or Receive Power)
4. Set Recording Time
5. Set predefined movement pattern and time
6. Run script
7. Read data offline

RESULTS

Channel measurements as data sets to be read and processed offline by numerical computing environments such as MatLab



INNOVATION

- On the implementation side, integration between PHY and MAC allows configuration of PHY parameters from higher layers, e.g., selection of beams and MCS
- On the experiment side, integration between LabVIEW and other platforms such as MatLab allows a friendly interaction with the mmWave system

IMPACT

The development of beam alignment/tracking algorithms is accelerated by the remote, easy, configurable and reproducible channel measurement setup offered by the mmWave ORCA facility.

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SHOWCASE 2

LOW LATENCY INDUSTRIAL COMMUNICATION

GOALS

This demonstration illustrates how effectively low-latency flexible SDRs establish a robust robot remote control in a real-world scenario.

CHALLENGES

- Providing low-latency communication in order to remotely balance inverse pendulum robots
- Increasing the network traffic and the number of robots while maintaining the robot's stability

CONCEPT

In this showcase, ORCA offers three various solutions:

- Low-latency IEEE 802.15.4 unslotted CSMA/CA (KUL)
- TDMA MAC based on low-latency PHY-MAC integration (IMEC)
- GFDM framework and FDMA MAC (TCD)

DEMO SET UP

- ORCA SC2 brings various wireless technologies together to form a non-homogeneous network, to build a real-time radio link in order to control a set of balancing robots (Fig. 1).
- Each robot transmits its sensory data, to the processing unit. This unit then processes the data and generates an appropriate command to keep the robot balanced (Fig. 2).
- To increase the traffic, the two nodes in the KUL network (Fig. 3) play both roles of the interface (for its own robot) and process unit (for the other node's robot).
- Through TCP/UDP link, a control unit can send a simultaneous command to all three networks. Hence, one can compare the networks' response time by observing the robot's reaction to the command.

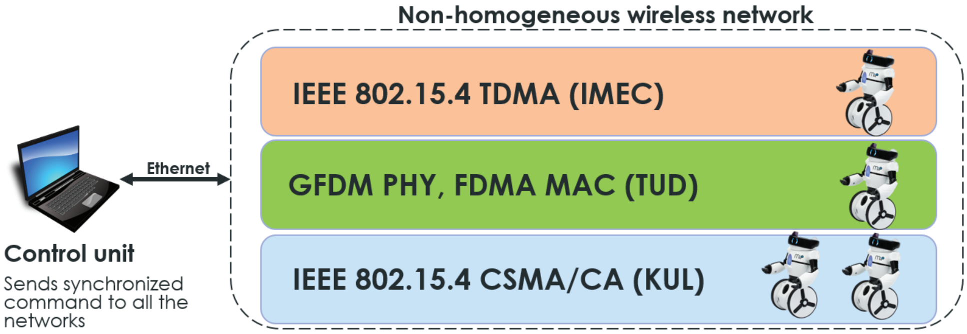


Fig. 1. ORCA Showcase 2, non-homogenous network for low-latency robot control

SHOWCASE 2

LOW LATENCY INDUSTRIAL COMMUNICATION

DEMO SET UP

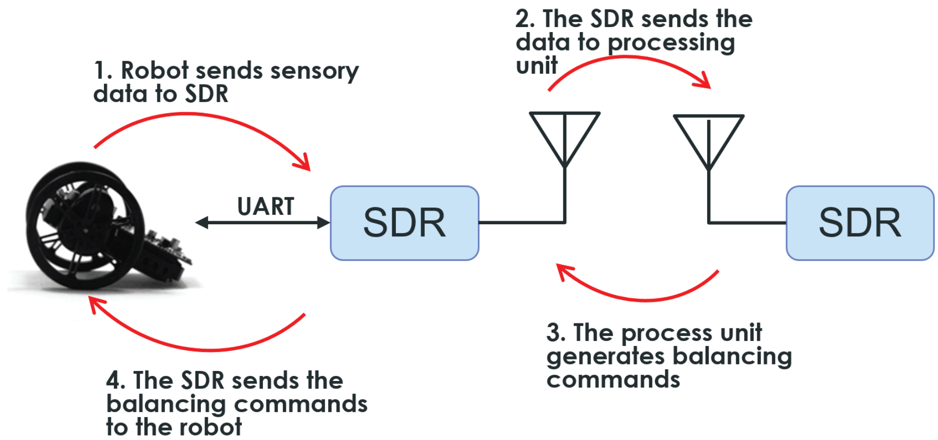


Fig. 2. Low-latency link for balancing robot, TDMA/FDMA

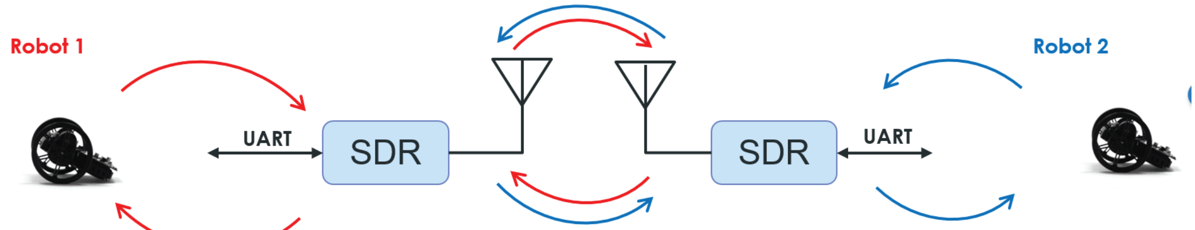


Fig. 3. Sharing spectrum between two robots using CSMA/CA

RESULTS

In this demo, ORCA shows a non-homogeneous network to control four balancing robots. Each sub-network provides reliable links. In fact, utilizing real-time SDRs in this showcase reveals that ORCA's solutions allow low-latency communication in real-world scenarios.

INNOVATION

In the KUL network, the innovative PHY/MAC architecture enables low-latency radio connection (1.3 ms PHY RTT) as well as run-time MAC programming to share the spectrum between more than one robot. In the IMEC network, the flexible framework TAISC is portable on several real embedded IoT devices and the communication between flexible IMEC-SDR and commercial IoT devices can be achieved. In addition, the GFDM transceiver in the TUD network allows adapting the physical layer to the demands of the network during runtime with reconfiguration times lower than 500 ns. Thus, very different waveforms can be used depending on the offered services.

IMPACT

The developed networks in SC2 open a wide perspective for researchers by employing three different technologies in a realistic scenario. In other words, it shows how ORCA facilitates experiments in which various networking technologies are required to perform a time-critical task.

Orchestration and Reconfiguration Control Architecture

SHOWCASE 3

LOW LATENCY AND HIGH THROUGHPUT INDUSTRIAL COMMUNICATION

GOALS

Support diverging traffic requirements (low latency + high throughput) within the limited spectral and hardware resources.

CHALLENGES

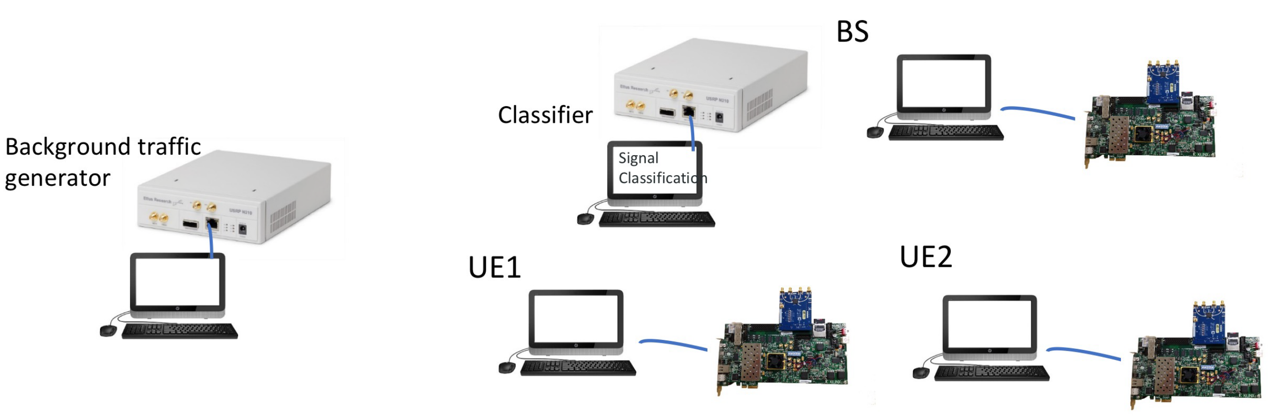
- Given the increasingly complex radio environment and diverging traffic requirements, context awareness becomes determinant for effective resource management of wireless networks.
- In order to supporting different traffic classes with limited resources, the system should be highly flexible and efficient

CONCEPT

- Apply deep learning for classification of background traffic behavior (duty cycle, long or short bursts) in different channels.
- Create slices based on the output of the classifier and the QoS requirements
- Use radio virtualization technologies to support concurrent traffic in different channels

DEMO SET UP

Physical setup: this demo consists of 3 sets of zc706 boards, representing a BS, and 2 UE devices; 2x USRP devices, one uses as a background traffic generator, and another is used to provide IQ samples for the deep learning module. This is depicted in the figure below:



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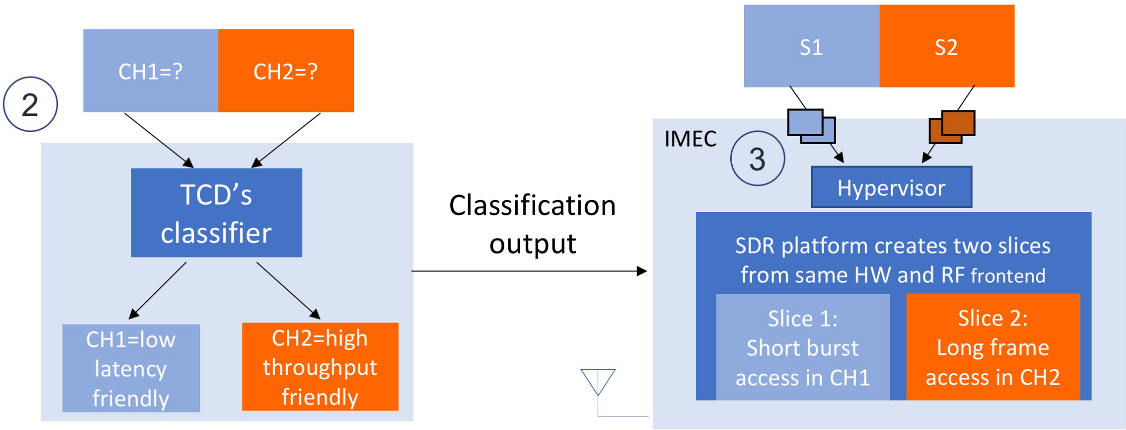
SHOWCASE 3

LOW LATENCY AND HIGH THROUGHPUT INDUSTRIAL COMMUNICATION

DEMO SET UP



Demo scenario:

- First step is to generate an RF signal dataset over-the-air with IQ samples+metadata to train a deep learning network.
- Second step is to apply the trained model for background traffic classification.
- Third step is to react upon the classifier's result, configure the slices, serve 2 slices simultaneously with one hardware logic.

RESULTS

The designed deep learning network can distinguish different waveforms and estimate their time of arrival, duration, bandwidth and frequency in spectrograms. The algorithm learns how to differentiate leakage from normal transmissions.

INNOVATION

- Concurrent transmit and receiving of multiple traffic streams on different channels via same radio hardware.
- New solutions applying state-of-the-art machine learning techniques to waveform classification. The designed deep learning algorithms can jointly estimate the types of transmitters, but also their RF parameters, such as centre frequency, bandwidth, frame duration, etc.

IMPACT

- A patent application on the radio virtualization technology has been filed
- The RF dataset generation framework, resulting datasets, deep learning training/testing tools, and RF classification SDR blocks are made available to researchers and developers.
- The architecture of radio virtualization is made available for OC experiments and extensions.

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SHOWCASE 4

INTERWORKING AND AGGREGATION OF MULTIPLE RADIO ACCESS TECHNOLOGIES (RAT)

GOALS

- Integrate three heterogeneous RATs in a single base station/access point
- Experimentation platform is starting point for research and optimization of RAT interworking techniques across all OSI layers

CHALLENGES

The integration of several RATs in one node is computationally demanding

- NI PXI real-time controller hardware with Linux RT operating system allows optimization of process scheduling
- Hardware acceleration implemented with FPGA-based NI USRP-RIO SDR

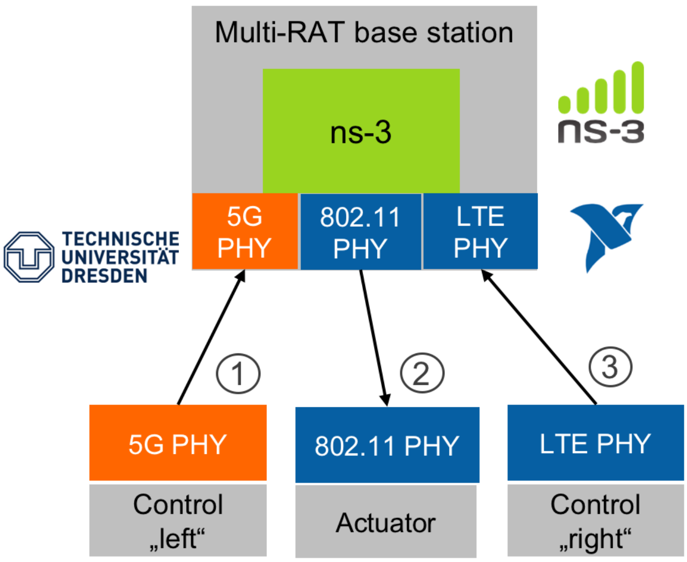
RAT interworking experiments require higher layers functionality

- Network simulator ns-3 contains models for LTE and Wifi protocol stacks

The connection between PHY (on FPGA) and MAC (on CPU) has RAT-dependent throughput and latency requirements.

- NI L1-L2 API is a way of MAC-PHY designed with these requirements in mind

CONCEPT



- One multi-RAT base station including a 5G, LTE and WiFi link running on an NI PXI controller
- Three physically separated terminals each running a selected RAT on an NI USRP device
- Mobile robot connected via WiFi can be controlled by “virtual” buttons through 5G and LTE link

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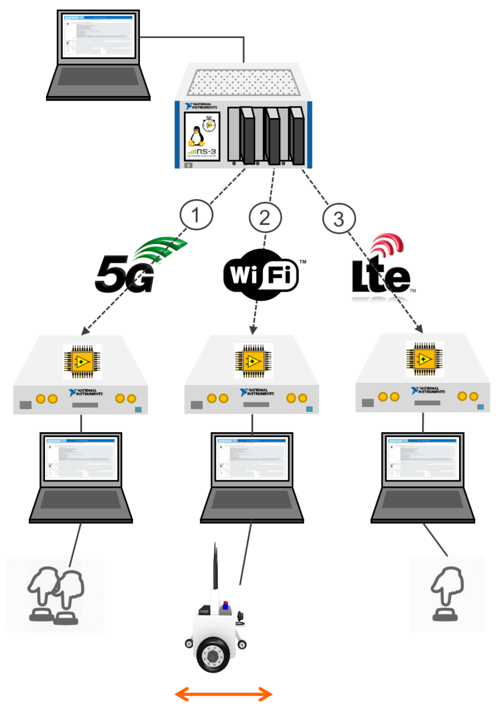
SHOWCASE 4

INTERWORKING AND AGGREGATION OF MULTIPLE RADIO ACCESS TECHNOLOGIES (RAT)

DEMO SET UP



1. Either of the two buttons connected to the 5G or LTE link can be used to control the moving direction of the robot
2. Control information is sent from the 5G and LTE terminals to the centralized base station
3. Base station coordinates packets and forwards control information to the actuator through WiFi link.
4. Robot moves according to the direction information

RESULTS

- First live demo showcasing a 5G/LTE/WiFi Multi-RAT system running on real-time SDR platform
- Application represents industrial use case of a remotely controlled mobile robot

INNOVATION

- Presented multi-RAT platform is relevant in scenarios like factory floor automation and communication. In such environments, each machine might come from a different vendor and each vendor might utilize a different RAT
- Aggregating, managing and interworking of RATs is an important topic of ongoing research for the operators of such factories

IMPACT

- Outside of ORCA, researchers might not have multiple, open and fully modifiable RATs at their disposal.
- The platform developed in SC4 saves time for researchers by providing a head start for RAT interworking experiments across all layers, without the need to invest significant effort in setting up and then integrating the individual PHY links

SHOWCASES

YEAR 2

SHOWCASE 1-4

MULTI-RAT INTERWORKING USING A 5G HIGH THROUGHPUT MMWAVE BACKHAUL

CHALLENGES

For this showcase, as SDR hardware platform the new NI USRP-2974 is used:

- It integrates an Intel CPU such on which the real-time host implementation of the NI LTE and WiFi Application Frameworks as well as the ns-3 instances for the different entities can run directly on the same device, minimizing the hardware effort.
- The connection between PHY (on FPGA) and MAC (on CPU) has RAT-dependent throughput and latency requirements. The NI L1-L2 API addresses these requirements for both LTE and WIFI.

RAT interworking experiments require higher layer functionality:

- Network simulator ns-3 contains models for LTE and WIFI protocol stacks that are used jointly in the real-time experimentation.

60 GHz mmWave backhaul link:

- At this frequency range, i.e, 60 GHz, RF impairments and path loss should be addressed carefully. In the base-band processing, we use the powerful NI PXI Chassis, while mmWave Sibeam antennas are used for transmitting the signals.
- The mmWave transmission allows high throughput, since the bandwidth is higher than normal sub 6Ghz systems.
- For addressing the mobility problem, we implemented a robust and reconfigurable beam steering algorithm.
- Beam steering algorithm and MCS can be optimized according to channel conditions.

GOALS

- Multi-RAT base station and terminal station with real-time capable LTE and WiFi implementations incorporating the new generalized NI L1-L2 API.
- LTE-WiFi Interworking technologies developed by open call partner.
- Run-time re-configuration of control parameters.
- High throughput mmWave backhaul link with beamsteering algorithm under mobility scenario.

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SHOWCASE 1-4

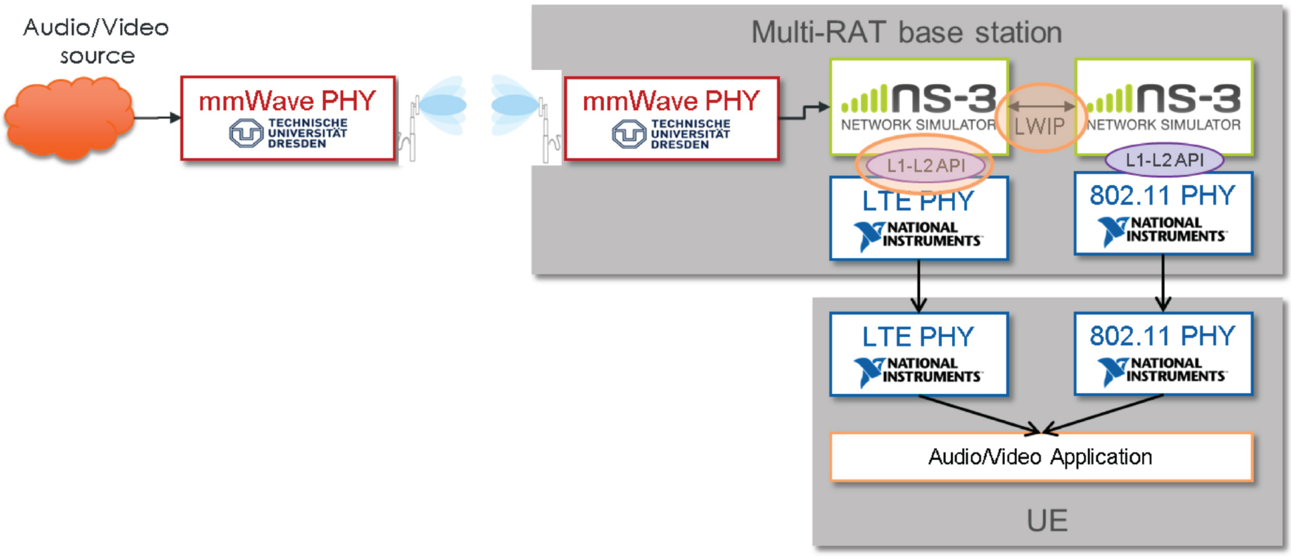
MULTI-RAT INTERWORKING USING A 5G HIGH THROUGHPUT MMWAVE BACKHAUL

CONCEPT

- Backhaul base station with high throughput mmWave link to serve large quantity of users

- One Multi-RAT base station including:
  - mmWave link connected to high throughput backhaul.
  - LTE eNB and WiFi Access Point including interworking technologies running on the same NI USRP-2974.
  - One Multi-RAT terminal station including an LTE UE and WiFi Station running on the same NI USRP-2974.

- Remote control terminal for run-time re-configuration using testman protocol.



INNOVATION

- First prototyping and experimentation platform that involves interworking between LTE and WiFi, with additional E2E inclusion of a 5G mmWave link.
- Presented Multi-RAT platform is relevant in scenarios like factory floor automation and communication. In such environments, each machine might come from a different vendor and each vendor might utilize a different RAT.
- Aggregating, managing and interworking of RATs is an important topic of ongoing research for the operators of such factories.
- This experiment demonstrates that the 60 GHz as a backhaul solution is feasible for practical applications. In addition, it has also been shown possible technical solutions for optimizing the mmWave link, e.g., with reconfigurable beam steering algorithm.

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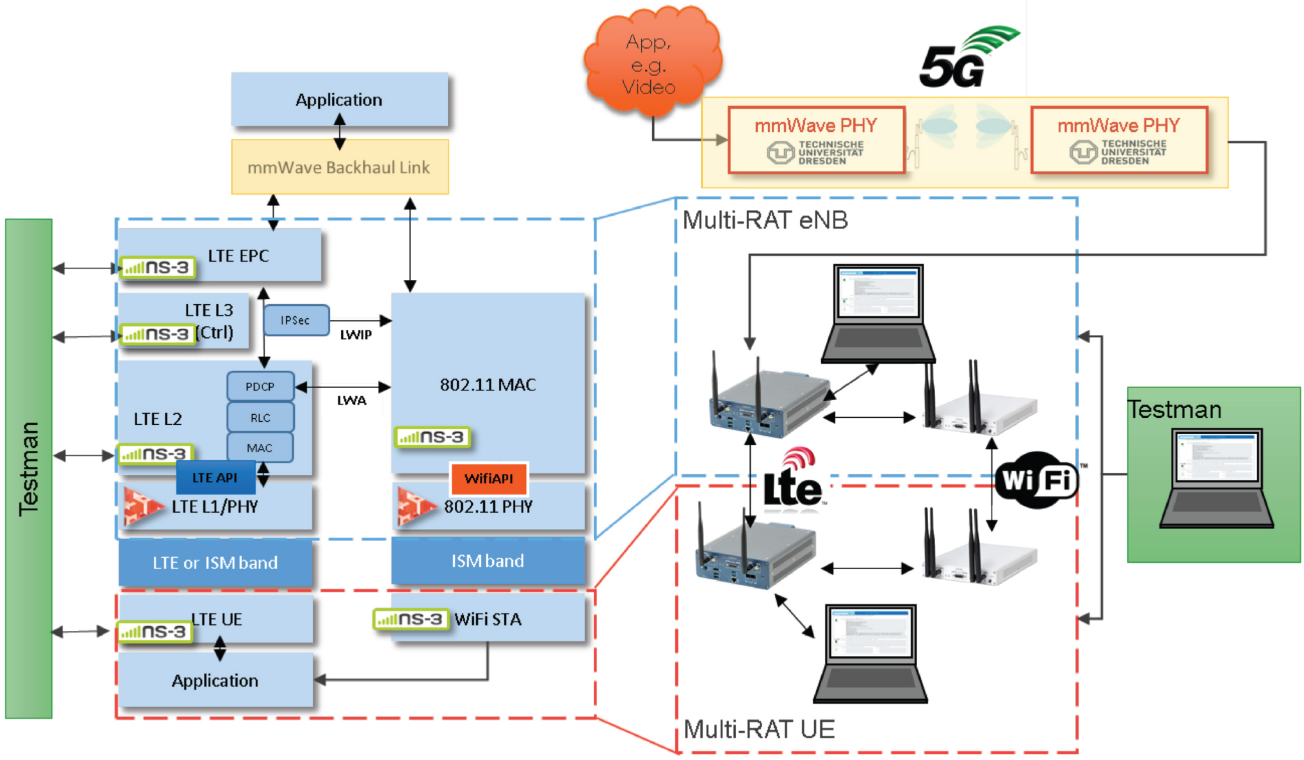
SHOWCASE 1-4

MULTI-RAT INTERWORKING USING A 5G HIGH THROUGHPUT MMWAVE BACKHAUL

DEMO SET UP



1. mmWave backhaul link:
   - Video stream is sent from backhaul to the multi-rat base station, that further routes it to final destination.
2. Real mobility scenario is emulated with robot, e.g., bus transporting people.
3. Multi-RAT part:
   - A user (passenger in the bus) is connected via LTE and gets the video stream on the Multi-RAT terminal station.
   - The resources for the user will be virtually limited (e.g. more users in the LTE cell). As a result, the video will become unstable.
   - LTE/WIFI interworking will be switched on via SDR control plane (testman).
   - The video stream recovers using the WIFI link through LTE/WIFI interworking

SHOWCASE 1-4

MULTI-RAT INTERWORKING USING A 5G HIGH THROUGHPUT MMWAVE BACKHAUL

RESULTS

- First prototyping and experimentation platform that involves interworking between LTE and WiFi, with additional E2E inclusion of a 5G mmWave link.
- Presented Multi-RAT platform is relevant in scenarios like factory floor automation and communication. In such environments, each machine might come from a different vendor and each vendor might utilize a different RAT.
- Aggregating, managing and interworking of RATs is an important topic of ongoing research for the operators of such factories.
- This experiment demonstrates that the 60 GHz as a backhaul solution is feasible for practical applications. In addition, it has also been shown possible technical solutions for optimizing the mmWave link, e.g., with reconfigurable beam steering algorithm.

IMPACT

- Outside of ORCA, researchers might not have multiple, open and fully modifiable RATs at their disposal running on the same SDR platform.
- The platform developed saves time for researchers by providing a head start for RAT interworking experiments across all layers, without the need to invest significant effort in setting up and then integrating the individual PHY links.
- The proof-of-concept of mmWave link as a backhaul solution was successfully implemented for line-of-sight conditions. In the future, the inclusion of a second antenna to increase coverage can be explored in order to allow more advanced experimentation.

Orchestration and Reconfiguration Control Architecture

SHOWCASE 2

LOW LATENCY INDUSTRIAL COMMUNICATION

GOALS

This demonstration illustrates how ORCA SDRs can provide low-latency communications for remote robot control where a high-level of reliability is required.

CHALLENGES

- Providing requirements for various types of applications.
- Efficient spectrum sharing for industrial applications.
- Maintaining flexibility without compromising latency performance.
- Optimum hardware resource utilization to enable concurrent transmission on multiple channels by using the same hardware accelerator.

CONCEPT

- Standard compliant and run-time reprogrammable SDRs.
- Latency-enhancements to baseline standard compliant operation.
- Multi-channel virtualized transmitters deployed on a single hardware.
- Full duplex capable communication nodes.
- Reliable GFDM link.

RESULTS

- The cloud-based robot controller achieves a round-trip time below 1.3 ms on a software defined radio based PHY and MAC.
- A GFDM transmission, until -83 dBm receive power and equivalent to 700 m free space path loss, is employed to utilize the spectrum optimally.
- The virtualized transmitters are run-time configurable while they share the same hardware resources.
- 80-90 dB self-interference suppression by analog and digital self-interference cancellers, which allows a high-throughput in-band full duplex wireless link.

INNOVATION

- Reprogrammable standard compliant and full-duplex capable SDRs with high and low level MAC and reconfigurable real-time PHY
- A virtual transmitter behaves as eight dedicated transmitters sharing a single powerful hardware platform.
- Flexible non-orthogonal waveform transceiver capable of low-latency FDD communications for outdoor scenarios.

Orchestration and Reconfiguration Control Architecture

SHOWCASE 2

LOW LATENCY INDUSTRIAL COMMUNICATION

DEMO SET UP

- Real-time networking for small robots: multiple standard compliant ORCA SDRs form a wireless network to connect two brainless robots to a central processing unit (Fig. 1 (up)).
- GFDM link for mission-critical communication: high-performance and robust GFDM communication, which enables advanced robot control (Fig. 1 (down)).
- Low Latency concurrent communication link: An SDR based hardware virtual transmitter communicates simultaneously with up to 8 commercial off the shelf chips on different frequency bands (Fig.2 (up))
- High-throughput bi-directional link: Two full duplex capable SDRs communicate simultaneously over the same channel. (Fig.2 (down)).

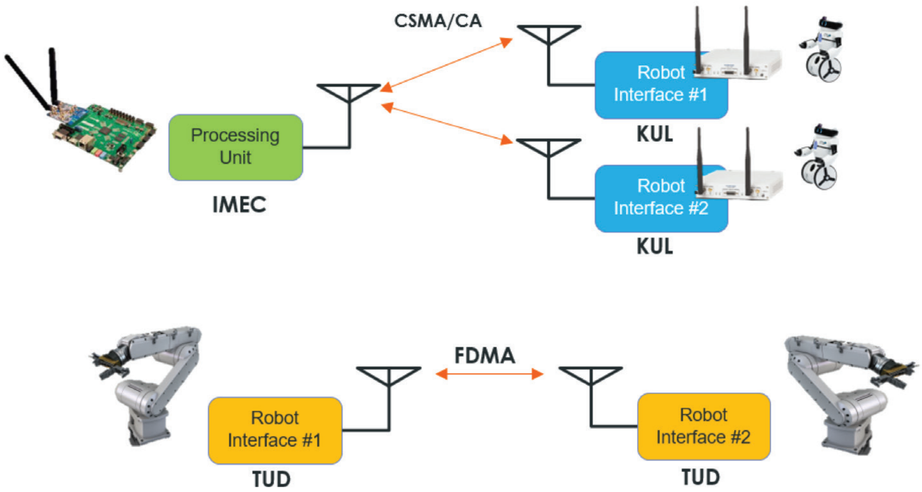


Fig. 1. Multiple wireless communication technologies for low-latency industrial applications.

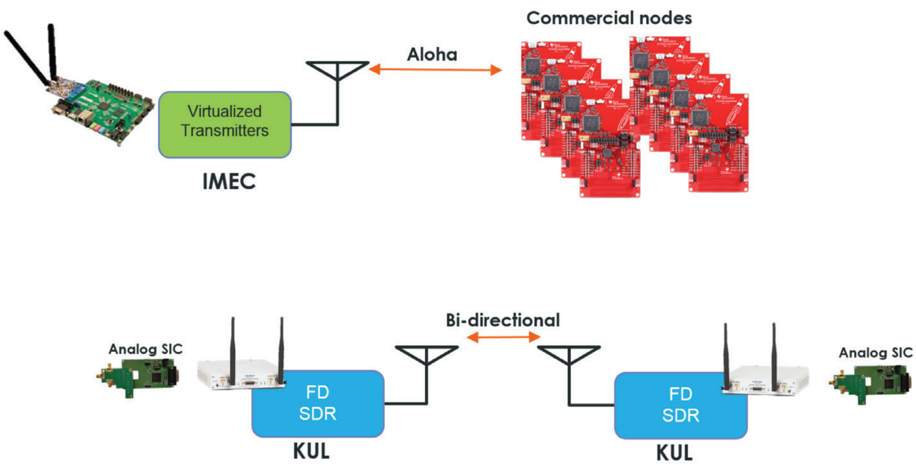


Fig. 2. (Up) A low latency concurrent communication link of the virtual transmitter with commercial off the shelf chips. (Down) In-band full duplex communication link by EBD-equipped SDRs

IMPACT

The presented ORCA achievements in this showcase open a wide perspective for researchers by employing various technologies, such as full-duplex, GFDM and hardware virtualization, in a realistic scenario where the reliability relies on the latency performance of the network.

