(one6G)

Taking communications
to the next level

PROTOTYPING IN 2023

Working group 4

WHITE PAPER

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one6g.org

Executive Summary

Demo1: The Brasil 6G project aims to develop advanced solutions for 6th-generation mobile communication networks, enabling Brazil to emerge as a hub for information and communication technologies. The project seeks to address national demands in upcoming communication standards, while also developing solutions adapted to the national context based on existing standards. This initiative provides the national industry with an opportunity to position itself in the development and implementation of 6G networks.

Demo2: Exploring the potential of telerobotic medical examinations by expanding on the telediagnostics framework developed in the research project ProteCT. Besides their promising use in telemedicine, emerging robotic applications can play a key role in supporting medical staff in many other areas of the hospital. To maximize synergies, it is essential to develop a fully interconnected medical environment. 6G, as a powerful wireless access technology can hereby help to deeply integrate robotic systems in hospitals and enable the development of truly intelligent novel healthcare applications.

Demo3: Revolutionizing the control of robotic systems by building a human robot interface which is intuitive and accurate. Extend Robotics demonstrates intuitive human robot interface which provides seamless connection between humans and robot using minimal hardware and with negligible latency. This kind of interface provides easy adoption of robots at affordable cost which is crucial for large scale deployment of robots in society and for industrial purposes. The Advanced Mechanics Assistance System (AMAS) from Extend Robotics turns a real robot into a physical avatar with fully immersive remote workspace and 3D vision. Showcase a robotic arm (weight ~approximately 7.5 Kg) to be controlled through VR headset and gesture joystick control.

Demo4: The robot MELISAC (Machine Learning Integrated Sensing And Communication) is a research testbed of the intelligent dual-arm-robot empowered by 6G technologies. It is powered by a large language model (LLM), which gives it the ability to understand and respond to natural language. It can leverage both Terahertz signal and optical signal for sensing objects with high resolution. The Terahertz signal can be used for data transmission in the sense of ISAC (Integrated Sensing And Communication). This allows to perceive the world around it in a highly detailed and accurate way, and to communicate with other devices and humans in real time.

Demo5: demonstration of 12.5 Gb/s transmission in the sub-THz frequency band by using 6.25 GBaud QPSK signal. The flexible testbed allows for real-time processing to generate and demodulate wide band IQ-signals, but also to research and develop sub-components of the system such as up- and down-converter. In this demo, the signal quality is evaluated in terms of bit error rate and constellation diagrams of the actual link. The demonstration is the result of a cooperation between Keysight and Karlsruhe Institute of technologies.

Demo6: real-time simulations of beyond 5G localization fully compliant with 3GPP specifications and environments, in both microWaves (FR1) and mmWaves (FR2), with possibility to fuse different types of measurements. A menu-driven GUI enables to select environments, frequency range, bandwidth, and type of measurements according to 3GPP specifications

Demo7: demonstrate a real-time system developed for tracking and classifying multiple targets moving in complex wireless environments (e.g., indoor environments) using a single MIMO radar operating at mmWaves. In particular, the system proposes machine learning-based clutter mitigation and target detection to reduce the severe clutter and the multipath propagation that affect reflected waveforms in harsh propagation conditions. Given a set of detections the proposed approach performs: (i) multi-target tracking (MTT) relying on a soft-decision data association and (ii) classification employing a deep neural network.

Demo8: 6G Integrated communication and sensing in sub-THz band with 270GHz based on Huawei baseband / IF boards and R&S frequency up/down converters for H-Band (220 to 330 GHz) [8].

Rohde & Schwarz and Huawei have demonstrated subTHz ISAC with multi-static ranging based on Huawei ISAC prototype and the new R&S high quality up-/Down-converter devices during the one6G summit 2023 in Munich.

Demo9: In Tele-Operated Robotics, i.e. robots controlled from a distance away, numerous difficulties arise with regards to the communication of data. Especially when multiple modalities (e.g. vision, arm control, audio, hand control) are used, there are several data streams each with their own deadlines which needs to be met. This leads us to present the following communication challenge: QoS optimalisation of multiple channels which need lots of bandwidth, at high update frequency, low latency, and synchronicity between the channels.

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1. Introduction

Objectives of one6G association are to evolve, test and promote cellular and wireless technology-based communications solutions, to support future global 6G research directions and their standardisation and to accelerate their availability and global market penetration in order to address society's connected mobility and industry needs with regard to future applications such as advanced autonomous driving, advanced manufacturing, advanced wireless e-health and others.

