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D2.4: Development and Integration of Showcases in Year 2

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Abstract	This document specifies the showcases to be demonstrated after the development of year 2. The showcases were defined in D2.1 with the purpose of being examples of how people can use ORCA facilities, and the functionalities were described in D2.2 such that the experimenters can have a clear understanding of what ORCA can offer.
Keywords	

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EXECUTIVE SUMMARY

The ORCA project intends to offer **end-to-end (E2E) experimentation** facilities to the research community making use of novel **Software-defined Radio (SDR)** and **Software-defined Networking (SDN)** evolutions. Thus, this deliverable provides examples on how the ORCA showcases and functionalities can be utilized by external partners. Comparing to Y1, the showcases in Y2 are further extended to demonstrate the functionalities that have been improved. In particular, Showcase 1 demonstrates a high throughput mmWave system that can be configured in real-time in order to optimize the use of resources. In this year's showcase, mmWave link is demonstrated as backbone link in showcase4. Showcase 2 targets at demonstrating spectrum sharing capability of ORCA SDRs applied to remotely controlled robots while maintaining low latency link performance. Showcase 3 demonstrates the coordination between SDN and SDRs, as well as the different types of radio slicing and virtualization applied to different contexts. And finally, Showcase 4 aims to combine LTE and WiFi as well as 5G type of links into a unified experimental platform for RAT interworking studies with E2E capabilities.

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ABBREVIATIONS

AP	Access Point
CPU	Central Processing Unit
CR	Cognitive Radio
CLAWS	Cross-Layer Adaptable Wireless System
DSS	Dynamic Spectrum Sharing
E2E	End-to-end
FPGA	Field-Programmable Gate Array
GFDM	Generalized Frequency Division Multiplexing
IBFD	In-Band Full Duplex
IQ	In-phase and Quadrature
LWA	LTE-WLAN Aggregation
LWIP	LTE-WLAN radio level integration with IP security tunnel
MAC	Media Access Control
MCS	Modulation Coding Scheme
mmWave	Millimeter Wave
NFV	Network Function Virtualisation
OCM	On-Chip Memory
ORCA	Orchestration and Reconfiguration Control Architecture
QoS	Quality of Service
PHY	Physical Layer
RAT	Radio Access Technology
RF	Radio Frequency
SDN	Software-Defined Networking
SDR	Software-Defined Radio
TDD	Time Division Duplex
UD	User Device
USRP	Universal Software Radio Peripherals
V-TX	Virtualized Transmitter
VR	Virtual Reality

1 INTRODUCTION

Future wireless communication systems will need to consider new aspects that were not so important before. For instance, simultaneous applications that possess diverging Quality of Service (QoS) requirements and high data rates will use the same wireless infrastructure, which is certainly challenging for the upcoming technologies, since the systems will have to support more than one wireless technology. In addition, the amount and variety of devices connected to the network will increase substantially, which also brings new challenges. Moreover, the lack of available spectrum gives rise to Dynamical Spectrum Sharing (DSS) and Cognitive Radio (CR) networking. In order to deal this new and more complex communication scenario, Software-defined Radio (SDR) devices will be utilized to achieve the requirements previously described. With the capability of providing a flexible physical layer (PHY) transceivers by adapting its parameters at real-time, SDRs are suitable for future applications because they can adapt according to the network needs, resulting in a more efficient system where the resources are used more wisely. In conjunction with SDRs, Software Defined Networking (SDN) will allow the virtualization of PHY instances, creating logical networks that are capable of providing services to diverse categories according to QoS requirements.

In this context, ORCA intends to merge SDR, DSS and SDN into a framework in order to allow end-to-end (E2E) networking experiments to the research community and industry, including real-time SDR platforms with low-runtime latencies, high throughput and flexibility. These experiments are meaningful to several market segments such as manufacturing, automotive industry, health care, etc.

In order specify what the ORCA facilities can provide, four showcases were defined in deliverable 2.1 (D2.1) [1]. The showcases target at being a basis for the possible experimenters. Additionally, in deliverable 2.2 (D2.2) [2], it was defined the ORCA functionalities organized as SDR Data Plane, Basic SDR Control Plane and Advanced SDR Control and Management. Similarly to the showcase definition for year 1 exposed in deliverable 2.3 (D2.3) [3], this deliverable aims at demonstrating functionalities that were available for year 2. The summary of showcases are specified below:

Showcase 1 – The high throughput Millimeter Wave (mmWave) demonstrator will show the real-time re-configuration capability of the E2E link at 60GHz.

Showcase 2 – The low latency systems are used for industrial applications and will demonstrate different platforms remotely controlling robots in the same spectrum.