Orchestration and Reconfiguration Control Architecture

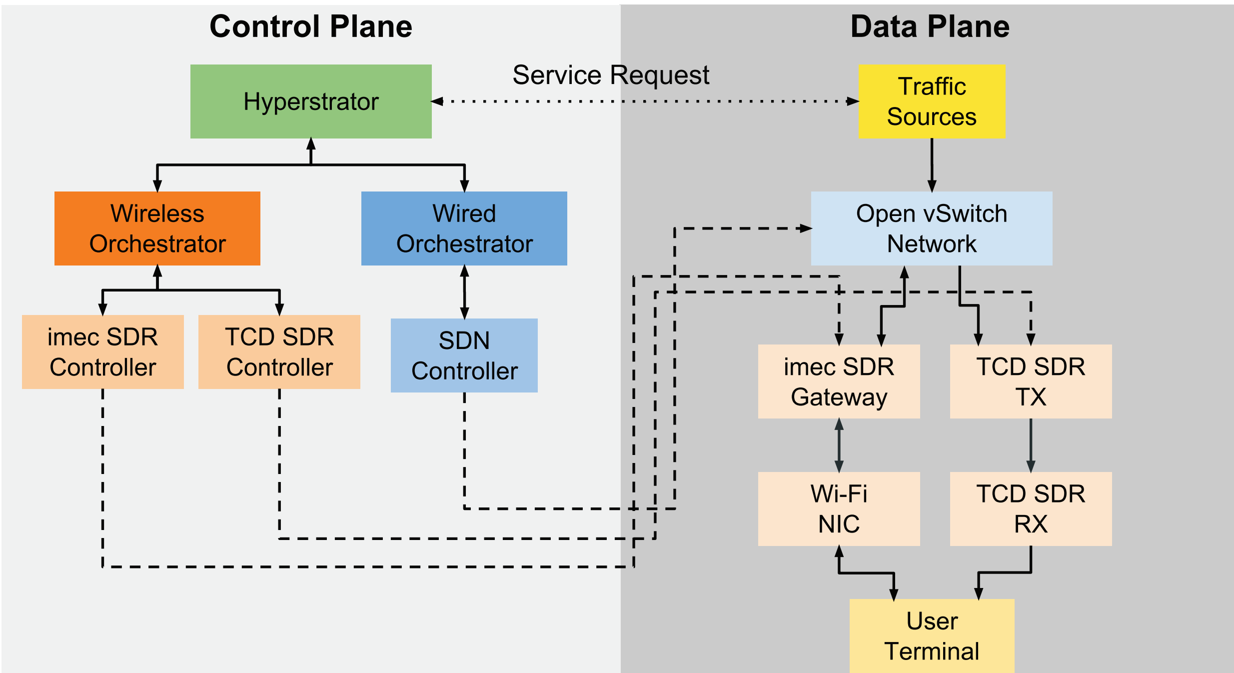
SHOWCASE 3

DEPLOYING E2E SERVICES THROUGH JOINT ORCHESTRATION OF SDR AND SDN

CONCEPT

- Create E2E network slices tailored to support diverging traffic requirements.
- Achieve cross-network segment orchestration through a hierarchical orchestration scheme, using a hyperstrator.
- Apply different radio virtualisation techniques on different SDR platforms depending on the traffic requirements.
- Show the advantages and trade-offs of the different radio virtualisation approaches:
  - The imec virtual radio interface is low-latency and can be compatible with commercial radios.
  - The TCD virtual radio interface possesses the flexibility to instantiate customised radio stacks.

DEMO SETUP



- In the data plane, there are traffic sources aiming at streaming data to a user terminal, traffic classes include high throughput, e.g., video streaming, and low latency, e.g., health monitoring/emergency assistance applications.
- The control plane has a hierarchy of orchestrators, where the hyperstrator receives E2E service requests and delegates the requirements of the wired and wireless network segments to the respective underlying orchestrators.
- The wireless network orchestrator decides to employ one of the available radio virtualisation techniques depending on the traffic class of the service, and then instantiates a radio slice on either the imec or the TCD virtual radio interfaces.
- The wired network orchestrator decides to establish either a high-throughput or a low-latency data path on a virtual wired network consisting of Open vSwitches, and then instantiates the core slice between the traffic source and the chosen virtual radio interface.
- The user terminal has both imec and TCD virtual radio interfaces, enabling a flexible routing of the traffic sources between the two infrastructures.

Orchestration and Reconfiguration Control Architecture

SHOWCASE 3

DEPLOYING E2E SERVICES THROUGH JOINT ORCHESTRATION OF SDR AND SDN

GOALS

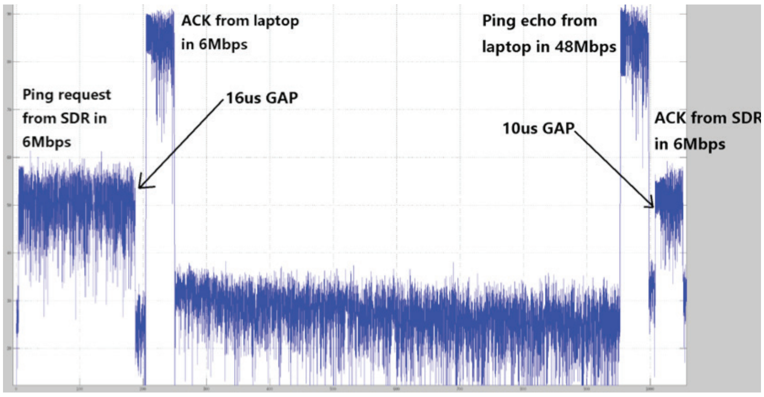
- Demonstrate how the functionality provided by ORCA can support E2E communication services.
- Deploy E2E network slices to support diverse traffic requirements of industrial use cases.
- Coordinate the operation of SDR and SDN for creating E2E network slices.

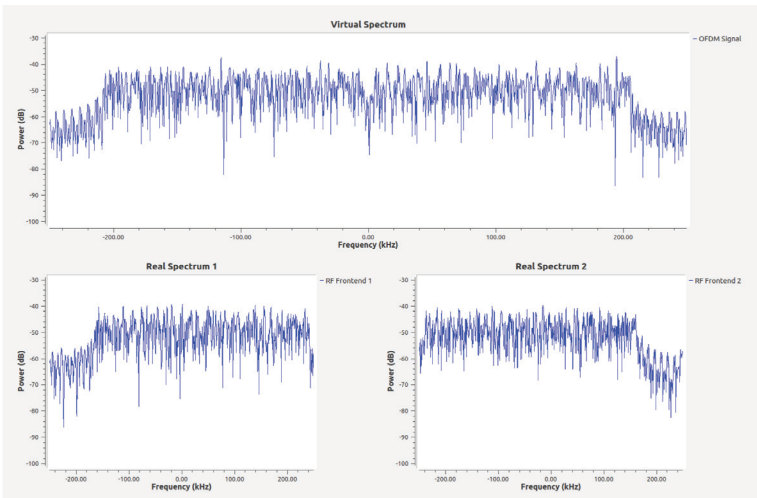
CHALLENGES

- Coordinating the orchestration of wired and wireless network segments for establishing routes and providing radio access.
- Creating an interface between the SDR and SDN for attaching the radio slices to the core slices.
- Performing many-to-many spectrum virtualization, allowing spectrum partitioning and aggregation.
- Making SDR radio interface compatible with commercial Wi-Fi.
- Creating multiple slices throughout all layers (from the driver in the embedded OS to the radio hardware on the FPGA)

RESULTS

- Full stack 802.11a/g SDR implementation: RF control; FPGA baseband; Linux mac80211 driver. Achieve critical SIFS timing and communication with commercial Wi-Fi.
- FPGA maintained real-time time slice handling: create, destroy, config (duty cycle, slot).
- Show the time taken for instantiating E2E services, including the components from the hyperstrator, orchestrators, and controllers.
- Show the E2E latency and throughput of the different types of network slices





SHOWCASES
YEAR 3

SHOWCASE 1

26 GHZ MM-WAVE COMMUNICATION FOR VIDEO STREAMING

GOALS

- Demonstrate the real-time beam tracking functionality for the 26 GHz mmWave antenna arrays of TUD.
- Demonstrate mmWave setup as an experimental support for the development of wireless communication systems in an industrial environment.
- Demonstrate the employment of TUD's multi-user system by allowing more than one sub 6 GHz link.

CHALLENGES

- Real-time beam tracking capability with mmWave frontend. It is necessary to perform the beam steering functionality on the FPGA, in order to guarantee fast beam tracking under the mobility scenario.
- The design of a control loop with low latency for beam tracking.
- The design of mmWave antenna that can be easily attached to any SDR platform.
- Design of a multi-user mechanism to coordinate the links with multiple users.

CONCEPT

We consider a remote-controlled robot moving around the factory hall with a camera attached to it for inspection purposes. The camera is constantly transmitting a live video stream to the AP through the mmWave link. Then, the base station forwards the video to a factory worker located remotely via a second mmWave link. Therefore, the mmWave solution is advantageous in two aspects:

- It uses a novel frequency band allowing more capacity of the network.
- The directivity feature of the electromagnetic waves makes it possible to use several links close to each other using the same time and frequency with very low interference level.

We take advantage of this aspect by employing a second mmWave link as backhaul, where the video is forwarded to the user who is not located in the base station.
In addition, the remote user can steer the robot using a sub 6 GHz link, which makes it possible to thoroughly inspect the production line remotely.

Orca Orchestration and Reconfiguration Control Architecture

SHOWCASE 1

26 GHZ MM-WAVE COMMUNICATION FOR VIDEO STREAMING

DEMO SET-UP

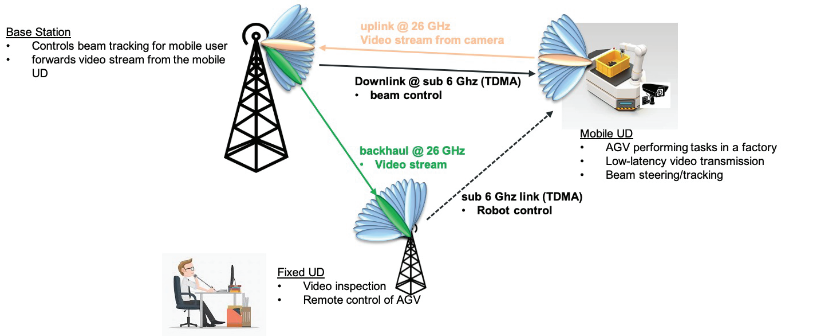
- The demo has three nodes:
1. Base Station (BS)
2. Mobile User Device (UD)
3. Fixed UD

- The mobile UD is an Automated Guided Vehicle (AGV) and sends a video stream to the BS through the mmWave uplink.

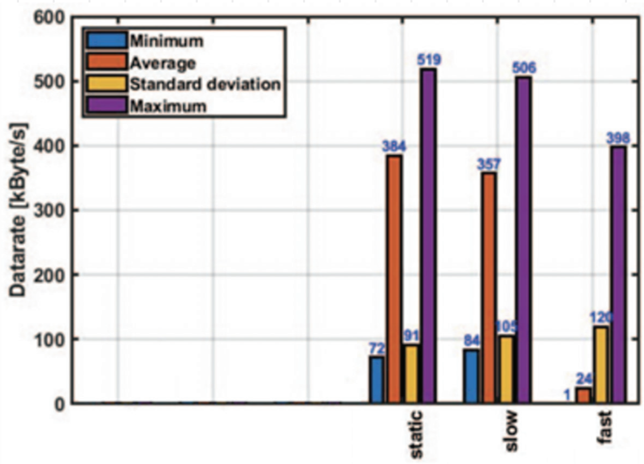
- The video is then forwarded to the Fixed UD using the backhaul mmWave link, for a video inspection application.

- The Fixed UD controls the AGV using a TDMA-based sub 6 GHz link.

- The BS performs the beam tracking algorithm and sends information to the Mobile UD via the TDMA-based sub 6 GHz link.



RESULTS



[1] Martin Danneberg, Roberto Bomfin, Ahmad Nimr, Zhongju Li, Gerhard Fettweis, "USRP-based platform for 26/28 GHz mmWave Experimentation". WCNC 2020 Smart Spectrum Workshop, April 2020, Seoul

This showcase demonstrates the fast beam steering algorithm of TUD. Under the mobility scenario, the system is able to successfully track the best beam pair with a maximum delay of 20ms and minimum delay of 2.5 ms when the best TX beam changes by one beam. In addition, the capacity of the mmWave frequency band is duplicated by reusing a second link with. Additionally, we demonstrate the employment of two sub 6 GHz links operating in TDMA mode.

The figure on the left depicts the measured end-to-end throughput of the mmWave uplink. For the mobility scenarios, we classified 3 cases. Namely, static, slow with 1.1km/hr, and fast with 2.2km/hr, where the beam tracking algorithm has been evaluated and published in [1]. For the low mobility scenario, the throughput loss is very low in comparison to the static case, demonstrating the feasibility of the beam tracking algorithm.
More information about the setup and the open source code are accessible in the TUD's testbed web page http://owl.ifn.et.tu-dresden.de/orca/mmwave26ghz/

INNOVATION

- The 26 GHz antenna arrays, easily integrated to the TUD's GFDM implementation for National Instruments' SDRs.

- A simple beam tracking algorithm can be employed for applications that do not require an ultra-reliable link, e.g., video streaming.

IMPACT

This showcase demonstrates the mmWave transmission for industrial communication using commercial SDR platforms, which opens a variety of possible extensions for future work, including the experimentation of implementations for the mmWave.

SHOWCASE 2

LOW LATENCY CONTEXT-AWARE IOT CONTROL

GOALS

The main goal is to demonstrate the low latency, reliable and flexible link control of mobile nodes or robots established via SDR, including two specific building blocks:

- The concurrent multi-channel virtual transceiver (TRX) as IoT gateway (GW)

- The integrated Doppler radar with full duplex communication capability tracking robots while controlling them

Both building blocks are established upon IEEE 802.15.4 PHY; the former aims to achieve better throughput/latency performance as an IoT gateway, the latter aims to increase the reliability of each single control link with full duplex MAC (collision detection and avoidance) and a Doppler radar (environment sensor).

CHALLENGES

-The receivers of multi-channel transceiver implementation share a single radio frontend, which has an Automatic Gain Controller (AGC). However, this AGC applies a global gain setting on all the channels, which causes issues when the transmitters of different channels are located at different distances. In order to overcome this issue, a simple AGC is implemented: it applies gain on each channel individually.

- Integration of a configurable Doppler radar system into a communication device, merely by reusing its already-existing waveform and hardware, is also one of the challenges in this showcase. Unlike the traditional radar systems, the Doppler radar in this showcase has to merely use the device's self-transmit signal, while this additional functionality does not affect communication.

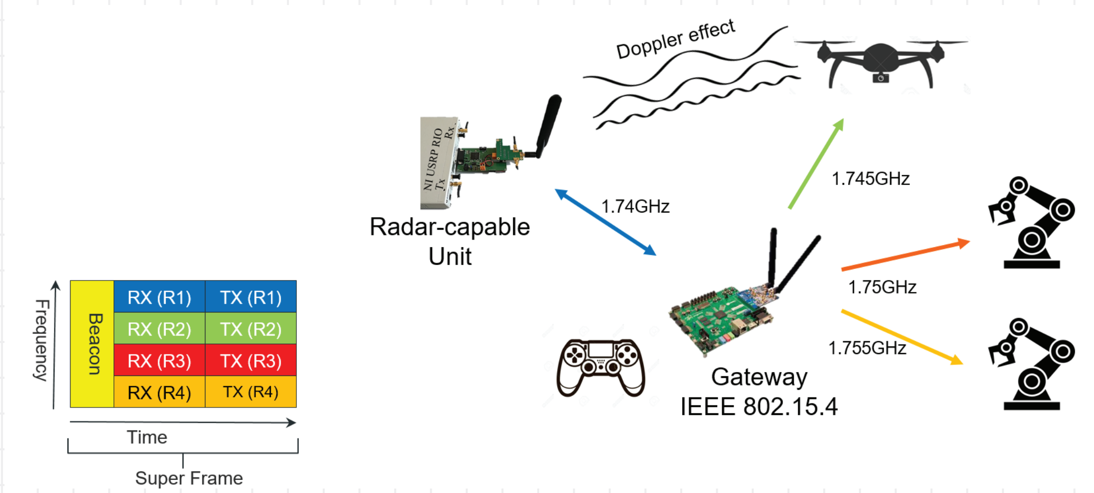
CONCEPT

The showcase use of a concurrent multi-channel TRX as an IoT GW. The GW is attached to a controller to steer multiple robotic arms. A radar communication system (RadCom) that makes use of signals transmitted for communication to estimate the moving object's speed. This information is helpful to identify if the target robot is reacting to the command, or if there are external mobile objects present. This feature helps to achieve ultra-high reliability by informing the control unit about the reaction of the devices, or applies the environmental information to implement an explicit response accordingly.

SHOWCASE 2

LOW LATENCY CONTEXT-AWARE IOT CONTROL

DEMO SET-UP



- A GW (zedboard) supports a 4x multi-channel Virtual transceivers. It operates on 4 channels concurrently.

- The first 2 channels are used to control 2 robotic arms, the remaining two channels are used for radio communication, and controlling a propeller (emulating a “drone”).

- The time and frequency slot used by the system is shown in the lower left corner of the figure below.

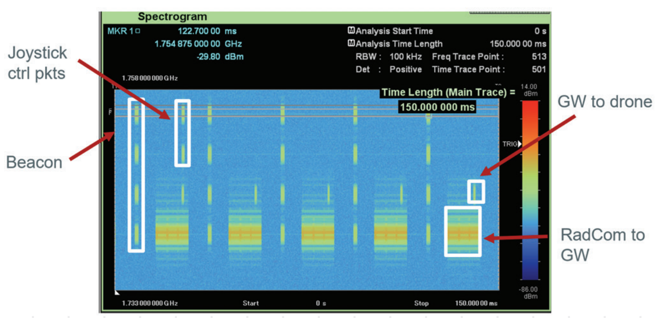
- Two additional zedboards are added as wireless interfaces of the robotic arms.

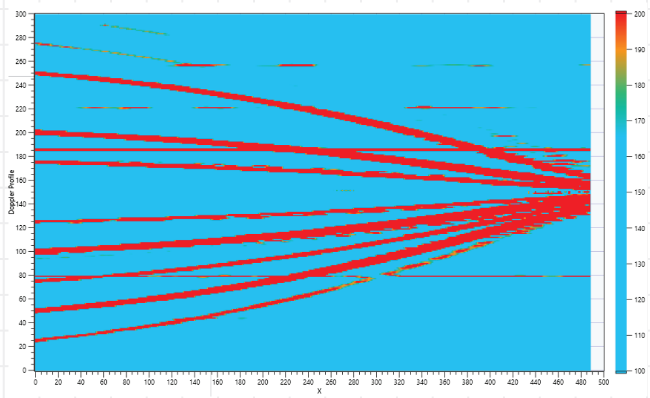
- The radar-capable unit enables simultaneous in-band full-duplex communication and Doppler radar.

- The radar-capable unit (RadCom system) controls the “drone” through the GW, and reuses the reflections of what it transmits to sense the reaction of the drone.

RESULTS

The robots are moving synchronized, the drone propeller’s angular speed is correctly controlled by the RadCom, and reflected by the Doppler profile. The spectrogram reflects the concurrent transmission capability of the GW, and the signals generated by the Doppler radar. The extracted Doppler image also shows that it is precise enough to indicate the drone's propellers rotational speed.





SHOWCASE 3

DISTRIBUTED END-TO-END NETWORK SLICING AND ORCHESTRATION

GOALS

- Demonstrate the deployment of customised and isolated end-to-end network slices.

- Demonstrate how end-to-end network slicing set up can be used to support different types of services with diverging service requirements on top of a shared physical network infrastructure.

CHALLENGES

One of the main challenges of this showcase is the coordination on the resource allocation among different network segments for deploying end-to-end network slices:

- First of all, it was necessary to virtualise network segments for creating customised and isolated network segment slices, e.g., a virtual radio access network (RAN), a virtual transport network (TN), and a virtual core network (CN).

- Then, decomposing the end-to-end network requirements per network segment, allowing the delegation of the resource management to separate specialised orchestrators, tailored for the particularities of each network segment.

- Finally, achieving a cohesive resource allocation across multiple network segment slices to ensure a consistent end-to-end QoS for the network slices.

CONCEPT

This showcase emulates a real network infrastructure that can be encountered in mobile network deployments. More precisely, we consider a scenario whereby the network provider (NP) can use its physical network infrastructure to offer network slices as a service (NSaaS) — in other words, creating network slices on the fly to support different types of communication services and serve service providers (SP).

- First, we instantiate network slices as a service, reacting to requests from SPs, which contain high-level end-to-end service requirements, e.g., throughput, delay, reliability.

- Then, our highlevel orchestrator, the hyperstrator, maps the high-level end-to-end requirements onto high-level local requirements for the separate network segments, enabling the decentralisation of the decision over the resource allocation and function placement to specialised orchestrators in charge of specific network segments.

- Moreover, our hyperstrator coordinates the deployment of network segment slices and ensures a cohesive and optimised performance across networks segments to guarantee a consistent end-to-end QoS for fulfilling the given service request.

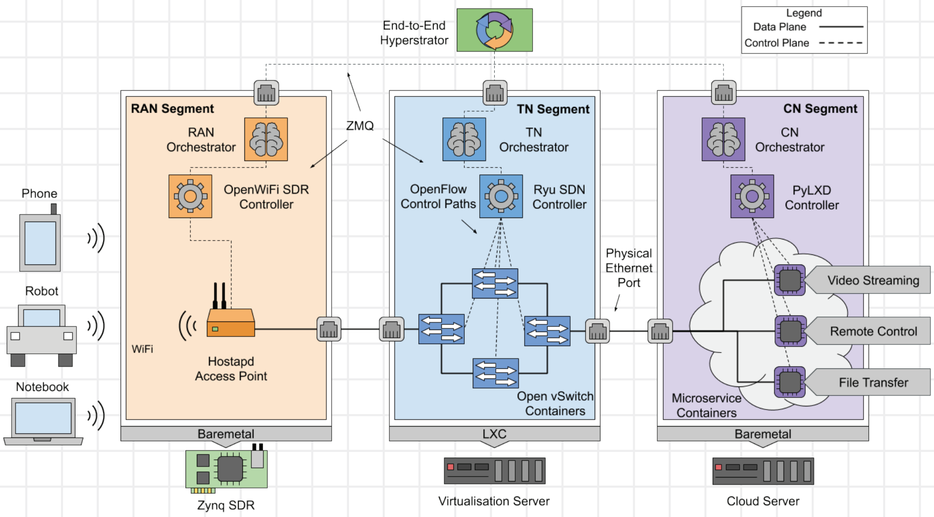
Orchestration and Reconfiguration Control Architecture

SHOWCASE 3

DISTRIBUTED END-TO-END NETWORK SLICING AND ORCHESTRATION

DEMO SET-UP

The demo consists of an experimental end-to-end network infrastructure comprised of three networks segments: a CN, a TN, and a RAN. We use this network infrastructure for supporting three distinct types of services: best-effort remote file storage for notebooks, high-throughput video streaming for handhelds, and low-latency remote vehicle control for autonomous cars; each assigned to a specific end-to-end network slice. The details are shown in the figure below.

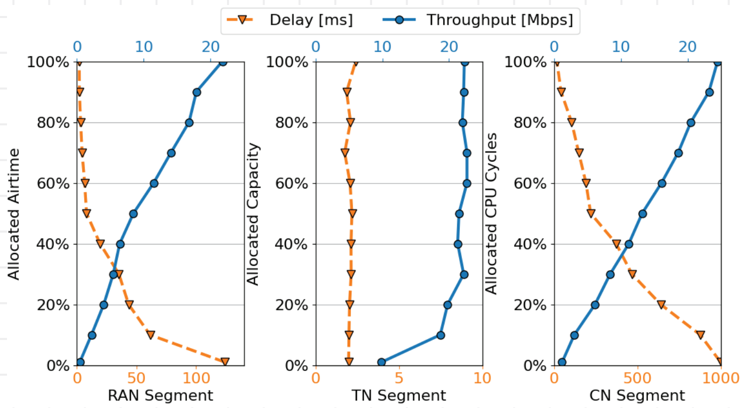


RESULTS

- We show the time required to setup a NS coordinated by the hyperstrator, the setup time is broken down to three segments (RAN ~60 ms, TN ~20 ms and CN ~2000 ms), in total it takes 2.2 second to initiate a NS through the hyperstrator.

- We vary the resource allocation of each network segment, while maintaining maximum resource allocation in other segments. We observe the end-to-end network performance varies with per segment resource allocation, as shown in the figure on the left.

- Hence by coordination through hyperstrator, network resources are allocated appropriately, we guarantee a coherent end-to-end network performance.



IMPACT

- This showcase demonstrates the coordination across multiple network segments for the deployment of customised and isolated end-to-end network slices, which opens a variety of possible extensions and future works, including modelling and analysis of traffic patterns to leverage statistical multiplexing on the allocation of heterogeneous resources to create network slices.

- In order to virtualise the RAN segment and precisely control air time per NS, we developed a WiFi radio hypervisor on an FPGA and embedded ARM platform, which resulted in an open-source project called openwifi. It is a full stack linux mac80211 subsystem compatible open-source Wi-Fi chip design, which is now publicly available for the research community on github (https://github.com/open-sdr/openwifi).

Orchestration and Reconfiguration Control Architecture

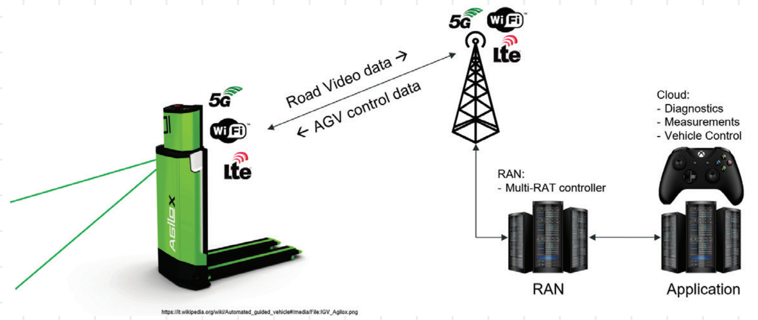
SHOWCASE 4

AGV NAVIGATION BASED ON MULTIPLE RADIO ACCESS TECHNOLOGIES

GOALS

- Demonstrate the concepts for interworking and aggregation of multiple radio access technologies (RAT) by leveraging the real-time Multi-RAT platform developed within ORCA project by NI, see D3.5 and D4.5 [1,2].

- Demonstrate a typical scenario of an industry 4.0 application on top of this platform for wirelessly connected automated guided vehicles (AGV) integrated into the ORCA factory of the future.



CHALLENGES

- Determinism and real-time behaviour are the keys for a reliable wireless system and the main development challenge.

- NI PXI or USRP 2974 real-time controller hardware with NI Linux RT operating system allows optimized process scheduling for real-time requirements of the higher layers which are represented by ns-3 modules for LTE and WIFI.

- 5G higher layer stacks were not fully available by the end of this project, see D3.5 [2]. That's why NI integrated an adapted LTE protocol stack towards the 5G flexible numerology physical layer (PHY).

- Implementation of PHY processing for all RATs on FPGA-based NI USRP-RIO SDR. The connection between PHY (on FPGA) and MAC (on CPU) with NI L1-L2 API has RAT-dependent throughput and latency requirements taken into account.

CONCEPT

- Multi-RAT base station and terminal station Software-Defined Radios (SDR) supporting LTE, WIFI and 5G radio access technologies

- RAT interworking technologies such as LTE-WLAN aggregation (LWA) for LTE-WIFI interworking and dual connectivity (DC) for LTE-5G interworking including runtime reconfiguration driven by a centralized Multi-RAT controller unit

- All RATs are implemented as full stack solutions supporting end-to-end data transfer

- Variable traffic routing during run-time allows seamless operation on application level

- Robot control application shows capabilities of wireless links in an industry 4.0 environment

[1] https://www.orca-project.eu/wp-content/uploads/sites/4/2020/05/ORCA_D3.5_Final_v1.0-compresso.pdf

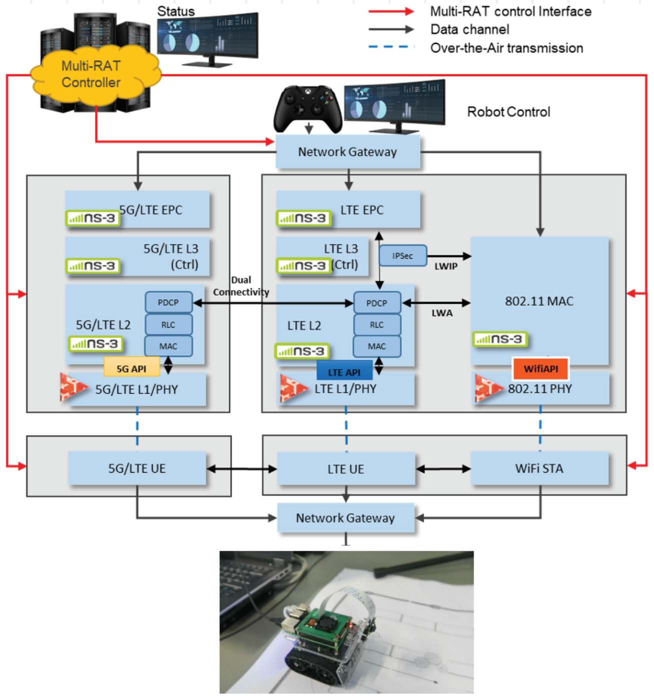
[2] https://www.orca-project.eu/wp-content/uploads/sites/4/2020/05/ORCA_D4.5_Final_v1.0_compressed.pdf

SHOWCASE 4

AGV NAVIGATION BASED ON MULTIPLE RADIO ACCESS TECHNOLOGIES

DEMO SET-UP

The demo setup depicted in the figure consists of a Multi-RAT base station and terminal station supporting LTE, WIFI and 5G RATs and their interworking technologies such as LWA/LWIP or DC. Controllable network gateway applications are used for flexible traffic routing during run-time to and from the robot control application based on decisions which are taken by the Multi-RAT controller.



- The demo setup focuses on wireless transmission in downlink direction. All three wireless links run in parallel, and LTE can be seen as the master path.

- The robot control application sends data packets to the network gateway, which forwards the packets to an available wireless link at the base station, e.g. LTE. where data is sent over-the-air and received by the respective terminal station.

- Another network gateway forwards the data from the terminal station to the steerable robot which is the final destination.

- Additionally, the robot provides a video stream from drivers perspective for control purposes.

- The Multi-RAT controller evaluates link and traffic conditions, and achieves RAT run-time reconfiguration by enabling/disabling LWA/LWIP/DC interworking functionality or reconfiguring the network gateways for RAT transparent communication.

- During RAT reconfiguration the robot is seamlessly steerable which is the key goal of this showcase and a proof for an industrial application with high reliability constraints.

RESULTS

With the end of the ORCA project a full stack Multi-RAT solution running on real-time SDR platform is made available to experimenters through the OWL/TUD testbed [3]. With the robot control application on top, capabilities for an industrial use case were validated. A Multi-RAT controller evaluates link and traffic conditions and allows run-time RAT reconfiguration.

IMPACT

- Provide the research community with open and fully modifiable RATs.

- Provide the research community with a head start for RAT interworking experiments across all layers, without the need to invest a significant amount of effort in setting up and then integrating the individual PHY links.

[3] http://owl.ifn.et.tu-dresden.de/orca/

OPEN CALL 1

FOR EXTENSIONS

Orca Orchestration and Reconfiguration Control Architecture

FINS
Federated Interface for Network Slicing

Open Call partner
FBK CREATE-NET

Patron
TCD

OBJECTIVES

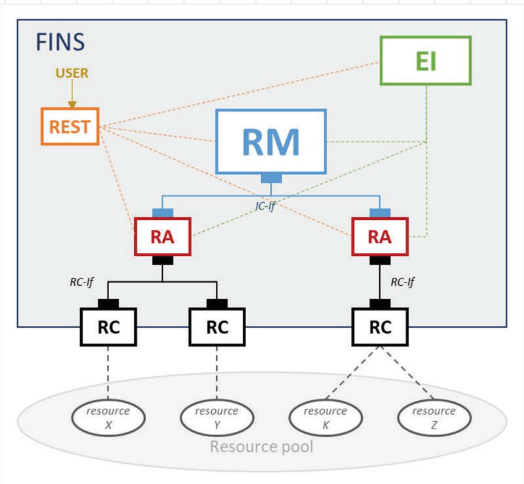
The FINS Framework main purpose is to support the experimenter in creating and operating in a hybrid SDN-SDR environment for slice experimentation. FINS Framework was specifically designed for being used in a remote virtualized testbed, providing support for automating the creation and management different radio-network end-to-end slices, and related resources.

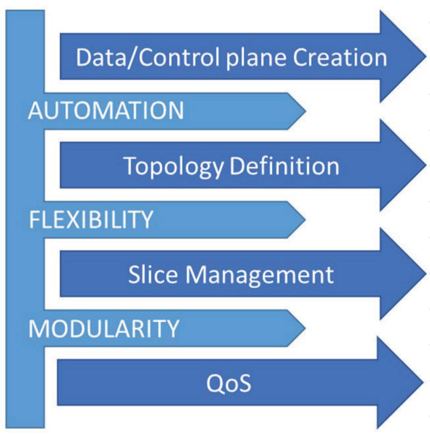
MAIN CHALLENGES

The main challenges in the definition of the FINS Framework were to provide an easy to use user environment (abstracting the slice creation details), to define tools for managing the SDR and SDN available resources, maintaining at the same time the programmability and flexibility of the experiment set-up and to keep it open to future extensions.

CONCEPT

FINS framework creates on an IRIS provisioned set of resources an environment capable of processing User requests for the creation of E2E slices over a given topology created with a subset of the available resources. Specific modules are envisioned to interface and control the different types of data-plane resources, according to the instructions coming from a centralized main module.