Different working groups (WG) has been established to prepare, approve and maintain the association's reports, white papers, and other outputs within the overall scope of their activities e.g. on technology overviews [3] and vertical use cases like WG1 [4]. Saying this Working group 4 covers all the steps from development to deployment, defining of testing procedures, setup of testbeds and trials jointly with the one6g members. Evaluation guidelines for all simulation, emulation and prototyping activities has been compiled and are available for members since 2022 [2].

Besides the continues work one major goal is to organize events in particular the annual *one6g summit* since the founding in 2020 where one6g partners presents and demonstrates their achievements in prototyping of 6G technologies and testbeds.

It is significant for the continuously increasing number of members and the scientific cooperation between the partners that the 2023 one6g summit stood out especially for the diversity of the exhibitors.

At 9 stations the visitors of the summit examine the various technical solutions and discuss them with the developers and researchers. Perhaps it was due to the work items on robotics [1] launched in 2023 that a significant portion of the demo also had robotics as a new promising use case for 6G to core.

On behalf of working group 4, the chairmen of the working group would like to thank all exhibitors whose assistances and supporters in the background for the one6g summit 2023 whose exhibits are described more closely in the following chapters. Of course, the expectations for 2024 are correspondingly high.

2. Abbreviations

6G	Sixth Generation of mobile communication system
ADC	Analog Digital Converter
AI	artificial intelligence
AR	Augmented Reality
BS	base station
CPU	central processing unit
ECA	error correction amplitude
eMBB	Enhanced Mobile Broadband
FDD	Frequency Division Duplex
GPGPU	general purpose graphics processing unit
GPU	graphics processing unit
Inatel	National Institute of Telecommunications
IPC	inter-process communication
ISAC	Integrated Sensing And Communication
ISAC	Integrated Communication And Sensing
LLM	Large Language Model
MAC	medium access control
MCS	modulation coding scheme
OR	Operating Room (surgery)
PHY	physical layer
QoS	quality of service
RAN	Radio Access Network
RIS	Reconfigurable Intelligent Surfaces
RF	Radio Frequency
SDR	software-defined radio
SIMD	single instruction multiple data
SNR	signal-to-noise ratio
TDD	Time Division Duplex
THz	TeraHertz Frequency
TVWS	TV white space
UE	user equipment
UHF	Ultra-High Frequency
URLLC	Ultra-Reliable Low Latency Communication
VLM	Vision Language Model
VR	Virtual Reality
XLA	Accelerated Linear Algebra

3. Demo #1

Brasil 6G Unlicensed Transceiver for Connectivity in Rural and Remote Areas

3.1. Abstract

The Brasil 6G Project is a national initiative for the creation of an ecosystem for the development of the Sixth Generation of mobile communication system (6G) in Brazil, capable of meeting important applications and use cases for the country's economic and social development. This project is coordinated by National Institute of Telecommunications (Inatel) with the collaboration of several Brazilian research institutes that aims to create a unified platform for the development of the next generation of mobile network. One of its proposals is the implementation of a real-time Radio Access Network (RAN) system that explores multiple technologies of the physical, data link, and network layers, using only off-shelf computers and software-defined radio (SDR). These features enable the usage of high-performance programming languages without the development of specific hardware, making it a more attractive and less costly option. The proposed prototype is the evolution of the 5G IoT transceiver, which was developed to provide Internet access to remote and rural areas. Thus, for the Brasil 6G Project, the former platform has been improved to meet some of the use cases and technological requirements inherent to the next generation of mobile networks. Among these features, the proposed demonstration will harbor artificial intelligence (AI) controlling, multiple simultaneous users, spectrum sensing, new waveforms, and long-range communication for remote and rural areas, providing comprehensive coverage and greater digital inclusion. As widely known, Brazil is a country with a large territorial extension and an important supplier of agricultural products. Therefore, the introduction of this technology in agribusiness will improve productivity by providing field automation, precision agriculture, and real-time information of crops, livestock, soil, weather, and agricultural machinery. Figure 1 illustrates some of the use cases that are being addressed by the Brasil 6G Project.

Figure 1: Use cases covered by the Brasil 6G Project.

3.2. 6G use cases and key technologies

The 6G transceiver developed in the project stands out as a low cost solution to provide connectivity for remote and rural areas, and consequently promote an increase in rural productivity. Figure 2 presents the block diagram of the proposed network illustrating applications for smart farming and agribusiness.