Showcase 3 – The low latency and high throughput demonstrator will show the different approaches to radio slicing, as well as the coordination between SDN and SDR to establish E2E services.

Showcase 4 – The Multi-Radio Access Technology (RAT) interworking platform will show various options to run E2E applications over multiple possible interworking radio access technologies such as LTE and WiFi.

2 SHOWCASE 1: HIGH THROUGHPUT

2.1 Motivation

The novel spectrum bands brought by the mmWave technologies will play an important role in the future communication systems. For instance, the data rate per user is expected to increase in the order of 10 Gbit/s. Due to limited bandwidth of conventional systems, the mmWave schemes become a very promising solution for these applications, since the bandwidth is largely increased in a way that users can experience higher data rates in cellular systems [4]. In addition, mmWave systems allow much more spectrum reuse than conventional systems, since the mmWave cells are much smaller and the transmitted signals are irradiated through narrower beams, decreasing interference substantially. Consequently, mmWave transmissions allow not only high throughput transmission due to large bandwidth spans, but it also supports larger number of users due to frequency reuse. Another feasible application is fronthaul or backhaul, in cases where wired connection are more expensive or not possible at all [5].

Another important aspect of future communication systems is the real-time reconfiguration capability. This is a key feature in order to allow efficient exploitation of the resources. Thus, this showcase intends to demonstrate the reconfiguration capability of the TUD mmWave communication system at 57-66 GHz. In particular, this real-time system can configure a beam-steering algorithm according to the channel behaviour, where the channel can be variant or static, depending on whether the user device is moving or not.

2.2 Demonstrator

This showcase targets at demonstrating the real-time re-configurability feature of the 60 GHz mmWave wave system (see [6] and [10] for details). The reconfigurable parameters include Modulation Coding Scheme (MCS), beam steering algorithm and mobility. Depending on the scenario, e.g., with or without mobility, MCS and the beam steering algorithm can be properly configured in order to maximize transmission rate with reasonable performance. Using an antenna rotation table, a mobility scenario can be simulated in a pre-defined way. The testbed is equipped with two moveable trolley structures depicted in the next figure. They are composed by the following components:

- *Sibeam V band transceiver and antenna array*: these components is capable of transmitting and receiving signals over-the-air in the V band, i.e., 57-66 GHz using the beam alignment feature.
- *Power Supply for Sibeam*: this component is simply the power supplier of the V band transceiver board.
- *PXI baseband chassis*: NI modular system based on PXI components to provide baseband processing and beamsteering MAC functionality

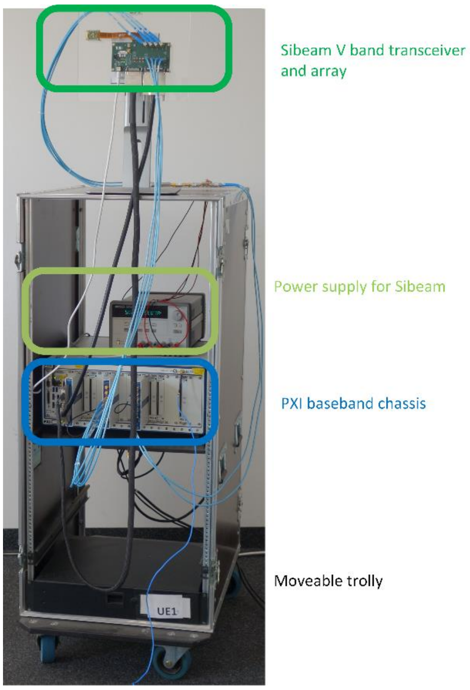

Figure 1 Testbed in a moveable trolley.

The demonstrator consists of two devices as the one depicted in Figure 1, which are the access point (AP) and user device (UD). The UD differs from AP with the rotation table where the antenna is mounted. The rotation table allows us to emulate mobility and study the system under more dynamical conditions.

2.3 Integration to Showcase 4 – mmWave backhaul

In year 2, we have integrated the mmWave demonstrator of Showcase 1 with the multi-RAT base station defined in Showcase 4, where the mmWave link will serve as the backhaul for the base station, as illustrated in Figure 5 in Section 5. Our motivation to perform such integration has two main aspects. First, the mmWave link as a backhaul solution will be common in future networks, in cases where fiber is not feasible to each cell, e.g., in cases of small base stations. Secondly, with this integration we demonstrate that this systems can be integrated to each other, increasing the range of possible experiments with the ORCA facilities. To avoid duplications, more details of this integration and how mmWave backhaul link is being used are available in Section 5.