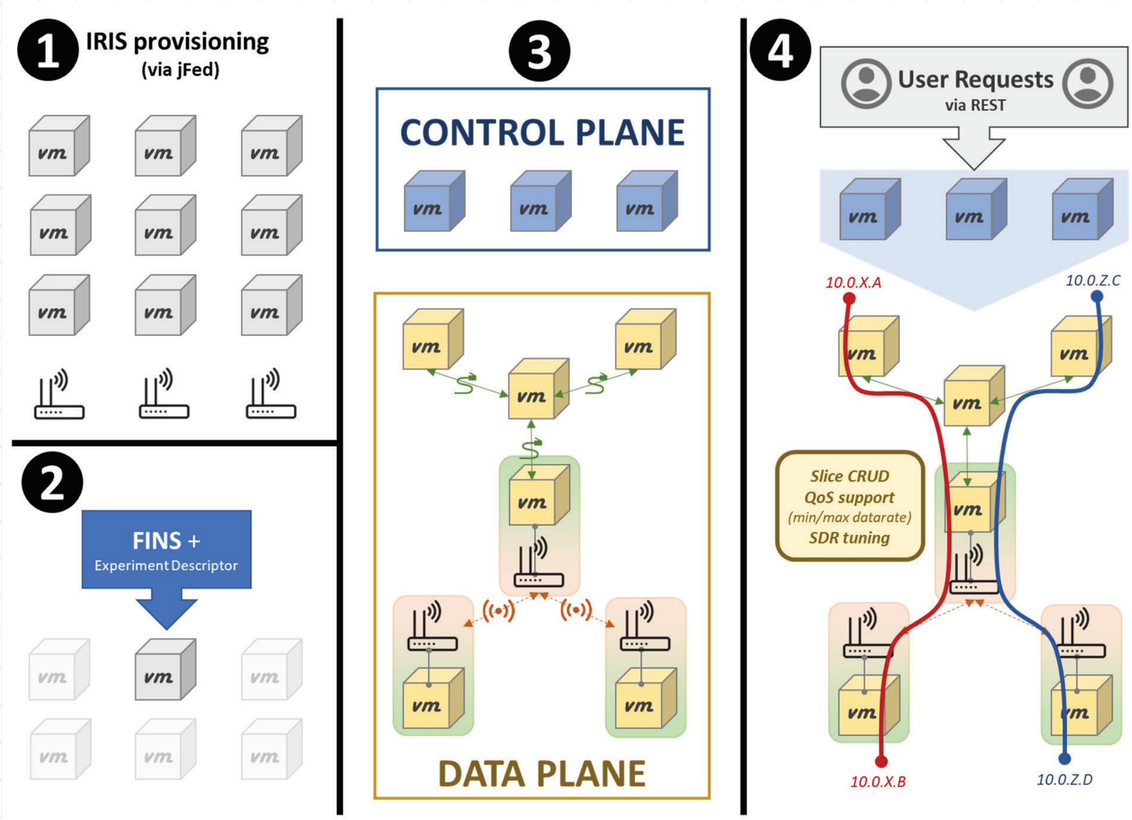


FINS

Federated Interface for Network Slicing

MAIN RESULTS

FINS is an end-to-end SDR/SDN slicing enabling framework for IRIS testbed. After a set of VMs and resources have been provisioned, FINS can be installed on one of those VMs. It requires an experiment configuration file as parameter at launch, to separate the VMs between control- and data-plane. In possession of these VMs, FINS can create, update and delete slices (spanning over SDN, SDR or both). It can also assign specific restrictions over minimum/maximum data-rate over the whole slice or on specific sections, as well as modify the configuration of different USRPs (in terms of frequency and/or modulation).



CONCLUSION

In IRIS testbed, FINS framework (through an automated and modular approach) can successfully manage a set of provisioned VMs with associated SDN/SDR resources, by imposing a user-defined topology and instantiating a control plane managing user requests for end-to-end SDR-SDN slices creation, update and deletion, with basic QoS support.

FEEDBACK

ORCA facility (specifically, IRIS testbed) provided a valuable support to the test and development of the FINS solution. With improved robustness and the introduction of some essential tools for a better user experience, it could become a very attractive service for experimenters in the SDR field.

Orchestration and Reconfiguration Control Architecture

DOLPHINE

Design of listen before talk IP processing up to 8 channels

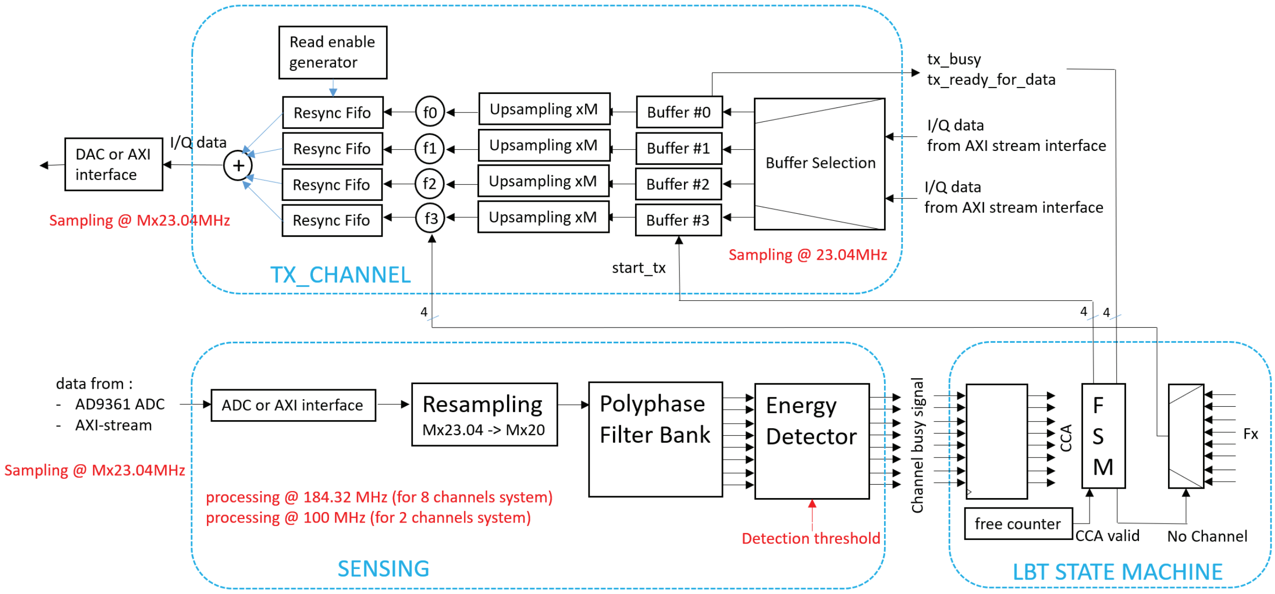
Open Call partner
CEA-LETI

Patron
imec

OBJECTIVES

The goal of DOLPHIN extension consists in designing an IP that completes Listen Before Talk functionalities in the spirit of the 3GPP LAA framework. It is able to simultaneously monitor up to 8 channels of 20 MHz bandwidth. Based on sensing information, the module establishes communication on selected channels. It is also able to deal with 4 pre-load PHY layer. The second step of the project is to integrate the IP into two platforms on the ORCA testbed and to carry out "on-air" measurements that emphasis the impact of the secondary LBT system transmission on primary system such as WiFi.

MAIN ARCHITECTURE



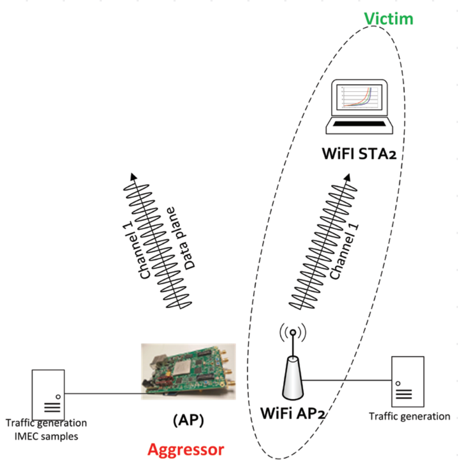
The high-level architecture of the "Listen Before Talk" module is given in the following figure, where M is the number of 23.04 MHz LTE channels. M is a configurable design parameter, it can vary on the capability of RF frontend. The IP core consists of three sub modules:

- Sensing module evaluates the energy level on the M channels
- LBT state machine identifies transmission opportunity and triggers transmission on the M channels.
- Tx channel module receives baseband IQ streams and provide it to the RF frontend when triggered by LBT state machine.

DOLPHINE

Design of listen before talk IP processing up to 8 channels

EXPERIMENT SETUP



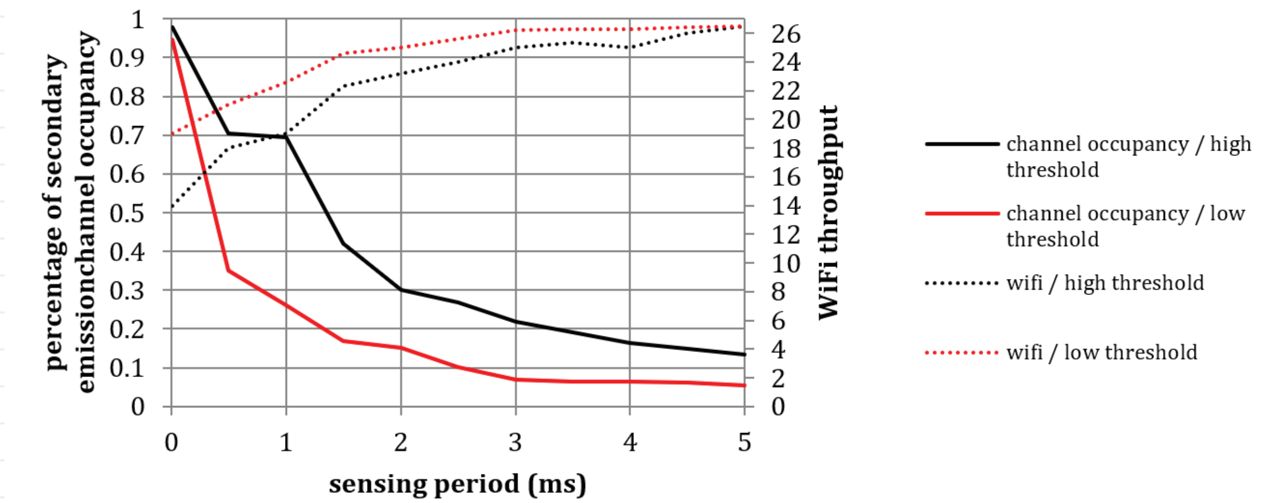
The setup of the main experiment consists in aggressor / victim scenario. The Aggressor is the LBT system where as the victim will be an existing system such as WiFi. The LBT module is based on periodic sensing to yield emission (or not) of a pre-loaded frame.

The LBT module has to show the ability of changing channel or measure the impact on WiFi when secondary emission occurs in the same channel.

MAIN RESULTS

The following figure shows respectively the timing of the periodic sensing that has been implemented in the LBT state machine and the impact of LBT module on WiFi. There are 3 cases:

- Small sensing period: The impact on WiFi is maximum, the system occupies the channel most of the time (>98% of the time).
- Sensing period close to secondary frame length duration: the channel occupancy of the secondary emission is 70% and the WiFi throughput falls to 22Mbps (max = 27Mbps).
- Long sensing period (>> secondary frame duration): In this zone, the impact on WiFi can be mitigated according to the targeted throughput loss.



FEEDBACK

Excellent communication with the patron and ability to access and provide an additional feature to a versatile and open platform. Thanks to the ORCA facility that we were able to get an “on-air” experimentation.

Orchestration and Reconfiguration Control Architecture

UP-ORCA

Unified platform for benchmarking 3GPP unlicensed LTE flavors in ORCA

Open Call partner
Universitat Oberta de Catalunya

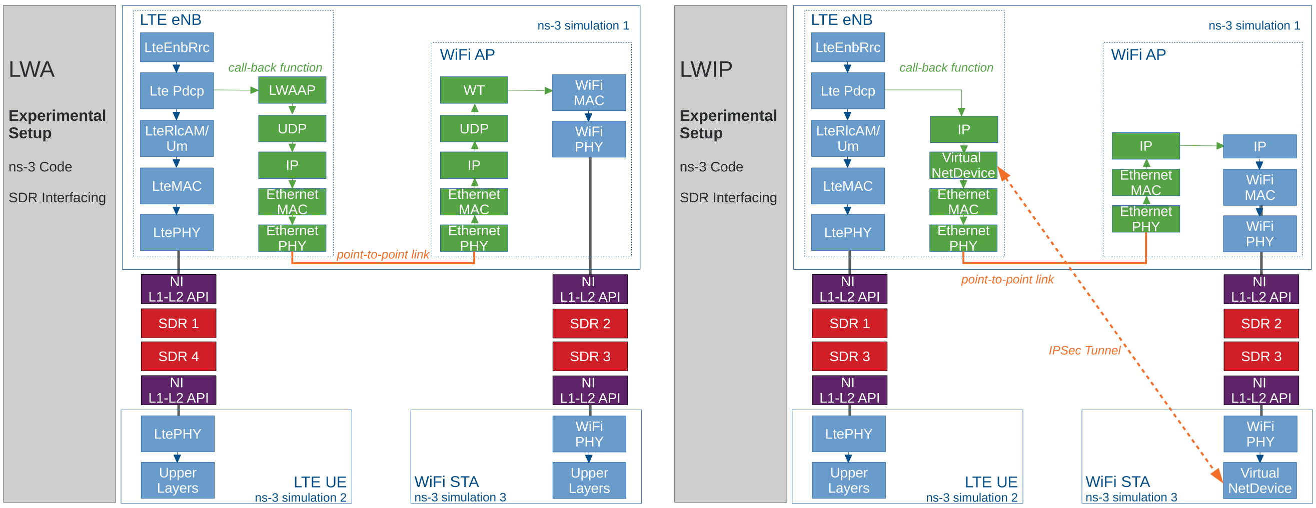
Patron
National Instruments

OBJECTIVES

We present the implementation of the LTE-WLAN Radio Aggregation (LWA) and LTE-WLAN Radio Level Integration (LWIP) protocols in NS-3 and their interfacing to ORCA SDR platforms. This implementation has been used to compare both technologies under different network conditions. It can also enable researchers and practitioners to explore online protocol orchestration depending on LTE and WiFi network status.

MAIN ARCHITECTURE

In this extension we have approached two main challenges. The first one has been the implementation of LWA and LWIP in NS-3 which has required enabling communication among devices belonging to different technologies and extracting packets at different layers of the protocol stack. The second one has been the interfacing to SDR platforms which has been possible thanks to the NI API development and the TU Dresden Testbed.



UP-ORCA

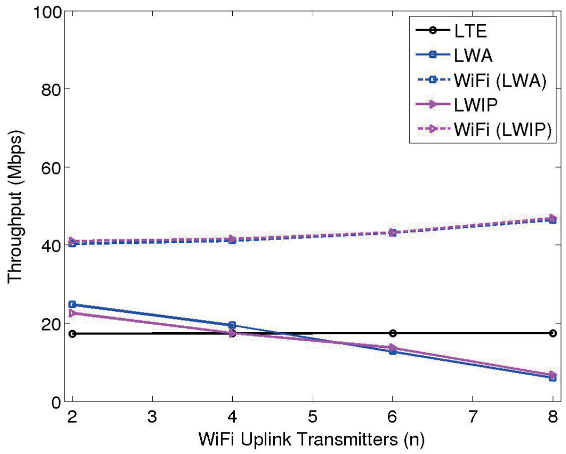
Unified platform for benchmarking 3GPP

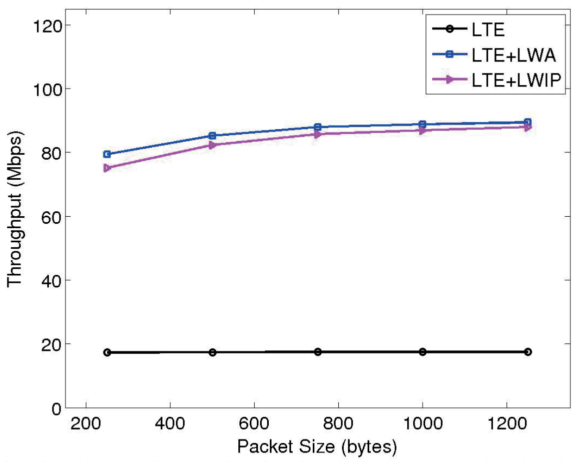
EXPERIMENT SETUP

Our implementation of LWA and LWIP has been interfaced to the ORCA SDR platforms using the NI L1-L2 APIs. We have implemented the LTE eNB, WiFi AP, LTE UE and WiFi STA running in 4 SDR devices and provide this testbed setup for future experimenters in the TU Dresden Testbed. Interfacing to other platforms (such as srsLTE or/and open WiFi SDR platforms) can be achieved without modifications in the provided NS-3 code and by developing the required APIs. This development can be done with the help of the NI L1-L2 API development description provided by NI.

MAIN RESULTS

We have evaluated LWA and LWIP in NS-3 with the goal to obtain more insight on their ability to augment LTE channel capacity under different settings and network conditions. We have seen that LWIP is slightly more inefficient due to the need to include IPSec overhead in the packet headers, which reduce the effective data that can be transmitted per channel attempt. This effect has more impact when the packets to be transmitted are small and persist when moderate contention with coexisting WiFi networks is considered. We have also evaluated the effect of having interferer WiFi networks in the vicinity and how the impact on throughput varies by changing the distance and transmission power.





CONCLUSION

This extension has allowed us to obtain a first take on which technology is more suitable to use depending on the network conditions. We have compared how effectively both technologies augment LTE capacity with varying packet sizes and at different conditions of interference with WiFi. This extension also enables researchers and practitioners to further evaluate both approaches and devise ways forward to protocol orchestration.

FEEDBACK

Our experience with the TU Dresden Testbed as well as the communication with the Patron have been satisfactory. We also value highly the resources and experience we have gained in this extension, especially the Patron background on SDR interfacing as well as their L1-L2 APIs. We also value the research outcomes from this extension, which enable new research directions on online LWA /LWIP protocol orchestration.

Orchestration and Reconfiguration Control Architecture

Real-Time Digital Self-Interference Canceller for In-band Full-Duplex Enabling up to 100 dB of Total Isolation

Open Call partner
Tampere University of Technology

Patron
KU Leuven

OBJECTIVES

The main objective of this Extension was to provide ORCA with the desired real-time digital self-interference cancellation (SIC) functionality to its full-duplex platform, which would fulfill the functional and technical requirement stated in the call. In addition, the wider scientific objective was to develop a high performance and resource-efficient nonlinear digital SIC solution, which, as part of the ORCA IBFD platform, would have high impact in terms of advancing IBFD experimental research and industrial adoption.

MAIN ARCHITECTURE

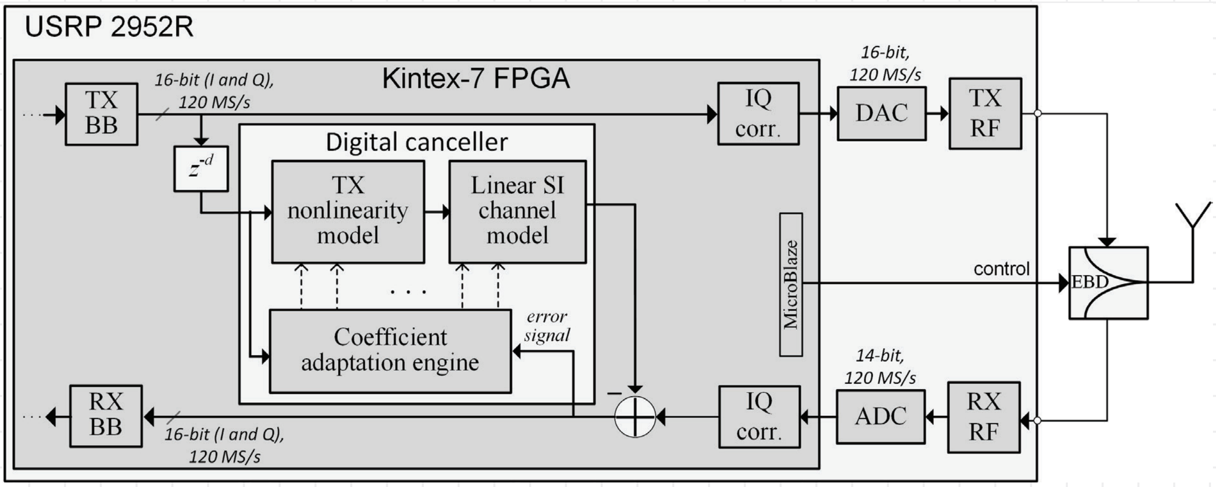
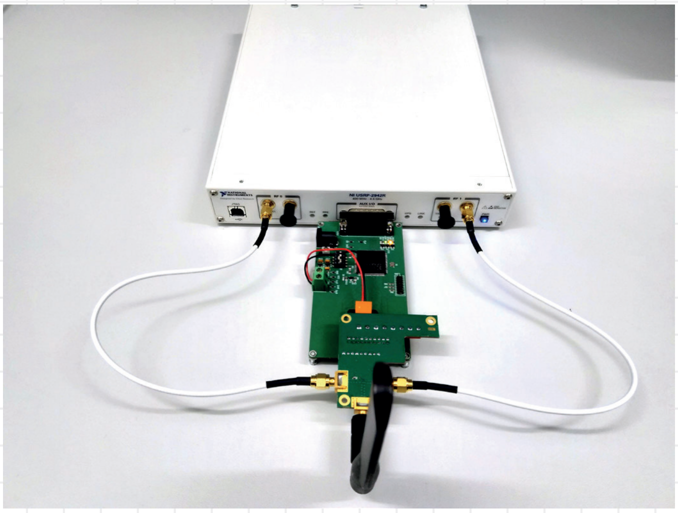


Figure 1 shows the high-level block diagram of the IBFD transceiver on the USRP platform, and the developed digital SIC solution implemented on the FPGA. The transmitter (TX) and receiver (RX) share the same antenna, being connected through an electrical balance duplexer (EBD) to provide RF isolation. The signal then goes through the receiver RF front-end and analog-to-digital conversion (ADC), after which the digital cancellation signal, which is an internally generated replica of the self-interference, is subtracted from the received signal. After the subtraction, the received signal is used together with the original transmit data to update the coefficients of the digital SIC.

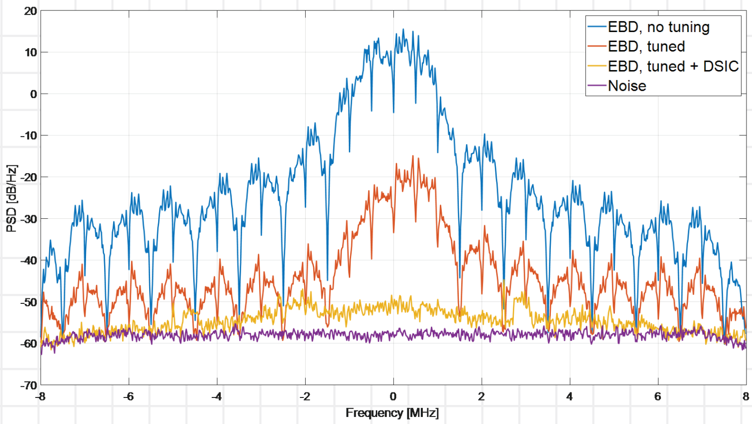
Real-Time Digital Self-Interference Canceller for In-band Full-Duplex Enabling up to 100 dB of Total Isolation

EXPERIMENT SETUP



The setup for the functional verification experiments is shown in Figure 2. It consists of the USRP 2952R device, which is controlled from a PC running LabVIEW Communications Suite 2.0, and the EBD, which acts as the RF isolator. This setup is used to verify that the designed canceller functions as expected, i.e., provides good cancellation and is stable.

MAIN RESULTS



In Figure 3, the power spectral densities of the measured self-interference with different cancellation settings are shown:

- EBD, no tuning: Spectra of the self-interference signal with the EBD untuned.
- EBD, tuned: RF cancellation with the EBD. Tuning the EBD provides 30 dB of additional isolation compared to the untuned case.
- EBD, tuned + DSIC: RF + digital cancellation. The developed digital canceller implementation provides a further cancellation of 30 dB in this particular example case. After the last stage of the cancellation process, the power density of the self-interference is pushed to within a few dB's of the noise floor.

CONCLUSIONS

The project yielded a novel digital SI cancellation algorithm with state-of-the-art complexity-performance trade-off, and two different FPGA implementations of this algorithm. The developed solution was shown to push the self-interference to within a few dB's of the receiver noise floor, and to facilitate true bi-directional full-duplex operation on the ORCA test-bed.

FEEDBACK

Communication and cooperation with the Patron was very good. Especially the help and advice on LabVIEW from the Patron proved crucial for the success of the project.
Getting feedback from imec legals on the agreement was very slow, leading to long delay in closing the agreement. All other correspondence with ORCA was smooth.

OPEN CALL 1
FOR EXPERIMENTS

CILANTRO

Cross layer network monitoring in ORCA

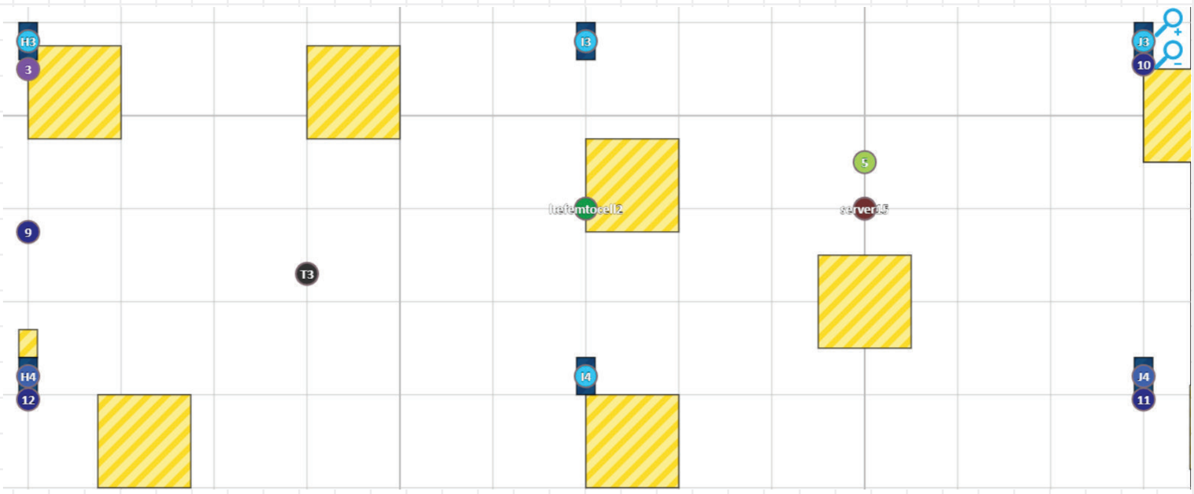
Open Call partner
NM2 s.r.l.

Patron
imec

OBJECTIVES

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

EXPERIMENT SETUP

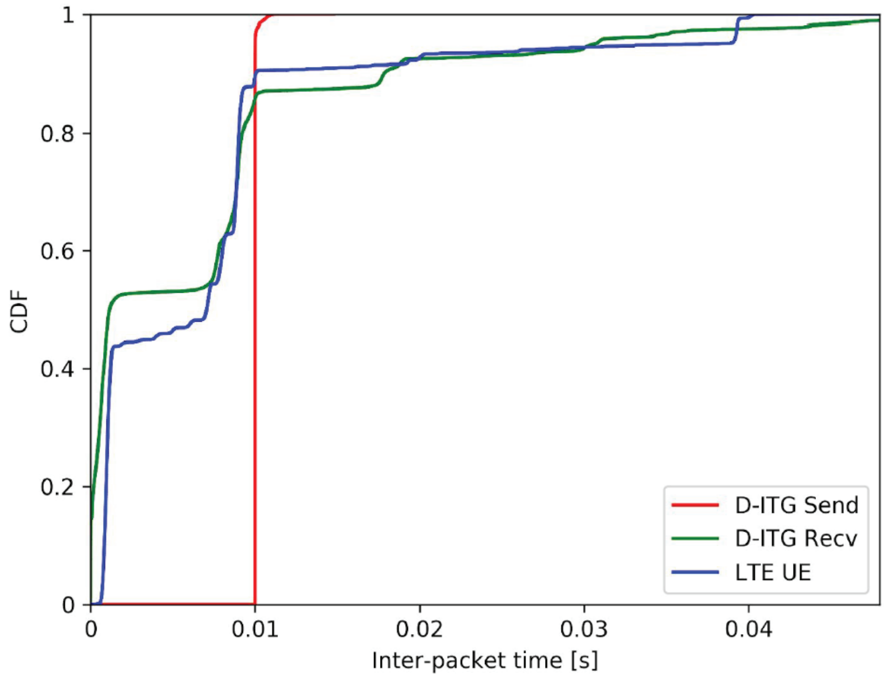


We explored several setups in w-iLab.t, explored the femtocell and various USRPs, looking for the best (and cost-effective) combination of SDR-based devices or COTS LTE devices that could provide useful lower-layer monitoring capabilities. We performed measurements also on a path originating with an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

CILANTRO

Cross layer network monitoring in ORCA

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.

CONCLUSIONS

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.

FEEDBACK

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.

Orchestration and Reconfiguration Control Architecture

CLUE
Coexistence of LTE-Unlicensed & Wi-Fi

Open Call partner
Eight Bells LTD

Patron
TCD

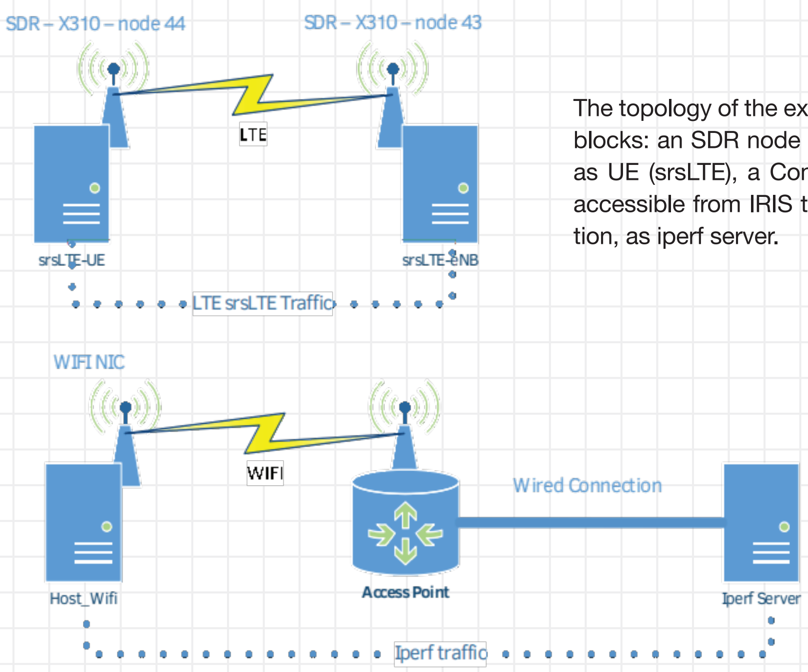
OBJECTIVES

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.

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.

EXPERIMENT SETUP



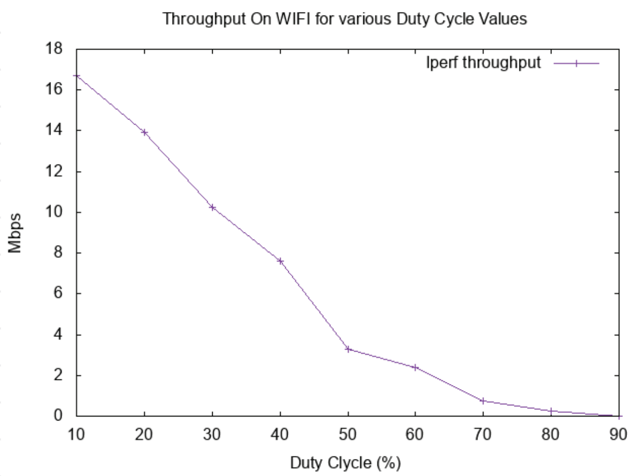
The topology of the experiment consisted of the following building blocks: an SDR node acting as eNB (srsLTE), a SDR node acting as UE (srsLTE), a Commercial WIFI access Point, a and a node accessible from IRIS testbed connected to AP via wired connection, as iperf server.

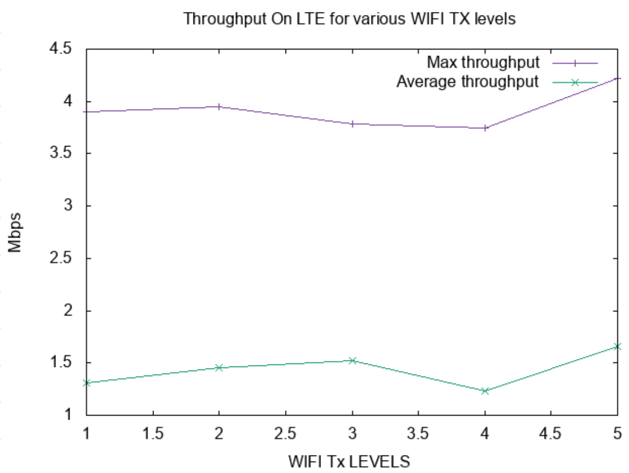
CLUE

Coexistence of LTE-Unlicensed & Wi-Fi

MAIN RESULTS

LTE has a dramatic impact on WIFI performance and on extreme scenarios where LTE is implemented with sleep periods, interference towards WIFI frequencies is so intense that tent to eliminate WIFI throughput. On the other hand, WIFI transmissions have marginal impact on LTE performance.





CONCLUSION

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.

FEEDBACK

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.

E2EWebRTC

Proof of Concept of an 5G End to End Computationally Intelligent WebRTC service leveraging ORCA's combined SDR/SDN approach

Orca – Orchestration and Reconfiguration Control Architecture

Open Call partner
Modio Computing PC

Patron
TCD

OBJECTIVES

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..

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.

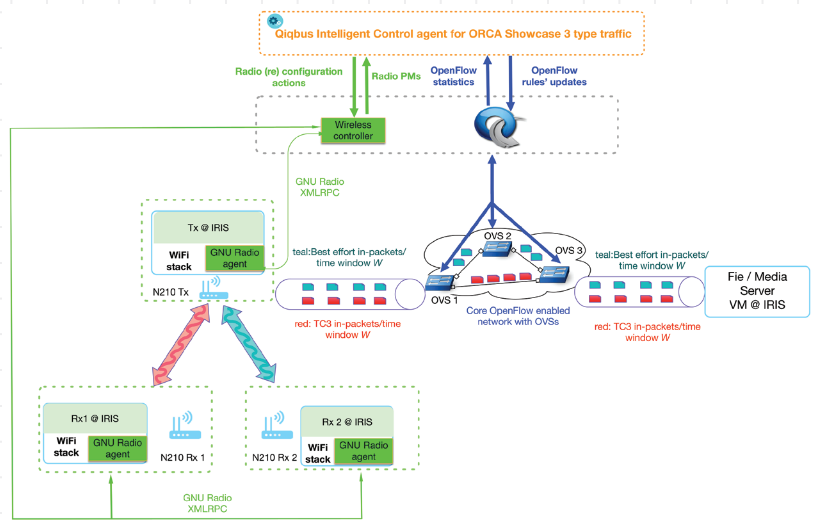
EXPERIMENT SETUP

Step 1 – Wireless and Wired monitoring metrics collection

Step 2 – Machine model training using experimental data

Step 3 – Integration with GNU Radio and OpenFlow within the IRIS testbed

Step 4 – Application of Model's output variables (e.g. radio parameters) to IRIS testbed



The experiment methodology entailed: collection of performance measurements from different network configurations (Step 1), training of machine learning models (Step 2), deployment of Qiqbus within IRIS using appropriate APIs (Step 3), iv) validation experiments that concluded that our approach caters for maintaining the SLA of a TC3 service.

Our setup involved:

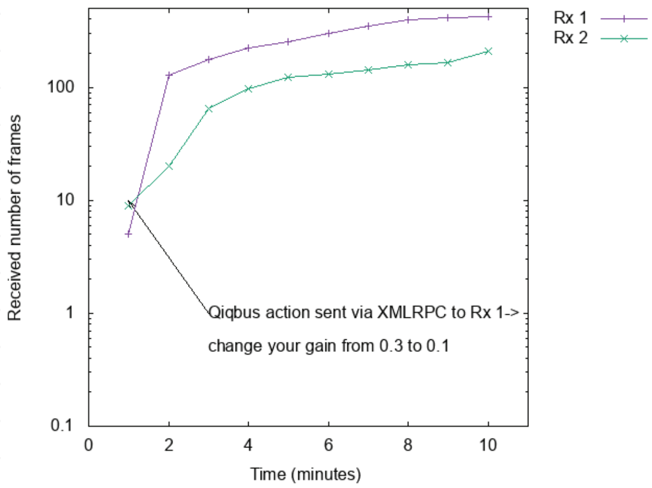
- A file server.
- Three VMs as OF switches controlled by Floodlight.
- Tx as the WiFi transmitter.
- Rx1 as a WiFi TC3 client.
- Rx2 as a best effort video client.
- The Qiqbus software which adds computational intelligence to the combined control plane so that Rx1 outperforms Rx2.

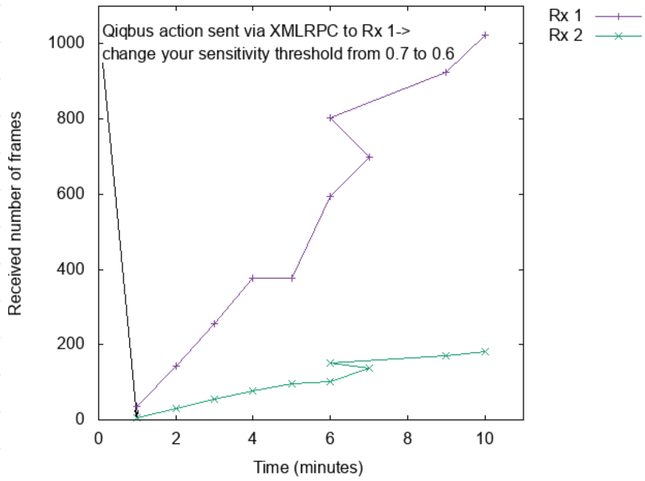
E2EWebRTC

Proof of Concept of an 5G End to End Computationally Intelligent WebRTC service leveraging ORCA's combined SDR/SDN approach

MAIN RESULTS

Our objective was to maximize the number of frames received by Rx1. Our clustering model decided that the gain of Rx 1 should become 0.1. The Figure 1 demonstrates that our clustering model correctly advised TC3 Rx1 to change its gain from 0.3 to 0.1, outperforming best effort node Rx2.





The experiment aimed to find the best configuration of the sensitivity parameter of Rx1 when all nodes operate in 802.11p. The Figure 2 demonstrates that after execution of our provisioning action, node Rx1 started performing better than Rx2, being able to receive more frames until the end of the video session.

CONCLUSION

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.

FEEDBACK

ORCA offers many options for experimenters and accessing output data (for example N210 radio measurements) is straightforward. The IRIS documentation is of high quality allowing a new experimenter to quickly use the tested. Furthermore, the support of our Patron was excellent. Concluding, the most impressive aspect about ORCA is that it caters for a wide range of combined SDR/SDN experiments.

Orchestration and Reconfiguration Control Architecture

FastFlow5G

Instantaneous end-to-end flow latency optimization in a cellular 4G/5G based network

Open Call partner
Universidade de Vigo

Patron
TCD

OBJECTIVES

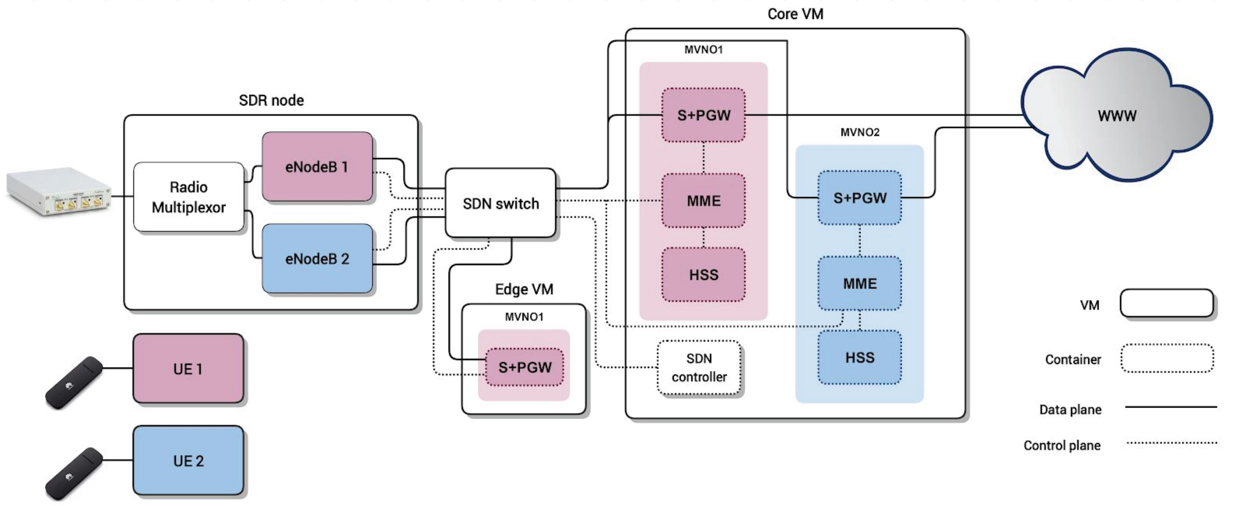
FastFlow5G seeks to prove that it is possible to adapt an end-to-end network in real time to new traffic requirements transparently to the session layer, by exploiting technologies such as SDN, SDR, RAN-Sharing and new paradigms such as Network Slicing, RAN Slicing, Edge Computing, Network Function Virtualization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

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.

EXPERIMENT SETUP

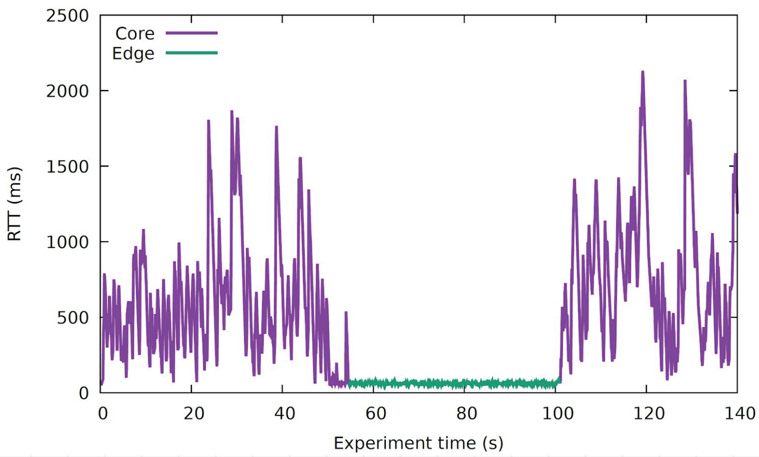
We have performed six different experiments to gain insight into solutions for flexible and dynamically reconfigurable 5G networks. Two LTE dongles (UEs) were connected to two laptops installed in the IRIS testbed. Each UE was connected to its corresponding LTE network, generated by an eNB. The two eNBs 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.

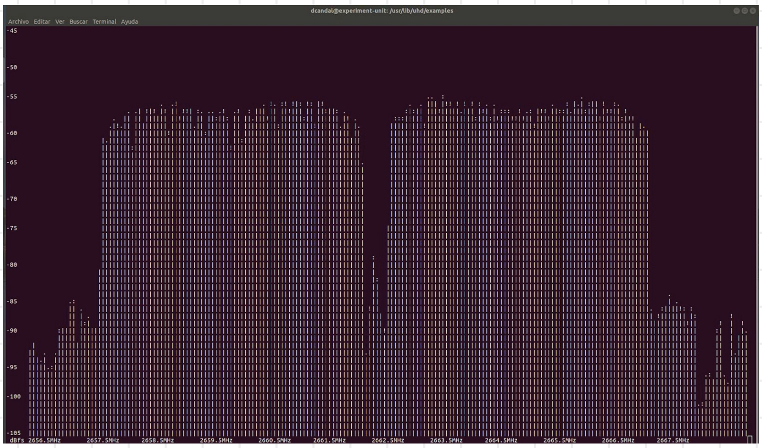


FastFlow5G

Instantaneous end-to-end flow latency optimization in a cellular 4G/5G based network

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 1, 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 2.

CONCLUSIONS

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.

FEEDBACK

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.

Orchestration and Reconfiguration Control Architecture

ACROSS

Autonomic cross layer protocol stack for SDR systems

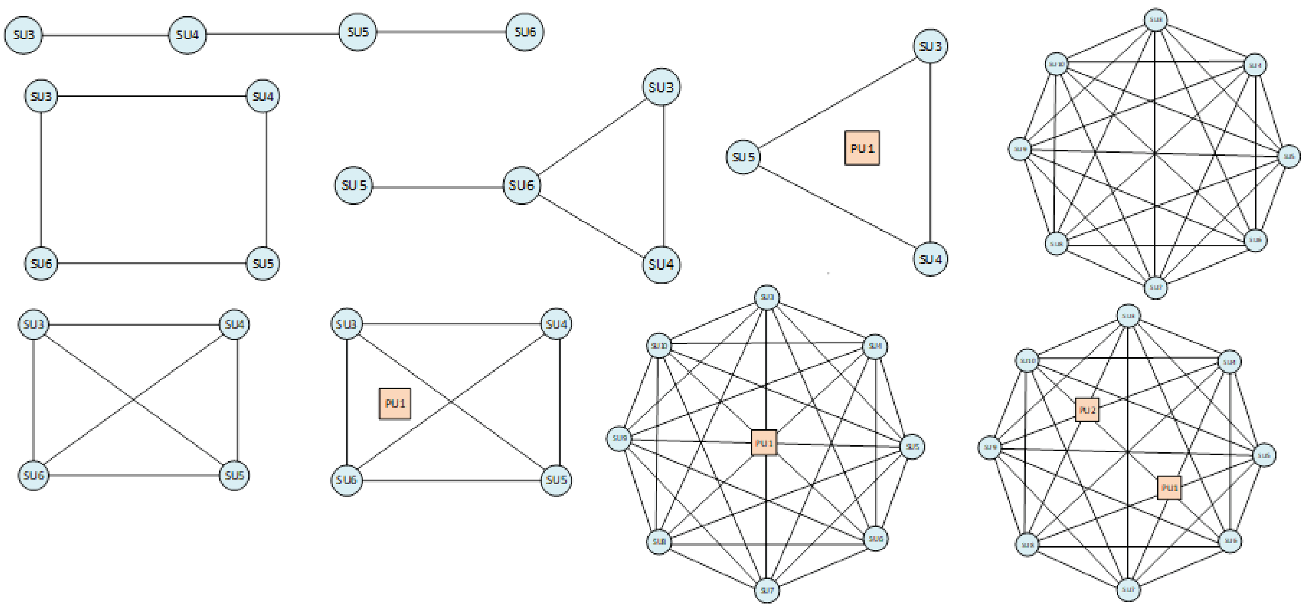
Open Call partner
ICCS

Patron
TCD

OBJECTIVES

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.

EXPERIMENT SETUP



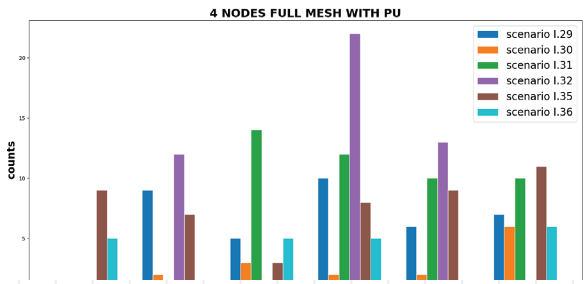
Our experiment involved setting up a secondary cognitive radio network consisting of 4, 7, 8 or 10 secondary users, with USRP devices running our cross-layered resource allocation approach, based on Markov Random Fields. Different types of topologies, such as line, triangle, square, partial mesh and 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.

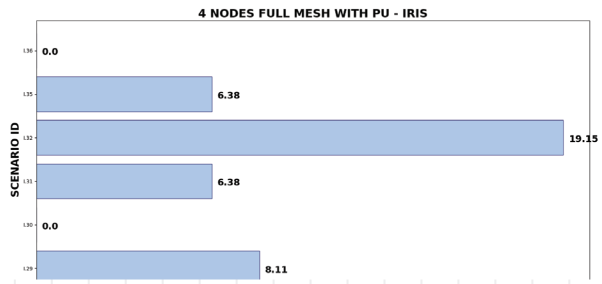
ACROSS

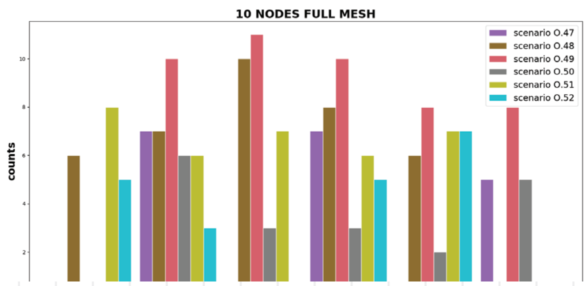
Autonomic cross layer protocol stack for SDR systems

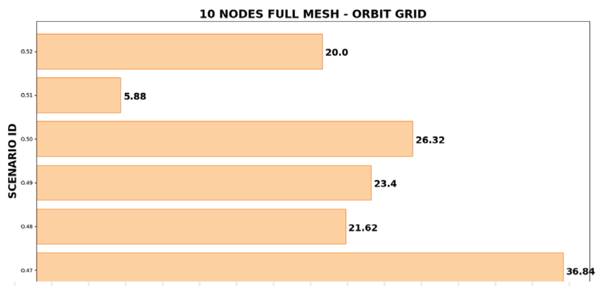
MAIN RESULTS

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:









CONCLUSION

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.

FEEDBACK

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.

Orchestration and Reconfiguration Control Architecture

WiIDCAT

Waveform Design and benChmArking Tool

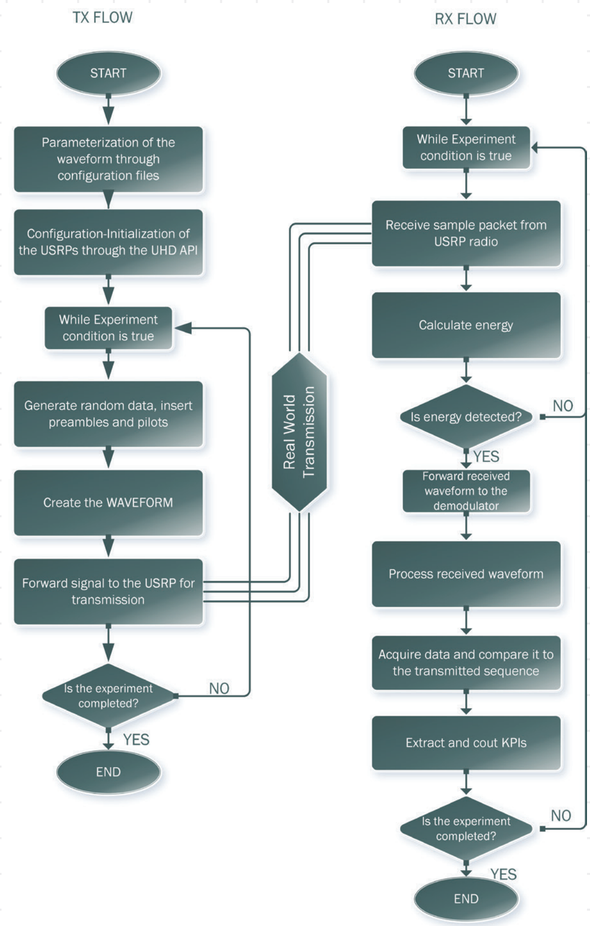
Open Call partner
University of Piraeus Research Center

Patron
Technische Universitaet Dresden

OBJECTIVES

WiIDCAT focused on the design, development, validation and exploitation of an SDR tool for waveform design, analysis and evaluation of multicarrier modulations, from conventional OFDM to schemes utilizing filterbanks, windows, signal extensions and other signal processing features. WiIDCAT objectives include: specification of a generic transceiver able to implement with parametric reconfiguration all known multicarrier modulations; development of SDR tools for real-world communication to investigate tradeoffs for each modulation; experimentation for transceiver validation and real-world KPI measurements for various modulations.

MAIN ARCHITECTURE



The WiIDCAT architecture is based on the implementation of novel generic transceiver suitable to design and analyze signals of every known multicarrier modulation with simple parameterization. The WiIDCAT software is implemented as an SDR tool that establishes real-world communication links and evaluate benefits/drawbacks of each modulation. The flow diagram of the WiIDCAT tool is presented in Picture 2.

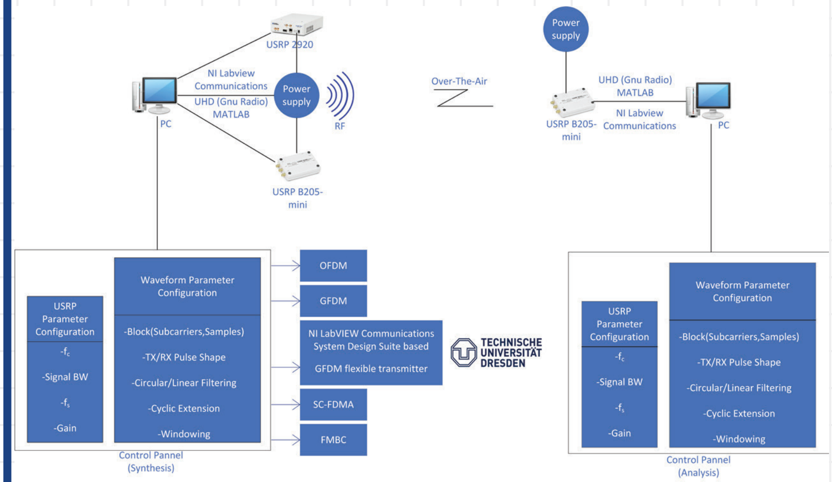
The transmitter synthesizes a waveform with use of basic parameterization, and transmits packets in a loop. The receiver senses the signal, acquires it, performs all detection and estimation tasks and measures KPIs that allow modulation technique benchmarking.

WiIDCAT toolbox processing flow

WiIDCAT

Waveform design and benchmarking tool

EXPERIMENT SETUP



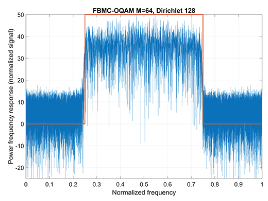
Experimentation procedure in WiIDCAT

In order to execute WiIDCAT experiments, the following components are necessary:

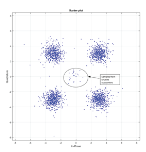
- Two PC Hosts – executing the WiIDCAT software and controlling the USRPs. Two system images (Windows and Linux) were prepared.
- Two USRP devices – one acting as transmitter and one as receiver.
- An experiment setup and configuration through remote control using jFed and TUD provided tools
- Software modules (MATLAB, C++, LabVIEW) installed and activated on the PC hosts for transmission, reception, collection of measurements and data storage.

A general view of the experiment setup with use of the TUD macro scale testbed is provided in the picture.

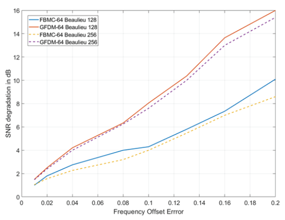
MAIN RESULTS



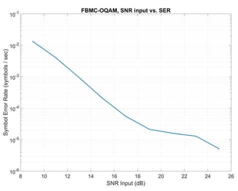
Analysis of OOB emissions



Receiver Operation Monitoring



Effect of Frequency offsets



BER vs. SNR for MC Rx

Examples of measurement results

- A methodology for waveform design and analysis experimentation was designed and applied.
- The operation of the novel unified transceiver was validated experimentally using various multicarrier modulations.
- Complete transceiver structures (focusing mostly on FMBC and GFDM) were developed including synchronizers, estimators and equalizers.
- The system performance was evaluated mainly in terms of Receiver robustness, Out-of-Band interference per filter prototype and tolerance on frequency offset misalignments.
- A set of experimentation tools, openly available to other researchers, was developed with analytical documentation.

A summary of results is presented in the picture.

CONCLUSIONS

An open-software tool that enables unified waveform experimentation was developed. The concept of the unified modulator-demodulator was verified through real-world measurements. Generic receiving functions were implemented and comparative analysis was performed showing small superiority of FBMC in terms of Rx robustness, tolerance in frequency offsets etc. for the specific deployment.

FEEDBACK

WiIDCAT and ORCA were a very positive and pleasant experience for UPRC and we have the will to aim at other possible future collaborations. The WiIDCAT experience in titles: small minor bugs; high equipment availability; stable remote operation; short learning curve; direct, friendly support from highly trained researchers.

OPEN CALL 2
FOR EXTENSIONS

Orchestration and Reconfiguration Control Architecture

DALI

Dual Connectivity Solution for ORCA

Open Call partner
Universitat Politecnica de Catalunya

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

Patron
National Instruments

OBJECTIVES

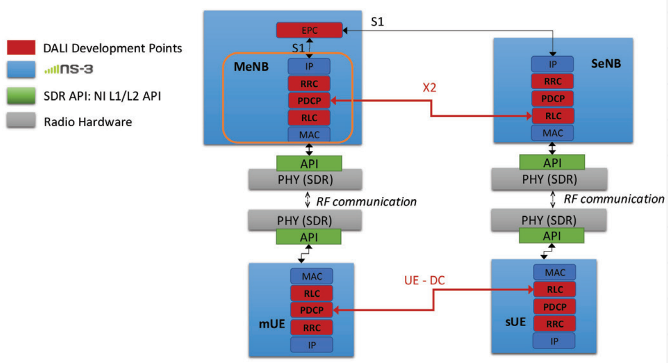
DALI extends the ORCA facilities with the E-UTRA Dual Connectivity (DC) capability through two implementations: i) an ns-3 LTE based implementation of DC, and ii) DC implementation built on the open-source LTE/EPC software provided by Open Air Interface (OAI) project.

CHALLENGES

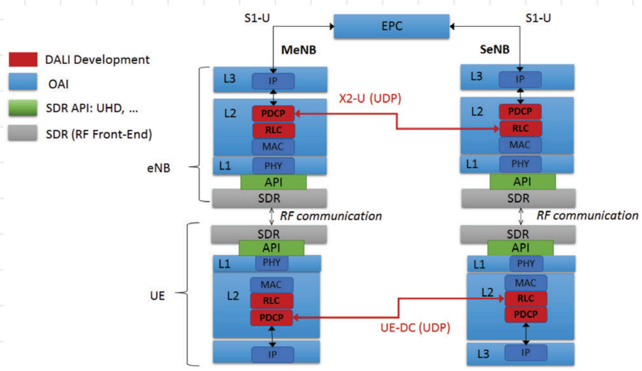
Although the complexity of OAI has been an important challenge, we could successfully implement our extension within OAI through rigorous efforts. The other challenge has been the CPU race conditions created between the ns-3 functionalities used and the NI API, which is also overcome through a collaborative effort with our patron NI.

CONCEPT

DALI Dual Connectivity setup (Figures X and Y) consists of two eNB nodes and two UE nodes (a Master and a Secondary in each case) and an EPC node. In line with 3GPP specifications for E- UTRA DC functionality, a link is stablished to communicate PDCP and RLC layers of different eNB nodes through X2 interface and a newly implemented DALI UE DC interface for communication between UEs.
As shown in Figures X and Y, in DALI, the eNB and UE pairs communicate through an SDR (alternatively, via simulated channels), and the LTE stack is implemented in ns-3 and OAI, respectively. In ns-3 DALI implementation, the ns-3 LTE stack runs on Linux RT, which interfaces the SDRs through the generic NI L1-L2 API. In OAI-based DALI implementation, the OAI LTE stack runs on Ubuntu distro of Linux with low-latency kernel, with the SDR interfacing is achieved through the generic Linux drivers/toolsets of the common SDR platforms, such as UHD for Ettus USRP SDR devices, Lime Suite for LimeSDR. In OAI implementation, the baseband processing is done on the Generic Purpose Processor (GPP) Linux machine.v



Architecture of DALI solution with ns-3 based real-time LTE devices

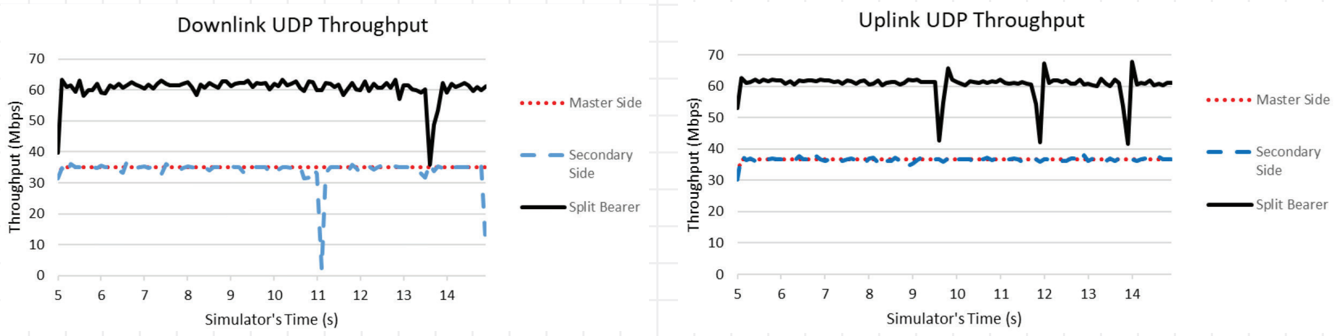


Architecture of DALI solution with OAI-based real-time LTE devices

DALI
Dual Connectivity Solution for ORCA

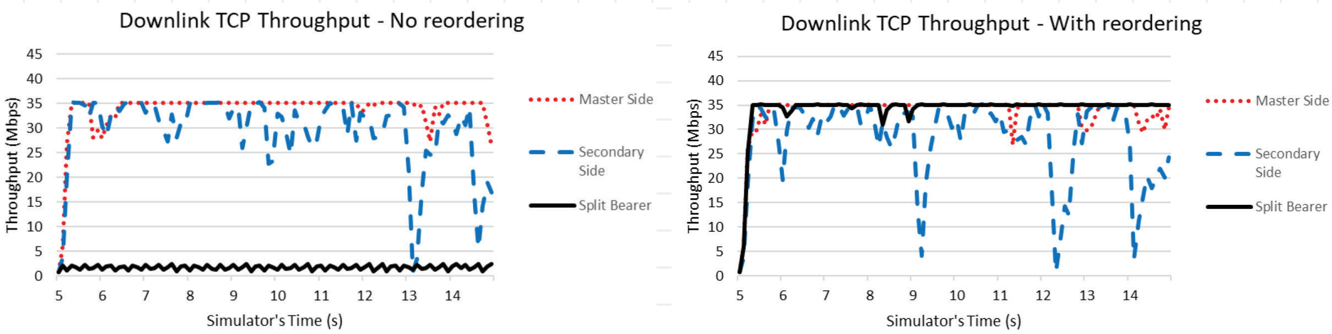
MAIN RESULTS

The validation of DALI has been done for both UDP-based and TCP-based applications. For ns-3 based implementation, the UDP-based application evaluation results are shown in Figure Z. It is clearly seen that split bearer option enabled by Dual Connectivity almost doubles the throughput for both downlink and uplink compared to that of a single bearer option at Master eNB or Secondary eNB.



UDP Throughput: Downlink (up) and Uplink (bottom)

However, TCP-based applications' throughput suffers from the out-of-order packets in case of dual connectivity as shown in Figure V. For this, DALI implements the reordering function implemented in DALI improves the throughput significantly as shown in the figure.



TCP Throughput for Downlink without (up) and with (bottom) with PDCP reordering function

CONCLUSIONS

The DALI solution has been validated through a five-stage testing process, starting with in-house tests with simulated channels and finally experimenting with SDRs at ORCA testbeds. The DALI project provides an easily reproducible solution, since it uses open-source software and standard interfaces, and paves way to rapid development and realistic testing of further DC extensions through ORCA.

FEEDBACK

ORCA was significantly useful due to the large variety of hardware and software resources it offers to conduct experiments. Access to these resources allows us to focus in the development of the solutions rather than setting up a testbed, which would bring technical and economic challenges. Additionally, the robustness of the testbed made possible to test the solutions under different conditions that were not initially planned which helped us to get better results.

Thanks to the ORCA facility that we were able to implement and validate our LTE Dual Connectivity solution within a realistic experimentation setup.

Orca

Orchestration and Reconfiguration Control Architecture

MISO

Millimeter - Wave Open Experimentation Platform

Open Call partner
IMDEA
Networks Institute

Patron
KU Leuven

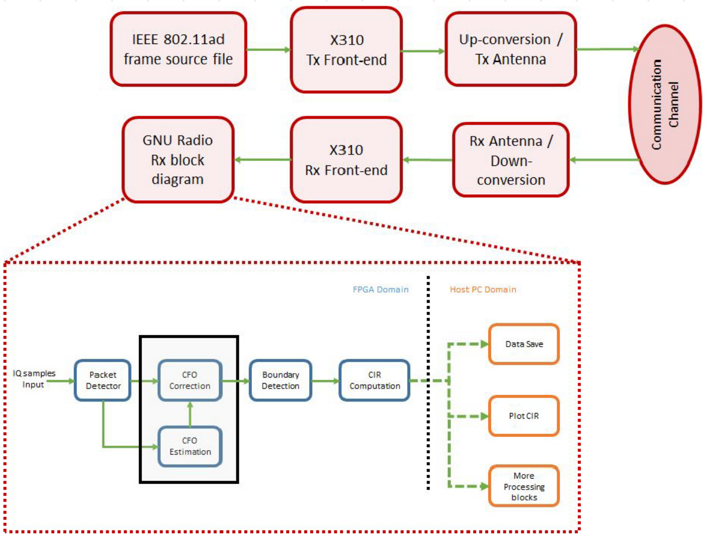
OBJECTIVES

In this project we proposed a mixed hardware-software design for mm-wave experimentation on software-defined radios (SDR). Specifically, we proposed to design and implement the hardware blocks to decode the preamble of single carrier (SC) IEEE 802.11ad compliant frames at a scaled-down frequency and their integration in the GNU Radio + RFNoC framework to be used in on-site and remote experiments in the laboratories from ORCA consortium.