2.4 Mapping to the ORCA KPIs

This showcase will contribute to the KPI’s 4 and 5. KPI 4 is related to use of real-time steerable antennas, and KPI 5 is related bi-directional Time Division Duplex (TDD) protocol enabling beam tracking. This showcase is in accordance with KPI 4 since we demonstrate a functioning real-time system exploiting the steerable mmWave antennas. Additionally, it is also related to KPI 5 since the beam tracking algorithm uses the bi-direction TDD protocol. This showcase demonstrates the capabilities to support the ORCA partners for performing research towards future communication networks.

2.5 Innovation Aspects

Main contributions & achievements

This showcase demonstrates a re-configurable real-time mmWave system with flexible beam steering algorithm and MCS. This setup is very relevant for research, since there is no cellular protocol with beam steering defined yet. With our mmWave equipment, this showcase intends to demonstrate the flexible real-time setup working under realistic environment. In addition, the mobility environment emulated by the rotation table can be further used for future research and experiments. Thus, the ORCA project achieves the goal of enabling mmWave related experiments to the research community and industry with our flexible mmWave system.

Additionally, this showcase is integrated with showcase 4, which can serve as an example for future experiments in TUD's testbed.

Beyond the state-of-the-art

This showcase investigates the benefits of having a real-time re-configurable mmWave link under mobility scenario. The outcomes are relevant for high throughput cellular systems. Since there is still no open real time cellular protocol available, this showcase can be a basis for future development of this technology.

2.6 Involved partners and their role

TUD provides and hosts the mmWave baseband including beam steering functionality with support of NI. NI will guide TUD to implement required changes to its platform to ease testbed management and configurability. This includes also the provision of additional configuration parameters if needed to control and monitor the NI platform. Furthermore, NI will provide guidance for planning of testbed experiments.

TUD is responsible for integrate the functionalities to the testbed and make it be accessible for external experimenters.

2.7 Conclusion

It is clear that the new spectral bands made possible by the mmWave transmission will play an important role for future communication systems. In particular, new applications such as Virtual Reality (VR) will demand high data rate transmission and cellular cells will be more dense. In this context, the real-time mmWave system of ORCA enables researchers to investigate the relevant aspects of PHY and MAC of these systems through TUD's testbed. Thus, this showcase was built in order to provide a flexible mmWave PHY structure with capabilities of real time reconfiguration, beam alignment and beam tracking, such that ORCA can contribute to the high throughput mmWave researches of the future communication systems, since the evaluation of new applications in a realistic platform will be made possible.

3 SHOWCASE 2: LOW LATENCY INDUSTRIAL COMMUNICATION

3.1 Motivation

Wireless communication systems for industrial applications is a major topic for the development of upcoming technologies, since it is not always possible or feasible to install complex cabled communication systems in a factory hall. Thus, with flexibility and potential of wireless systems, new applications that can improve the production processes are possible. For instance, remotely controlled robots will be deployed with more flexibility and less costs. In this cases, the wireless connection has to deal with low-latency, reliability and optimization of radio resources, since in general there are several applications that require the spectrum. In this context, this showcase aims at demonstrating the capability of ORCA's SDRs of sharing the same spectrum under the low-latency constraint, where three different systems work simultaneously to remotely control multiple robots, a scenario which is expected in an industrial factory. We also demonstrate how different PHY-MAC architectures developed by ORCA partners can communicate with each other, and with standard compliant off-the-shelf devices.

3.1 Demonstrator

Figure 2 shows the overview of the SC2 demonstration where five communication devices share the spectrum. The two KU Leuven SDRs benefit from an advanced cross-layer architecture which enables flexible run-time reprogramming of the MAC layer. These two SDRs are interfaced with two reverse pendulum robots. These brainless robots rely on the IMEC SDR, which plays the role of a central processing unit and generates appropriate commands for the robots to maintain balance. The IMEC SDR makes use of the TAISC framework running on an ARM processor for MAC layer, and IP cores in FPGA for PHY layer, making it both flexible and low-latency. This network has to provide low-latency communication between the clients, i.e. the balancing robots, and the processing unit in such a manner that minimizes the interval between reading the sensory data and applying moving commands. Still this network shares the spectrum opportunistically between the robots and the processing unit, while the GFDM has to provide a very robust low latency link providing sufficient data rate for the robotic arms.