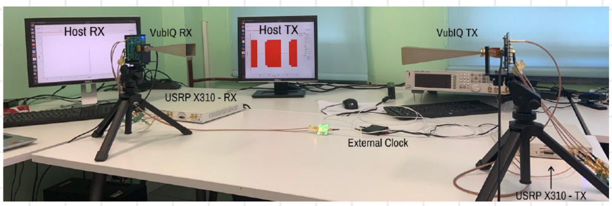
CHALLENGES

Reducing the sampling frequency of a 60GHz communication system is a big challenge since the imperfections do not scale as well. Besides, the integration of multiple high-speed signal processing blocks while using the maximum bandwidth of USRP devices require efficient hardware implementations to fit into the FPGA device, meet timing constraints and leave space to further upgrading of the design.

CONCEPT



Block diagram of the developed mixed hardware-software system



Example experiment setup for on-site experiments.

The designed system can be used in on-site experiments (using USRP devices and 60 GHz RF front-ends) and also in any of the remote laboratories provided by the ORCA consortium with X310 devices available and RFNoC framework.

Tx side is implemented including IEEE 802.11ad compliant single carrier frames from files which are outputted from the X310 USRP devices using a basic Tx daughter board (to output baseband complex IQ samples). The baseband signal is fed to a 60GHz RF front-end from the remote laboratory or one available from IMDEA Networks facilities (VubIQ 60GHz kit, for example).

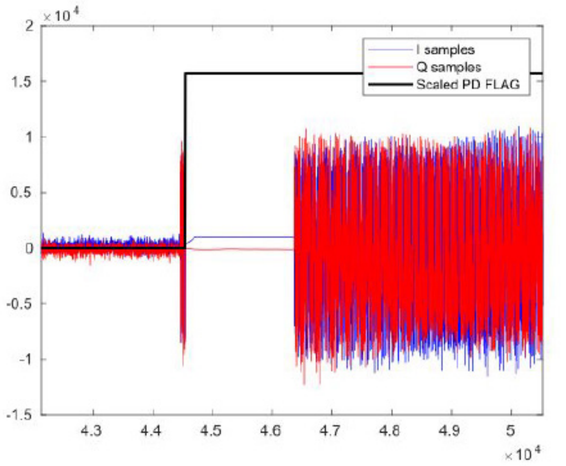
At the receiver side, after down conversion of the signal to baseband, it is fed to the USRP device using a basic Rx daughterboard. At the FPGA side, the signal passes through the RFNoC blocks implementing the preamble processing blocks, as can be seen in Figure 28. After CIR computation, 128 complex samples (corresponding to the computed CIR) per detected frame are sent to the host PC (local or remote, depending on the experiment) to save the data of the experiment, plot it or continue processing the frame using software blocks.

www.orca-project.eu

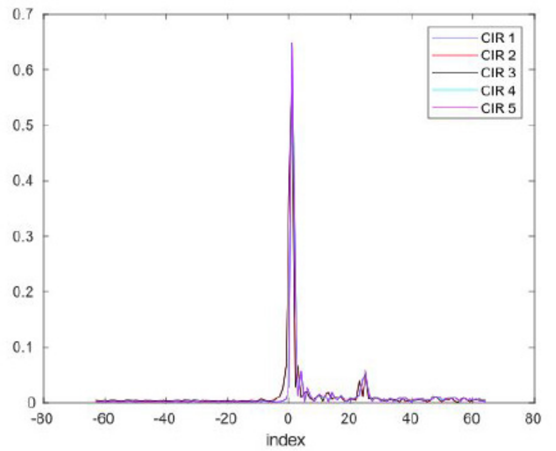
MISO
Millimeter - Wave Open Experimentation Platform

MAIN RESULTS

We designed and implemented the main preamble processing blocks to decode frames with the same structure of IEEE 802.11ad compliant frames but with a scaled-down sampling frequency. Implemented blocks were wrapped with an AXI interface and integrated in the RFNoC framework to be used with X310 USRP devices in the GNU Radio + RFNoC framework. Designed system is area/timing efficient allowing the use of the maximum available bandwidth of the USRP device while leaving FPGA space to include more processing blocks in future extensions of the project. The design have been validated in on-site experiments using 60GHz RF front-ends available at IMDEA Network facilities as well as in remote laboratories from the ORCA consortium.



Packet Detector Output showing the flag and output switching when a valid frame is detected.



Output of the Channel Impulse Response (CIR) block, showing the CIR of five consecutive frames.

CONCLUSIONS

MISO project provide the basis for mm-wave experimentation using USRP devices which are cost efficient to build massive remote laboratories to expand the research and academic activities involving mm-wave communication systems to small research groups and universities around the world without the need of having expensive equipment which is not always possible.

FEEDBACK

Overall we were very satisfied with this project. The work and tasks were extremely well aligned with our interests and expertise, the overhead for running the project was very manageable so that we could fully focus on research and implementation tasks, and the resources provided by the project allowed to implement a low cost system that both will be used internally for our research as well as serves as a very useful testbed platform for others.
Thanks to the ORCA project we were able to design and implement a highly flexible platform for local and remote millimeter-wave experimentation on lost cost software-defined radios.

Orchestration and Reconfiguration Control Architecture

POLAR CODE

Efficient Polar Encoding and Multi-Mode Decoding for FPGAs

Open Call partner
École Polytechnique Fédérale de Lausanne

Patron
Technische Universitaet Dresden

OBJECTIVES

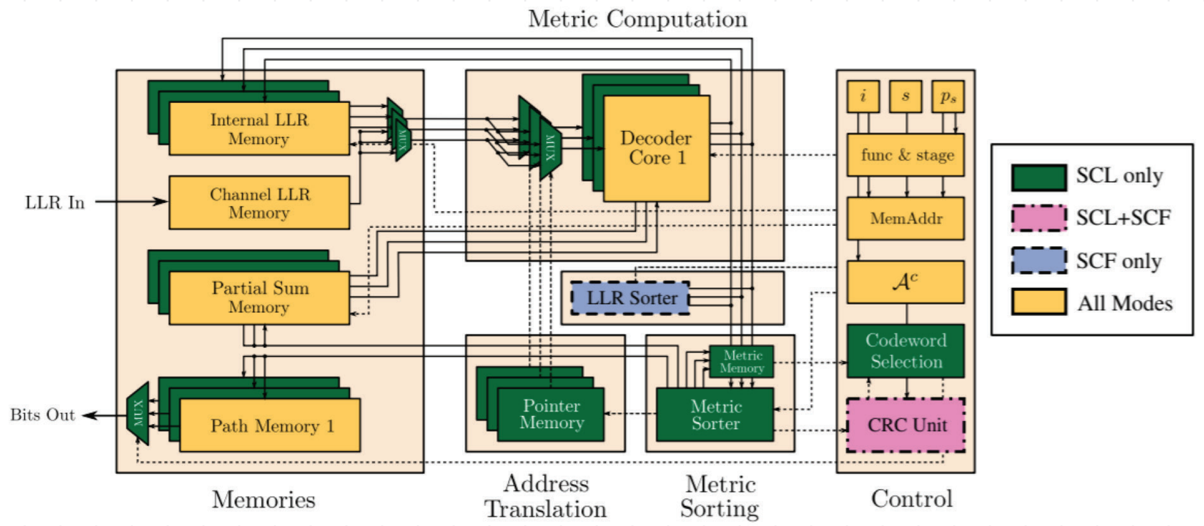
The first goal of this project was to develop an FPGA Polar decoder to add Polar coding capabilities to ORCA. This is interesting due to their superior error-correction performance and due to the timely relevance as Polar codes have been established as part of 5G-NR. Our second goal was to provide a decoder that can switch between different algorithms, which provides a means to compare them in a full system.

CHALLENGES

The first challenge lies in providing a single decoder core that can perform different decoding algorithms and can be tuned to different complexity-performance tradeoffs. Combining specifically SC, SCL, and SCF decoding allows for effective reuse of resource- hungry core components. The sequential SCF decoding is specifically designed to allow runtime tuning between performance and complexity.

CONCEPT

For this project, we use a decoder architecture that builds on a variable number of SC decoder core instances, extended with a list processing unit. The number of instances scales the error-correction performance, but also the hardware complexity of the decoder. By adding a simple sorter and a modified controller, the SCF decoder allows to also explore tradeoffs between throughput and error correction performance at run- time. The corresponding SCF decoder re-uses hardware resources for the SC/SCL decoder, which allows to add the SCF functionality with almost no hardware overhead. The provided figure below illustrates the components of the decoder.



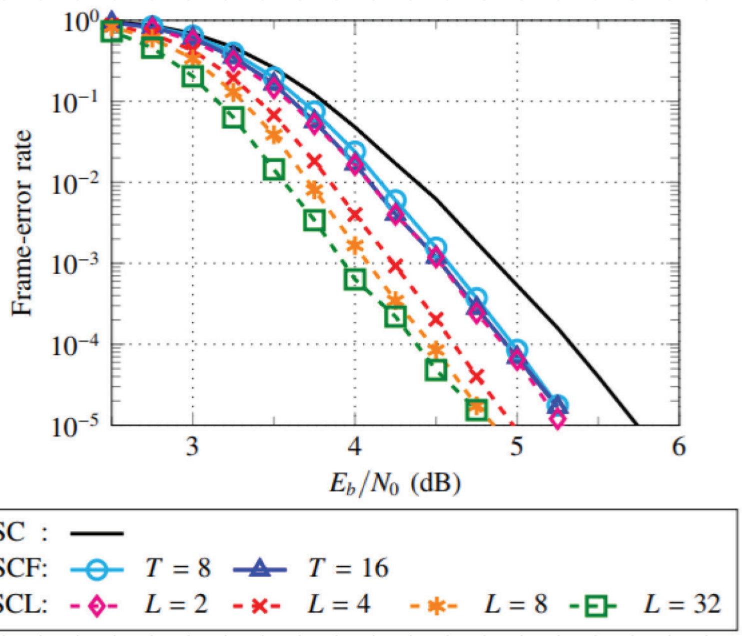
Multi-mode polar decoder architecture

POLAR CODE

Efficient Polar Encoding and Multi-Mode Decoding for FPGAs

MAIN RESULTS

The decoder developed in this project supports several modes that allow tradeoffs between performance and complexity. The provided figure illustrates these tradeoffs. Since the decoder is primarily intended for the control channel (as specified in 5G-NR), it is designed to keep FPGA resource utilization below 20% (for a block size of N=1024). At the testbed specified clock frequency of 100MHz, it achieves 20Mbps throughput in SCL mode. The encoder throughput reaches up to 100 Mbps.



Multi-mode polar decoder error-correction performance. The FPGA design with 20% resource utilization allows for a list size of L=2. Larger list sizes require more resources.

CONCLUSIONS

The project provides the ORCA testbed with a multi-mode Polar encoder and decoder. By supporting different modes, it enables experiments that compare the impact of different decoding efforts on the system level, including the impact of the variable decoding latency of the SCF algorithm. The decoder is mainly targeted for decoding of control channel packets, as it is optimized for resource consumption rather than for throughput.

FEEDBACK

The collaboration with the ORCA team at TUD was very efficient. Clear specifications were provided by the patron (TUD) and the integration of the delivered VHDL IP module into the test and verification environment provided by TUD was straightforward. The test and debug process itself was carried out in collaboration with TUD and did not require a local LabView setup. The latter might have helped in the final stages of the debug process, but was also not required.
Thanks to the ORCA facility, we were able to provide a re-usable IP core for testing and integrating Polar codes into a real-world test environment.

Orchestration and Reconfiguration Control Architecture

ReproRun

Reprogramming FPGA devices at run time using partial reconfiguration in SDR platforms

Open Call partner
Centre Tecnològic Telecomunicacions Catalunya

Patron
imec

OBJECTIVES

ReproRun provides a run-time partial reconfiguration (PR) framework for the FPGA devices of two SDR platforms. The on-field reconfiguration concerns both the functions running at the programmable logic (PL), as well as the processing system (PS) of FPGA devices. The PL partial bitstreams and PS firmware are fetched from a remote location.

CHALLENGES

The main challenge of ReproRun was that the run-time partial reconfiguration framework had to be developed for two different SDR platforms featuring different FPGA devices. The combined PL and PS reconfiguration added novelty to the project but increased the development, testing and validation complexity.

CONCEPT

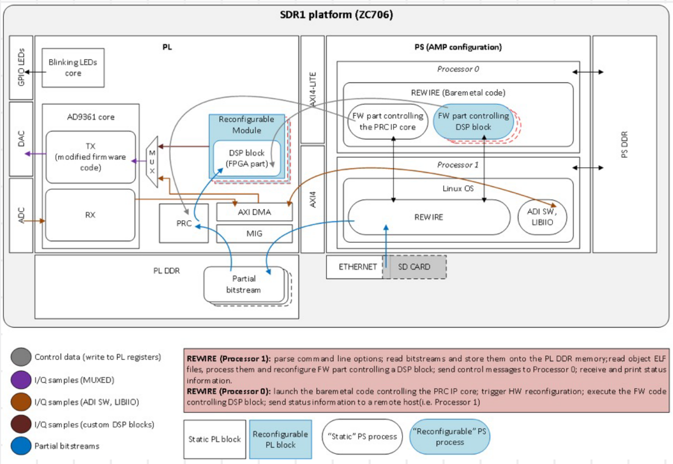
ReproRun is able to seamlessly reconfigure at run-time part of the PL area of an FPGA device with a partial bitstream and also the firmware running at PS embedded in the same FPGA device (i.e., hardwired or soft microprocessor). The firmware among other functions includes a software bare metal application (BMA) that programs parameters of the PL-based function/application. The concept of ReproRun was applied in the two SDR platforms selected by the Patron. Despite some key differences in the two SDR platforms, the core functionality of the developed framework remains the same. The Run-timE firmWare reconfIguration contRollEr (REWIRE) was developed to handle the PS-based run-time firmware reconfiguration. In SDR1, part of REWIRE runs at the Processor 1 (i.e., CPU1 of the ARM processor running embedded Linux), while the other part of REWIRE runs at Processor 0 (i.e., CPU0 of the ARM processor running bare metal applications). An asymmetric multiprocessing (AMP) design framework was adopted towards this end. In SDR2, part of the REWIRE functionality runs in the host processor (desktop Linux, Processor 1) and another part runs at a MicroBlaze soft microprocessor (bare metal application, Processor 0). Processor 0 in SDR2 includes a library that fetches the partial bitstreams and BMAs (objet files) from the TFTP server running at a remote host (TFTP runs on top of the lwIP framework in Processor 0). REWIRE is able to parse command line options; read bitstreams and store them in the PL DDR memory; read object ELF files, process them and reconfigure firmware part controlling a DSP block; send control messages to Processor 0; receive and print status information. REWIRE also signals the partial reconfiguration controller (Xilinx IP core) to apply the partial reconfiguration. The use of the SDR2 implied an integration of the ReproRun framework with the RFNoC code. For this reason, a separate Ethernet connectivity was dedicated for the ReproRun and RFNoC frameworks, while the access to SDRAM was shared. In addition, the ZPU soft processor of the RFNoC firmware was not used for the development goals of ReproRun, in order to decouple the software processing (avoiding as such the use of an RTOS). In both SDR platforms, the FPGA devices are configured with a static bitstream, which has a simple application in free run mode (blinking hard or soft leds in SDR 1 and SDR2 respectively). In SDR1 the partial bitstreams are a DDS function and a LTE waveform playback function. In SDR2 the partial bitstream is the CORDIC function of the siggen RFNoC example.

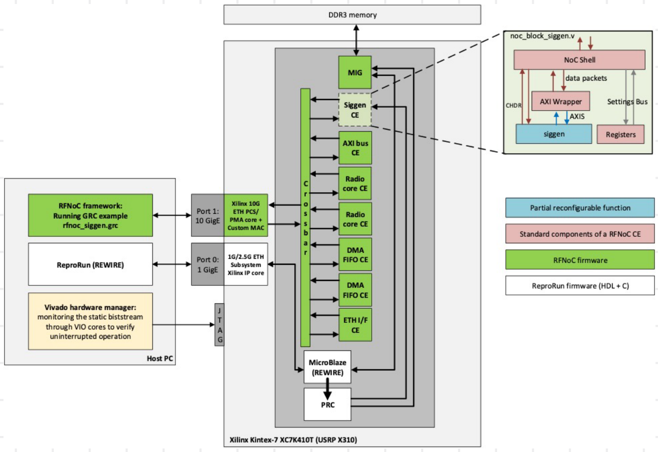
ReproRun

Reprogramming FPGA devices at run time using partial reconfiguration in SDR platforms

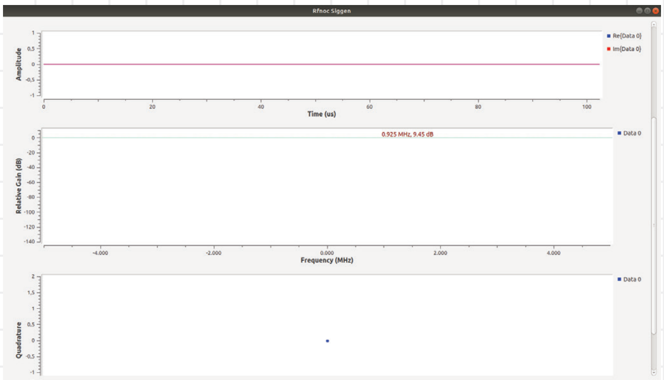
CONCEPT

The concept and experimental setup of the two SDR platforms can be seen in the figures that follow:

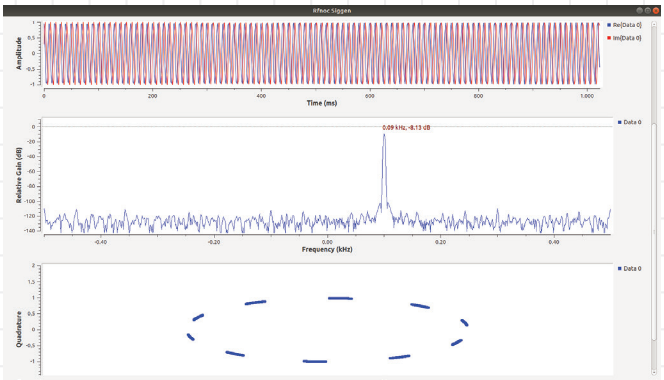




MAIN RESULTS



The Siggen RFNoC GRC example is not working when only the static bitstream is configured.



After configuring the partial bitstream, the siggen RFNoC example produces the correct/expected output.

CONCLUSIONS

Reprorun provides a seamless run-time reconfiguration framework of PL-based partial bitstreams together with their corresponding PS-based firmware, for two popular SDR platforms featuring two different FPGA devices. This combined on-the-field reconfiguration of hardware-accelerated and firmware functions is a novel top-up feature for 5G enabling technologies and other end-applications.

FEEDBACK

This Extension perfectly aligns with the scientific roadmap of CTTC's team and opens up new opportunities for research synergies, collaborations, dissemination and hopefully exploitation. The communication with the Patron was fluent and the support satisfactory. Targeting only one SDR platform would have helped us to develop more advanced partial reconfiguration features.

Thanks to the ORCA facility we were able to develop a run-time partial reconfirmation framework for FPGA devices featured in two popular SDR platforms, as well as develope a flexible SDR framework featuring run-time reconfigurable FPGA-accelerated DSP functions"

orca

OPEN CALL 2 FOR EXPERIMENTS

Orchestration and Reconfiguration Control Architecture

SIREN

ServIce level agReement ENforcement in ORCA

Open Call partner
Scuola Superiore Sant'Anna

Patron
Trinity College Dublin

OBJECTIVES

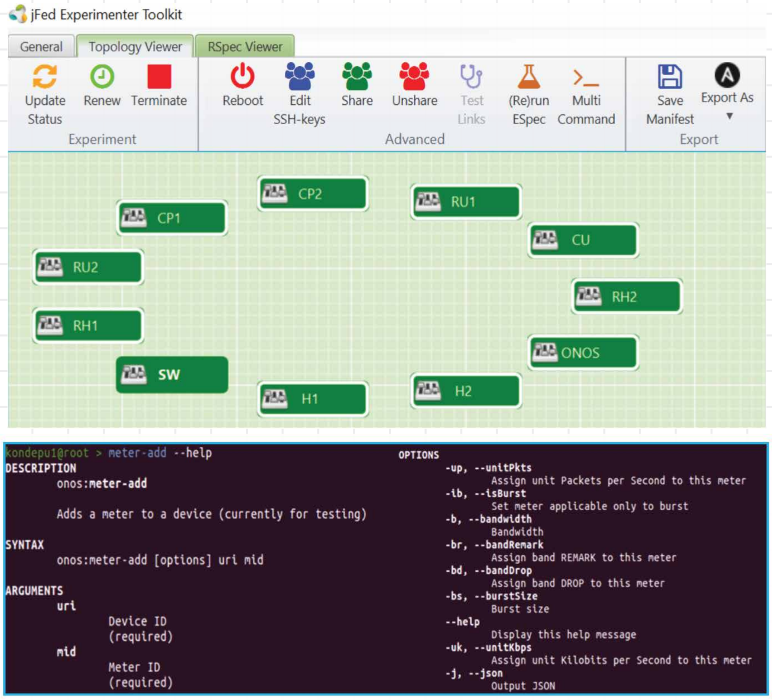
The ServIce level agReement ENforcement in ORCA (SIREN) project objective was to evaluate the viability of a solution based on Software Defined Network-Software Defined Radio (SDN-SDR) controllers in mapping Service Level Agreement (SLA) into slice Key Performance Indicators (KPIs) and enforcing KPI thresholds through specific network configurations.

CHALLENGES

To do so the SIREN project complemented current SDN-SDR control software (e.g., Openflow, FINS) with functions of SLA mapping into KPIs, KPI enforcement, and KPI monitoring.

EXPERIMENT SETUP

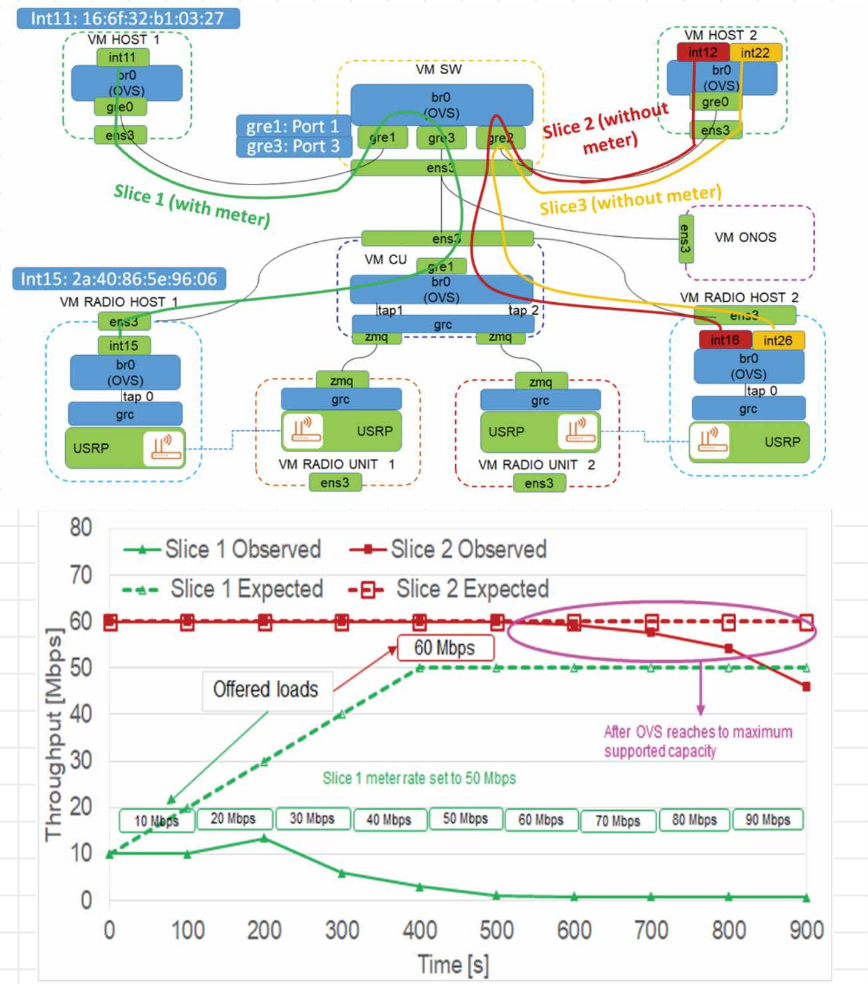
The performed experiments evaluated the capability of the proposed solution to fulfill such requirements by means of application-level active probes.
Moreover, it investigated how different KPIs contributed to the end-to-end performance.



SIREN

ServIce level agReement ENforcement in ORCA

MAIN RESULTS



The Figure shows the throughput obtained and expected when the Slice 1 meter set to 50 Mbps and Slice 2 offered load is set to 60 Mbps without meter. The experiment duration is set to 900s and every 100s the Slice 1 offered load is increased by 10 Mbps. Slice 2 provides minimum guaranteed capacity (i.e., 60 Mbps) until the overall offered load reaches the maximum supported capacity of the OVS.

CONCLUSIONS

The utilization of meters allows to guarantee to a certain slice, based on Openflow, minimum capacity by limiting the traffic of the traffic sharing the same link. The meters, which are dropping packets, are effective when the link capacity is fully utilized by the flows sharing the link.

FEEDBACK

The ORCA facilities provided by the considered testbed were very good to perform the experiment. ORCA provided a base experiment setup that we could simply modify and integrate to evaluate our proposed solutions. An important added value was the availability of sample setups that shortened the time to experiment.

Thanks to the ORCA facility we were able to evaluate the viability of software switch meters to guarantee slice performance isolation in terms of minimum guarantee capacity

Orchestration and Reconfiguration Control Architecture

ORCA-RAT

Experimental Study of Multi-RAT Networks

Open Call partner
Technische Universität Darmstadt

Patron
National Instruments

OBJECTIVES

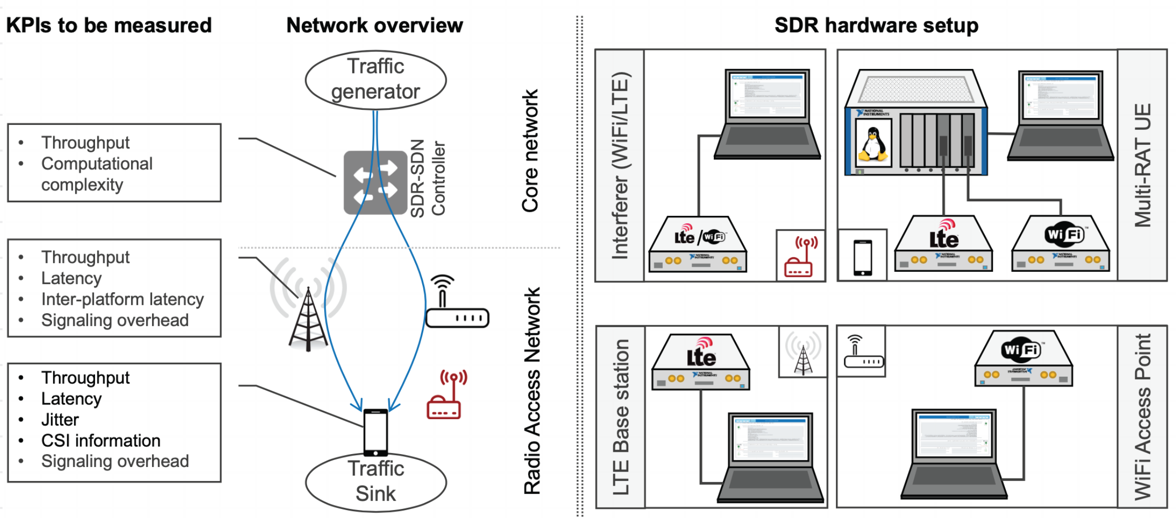
We aim to understand the complications of coupling different radio access technologies (RATs) which not only operate on different channel but also use different channel access mechanisms (OFDMA and CSMA). In particular, we aim to provide design insight into choice of RAT coupling and coordination strategies.

CHALLENGES

We face two main challenges in this experiment. Firstly, we had to modify the implementation to collect additional performance metrics at different layers of network stack and defining methods to report these values back to the central controller. Secondly, implementing the necessary functionalities to enable bi-directional TCP connections.

EXPERIMENT SETUP

Our experiments rely on the multi-RAT capability as well as the full-stack implementation of ORCA LTE-WLAN radio aggregation (LWA) and LTE-WLAN radio level integration (LWIP). PHY layer and a portion of MAC layer functionalities are implemented in the FPGA on the SDRs. The SDRs are then connected to NS3 via the L1/L2 API to complement the rest of the network stack up to the application later.



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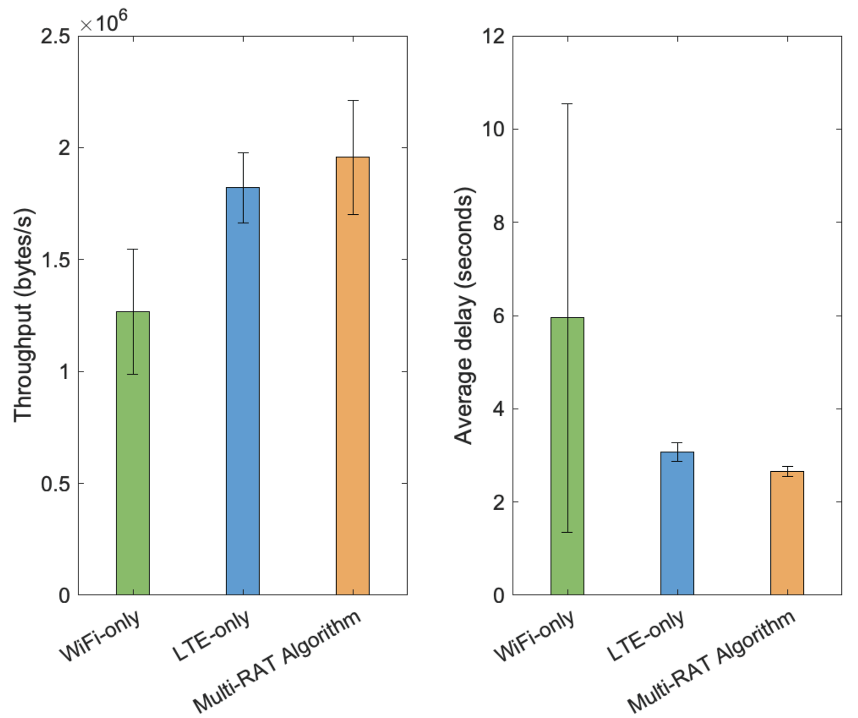
ORCA

ORCA-RAT

Experimental Study of Multi-RAT Networks

MAIN RESULTS

ORCA-RAT aim at evaluating the performance of a real-time full-stack multi-RAT system. We have implemented a feedback mechanism to allow the eNodeB to access KPIs such as throughput and delay figures. Furthermore, we have devised a simple RAT selection algorithm which operates based on these KPIs. Our results show channel variation has high impacts on the performance of higher layer protocols (TCP in this experiment) and leveraging even simple RAT selection strategy to account for such variations can significantly reduce the delay/jitter experienced by the applications as well as increasing the throughput.



CONCLUSIONS

This is the first full-stack and real time experimental study of multi-RAT systems. In particular, we have shown how selection of RAT impacts the overall network capacity. Furthermore, we demonstrated the effect of RAT selection and rate imbalance between RATs on the higher layers of stack such as TCP congestion control mechanism. The outcome of this experiments can be used as design guideline for future multi-RAT systems in particular after integration of millimetre-wave radio which will increase the rate imbalance even further.

FEEDBACK

Our experience with ORCA consortium in general and our patron, National Instruments, in particular has been satisfactory. None of the aforementioned results could have been achieved without access to ORCA test facility as well as the support from patron.

Thanks to the ORCA facility, we have obtained the necessary resources and support to conduct the first experimental study of LTE-WLAN multi-RAT systems.

Orchestration and Reconfiguration Control Architecture

multiRATsched

The extension of multi-criteria LTEMAC scheduler for multiple RAT environment

Open Call partner
IS-Wireless

Patron
National Instruments

OBJECTIVES

The goal of proposed work is to utilize and exploit ORCA tools and facility to evaluate the performance of proposed LTE MAC scheduler and SD-RAN controller in the multi-RAT environment.

CHALLENGES

Testbed availability is one the biggest challenges faced during the project. Moreover, remotely accessibility of testbed was challenging as well as multiple nodes (PCs and USRPs) have to be accessed remotely with proper setting configurations.

EXPERIMENT SETUP

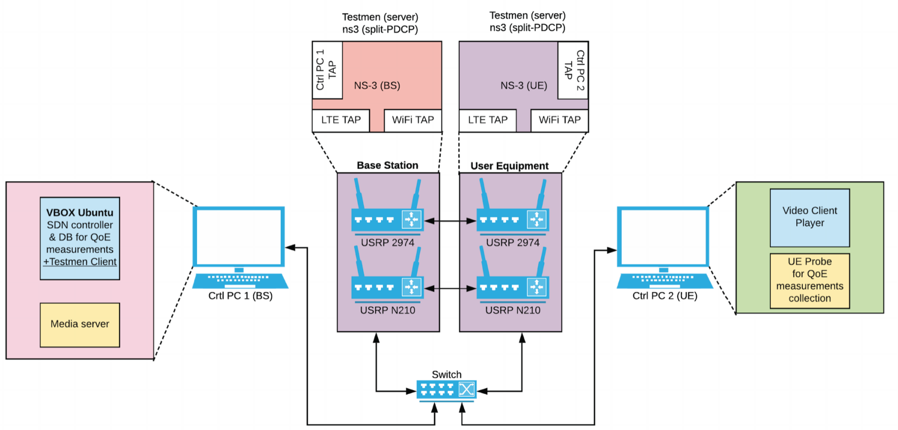


Fig. 1 Experimental Setup

Figure 1 shows an overview of the experiment setup and connectivity of the implemented modules within TUD testbed. For the experiments, the media server is implemented within the Win7 Host PC connected to the eNB PXI controller whereas media client is made at the Win7 Host PC connected the UE PXI controller. The RAN controller modules and the database for the QoE related information exchange are implemented inside the Ubuntu PC. In order to exploit the multi-RAT use case of the testbed, noise is purposely added to the LTE link so that RAN controller can trigger automatic switching to WiFi link based on the SINR and QoE measurements. For the addition of the noise, separate Labview process is generated for noise. The noise generator output is combined with the transmission of LTE link using the combiner in the cabling setup. The experiment utilizes the testbed in the TAP bridge configuration which means that external traffic is forwarded to the NS3 generated traffic. Therefore, two packet forwarding scripts are used at PXI controllers: first at eNB PXI controller for forwarding the media traffic from media server into the NS3 TAP bridge; and second at UE PXI controller to forward the media traffic from the NS3 TAP bridge to media client.

multiRATsched

The extension of multi-criteria LTEMAC scheduler for multiple RAT environment

MAIN RESULTS

Four different scenarios:

1. Round Robin scheduler in LTE without RANC;
2. Proportional Fair scheduler without RANC;
3. SINR based information centric LWA switching from LTE to WiFi using RAN controller;
4. QoE-aware LWA switching from LTE to WiFi via RAN controller.

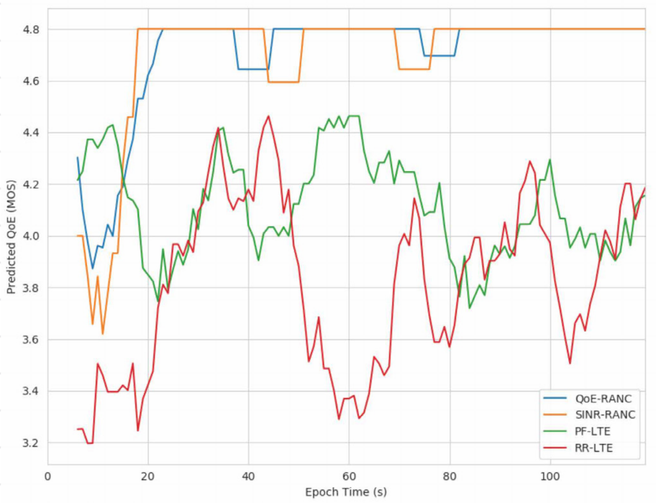


Fig. 2 Predicted QoE (MOS) over Epoch Time (s) for each scenario

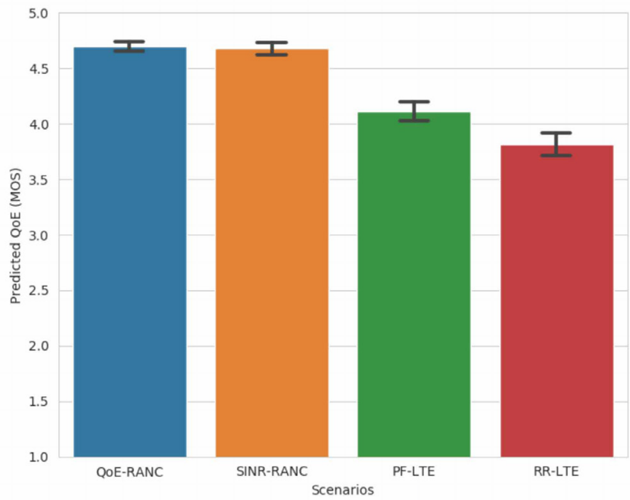


Fig. 3 Accumulated average predicted QoE for each scenario

CONCLUSIONS

With the ORCA consortium testbed, testing and validation of RAN controller product and radio resource management algorithm, both from IS-wireless, in the multi-RAT environment by just focusing on the prototype design and development without carrying about the underlying infrastructure implementation for the multi-RAT scenario.

FEEDBACK

ORCA experimentation testbed allows us to experiment the ideas and concepts in a realistic environment together with the support from patron and open source code availability. The patron also organized a workshop including essential training which proved to be quite useful to learn the functionalities of the ORCA testbed.

All in all, we had a great experience regarding communication and support from the testbed patron. Moreover, with the help ORCA facility we have been able to test and experiment novel ideas that were not tested before in realistic testbed environments. This helped us to understand the concepts as well as we managed to train ourselves with testbed and issues related with real life testing.

Orchestration and Reconfiguration Control Architecture

MinDFul

MmWave Link Doubling Full-Stack Experiments

Open Call partner
University College Cork

Patron
Technische Universität Dresden

OBJECTIVES

In this project, we aim at making the millimetre wave (mmWave) channels more stable by using an auxiliary radio frequency (RF) system along with the main RF system to use the auxiliary one when the main link is blocked. Its main applications are in virtual reality games and autonomous vehicles.

CHALLENGES

The main challenges of this project were: (1) developing and debugging the ideas in the complicated software system, which is implemented in LabVIEW; (2) recording data when the experiments were running and extracting data from the recorded format.

EXPERIMENT SETUP

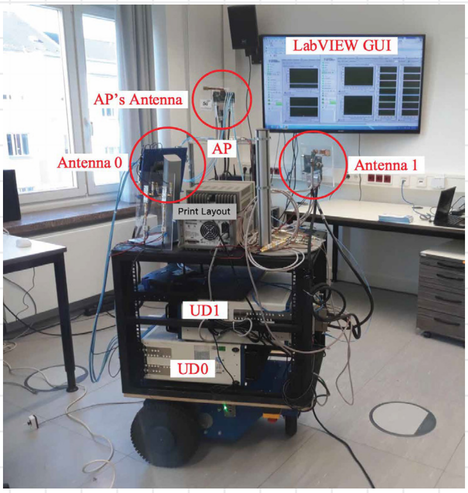


Figure 1. Setup of movement experiments.

In Figure 1, we mount all hardware of UD0 and UD1 on a trolley and move it using a robot. Antennas of two UDs are mounted back-to-back in such a way that they both cover almost 360^0 around them together. We move the robot to left and right three times in a minute. As the robot has 3 wheels, moving it to left and right causes antennas of UD0 and UD1 to be located at 3 different positions with respect to AP, shown in Figure 2.

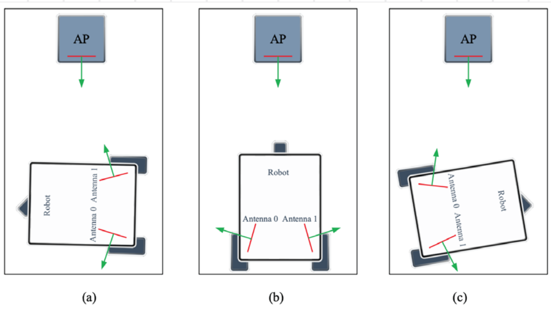


Figure 2. Top view of three extreme positions of the UDs when moving robot to left and right for movement experiments.

In Figure 2-(b), the robot's front wheel is straight, and the trolley is faced toward the AP. But, none of the UD antennas directly face to AP's antenna. The antenna faces are toward left and right and there may be small transmission/reception line-of-sight (LoS) between UD and AP antennas. When we move robot to the left, we stop at position of Figure 2-(a). In this position, Antenna 1 has a good LoS with the AP's antenna and the communication will be gone through UD1. Here, UD0's antenna has no LoS with AP's antenna, and the signal power is very small such that data rate will be zero even with strong modulation/coding schemes (MCS). When we move the robot to the right, we stop at the position of Figure 2-(c). Here, Antenna 0 has a good LoS with the AP's antenna and the communication will be gone through UD0.

MinDFul

MmWave Link Doubling Full-Stack Experiments

MAIN RESULTS

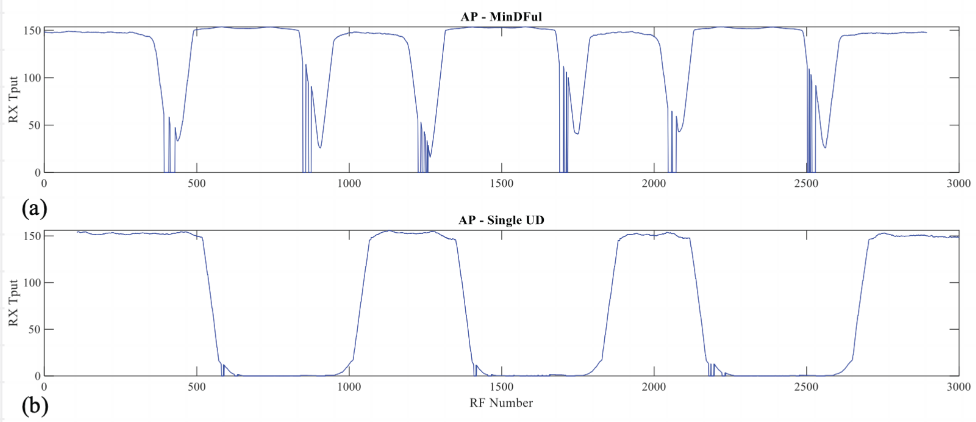


Figure 3. Received throughput over time for movement setup using MCS of 3/4 QPSK. (a) MinDFul; (b) Single-UD. While in single UD setup, there are large gaps at which the data rate falls to zero because of lack of LoS of UD's antenna with the AP's antenna, using double links in MinDFul could almost fill these gaps and made them smaller, and so made the mmWave channel more stable.

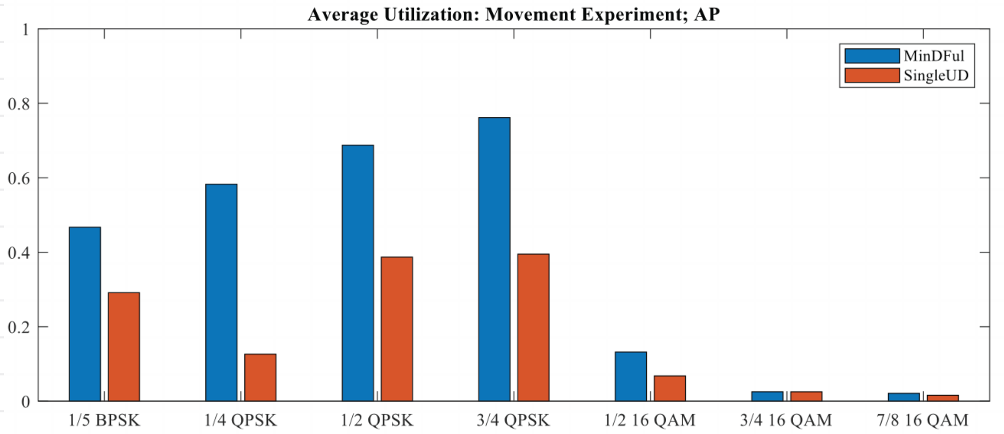


Figure 4. Average utilization of MinDFul compared to Single UD setup for Movement Experiment vs different MCSs. Using double links in MinDFul doubled the utilization with respect to single UD setup.

CONCLUSIONS

Our developed solution and experiments show using two links in one side of wireless communication which moves frequently, or its antennas can be blocked, we can increase the utilization of the mmWave channel and making it more stable. These results are promising for applications which require +10Gbps wireless data-rate.

FEEDBACK

The ORCA's mmWave testbed is one of the best available ones for research community in the sense that new ideas can be implemented in software and it covers both PHY and MAC layers. Lack of good documentation requires testbed designers' support and using LabVIEW makes software development and debugging difficult.

Thanks to the ORCA facility we were able to implement and test our ideas on making the mmWave channel more stable to show it can be considered as a promising solution for ultra-high data-rate demanding applications such as VR games and autonomous vehicles.

Orca Orchestration and Reconfiguration Control Architecture

MAGNUM

Multi-Access edGe computiNg for FutUre Wireless SysteMs

Open Call partner
Ss.Cyril and Methodius University

Patron
Rutgers

OBJECTIVES

The main goal of the MAGNUM experiment is to investigate the container-based virtualization of radio access networks and identify its main benefits and drawbacks. The experiment also analyses the effects of scalability and traffic types and provides valuable insights for future practical deployments of full-stack containerized MEC-based RAN solutions.

CHALLENGES

Exploit the software-defined operation of LTE and implement a Docker-based LTE virtualization. Analyse the computational resource footprint based on the underlying communication/network load and configuration. Evaluate the effect of scalability in terms of active UEs and their traffic types. Discover the most appropriate computational resource scaling solution.

EXPERIMENT SETUP

The MAGNUM architecture comprises of two core logical entities, Remote Radio Heads (RRHs) and Multi-access Edge Computing (MEC) segment (Figure 1). The RRHs contain the RF hardware in the system and that do not perform any baseband signal processing. MAGNUM uses the Universal Software Radio Peripheral (USRP) X310 and B210 devices as RRHs. The MEC segment incorporates a container-based virtualization of an LTE base station that utilizes the docker framework. The specific experiment platform uses the Amarisoft commercial LTE BBU software, implementing a full stack LTE Rel.14 base station. The LTE mobile stations i.e. UEs, are also ran over USRP devices and use the srsLTE software.

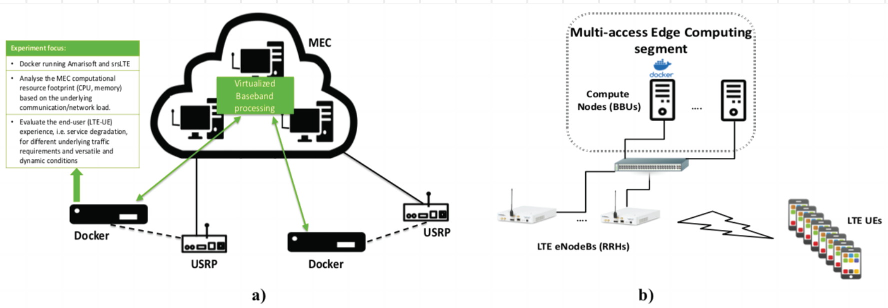


Figure 1 – MAGNUM experiment: a) Outline of the experiment; b) Platform generic architecture

The MEC segment runs over a set of dedicated compute nodes. The nodes represent the available MEC pool of resources such as, CPU and RAM that are allocated to the virtual LTE instances. The nodes run on a server-grade machines with Intel Xeon processors over an Ubuntu 16.04 LTS using a low latency kernel. The fronthaul link between the RRHs and the BBUs is enabled by 10GbE links, routed over an 10GbE switch. Figure 2 depicts the implementation layout of the MAGNUM experiment in the ORBIT testbed.

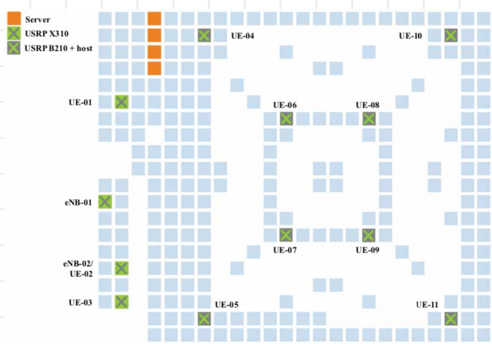


Figure 2 – MAGNUM experiment layout over ORBIT's grid

MAGNUM

Multi-Access edGe computiNg for FutUre Wireless SysteMs

MAIN RESULTS

Fostering efficient operation of the enabling self-organization and intelligence-based technologies for Cloud-RAN deployment, requires large knowledge base and understanding of the virtualized RAN performance behavior. MAGNUM specifically focuses on evaluating the full stack containerized LTE performance behavior for different system configuration and traffic loads. The results will be used as the primary step in understanding large scale commercial deployments. The experiment also focuses on the resource scaling and its impacts on the underlying user performance.

The MAGNUM experiment showcases the benefits of RAN virtualization and its fast deployments and rapid/diverse system reconfigurations. These benefits come at a price of higher computational cost, which is not significantly affected by the number of served UEs, but significantly affected by the physical layer configuration of the RAN. Infrastructure issues such as fronthaul design, need to be carefully considered, in order to provide stable and reliable virtualized RANs.

Figure 3 presents the time series of the CPU utilization and the LTE cell reconfiguration time between LTE bandwidths of 5 MHz and 10MHz for the SISO and the MIMO case. These results show that the reconfiguration delay is in order of few seconds, which proves the flexibility and the swiftness of the virtualized LTE solution. Moreover, the results clearly show that the MIMO configuration requires higher processing power, compared to the SISO case.

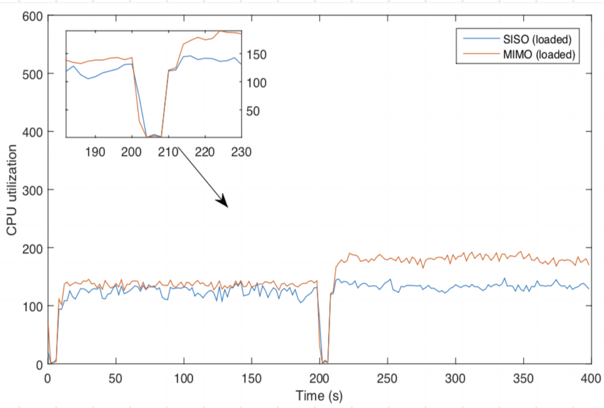


Figure 3: Time series of the transitions between 5 MHz (0-200s) and 10 MHz (200-400s) in terms of CPU utilization, for the SISO and MIMO case and fully loaded LTE base station

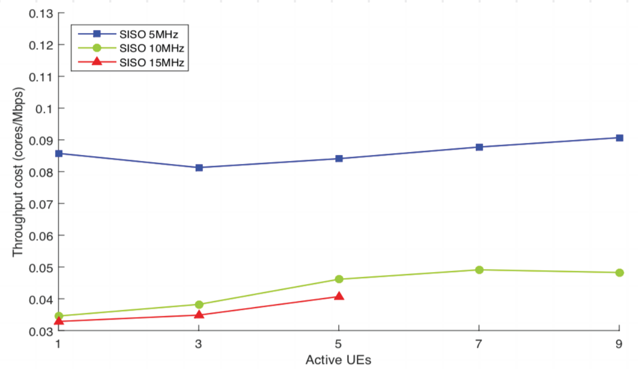


Figure 4 depicts the throughput cost in dependence of the number of active UEs, for a containerized full stack LTE base station in SISO mode. The throughput cost is defined as the ratio between the number of CPU cores used for each served Mpbs of aggregate traffic. The results clearly show that serving higher number of users, as well as using lower channel bandwidths is more resource costly, but the scalability effect (number of UEs) is not significant.

Figure 4: Throughput cost vs number of UEs for a containerized full stack LTE base station in SISO mode

CONCLUSIONS

The main benefits of RAN virtualization are the fast deployments and rapid/diverse system reconfigurations. The number of served UEs has no significant impact on CPU consumption in LTE and 5G deployments, but physical layer configuration does. A high capacity, low latency fronthaul implementation is a necessity in C-RAN solutions.

FEEDBACK

ORCA provides a playground for fostering and experimenting with new ideas in the area of wireless networks. It is easy to use and deploy experiments on the platform. Thanks to the software tools and the hardware provided by ORCA it was easy to run the envisioned experiment.

Thanks to the ORCA facility we were able to demonstrate the advantages of a full-stack virtualized cellular RAN and provide valuable insights for future practical large-scale deployments.

ELASTIC

Experimental validation of resource management algorithms for elastic network slicing based on end-to-end QoS

Open Call partner
Allbesmart LDA

Patron
Trinity College Dublin

OBJECTIVES

The main objective of this experiment is the validation of elastic resource management algorithms able to serve multiple Network Slice Instances (NSI) over the same physical resources while optimizing the allocation of computational resources to each slice based on its requirements and demands. The experiment deploys a use case on top of the IRIS testbed that provides two services over two network slices, with a focus on the QoS-aware controland CPU usage.
The goal is to have two competing network slices on the cloud infrastructure: one emulating a MVNO Public Safety service with high throughput and reduced latency requirements and the other emulating an OTT service provider (delay tolerant–best effort slice). A resource management algorithm is implemented and evaluated in terms of performance gains when operating under computational resource limitations.

CHALLENGES

The main challenges of this experiment can be divided into two distinct dimensions: understanding how the srslte software uses computational resources under distinct eNodeB configurations and traffic profiles and how to manage computational resources so that the high priority slice can cope with stringent SLA requirements without disrupting the low priority slice.

EXPERIMENT SETUP

The experiment setup created in IRIS uses four computing nodes, as can be seen in the diagram shown in Figure 1. Machine A implements the EPC and eNodeB components of the LTE network, while machine B contains the UE component. Machine C is used to exchange traffic patterns with the UE through the LTE network, using the iperf tool. Finally, machine D implements the ELASTIC algorithm: it receives traffic and CPU usage data from the two probes and determines the actions to perform in order to comply with QoS requirements.

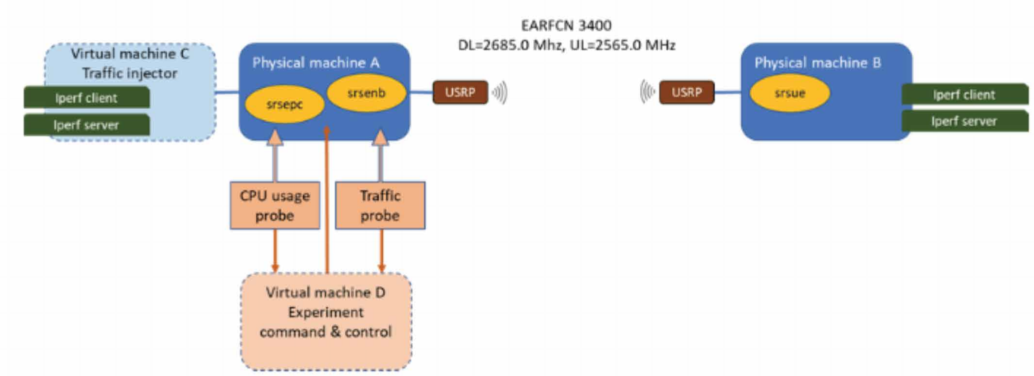


Figure 1 - Experiment setup in IRIS.

The two B210 USRPs are configured in single antenna mode, using the LTE EARFCN frequencies: DL=2685.0 MHZ, UL=2565.0 MHz. Access to each virtual machine is achieved through JFED, using SSH terminal sessions.

ELASTIC

Experimental validation of resource management algorithms for elastic network slicing based on end-to-end QoS

MAIN RESULTS

The ELASTIC algorithm proved to be very effective to increase the TCP throughput of the high priority slice if more CPU resources are required to comply with stringent QoS requirements. Testing revealed gains of 48% in downlink, 55,6% in uplink and 49,8% in simultaneous downlink and uplink. Figure 2 shows the results of theTCP downlink test.

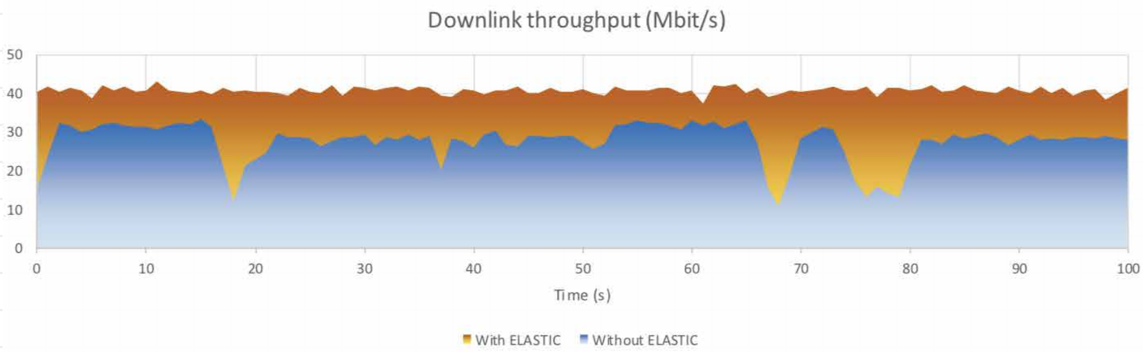


Figure 2 – TCP download throughput comparison.

ELASTIC was also successful dealing with UDP traffic bursts, even with high throughput demand in both directions at the same time. Figure 3 illustrates how ELASTIC deals with UDP traffic bursts and its impact on CPU usage.

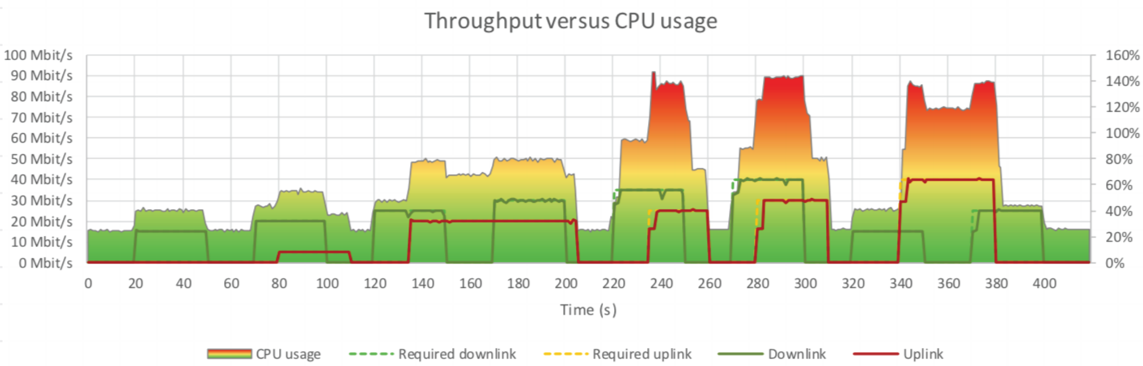


Figure 3 – How ELASTIC handles UDP traffic bursts.

CONCLUSIONS

When two competing cloud RAN LTE slices are implemented over the same computational infrastructure, optimized management of computational resources is an effective instrument to ensure that the high priority slice can cope with demanding QoS requirements under shortage of computational resources. The ELASTIC algorithm implemented in this experiment proved to be effective to increase the performance of the priority slice without disrupting the operation of the low priority slice.

FEEDBACK

ORCA was extremely useful to support this experiment, by allowing our company to have remote access to equipment and resources, namely USRPs and computational nodes, that are usually beyond our reach. The way how different network scenarios can be easily created within JFED, even interconnecting nodes of distinct testbeds, has been perceived as a major advantage of ORCA.

Thanks to the ORCA facility we were able to substantially increase our expertise on cloud RAN technologies and test resource management algorithms using radio equipment that otherwise would be beyond our reach.

Orchestration and Reconfiguration Control Architecture

BEE

Building Emergency Ecosystems

Open Call partner
Level7 S.r.l.

Patron
imec

OBJECTIVES

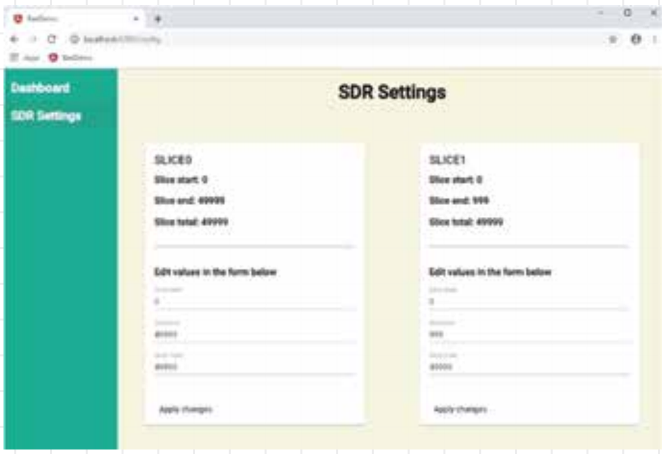
The goal of the BEE experiment is to provide a robust wireless access infrastructure in indoor environment where emergency services should be provided. The use of the existing wireless infrastructure will permit a better use of resources as well as better indoor support and deployment.

CHALLENGES

The main challenge in the BEE experiment has been to use implement QoS/QoE ideas in a novel and open SDR implementation. The support from the ORCA facilities permitted to quickly focus on the main aspects of SDR technologies and provide traffic differentiation.

EXPERIMENT SETUP

The BEE experiment controls the SDR device in order to support emergency scenarios. The SDR can be driven in real time via the GUI thanks to the APIs.



BEE

Building Emergency Ecosystems

MAIN RESULTS

The SDR device permits traffic differentiation and the full support of an emergency terminal that whose traffic is never degraded, while normal traffic can show degradation.

```
paolo@dssj5: ~
64 bytes from 192.168.50.5: icmp_seq=1950 ttl=64 time=1.09 ms
64 bytes from 192.168.50.5: icmp_seq=1951 ttl=64 time=1.09 ms
64 bytes from 192.168.50.5: icmp_seq=1952 ttl=64 time=1.12 ms
64 bytes from 192.168.50.5: icmp_seq=1953 ttl=64 time=1.10 ms
64 bytes from 192.168.50.5: icmp_seq=1954 ttl=64 time=1.06 ms
64 bytes from 192.168.50.5: icmp_seq=1955 ttl=64 time=1.07 ms
64 bytes from 192.168.50.5: icmp_seq=1956 ttl=64 time=1.08 ms
64 bytes from 192.168.50.5: icmp_seq=1958 ttl=64 time=1.07 ms
64 bytes from 192.168.50.5: icmp_seq=1959 ttl=64 time=1.09 ms
64 bytes from 192.168.50.5: icmp_seq=1960 ttl=64 time=1.07 ms
64 bytes from 192.168.50.5: icmp_seq=1963 ttl=64 time=1.27 ms
64 bytes from 192.168.50.5: icmp_seq=1964 ttl=64 time=1.09 ms
64 bytes from 192.168.50.5: icmp_seq=1965 ttl=64 time=1.06 ms
64 bytes from 192.168.50.5: icmp_seq=1966 ttl=64 time=1.35 ms
64 bytes from 192.168.50.5: icmp_seq=1967 ttl=64 time=1.08 ms
64 bytes from 192.168.50.5: icmp_seq=1968 ttl=64 time=1.08 ms
64 bytes from 192.168.50.5: icmp_seq=1969 ttl=64 time=1.08 ms
64 bytes from 192.168.50.5: icmp_seq=1970 ttl=64 time=1.09 ms
64 bytes from 192.168.50.5: icmp_seq=1971 ttl=64 time=1.07 ms
64 bytes from 192.168.50.5: icmp_seq=1972 ttl=64 time=1.10 ms
64 bytes from 192.168.50.5: icmp_seq=1973 ttl=64 time=1.08 ms
```

Ping results for the "panic button" terminal during the emergency status

```
paolo@dssk5: ~
64 bytes from 192.168.50.5: icmp_seq=1939 ttl=64 time=49.8 ms
64 bytes from 192.168.50.5: icmp_seq=1940 ttl=64 time=48.8 ms
64 bytes from 192.168.50.5: icmp_seq=1945 ttl=64 time=15.9 ms
64 bytes from 192.168.50.5: icmp_seq=1946 ttl=64 time=14.3 ms
64 bytes from 192.168.50.5: icmp_seq=1947 ttl=64 time=12.8 ms
64 bytes from 192.168.50.5: icmp_seq=1948 ttl=64 time=10.8 ms
64 bytes from 192.168.50.5: icmp_seq=1949 ttl=64 time=8.83 ms
64 bytes from 192.168.50.5: icmp_seq=1950 ttl=64 time=6.82 ms
64 bytes from 192.168.50.5: icmp_seq=1951 ttl=64 time=4.81 ms
64 bytes from 192.168.50.5: icmp_seq=1952 ttl=64 time=2.78 ms
64 bytes from 192.168.50.5: icmp_seq=1953 ttl=64 time=1.10 ms
64 bytes from 192.168.50.5: icmp_seq=1954 ttl=64 time=49.6 ms
64 bytes from 192.168.50.5: icmp_seq=1955 ttl=64 time=47.8 ms
64 bytes from 192.168.50.5: icmp_seq=1956 ttl=64 time=45.9 ms
64 bytes from 192.168.50.5: icmp_seq=1957 ttl=64 time=44.8 ms
64 bytes from 192.168.50.5: icmp_seq=1961 ttl=64 time=44.5 ms
64 bytes from 192.168.50.5: icmp_seq=1962 ttl=64 time=42.8 ms
64 bytes from 192.168.50.5: icmp_seq=1963 ttl=64 time=40.8 ms
64 bytes from 192.168.50.5: icmp_seq=1965 ttl=64 time=40.7 ms
64 bytes from 192.168.50.5: icmp_seq=1966 ttl=64 time=38.9 ms
64 bytes from 192.168.50.5: icmp_seq=1967 ttl=64 time=37.8 ms
64 bytes from 192.168.50.5: icmp_seq=1968 ttl=64 time=36.2 ms
64 bytes from 192.168.50.5: icmp_seq=1969 ttl=64 time=35.4 ms
64 bytes from 192.168.50.5: icmp_seq=1970 ttl=64 time=33.8 ms
```

Ping results for the for the normal terminal during the emergency status

CONCLUSIONS

The ORCA facilities permitted Level7 to successfully implement the BEE experiment that will be the foundation for new added value services and novel experiments on the SDR/SDN architectures.