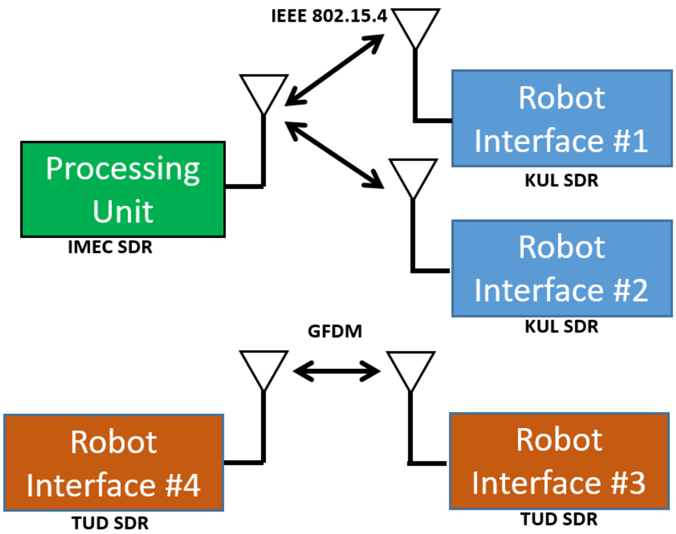

Figure 2 ORCA SC2 heterogeneous network for cloud-based remote robot controlling and efficient spectrum utilization

Additionally, the two KUL In-Band Full Duplex (IBFD) SDRs present a low-latency full duplex network in which concurrent send and receive is possible at the same channel. We demonstrate how

IBFD technology helps to improve latency and throughput in a real-life scenario. Employing flexibility, reconfiguration and re-programmability, this demo also shows a run-time half and full duplex mode selection.

Furthermore, IMEC demonstrates a five-node network, which comprises one SDR running 4 virtualized transmitters (V-TX), and four receivers running on 4 different devices. The V-TX is able to transmit the data at the same time on different channels. The four receivers operating at different frequency are capable to decode the data sent by V-TX, showing that the virtualized transmitters on SDR are operating correctly.

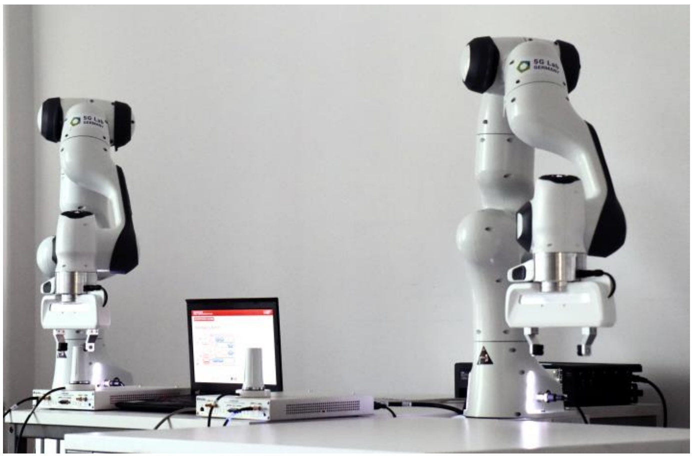

Figure 3 Demonstrator using FRANKA EMIKA robot arms connected to the USRP-SDR platform.

TUD shows a low latency, bidirectional link between two robot arms, like in Figure 3. The robot arm on the left is manually controlled, whereas the second arm is connected via a low latency link, ready to copy any movement. During several events, the visitor could experience the seamless remote operation of the second arm. The goal is to grasp different cubes and puzzles them together. This demo requires a robust link, because the second arm will stop moving if a certain packet error rate is exceeded. Further, this demonstrator shows a full control loop over a wireless system, due to the force feedback information that are send back from the second robot arm to the first. Thus, the operator/visitor controlling the first robot arm can feel the mass of the object or in case an obstacle is hit the respective impact.

3.2 Mapping to the ORCA KPIs

This showcase is related to KPI 7 (Implementation of a MAC protocol that operates with full duplex communication in real-time with at least 4 nodes), KPI 12 (Integrated SDR-SDN operation virtualizing a single physical network, involving a wired part (LAN) and a wireless part, into multiple virtual network, each virtual network (vertical slice) tailored to different traffic classes), and KPI 17 (Capability to change waveforms and/or MAC protocols during operation of the network (run-time reconfiguration)).

3.3 Innovation Aspects

Main contributions & achievements

This showcase illustrates how ORCA employs different technologies to establish a heterogeneous network of flexible standard compliant SDRs. The network is suited to satisfy latency restrictions required in an industrial scenario where multiple clients need reliable and real-time communication and efficient spectrum utilization.

Beyond the state-of-the-art

While most of the available off-the-shelf communication devices suffer from a rigid PHY realization or slow MAC implementation, the enhanced cross-layer adaptable wireless system (CLAWS) PHY-MAC architecture in the KUL SDR enables an application-dependent trade-off between flexibility and low-latency. Users can use a MAC protocol implemented in a MicroBlaze softcore, or alternatively rely on the fast bare metal dedicated MAC implementation that is tightly coupled with the PHY to achieve minimal latency. In addition, this implementation has a lot of features to interrupt the MAC from the PHY, e.g., for the transmitter based collision detection.