FEEDBACK

The ORCA facilities permits the experimenters to focus on the main topic of the research in order to speed up the implementation of new added value services or ideas.

Thanks to ORCA we have been able to focus on the main topic of our research without wasting time in secondary aspects thus speeding up the time to market.

Orca Orchestration and Reconfiguration Control Architecture

Concurrent HaLow

Concurrent multiple sensing for better channel utilization of Wi-Fi HaLow networks

Open Call partner
Methods2Business

Patron
imec

OBJECTIVES

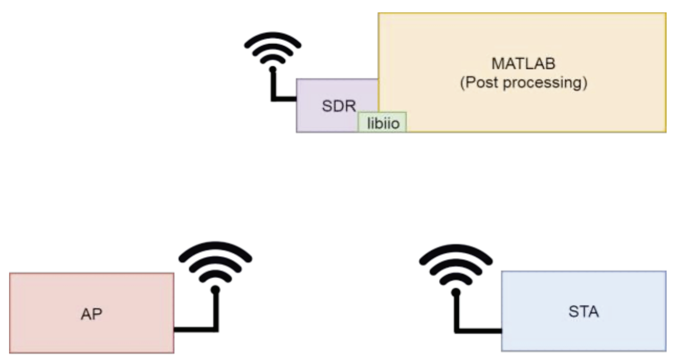
Methods2Business' major objective was to prove that concurrent sensing of multiple channels in a Wi-Fi HaLow network leads to a more efficient channel utilization, maximizing the throughput of Wi-Fi HaLow devices in the network. The intention was to apply the Digital Down Converter (DDC) filters provided by the ORCA project for the channel sensing and develop a mechanism for channel switching.

CHALLENGES

The two main challenge were on one side to identify a reliable metric for classifying channels in a Wi-Fi network based on the measured wireless activity in the channel, and on the other side, to develop an efficient mechanism for channel switching that complies with the IEEE 802.11ah standard.

EXPERIMENT SETUP

The experiment consists of two Xilinx ZC706 Evaluation Kit - Zynq® 7000 SoC boards: the first one represents an Access Point (AP) and the second one represents a Station (STA). The traffic between them is captured with an SDR-based sniffer that is connected to MatLab using the libiio library from Analog Devices Inc. The figure below shows the experiment setup at the imec w-iLab.t.2 lab.



Concurrent HaLow

Concurrent multiple sensing for better channel utilization of Wi-Fi HaLow networks

MAIN RESULTS

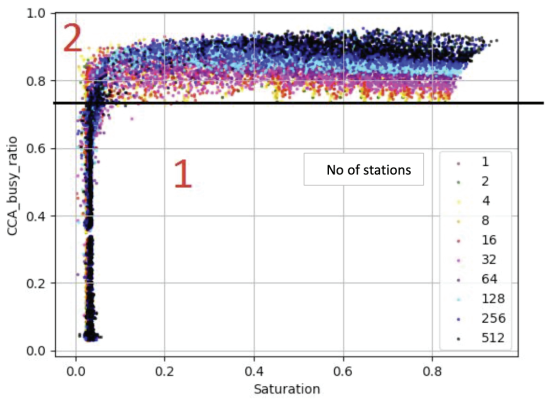
Methods2Business developed two metrics for channel classification, one based upon the CCA_busy_ratio which represents the percentage of period of time that the channel is occupied and another one based upon the Traffic Saturation Metric (TSM) representing the average channel idle time. Based on these two metrics, channels could be classified.

The figures below show the CCA_busy_ratio and the Traffic Saturation Metric in function of the saturation of the network which is defined by the following formula.

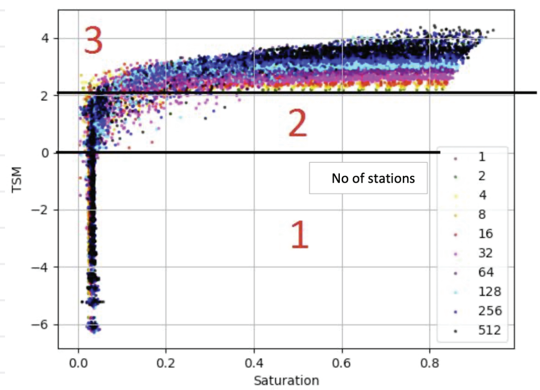
SAT = 1- Effective throughput/Desired throughput / where Desired throughput is the sum of the throughputs STAs are trying to achieve

The numbers (1, 2 and 3) mean: 1- No Saturation, meaning effective throughput equals desired throughput. 2- Partial saturation. 3- Full saturation

As indicated by the figures below, classification based upon the Traffic Saturation Metric gives a more precise indication of the channel condition.



CCA_busy_ratio in function of network saturation



Traffic Saturation Metric in function of Network Saturation

In addition to channel classification, Methods2Business developed two mechanisms for channel switching, one to be applied during initialization of the network and another for a network in operation.

CONCLUSIONS

Concurrent sensing of multiple channels to enable channel switching, is a promising concept for maximizing throughput in a Wi-Fi HaLow network. The mechanisms developed for channel sensing based on ORCA's DDC filters and channel switching, were illustrated using the imec test facility and showed promising results for further implementation in Methods2Business commercial Wi-Fi HaLow access points.

FEEDBACK

Methods2Business is very satisfied with the ease of use and tool support provided in ORCA to bring-up our full Wi-Fi HaLow MAC and Baseband implementation for a client and an access point on the available prototyping boards (ZYNQ FPGA with AD9361 radio cards) present in the imec w-iLab.t.2 lab. Thereafter, it was very straightforward to run remotely our intended experiments. For the near future, Methods2Business sees great opportunities to further exploit the services offered by imec w-iLab.t.2 lab facilities for offering remote access to our Wi-Fi HaLow demonstration platform to early adopters of the Wi-Fi HaLow technology all over the world.

Thanks to the DDC filters provided by the ORCA team and the access to the Testbed of the imec test lab, Methods2Business was able to develop and test a working mechanism for channel sensing for the purpose of channel switching to maximize the throughput of devices in the network. Methods2Business will apply these concepts into their access point products to create a competitive advantage in the market. The Methods2Business team very much appreciated the professionalisms of the people running the imec test lab and the in-depth knowledge in wireless networks of the ORCA team.

OPEN CALL 3
FOR EXPERIMENTS

Orchestration and Reconfiguration Control Architecture

CSI-MURDER

Experimental analysis of CSI-based anti-sensing techniques

Open Call partner
University of Brescia

Patron
imec

OBJECTIVES

The goal of the Experiment is to study and propose an anti-sensing technique against novel device-free CSI-based localization frameworks. In particular, we intend to safeguard users' privacy by preventing both passive and active environment sensing attacks without affecting too much the ongoing Wi-Fi communications.

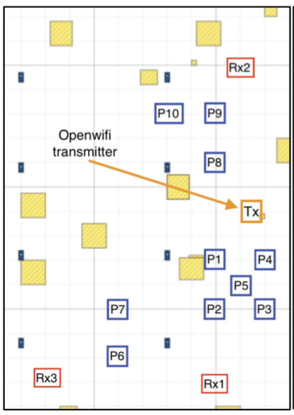
CHALLENGES

- Choose from the Wi-Fi sensing literature a passive localization technique and deploy it using lab facilities

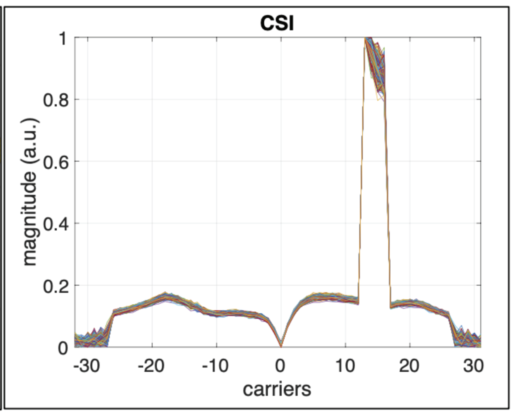
- Find and implement a randomization mechanism at the Wi-Fi physical layer that makes the localization technique above useless without compromising the communication capabilities of the randomized devices, should they be actively adopting randomization or passively being randomized from an external device.

EXPERIMENT SETUP

The experiment demonstrated that it is possible i) to use the facilities in w.iLab.2 to discover the location of a victim moving in the lab (e.g. among 10 target positions as shown in Figure a) by analyzing the CSI received at a given node; and ii) to adopt a proper countermeasure at the transmitter to make the deployed localization technique useless. In fact, the countermeasure is able to modify the CSI almost arbitrarily. We show the effect of amplifying 4 adjacent subcarriers in Figure b, but in general we can generate random patterns that do not depend on the actual channel condition, so that CSI cannot be used anymore for localization purposes.



a)



b)

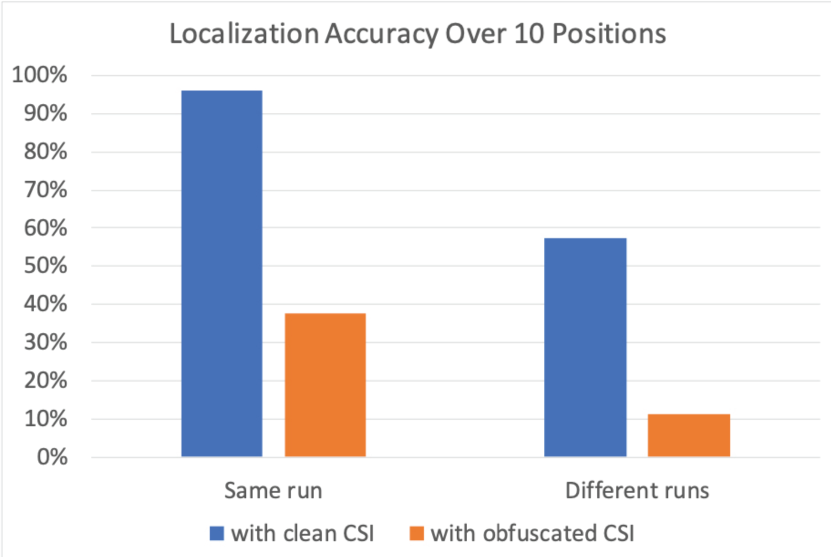
www.orca-project.eu

CSI-MURDER

Experimental analysis of CSI-based anti-sensing techniques

MAIN RESULTS

The Figure shows the average classification accuracy of a person over 10 possible target positions in the w.iLab.2 testbed. The label same run refers to the fact that training and testing samples are drawn (without reinsertion) from the same CSI collection experiment, while for label different runs we collected training and testing CSI samples at two different times. It is interesting to notice that the localization system still works fairly well in the second case, but more importantly we show that the proposed anti-sensing techniques disrupts localization accuracy in both cases.



CONCLUSIONS

This is the first study to characterize the possibility of obfuscating Wi-Fi frames to prevent environment sensing. Our experiments in the w.iLab.2 testbed confirm that an eavesdropper is not able to infer the location of a victim in a room, while Wi-Fi communications are preserved. The outcome of this experiment can be used for designing future privacy-aware chipsets.

FEEDBACK

Our experience has been positive. Many results in this Experiment could not have been achieved without the tools available in the testbed and the constant support of our patron, which promptly solved a few issues that we encountered while using the facility.

Thanks to the ORCA facility, we have obtained the necessary resources and support to conduct the first systematic and experimental study of an obfuscation technique to prevent unauthorized use of CSI information to breech people privacy. Such results, beyond opening an entire new field of research, are also fundamental to guarantee the future socio-economic sustainability of Wi-Fi technology.

Orchestration and Reconfiguration Control Architecture

MARRMOT

Massive MIMO for reliable remote monitoring

Open Call partner
Lund University

Patron
KU Leuven

OBJECTIVES

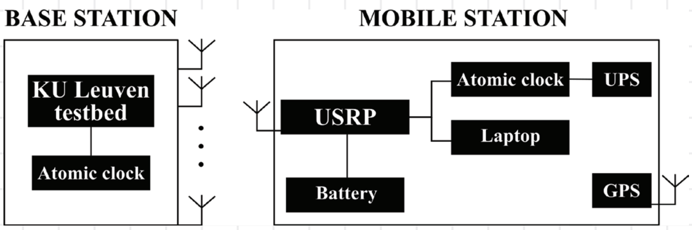
The goal of the experiments was to extend the KU Leuven testbed to a real- time sub-GHz massive MIMO system, respecting the regulations in the unlicensed band, validate the results and perform measurements comparing different antenna array configurations and frequencies.

CHALLENGES

The main challenge during the implementation phase was the LabVIEW implementation in an already quite involved framework and for the experiments; the Corona pandemic also caused delays. The unstable Belgian summer weather made planning for the outdoor measurements difficult.

EXPERIMENT SETUP

For the outdoor experiments, the base station was on a balcony with either a Uniform Linear Array or a Uniform Rectangular Array. All the user equipment for the mobile station was in a cargo bike, making it completely mobile. The two systems were synchronised through atomic clocks.



Picture 1: Block diagram of experiment setup

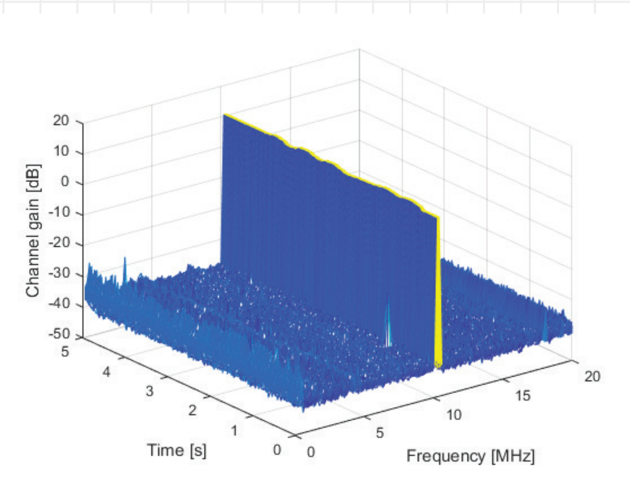
Picture 2: Rectangular array on the balcony of KU Leuven, with the bike-mounted mobile station in front

MARRMOT

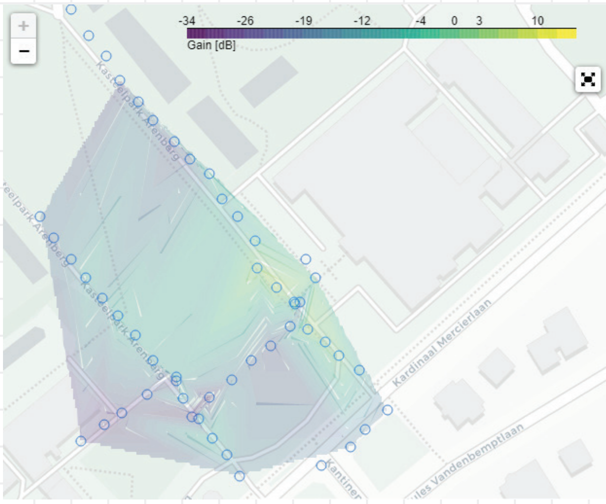
Massive MIMO for reliable remote monitoring

MAIN RESULTS

It was possible to extend the KU Leuven testbed to a real-time sub-GHz massive MIMO system, respecting the regulations in the unlicensed band, with EVM and channel capturing capabilities. The feasibility of performing experiments with the setup, as well as the achievable range, have been validated and tested.



Picture 3: Plot of the channel gain over time and frequency, showcasing the working narrowband implementation and channel logging.



Picture 4: Map of the measurement points, marked with circles, and the interpolated median channel gain in colour when deploying a uniform linear sub-GHz antenna array.

CONCLUSIONS

It is now possible to run the KU Leuven testbed with a sub-GHz antenna array, respecting applicable regulations and make unique experiments, which will enable interesting results and further analysis.

FEEDBACK

Due to the already quite involved framework running on the testbed, it can be hard to implement and validate changes. Despite that, our previous experience with similar testbeds and the complementary expertise of the patron has made the process smooth and the collaboration with the patron has worked very well.

Thanks to the ORCA facility we were able to implement, test and validate a real-time sub- GHz massive MIMO system.

Orchestration and Reconfiguration Control Architecture

NFV2X

Network Function Virtualization for Vehicle to Anything Configurations

Open Call partner
Feron Technologies

Patron
imec

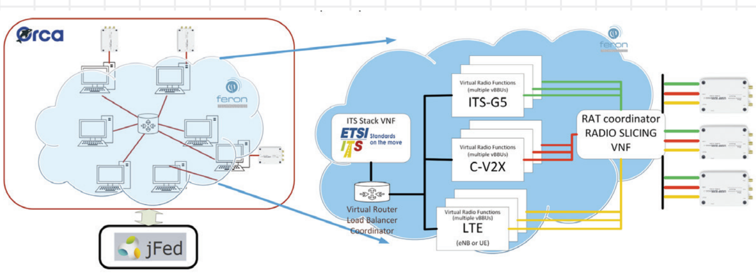
OBJECTIVES

The goal of NFV2X was to investigate configurations and perform experiment campaigns that address issues of network slicing and virtualization that extends up to the radio. This is performed by addressing several emulated scenarios for the automated driving-connected vehicle use case.

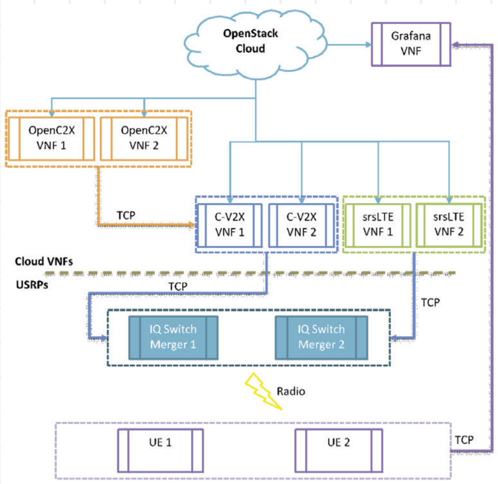
CHALLENGES

The NFV2X project: transformed ORCA resources into a Network Function Virtualization Infrastructure; extended the ORCA IQ Switch for Radio Slicing over both V2X radio standards and LTE; unified various virtualization manifestations; performed experiment campaigns for various V2X-focused use cases for system validation.

EXPERIMENT SETUP



The NFV2X concept – experimentation with multilevel virtualization



The experiment configuration

Virtualization is a major structural feature for 5G and an enabling force in order to fulfil its demanding objectives Virtualization is applied in multiple stages -from the core to the edge- and occurs in various forms and manifestations:

- **Virtual partitioning of the mobile radio access network (RAN) or radio network slicing**
- **The C-RAN concept and the use of Network Function Virtualization (NFV) and Software Defined Networking (SDN)**
- **Software-Defined-Radio (SDR) slicing for joint support of multiple interfaces**
- **5G core and higher-layer virtualization with NFV and SDN**

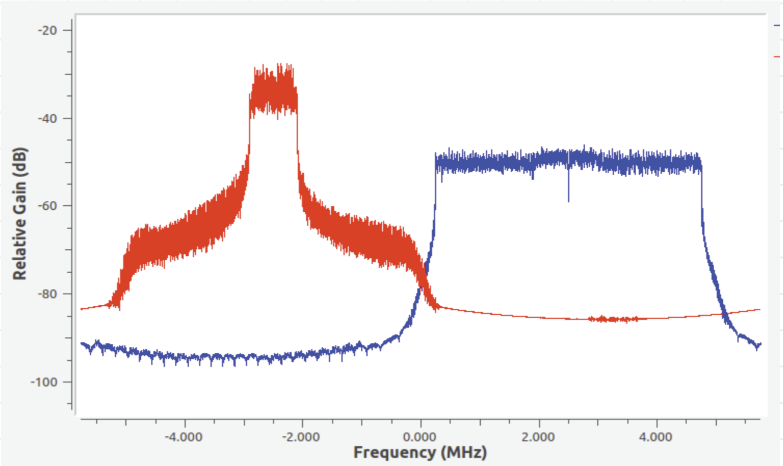
NFV2X addresses all the aforementioned cases, with an experiment configuration that allows multi-dimensional analysis and experimentation. In NFV2X, an OpenStack cloud is deployed over the ORCA resources, and all the major system components of an end-to-end softwarized modem are implemented as Virtual Network Functions – form monitoring tools, to baseband processing (see figures). Focus is given in V2X communications with the use of all possible radio technologies considered today.

NFV2X

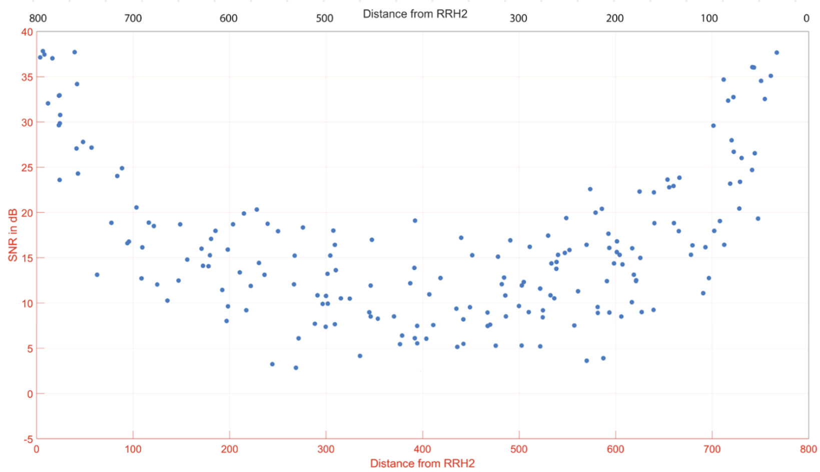
Network Function Virtualization for Vehicle to Anything Configurations

MAIN RESULTS

The NFV2X setup was used to test, validate and evaluate various levels of virtualization in radio. Radio slicing between different technologies and services was investigated (e.g. figure) – implementing VNFs of fully flexible systems with multiple radio systems – and introducing new potential for SDR development.



IQ Switch with LTE-CV2X transmitting CAM messages at a 10msec rate (left channel) and an LTE-CV2X slice transmitting ftp traffic (full resource allocation) (right channel)



Additionally, the platform was used to evaluate the benefits of C-RAN manifestations on emulated vehicular scenarios and how it can be utilized to maintain the quality of the links above a predefined level (see figure on the left).

SNR vs. distance when a virtual RSU utilizes two remote radio heads (LTE-CV2X)

CONCLUSIONS

A generic experiment configuration was developed allowing us to investigate various levels of network and radio virtualization – from radio slicing to C-RAN. The configuration was tested on vehicular communication technologies allowing us to develop flexible and interoperable setups.

FEEDBACK

The NFV2X experience was dictated by a platform of stable remote operation, short learning curve, high system availability, direct and qualitative support. NFV2X and ORCA were a very positive and pleasant experience for Feron Technologies and we have the will to pursue new future collaborations.

OCTAGON

Orchestration of complex tasks through OTA reprogramming of wireless nodes

Open Call partner
INTELLIA ICT

Patron
imec

OBJECTIVES

OCTAGON intends to:
• adapt different task assignment schemes taking advantage of the real nodes and the features offered by ORCA control plane.
• integrate the energy efficiency algorithms with ORCA.
• validate their proper execution via the offered SDR capabilities and evaluate their performance.

CHALLENGES

• The evaluation of optimised energy efficiency schemes in real nodes.
• The over-the-air reprogramming of wireless nodes to minimise energy consumption.
• The provision of a set of best practices and practical recommendations to wireless network experimenters for the domain of energy consumption.

EXPERIMENT SETUP

For the first set of OCTAGON experiments, up to eight nodes were allocated at the same time from wilab2 testbed by assuming a set of directed network communication edges. We considered a predefined set of 4 algorithms, with different complexities that represent the pool of available subtasks: two sorting algorithms with different computational complexities (QUICKSORT and BUBBLESORT) an average number calculation algorithm (MEAN), and an algorithmic calculation of the 'n' power (POWER). We also considered tasks with exactly one sink subtask.

The average number of subtask vertices per task was 7 while the average number of subtask edges per task was 12 (i.e., some subtasks provide output to multiple parent subtasks). The average number of measurements produced per subtask was set to 80 values. Furthermore, 320 Kbit were exchanged per subtask edge on average.

After each experiment execution, we measured the total energy consumed by each node. The first set of experiment was executed over the Zolertia Re-Mote nodes where the calculation of the consumed energy was feasible by taking advantage of an energy plugin. By adding the energy consumed in each node, we could calculate the total energy required to be spent by the network W in order to carry out the task T.

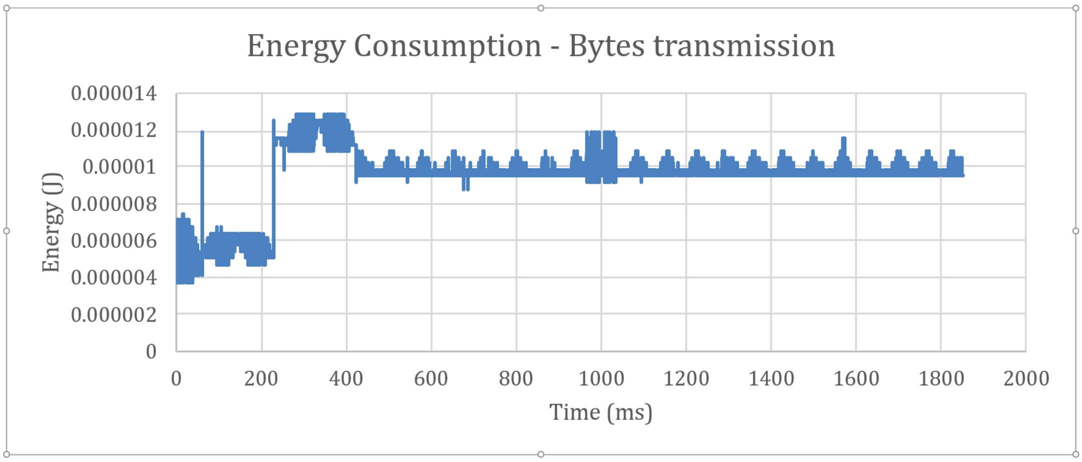
In the second set of experiments, the network was consisted of one Xilinx ZC706 SDR node and six commercial wifi nodes. We were capable of allocating one Xilinx node to verify the feasibility of the OTA reprogramming and SDR management concepts. We deployed our algorithms and we managed to reconfigure the nodes over-the-air (OTA) by stopping/starting the subtask algorithms. The energy costs were estimated using the NS2 energy model.

OCTAGON

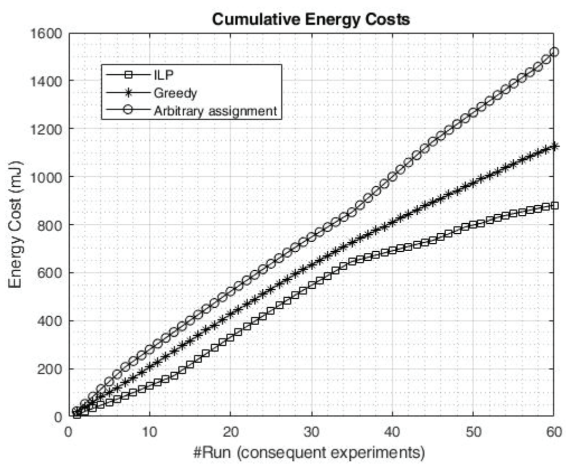
Orchestration of complex tasks through OTA reprogramming of wireless nodes

MAIN RESULTS

The experimental tests validated the results of an energy-efficient scheme for task allocation over a real network. The experiment investigated both the execution energy costs (energy costs caused by the execution of the subtasks in the nodes) and the communication costs (energy costs caused by the exchange of data required between the nodes in order to facilitate the proper execution of the subtasks).



Energy consumption for transmitting data



Cumulative energy costs (execution + communication) for different task assignment schemes

CONCLUSIONS

The OCTAGON experiment (a) proved the feasibility of the concept in SDR nodes by allowing for OTA reprogramming and SDR-based reconfiguration, (b) estimated the energy costs for the SDR experiment using an external energy model, and (c) applied the optimisation results in real network nodes and calculated and compared real energy costs resulted within the network.

FEEDBACK

The experience in using the ORCA was great. Supporting real energy calculations on all ORCA nodes would be a plus in order to facilitate applications that need access to real energy costs such as the ones dealing with optimized energy efficiency based on SDR technology.

Thanks to the ORCA facility we were able to test our optimisation scheme on real nodes.

Orca Orchestration and Reconfiguration Control Architecture

5G-ROSE

5G Broadcast SDR Experiment

Open Call partner
Universidad Politècnica de València

Patron
Trinity College Dublin

OBJECTIVES

The main objective of the experiment has been to develop a virtualised Single Frequency Network (SFN) using open source LTE software implementation. Other secondary objective has been the physical layer update, extending the srsLTE suite with all the PHY updates of FeMBMS Release-14 and to perform Network Slicing with HyDRA software testing unicast and multicast content using the same physical resources.

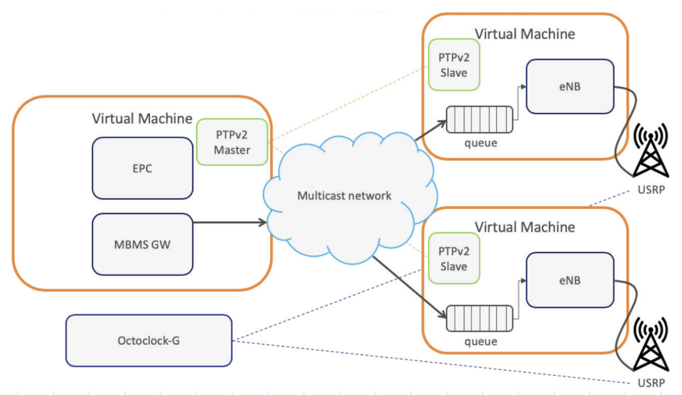
CHALLENGES

One of the great challenges that we have encountered in the project has been to carry out the sync protocol, along with updating the physical layer, in the time that the project has lasted. These problems have been related to the free code platform srsLTE, which has presented many hardcoding problems and errors. On the other hand, everything related to virtualisation has been quite easy, thanks to the help of the project coordination.

EXPERIMENT SETUP

Experiment 1:
The minimum setup needed for this experiment using virtual machines is (as shown in the figure here below):
- **Four virtual machines, three of them connected to a USRP**
- **Three USRP x310, all connected to the Octoclock-G**
- **The srsLTE version with MBSFN features (https://github.com/Borjis131/srsLTE.git)**
- **PTPd sourceforge implementation (https://sourceforge.net/projects/ptpd/)**

First the virtual machines and USRP will be reserved using the rspec file attached through jFed. The first virtual machine, without an USRP connected, will act as EPC and MBMS gateway. The two machines connected both to USRPs and Octoclock, will act as eNodeBs and the fourth machine connected to the USRP, will act as the UE.



Architecture using virtual machines

First a PTPd daemon is started as Master in the first VM. And two PTPd daemons are started as Slave in the eNBs VM. This step will synchronise the virtual machines to share the same clock. After starting the daemons, the LTE components will be started, EPC and MBMS-GW in VM, eNB in the second and third VM and UE in the third VM. The MBMS gateway will be started using the configuration file provided and specifying the sync_sequence_packets that will be sent every SYNC sequence.

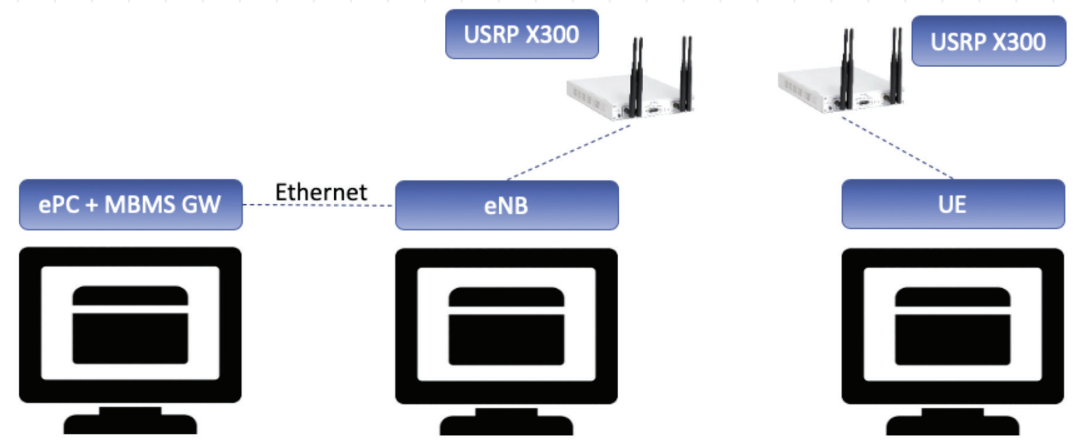
The expected behaviour of this experiment is to receive the video transmitted, by using ffmpeg software, over the MBMS GW through the SFN created. The UE should decode it and reproduce it using ffplay.

EXPERIMENT SETUP

Sub-experiment 2-1

In this sub-experiment, three virtual machines have been used (see figure below). The setup consists in:

- **1 VM acting as ePC and with the MBMS gateway (GW) active.**
- **1 VM acting as eNB, connected to the ePC through an Ethernet connection. This virtual machine is connected to a USRP X300.**
- **1 VM acting as User, connected to a USRP X300.**
- **SrsLTE code with the added features: Available at https://github.com/alibla/srsLTE.git**



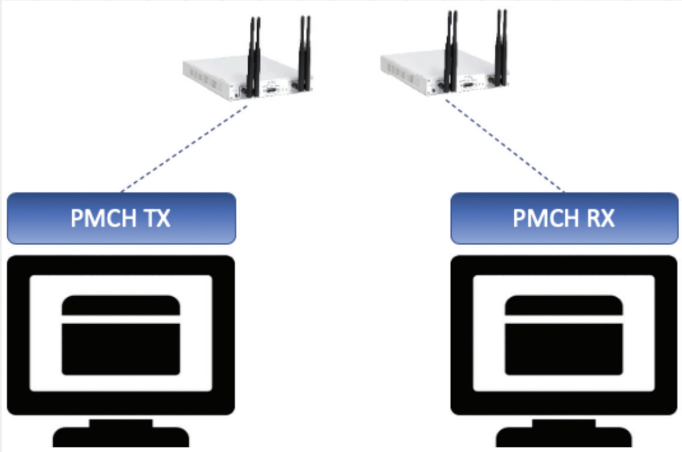
Sub-experiment 2-1 Setup

The choice of separating the ePC and MBMS GW with the eNB into two virtual machines is due to the high performance it has shown. The user is expected to be able to connect to the created LTE network and, subsequently, to be able to receive and decode the content received by the PMCH with the new numerology.

Sub-experiment 2-2

In this case, just two VM have been required, as can be seen in the figure on the left. Each VM has been connected to one USRP X300.

In this case, as the control signal is already known by both transmitter and receiver, the configuration that can be edited is reduced to parameters such as bandwidth, that is the PRBs, and also with more related parameters of the USRP, such as transmission or reception gains, etc. Since the full stack protocol is not necessary, as it is a simulation of physical channels, only random content is retransmitted. The virtual machine that receives only has to decode that content and show it on the screen.



Sub-experiment 2-2 Setup

MAIN RESULTS

Experiment 1

The current code developed works as expected but the reception at the UE is not currently possible due to unknown errors dropping all the received packets. The figure below shows the reception of the packets at the UE in the RLC level in which the parts of the packets are concatenated and sent to the GW level. The screenshot shows an example of the received packets.

```
15:40:52.660026 [RLC ] [I] Concatenating 769 bytes in to current length 0. rx_window remaining bytes=1593, vr_ur_in_rx_sdu=10, vr_ur=10, rx_mod=32, last_mod=11
             0000: 83 e6 10 13 51 00 00 00 00 00 00 00 04 45 00 02
             0010: f4 a4 d5 40 00 10 11 26 15 ac 10 00 fe ef ff 00
15:40:52.660041 [RLC ] [I]  Rx SDU vr_ur=10, i=1, (update vr_ur middle segments)
             0000: 83 e6 10 13 51 00 00 00 00 00 00 00 04 45 00 02
             0010: f4 a4 d5 40 00 10 11 26 15 ac 10 00 fe ef ff 00
15:40:52.660056 [GW  ] [I] RX MCH PDU (769 B). Stack latency: 0 us
             0000: 83 e6 10 13 51 00 00 00 00 00 00 00 04 45 00 02
             0010: f4 a4 d5 40 00 10 11 26 15 ac 10 00 fe ef ff 00
```

Packets received at RLC and GW

Experiment 2

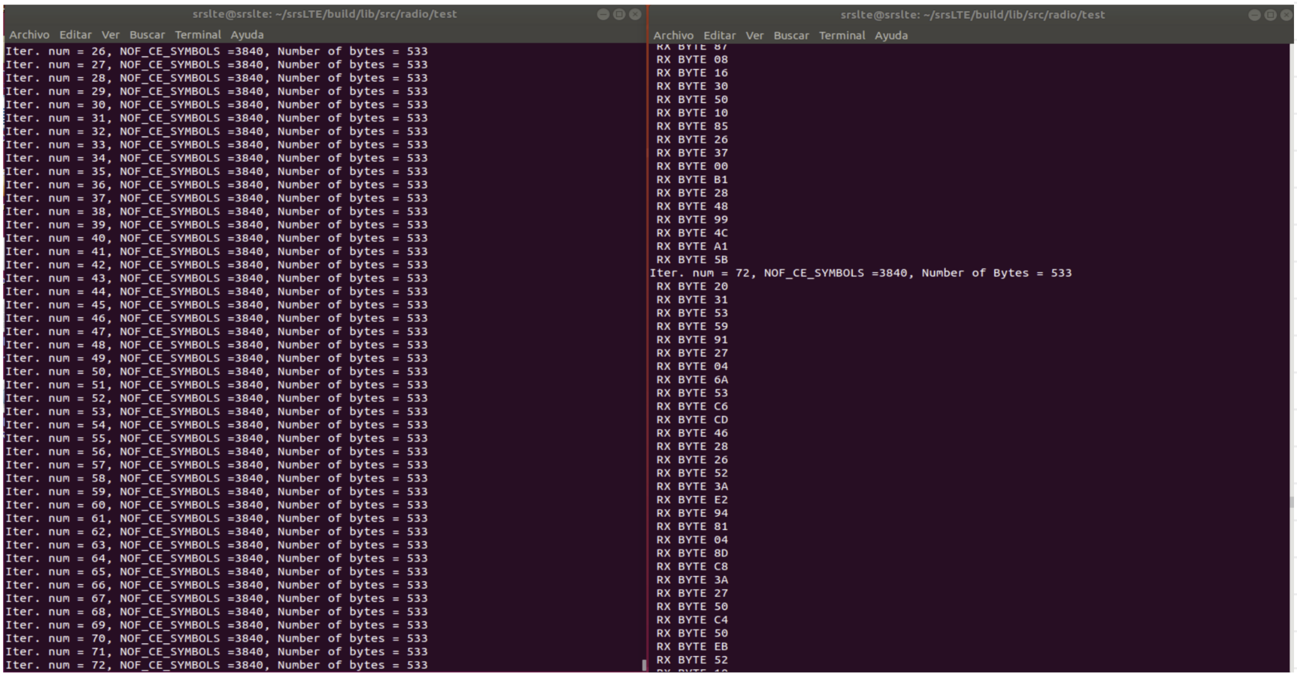
For sub-experiment 2-1, as can be seen in the figure below, one user is able to connect to the network with the new numerology. But, errors are observed, all of them directly related to the PDCCH physical control channel. These errors indicate an erroneous calculation of the channel's own parameters, such as ncce, number of CCE, and location L. Apart from the observed errors, no content has been sent from the eNB to the user.

```
[INFO] [B200] Asking for clock rate 23.040000 MHz...
[INFO] [B200] Actually got clock rate 23.040000 MHz.
Setting frequency: DL=2685.0 Mhz, UL=2565.0 MHz
Setting Sampling frequency 11.52 MHz

==== eNodeB started ===
Type <t> to view trace
RACH:  tti=351, preamble=31, offset=1, temp_crnti=0x46
RACH:  tti=371, preamble=47, offset=1, temp_crnti=0x47
/home/srslte/srsLTE/lib/src/phy/phch/pdcch.c.626: Illegal DCI message nCCE: 16, L: 3, nof_cce: 10, nof_bits=27

/home/srslte/srsLTE/lib/src/phy/enb/enb_dl.c.382: Error encoding UL DCI message

/home/srslte/srsLTE/srsenb/src/phy/cc_worker.cc.608: Error putting PUSCH 0

RACH:  tti=391, preamble=0, offset=1, temp_crnti=0x48
RACH:  tti=411, preamble=13, offset=1, temp_crnti=0x49
RACH:  tti=431, preamble=39, offset=1, temp_crnti=0x4a
/home/srslte/srsLTE/lib/src/phy/phch/pdcch.c.626: Illegal DCI message nCCE: 8, L: 3, nof_cce: 10, nof_bits=27

/home/srslte/srsLTE/lib/src/phy/enb/enb_dl.c.382: Error encoding UL DCI message

/home/srslte/srsLTE/srsenb/src/phy/cc_worker.cc.608: Error putting PUSCH 0

Disconnecting rnti=0x46.
RACH:  tti=451, preamble=50, offset=1, temp_crnti=0x4b
/home/srslte/srsLTE/lib/src/phy/phch/pdcch.c.626: Illegal DCI message nCCE: 16, L: 3, nof_cce: 10, nof_bits=27

/home/srslte/srsLTE/lib/src/phy/enb/enb_dl.c.382: Error encoding UL DCI message

/home/srslte/srsLTE/srsenb/src/phy/cc_worker.cc.608: Error putting PUSCH 0

Disconnecting rnti=0x47.
Disconnecting rnti=0x48.
Disconnecting rnti=0x49.
Disconnecting rnti=0x4a.
User 0x4b connected
```

eNB Messages

MAIN RESULTS

In case of sub-experiment 2-2, as shown in the figure below, it is easy to identify that in the receiver side (the command window on the right side) the signal is being received. The transmitter (on the left side of the figure) generates a random signal, that is copied locally, in order to compare with the received signal, and it is transmitting the signal over the air. Comparing the signals, we are observing an error rate of around 20% is being observed for each of the subframes that are being sent.



Sub-experiment 2-2 running in real time

CONCLUSIONS

This work consists of the implementation of a virtualised SFN for the transmission of 5G broadcast services in an SDR laboratory environment. The implementation uses the IRIS testbed facility in Trinity College of Dublin (Ireland) and it is based on the srsLTE open-source software. The work is divided into three parts, i.e. the development and testing of the first virtualised MBSFN transmission; the introduction of physical layer Rel-16 components; and, as part of our future work, the implementation of network slicing for the simultaneous transmission of both unicast and multicast content. It has been described in detail the implemented technologies as well as the setup to carry out the experiment.

FEEDBACK

The IRIS testbed, the main testbed used for the experiments presented, has been a useful software tool and we would like to contribute to the development of this testbed by sharing the results of the experimentation and the errors encountered. And continue contributing to the development testing new architectures, providing the results of these experiments.

Thanks to the ORCA facilities and the great help and effort that the project coordinators have given us, it has been possible to carry out the experiments.

Orca Orchestration and Reconfiguration Control Architecture

SOFTUCITY

Software Defined Radio and multiple nodes cooperation for ubiquitous identification of RF attacks in Cities

Open Call partner
HOP Ubiquitous S.L

Patron
Rutgers

OBJECTIVES

RF attacks identification, detection and mitigation adaptive to dynamic context
The first objective is focused on the understanding of the vulnerabilities from specific systems, end-to-end communication protocols and the affected scenarios. In details, the experiment will focus on the communication protocols FM RDS-TMC and GPS, since they are well-identified as commonly used protocols in urban environments with well-known spoofing attacks.

Multiple SDR nodes cooperation for ubiquitous identification
The second objective aims to extend the capability of the individual SDR nodes to cooperate among the multiple nodes deployed in a city.

Evaluation of the solution for its exploitation and transferability
The final objective is to use and demonstrate the use of the proposed solution into the urban solution/devices manufactured by HOPU.

CHALLENGES

Softucity is an innovative experiment addressing the detection, identification, and neutralization of rogue/suspicious RF communications in urban environments.

Softucity aims to monitor and surveillance the use of the RF spectrum in order to detect, identify and mitigate potential attacks. First, jamming attacks to impact on availability of networks. Second, spoofing over specific frequencies such as GPS and FM for RDS-TMC since its usage in navigation systems. These technologies vulnerabilities influence in public safety since potential attacks for traffic management, and over unmanned air/ground vehicles (e.g. drones, autonomous cars). Softucity will create a near-real time Radio Environment Map (REM) and will detect/identify these attacks, and contribute to their mitigation and neutralization. In order to cover large areas, this experiment will study the support of multiple RATs and flexibility for dynamic configuration over the SDR nodes.

Softucity aims to deploy SDR-based technology in the SmartSpot product from HOPU.

EXPERIMENT SETUP

The proposed methodology that Softucity will follow is articulated in the following phases:

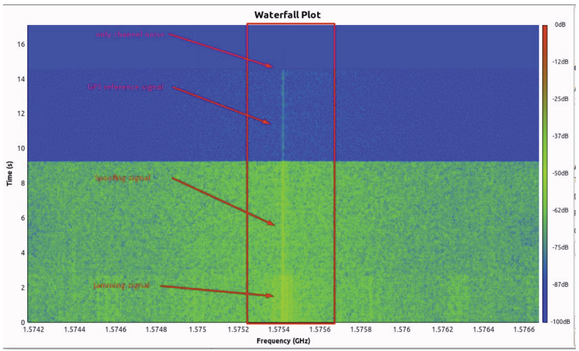
- **Phase one: analysis, Definition and Design of the experiments**
- **Phase two: implementation and execution of the experiments**
- **Phase three: analysis, evaluation of the experiments and feedback**

SOFTUCITY

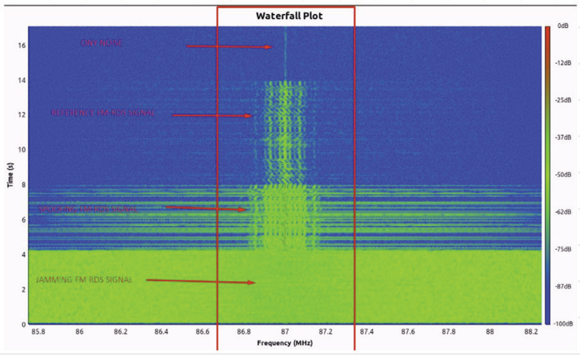
Software Defined Radio and multiple nodes cooperation for ubiquitous identification of RF attacks in Cities

MAIN RESULTS

As the main goal of these experiments is a speedy detection and mitigation of spoofing attacks, two Radio Emission Map have been generated by the monitor node as a Waterfall graph. With this type of graphs, both GPS L1 band frequency and FM-RDS-TMC services are monitored through time and it is drawn in order to detect significant changes of the GPS signal patron or FM-RDS-TMC services.



GPS L1 Band service Waterfall Graph where a spoofing attack is disabled with a jamming signal



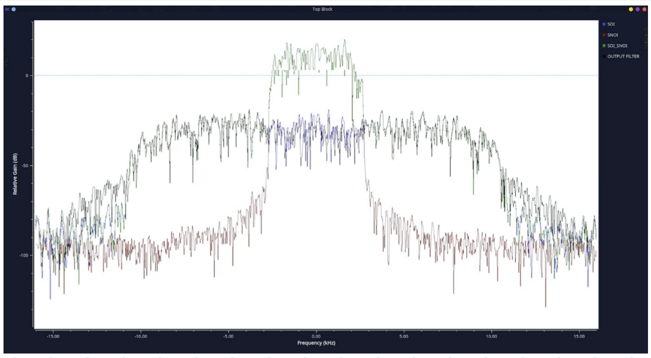
FM-RDS-TMC service Waterfall Graph where a spoofing attack is disabled with a jamming signal

In a third experiment, successive interference cancellation with adaptive filters over SDR devices has been developed in a cooperative way using 2 monitor nodes: one monitoring signal noise and the other one monitoring the mixed signal (noise + signal of interest).

Multiple SDR nodes cooperation for ubiquitous identification: one for monitoring and the other one for sending jamming signals.

Finally, it has evaluated this solution for its exploitation and transferability on embedding GNU Radio over an ARM based embedded board.

(Right) Signal of Interest is equal to output filter due to cancellation of interference being applied



CONCLUSIONS

The project has developed a set of SDR-based experiments for identification and mitigation of RF jamming and spoofing attacks against important networks that are used for public safety (e.g. GPS and FM RDS-TMC). The proposed experiments have used a number of cooperating SDR nodes and their dynamic reconfigurability to support creation of a near real-time Radio Emissions Map that can be used for bot detection and localization of unauthorized emitters/interferers.

FEEDBACK

Softucity aims to provide feedback to the ORCA consortium about the experience working with ORCA facilities, tool suites and testbed use mechanisms (e.g. reservation tools, schedulers). It also provides an experiment and experience about the role of SDR to address these challenges, supporting this complementary research domain and opportunity for ORCA consortium about this other nature of European Projects and research activities, more focused on security and urban innovation actions. Softucity has delivered a full experience and validation in terms of performance, about how to transfer GNURadio projects from lab environment to a commercial product.

Thanks to the ORCA facility we were able to complete the extension of Smart Spot for Radio Emissions Monitoring (REM), extending our market to urban safety and security.

Orchestration and Reconfiguration Control Architecture

XTRA-CARS

eXploiting multi-radio access Technologies for emeRgency communicAtions in vehiCulAr envirRonmentS

Open Call partner
Università degli Studi di Modena e Reggio Emilia

Patron
NI

OBJECTIVES

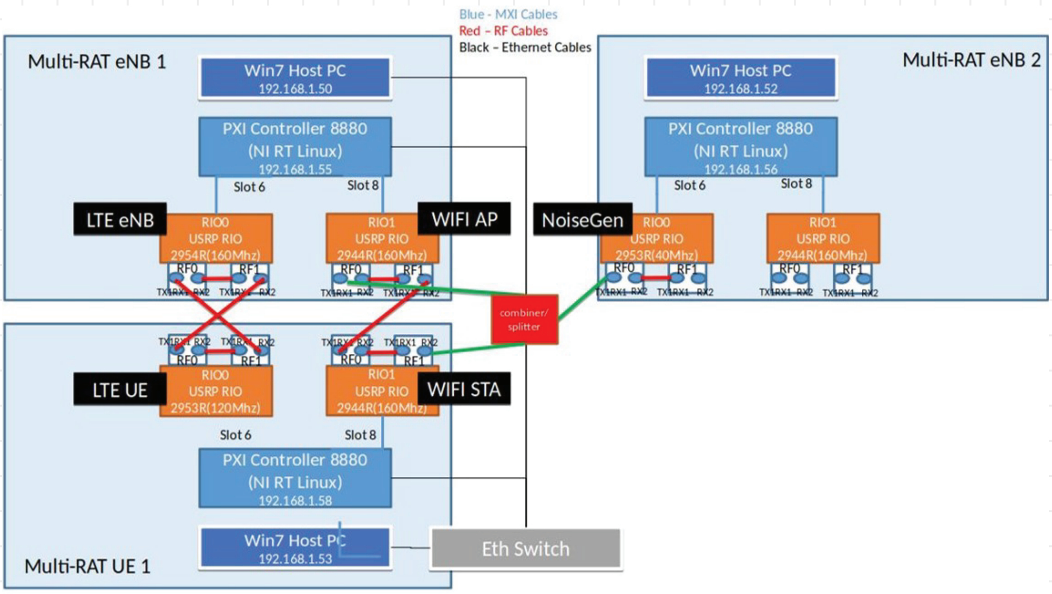
The experiment aimed at exploring the adoption of Multi Radio Access Technologies in a vehicular environment. The intent was to investigate the dynamic reconfiguration of LWA for the data dispatch to an emergency vehicle, guaranteeing its communications the highest priority through an adequate reservation of radio resources.

CHALLENGES

The first challenge was to recreate within the ORCA testbed an environment that effectively mimicked the presence of different vehicle types and their mutual influence. Secondly, the dynamic reconfiguration of LWA had to be implemented, relying on real time measurements of MAC KPIs.

EXPERIMENT SETUP

In addition to the SDR taking the role of the MultiRAT eNB, a pair of SDRs was alternatively utilized to represent: (i) the emergency vehicle or (ii) an ordinary car; a further SDR generated noise that represented ordinary vehicular traffic in circumstance (i), or the traffic directed to the ambulance in circumstance (ii). In both cases, the amount of noise was dynamically set through ns-3. Furthermore, in circumstance (ii), the amount of packets transmitted to the ordinary vehicle on the Wi-Fi DL interface was also dynamically tuned through ns-3.



Testbed configuration

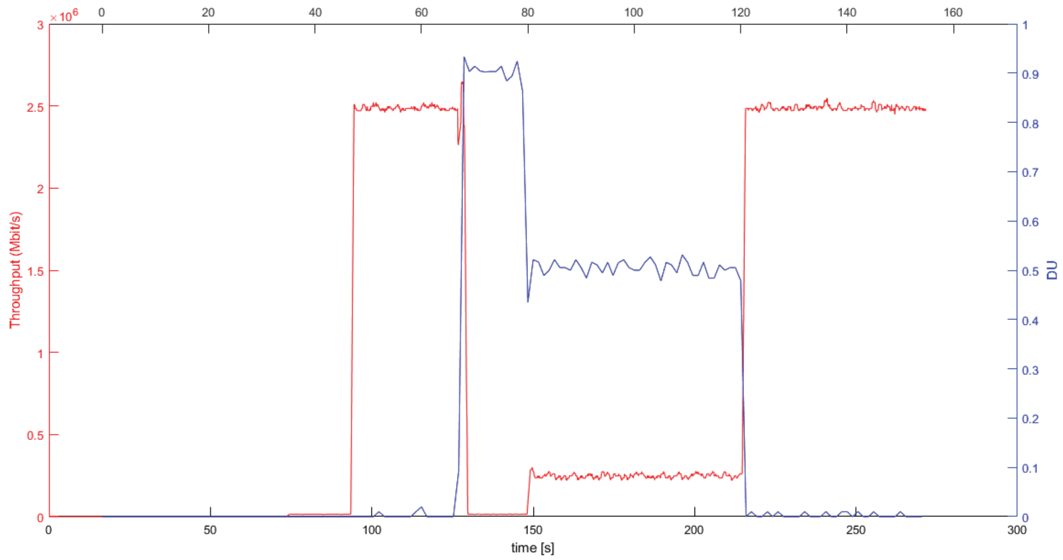
XTRA-CARS

eXploiting multi-radio access Technologies for emeRgency communicAtions in vehiCulAr envirRonmentS

MAIN RESULTS

We demonstrated that LWA can be employed dynamically, on a per-vehicle basis, in order to warrant different throughput levels to cars belonging to different categories. We validated this statement in the specific setting where an ITS application has to guarantee an emergency vehicle the exclusive usage of all Wi-Fi resources, at the expense of ordinary vehicles. These are gradually allowed to use LWA again, to a different extent, depending on the selected Wi-Fi performance indices, i.e., the radio channel occupancy and/or the delay incurred by the packets, whose values have to be kept under control.

As a meaningful example of the testbed results, the figure below reports the DL throughput variations experienced by the UE that embodies the ordinary car, when the noise intensity representing the traffic directed to the ambulance varies.



Variations of Wi-Fi DL throughput for the ordinary vehicle (red) in response to different emergency traffic levels (blue)

CONCLUSIONS

The experiment demonstrated that in a critical road situation, LWA can be successfully adopted to enhance the bandwidth employed for the communications to an emergency vehicle. Both simulations and testbed experiments showed the effectiveness of the dynamic LWA approach and the feasibility of its real-time implementation.

FEEDBACK

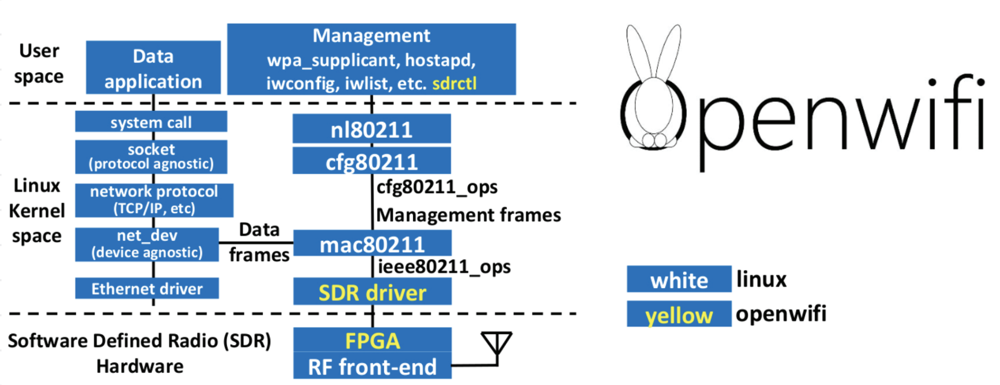
The expertise and support from the ORCA patrons were excellent and always timely. We unfortunately experienced intermittent connectivity issues with the testbed server at the University of Dresden; when this happened, it forced us to reconfigure the testbed from scratch or to patiently wait until the connection became operational again. The main bottleneck was definitely represented by the remote access.

Through the ORCA facility, we tested in a real environment an LWA strategy to flexibly reallocate Wi-Fi and LTE radio resources among different classes of users. We could achieve this goal leveraging on powerful SDRs that also allowed us to gain practice with FPGA programming through LabVIEW.

GOLDEN NUGGETS

OPENWIFI

Openwifi is a Linux mac80211 compatible full-stack IEEE802.11/Wi-Fi design based on SDR (Software Defined Radio), the implementation (FPGA hardware and driver) is opensource, available at https://github.com/open-sdr/openwifi. We indicate future road map and provide support in the same github repository. Openwifi is compatible with commercial Wi-Fi card, but has some customized features, such as allocating air time per connected station allowing the creation of network slices in time domain. This feature is used in ORCA showcase "Distributed End-to-end Network Slicing" on Page 36. We encourage interested users to try out openwifi in w-iLab.t testbed (https://doc.ilabt.imec.be/ilabt/wilab/tutorials/openwifi.html).

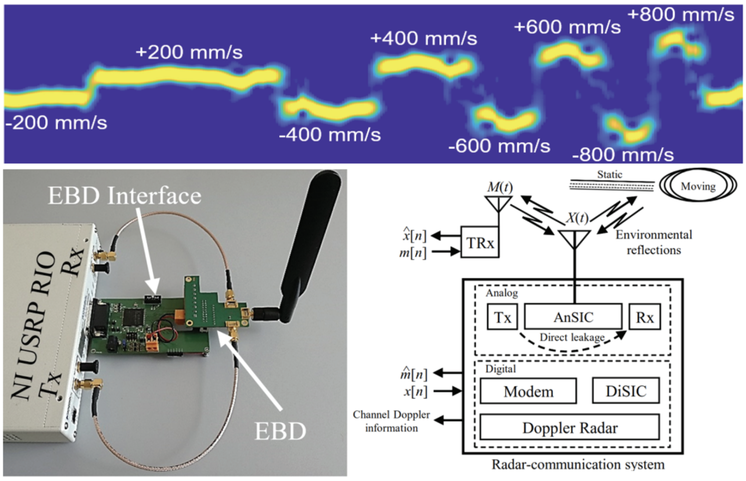


26 GHZ MMWAVE SDR FRONTEND

A 26 GHz mmWave frontend is designed to operate with commercial SDR. The frontend contains 16 inputs which defines 16 beams. The beam selection is easily performed by means of a switch. With this setup, a real time beam-tracking solution is achieved to cope with moderate speed mobility, this is used in ORCA showcase "26 GHz mm-Wave communication for video streaming" on Page 32.

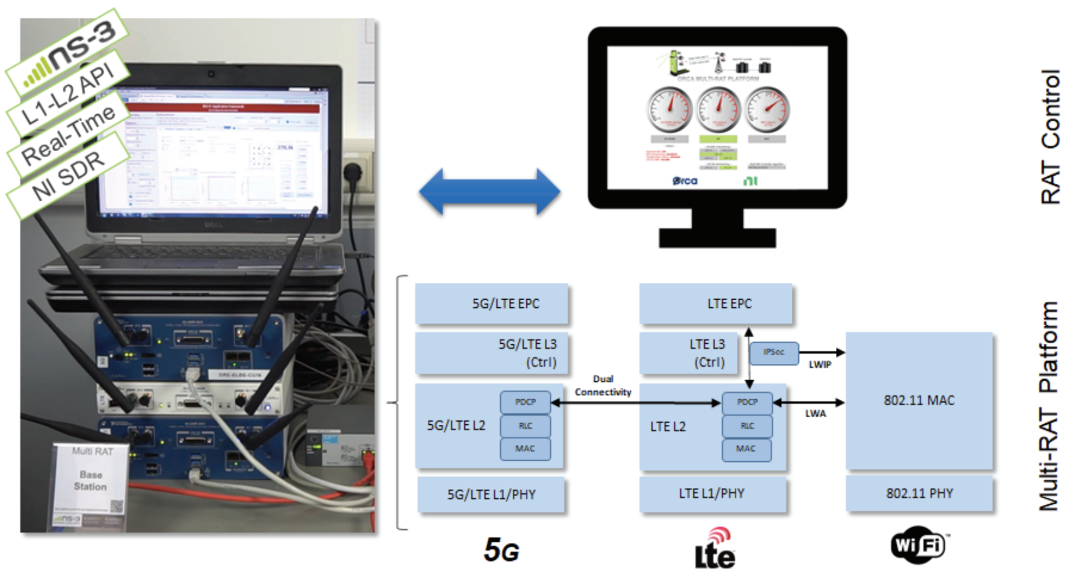
RADAR-COMMUNICATION SYSTEM

A radar-capable communication system is designed in such a way that enables simultaneous in-band full-duplex communication (IBFD) and opportunistic wireless sensing. This SDR-based system allows precise Doppler sensing by reusing the self-transmit signal as a probe to the environment. Due to insignificant radar processing overhead and minimal FPGA resource requirements, the RadCom system is privileged to the traditional in-band full-duplex designs, allowing for a broad range of applications such as body and hand gesture detection. The RadCom system is used in ORCA showcase “Low latency context-aware IoT control” on Page 34, where it controls an emulated drone and concurrently senses its reaction.



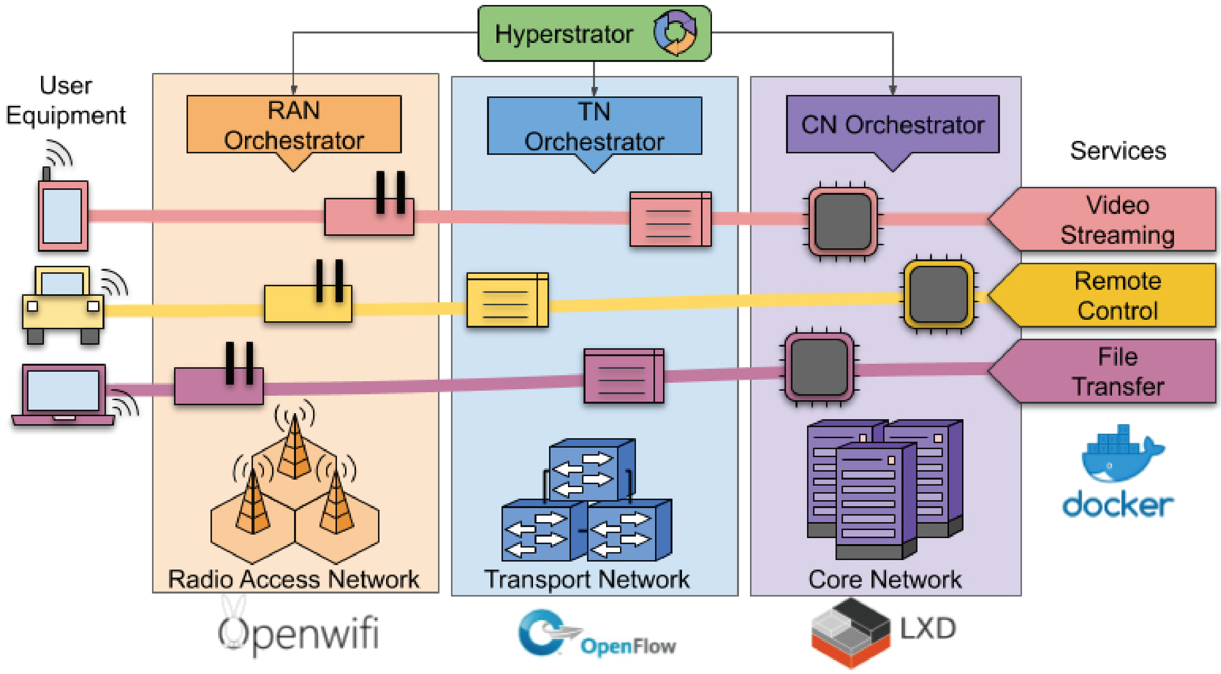
MULTI-RAT

The Multi-RAT platform for experimentation on RAT interworking technologies combines a Multi-RAT base station and terminal station. Both are running on NI USRP Software-Defined Radios (SDR) supporting LTE, WIFI and 5G radio access technologies. RAT interworking technologies such as LTE-WLAN aggregation (LWA) for LTE-WIFI interworking and dual connectivity (DC) for LTE-5G interworking are available. Runtime re-configuration driven by a centralized Multi-RAT controller unit allows orchestration of the setup. All RATs are implemented as full stack solutions supporting end-to-end data transfer.
The Multi-RAT platform as the core component of an industrial application is described in SC4 on page 38.



HOEN

The Hierarchical Orchestration of End-to-end Networks (HOEN) is an architectural framework for managing and slicing networks composed of different segments, e.g., radio access, transport and core networks. Our hierarchical orchestration approach allows each network segment to be independently managed and optimised by a specialised orchestrator, tailored for the particularities of each segment. We use higher-level orchestrator for coordinating the resource allocation across multiple network segments and deploying end-to-end network slices as a service. We provide a proof-of-concept implementation in ORCA showcase "Distributed End-to-end Network Slicing" on Page 36. We advise the reader to find more implementation details at: https://www.orca-project.eu/hierarchical-orchestration-of-end-to-end-networks/



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Orchestration and Reconfiguration
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