The IMEC SDR provides a flexible and low latency state-of-the-art solution, which in terms of latency, outperforms the off-the-shelf commercial chipsets. This is achieved by unifying the flexible MAC layer implemented in TAISC, a cross-platform MAC protocol compiler and execution engine and capable of modifying the MAC protocol even after deployment, running on ARM processor and low-latency PHY layer implemented in FPGA. Reducing turnaround time in PHY layer, employing On-Chip Memory (OCM) in ARM processor and low latency communication link between FPGA and ARM processor are the major sources of achieving low latency.

The GFDM transceiver shows a 300 µs link between two robotic arms enabling a control loop application running over a wireless network. Further, this demo needs to ensure that a specific packet error rate (less than 20 wrong packets) is not exceeded while maintaining a static packet rate of 10 packets per millisecond.

3.4 Involved partners and their role

TUD will apply the GFDM PHY to control a robot arm from distance by moving another robot arm in a different location. GFDM is able to avoid signals generated by KUL and IMEC radios, and make use of the remaining spectrum very efficiently.

KUL and IMEC will demonstrate a 3-node mesh network, comprising two different types of standard compliant SDRs. The network provides low-latency and reliable communication between two robots and a central processing unit.

KUL will also present a 2-node network, including IBFD devices and shows how full duplex technology improves the latency requirements in a real-life scenario, whereas IMEC demonstrates 4 virtualized Zigbee transmitters successfully operating on a single SDR.

3.5 Conclusion

This showcase demonstrates how different ORCA systems can work simultaneously by sharing the same spectrum, in which we utilize this functionality for an industrial application. Each of the systems is able to maintain a very low latency wireless link in order to reach the industrial use case requirements. The considered use cases in this showcase are (i) operating robots at dangerous locations remotely via a local robot whose movement is copied exactly with very low latency and (ii) balancing “brainless” robots by running processing algorithm running in the “cloud”.

4 SHOWCASE 3: LOW LATENCY AND HIGH THROUGHPUT INDUSTRIAL COMMUNICATION

4.1 Motivation

The first motivation of this showcase is to demonstrate how the functionality provided by ORCA can support diverse traffic requirements in industrial communication. On the one hand, today's radio hardware has dramatically evolved, and developers may expect redundant and programmable resources located very close to the radio front-end. One the other hand, most radio access technologies in commercial application still rely on dedicated hardware chipsets, while researchers in academic world often rely on processing power located in the host device such as a CPU. This showcase exploits processing power and resources at various locations to achieve flexible and efficient radio implementation. More particularly, the flexibility of radio will be established on virtualized radio instances, these instances can be easily constructed, configured, and replaced/removed.

Another motivation of this showcase is to demonstrate the integration of virtualized radio instances created on SDR devices with SDN. SDN is a more established field, aiming to achieve easily programmable network connections by separating the data and control planes of a network. Moreover, SDN is tightly compared and often coupled to Network Function Virtualisation (NFV). NFV is service oriented and processes interesting features to handle diverse traffic requirements. This showcase aims to exploit basic SDN/NFV functionalities and tools for establishing highly flexible radio network.

4.2 Demonstrator

The control plane of this demonstration has an SDN controller, which communicates with both TCD and IMEC radio infrastructure and an Open vSwitch [7] instance. In the data plane, there is a traffic source streaming data to a user application, also connected to the Open vSwitch. The considered data types include high throughput traffic such as video streaming, or low latency traffic such as health monitoring/emergency assistance applications. The user device has both IMEC and TCD virtual radio interfaces, which enable user traffic to be flexibly routed between the two infrastructures. The selection of one infrastructure or the other is triggered by certain events, such as a change in spectrum occupancy or in traffic load on the network. The SDN controller will then establish the necessary data path in the virtual wired network, and the selected radio infrastructure will initiate virtual radio instances and serve the traffic. Different virtual radio instances may be initiated or configured depending on the traffic type being served. For example, a high throughput traffic stream may be allocated with wider spectrum bandwidth than the regular traffic. The overview of this demonstrator is illustrated in the figure below.

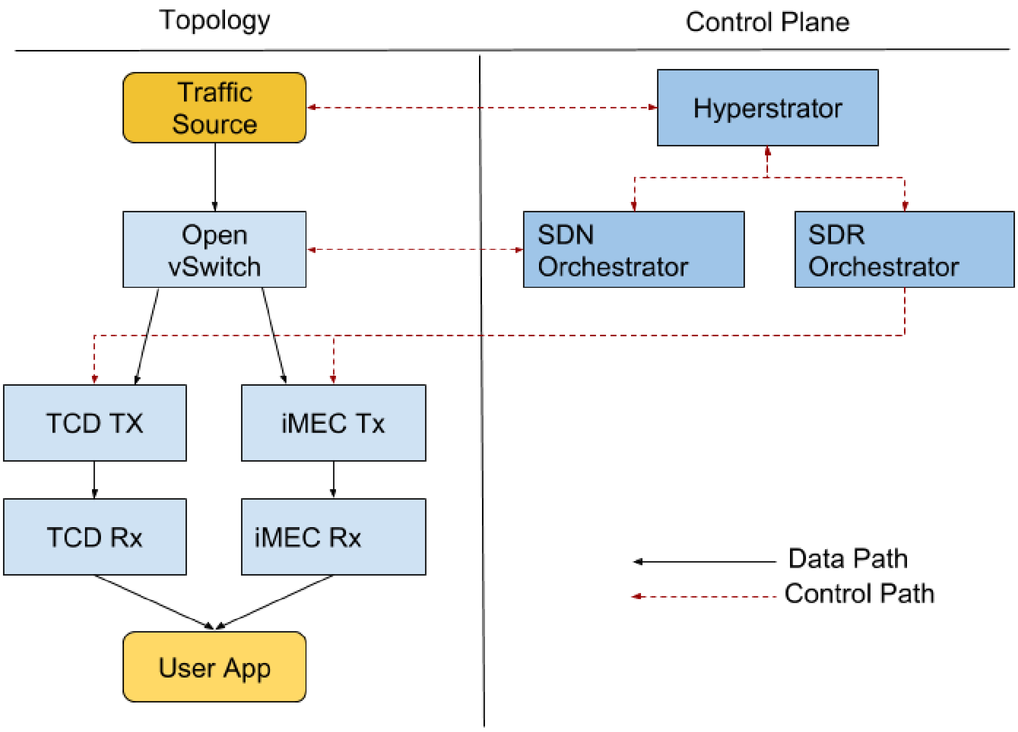

Figure 4 Showcase 3 demonstrator overview.

The virtual radios are created via two different approaches. TCD radio is using MySVL [8] running on host PC, which allows the flexible splitting and aggregation of radio spectrum allocated to multiple baseband IQ streams. The IMEC radio is using digital up/down conversion combined with filter banks on the FPGA of SDR device, allowing IQ samples of different radio stacks to be mapped to a set of predefined bands. It is also noted that the radio stacks (PHY, MAC, etc) of the 1st approach is realized on host CPU; whereas the 2nd approach allows radio stacks to be either partially or completely realized on the embedded device, and the virtualization of radio instance includes the radio stack, i.e. the PHY.

4.3 Mapping to the ORCA KPIs

This showcase is related to KPI 12 and KPI 13. KPI 12: “Integrated SDR-SDN operation virtualizing a single physical network, involving a wired part (LAN) and a wireless part, into multiple virtual network, each virtual network (vertical slice) tailored to different traffic classes.” KPI 13: “Split of control and data plane and dual connectivity of user terminal.”

4.4 Innovation Aspects

Main contributions & achievements

The main achievements of this showcase are (i) radio virtualization via different approaches (host PC vs FPGA), and (ii) the integration of basic SDN functionality with SDR to realize a virtualized network in joint wired and wireless network.

Beyond the state-of-the-art

There exist some efforts to bridge SDN with SDR, a quite known one is the SDN-R [9] initiated by ONF, aiming to extend an SDN controller for radio communication. This work however uses a different approach, each network segment has its own "manager", they still jointly communicate to create E2E network slices, rather than extending/porting an existing manager to do global control. We believe this approach is beyond the state of the art, and has long term benefit as each network segment has full freedom for network optimization.

4.5 Involved partners and their role

TCD and IMEC are involved in this showcase. TCD and IMEC each made development of radio virtualization in a different manner. TCD also made contribution of the basic SDN controller and configuration of the virtual switch in wired network setup. Both TCD and IMEC made developments to communicate with the SDN controller to reach E2E network connection.

4.6 Conclusion

In conclusion this showcase illustrates radio virtualization achieved in two different approaches, one approach is implemented on host PC using MySVL, which has advantage at flexibility; whereas the other is implemented in FPGA using digital up and down conversion combined filter banks, which is more optimized for performance in terms of processing bandwidth and latency. The virtualized radios can be instantiated to cope with network request, which is achieved by integrating with SDN functionality.

5 SHOWCASE 4: INTERWORKING AND AGGREGATION OF MULTIPLE RADIO ACCESS TECHNOLOGIES

5.1 Motivation

The focus of this showcase is drawn towards the heterogeneous usage of multiple RATs. Current communication networks incorporate multiple such technologies, which can be used to deliver specific services to the user. While previous research was drawn towards investigations on a single RAT the intention of Showcase 4 is to combine different access technologies in a single testbed to enable research and experiments regarding trade-offs when technologies such as 3GPP LTE, Wireless LAN 802.11 and 5G are used and are working together to exchange data. This showcase shall shed light towards optimal operation of data transmission over these technologies and reveal drawbacks and advantages.

5.2 Demonstrator

The overall targeted Multi-RAT experimentation platform is described in detail in D2.1 [1]. The demonstrator that visualises the implementation results from Year 2 is shown in Figure 5. The applied functionality in this demonstrator is explained in technical detail in deliverables D3.3 [10] and D4.3 [11].

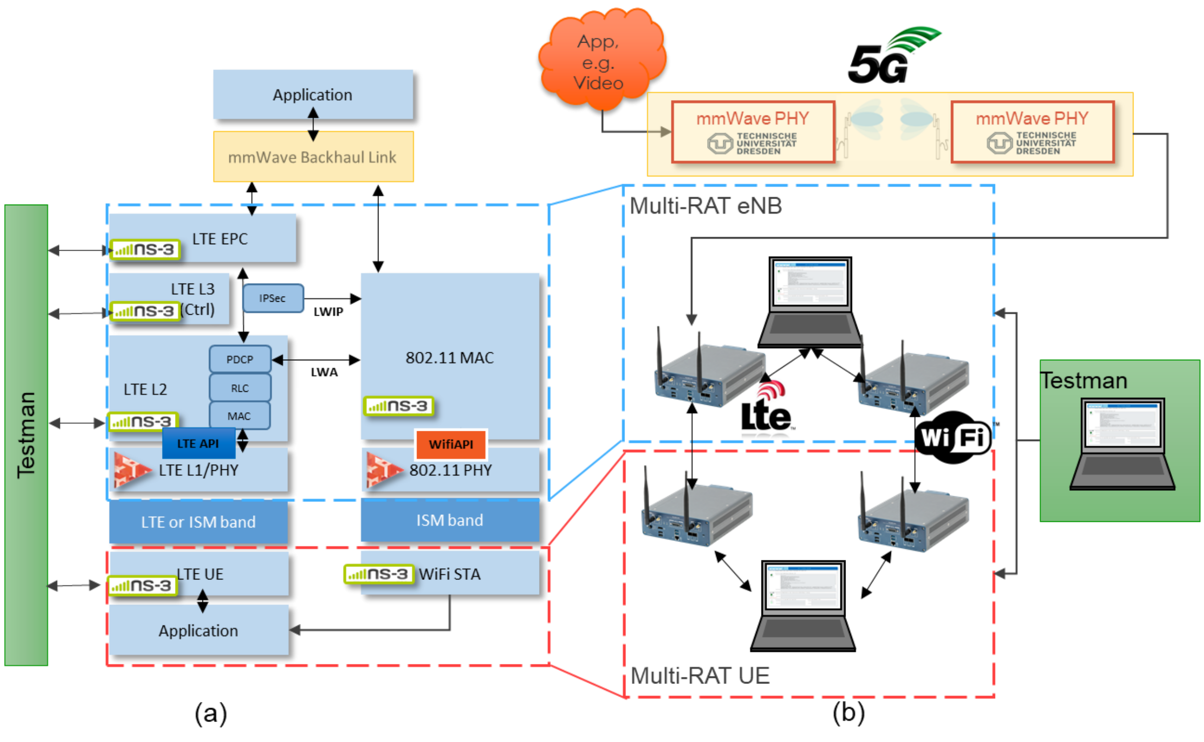

Figure 5 Showcase 4 demonstration scenario from Year 2.

Particularly, the showcase demonstrator aims to integrate the new real-time capable LTE implementation incorporating the new generalized L1/L2 API on LTE Application Framework side as well as on the ns3 side. As a hardware option for this showcase, the new USRP-2974 is considered as it integrates an Intel CPU such that the real-time host implementation of the LTE application framework as well as the ns3 instances for the different entities can run directly on this device, minimizing the hardware effort. The LTE eNB and WiFi Access Point are logically combined to a Multi-RAT base station serving a virtual Multi-RAT UE. To reconfigure different parameters of the setup, a control PC is used with the TestMan implementation for ns3 remote-control, which was implemented in Y2 and is described in D4.3 [11].

To emphasize the possibility to integrate a mmWave link into the setup, in this scenario the 60GHz mmWave system described in D3.1 and D3.3 is used as a back haul link. with the described functionality from Section 2 to integrate Showcase 1 and 4. This can be seen as a first step towards integration of 5G capable technology into the RAT interworking showcase as mmWave backhaul links will become broadly available in cases where fiber connection of base stations to the core network are too costly to be deployed.

With the setup of this showcase, experimenters can start diverse experiments, incorporating simple networking examples and more involving interworking technologies such as LTE-WLAN Aggregation (LWA) and LTE-WLAN radio level integration with IP security tunnel (LWIP).

5.3 Mapping to the ORCA KPIs

The Year 2 activities were focusing on further enhancing the data plane of the platform as well as the introduction of a remote-control interface that will enable a split of data and control plane. Additionally, the logical merge of LTE and WiFi devices in a single node of ns3 enables connectivity of a user terminal over two different RATs. These two focus areas of Year 2 map directly to KPI 13 (Split of control and data plane and dual connectivity of user terminal). The addition of RAT interworking techniques such as LWA and LWIP in Year 2 through the Open Call 1 for Extension and the incorporation into the overall Multi-RAT networking example have drawn insights into the interaction of two radio access technologies and therefore map directly to KPI 14 (Interaction between two RATs to research where and how legacy and 5G RAT need to exchange information).

5.4 Innovation Aspects

Main contributions & achievements

The main contribution of this showcase is the integration of multiple radio access and transmission technologies into a single platform for experimentation. The LTE and WiFi systems are now completely real-time capable and therefore closer to real stack implementations of the market. Furthermore, the E2E capabilities shown in this Showcase allow for a diverse application involvement to understand the influence of different applications on the transmission and usage of various RAT interworking strategies. The remote control gives the experimenter two options at hand. First, simple reconfiguration of the platform can be achieved. Secondly, the remote control can also be used to envisage simple SDN-type of control experiments. Lastly, the introduction of support for the USRP-2974 is of great advantage as it reduces the hardware footprint in the testbed.

Beyond the state-of-the-art

The showcase 4 claims to be the first prototyping and experimentation platform that involves interworking between LTE and WiFi, with additional E2E inclusion of a 5G mmWave link. Such a diverse setup was not made available before to do experiments. The anticipated gains of interworking technologies that are shown in the literature can now be proven with real experiments. For such scenarios, a fast adaption of the complete setup is needed. NI's prototyping platform including latest SDR technology with a streamlined toolflow, and the additional incorporation of ns3 as a widely used network simulation environment, fulfil these constraints and equip researchers and experimenters with the necessary tools.

5.5 Involved partner and their role

NI:

- Provides the Multi-RAT platform prototype setup for RAT interworking studies with 3GPP LTE and 802.11:
    - LabVIEW based real-time implementations of 3GPP LTE and 802.11 PHY layer running on standalone USRPs or USRPs with PXI connection
    - Real-time capable L1/L2 APIs for LTE and WiFi to interconnect 3GPP LTE and 802.11 PHY layers to the upper layers within ns3
    - Ns3 extensions for networking examples as well as interworking technologies (LWA/LWIP)
    - Remote control of the setup via TestMan interface

TUD:

- Provides the mmWave link Physical layer and beamsteering MAC implementation with necessary interfaces for E2E capabilities

5.6 Conclusion

Within Showcase 4 the goal is to gain insights into interworking techniques between multiple RATs such as LTE, 802.11 as well as 5G. The described Year 2 platform allows for transmission using either LTE or the Wifi system but also incorporates routing to a combined LTE/Wifi UE as well as interworking strategies between these two radio access technologies using the latest real-time capable implementation of the PHY layers. The incorporation of a mmWave link as a 5G backhaul option further enhances the possibilities of experiments in the context of E2E application experiments involving different transmission technologies. Lastly, remote control paves the way towards free orchestration of the platform into the direction of SDN-like approaches.

6 CONCLUSIONS

In the deliverable D2.1 [1], ORCA defined four showcases that exemplify how the facilities can be explored from a general viewpoint. Also, many functionalities were described in D2.2 [2] such that ORCA capabilities can be easily consulted by interested third parties. Therefore, this document was designed as a complement of D2.1 and D2.2, in which we report how the ORCA functionalities can be explored in a more detailed and practical manner. In particular, Showcase 1 demonstrates a high throughput mmWave system that can be configured in real-time in order to optimize the use of resources. Showcase 2 targets at demonstrating spectrum sharing capability of ORCA SDRs applied to remotely controlled robots while maintaining low latency link performance. Showcase 3 demonstrates the coordination between SDN and SDRs, as well as the different types of radio slicing and virtualization applied to different contexts. And finally, Showcase 4 aims to combine LTE and WiFi as well as 5G type of links into a unified experimental platform for RAT interworking studies with E2E capabilities.

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