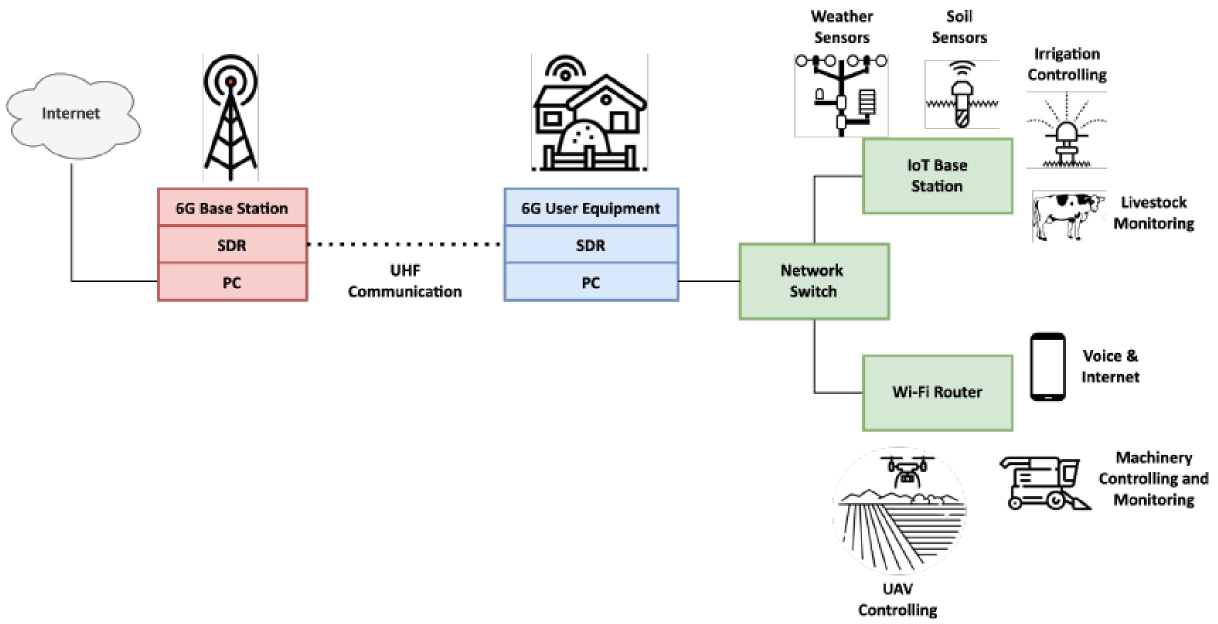

Figure 2: 6G Network: block diagram of system applications for agribusiness.

In this system, the user equipment (UE) is located as far as 50 km of the base station (BS), where the recent networks would not offer any coverage. The UE consists of an SDR and an off shelf computer embedded with an Ethernet infrastructure capable of providing Internet access to the base stations for weather, soil, and livestock monitoring, and other Wi-Fi dependable systems, such as smartphones, drones, and agricultural machinery. The BS, by its turn, operates with a similar equipment, which greatly reduces the implementation cost of the solution. The BS and UE communicates over the Ultra High Frequency (UHF) band by exploring TV white space (TVWS). In this case, the BS transceiver is embedded with spectrum sensing capabilities that allocates transmission to vacant channels without interfering other primary users, as depicted in Figure 3. Field tests were carried out with this network, which was able to provide a coverage radius of 50 km, reaching rates of 100 Mbps. The prototype of both BS and UE are illustrated in Figure 4.

Figure 3: Demonstration of the dynamic spectrum allocation.

Figure 4: Base station and user terminal used in the 6G network demonstration.

3.2.1. Demonstration

The 6G transceiver includes features, such as AI controlling, spectrum sensing, new waveforms and multiple users support. This new transceiver will inherit all its predecessor structure, wherein all signal processing and package management were performed by software-level applications coded in C/C++ or Python, and RAN was controlled by the GNU Radio [5] framework.

To implement multiple users support and AI controlling, the transceiver network stack was remodeled, as depicted in the block diagram of Figure 5. Here, the medium access control (MAC) layer was developed to interface the Ethernet network with the transceiver by managing the physical layer (PHY) and the user data transmission and reception. The inter-process communication (IPC) layer intermediates the data traffic between MAC and PHY. Finally, in the PHY layer, wireless signal transmission and reception is performed by integrating multiple processing techniques such as channel coding/decoding, digital modulation/demodulation, and frame formatting. Moreover, the prototype will feature an AI-based solution capable of adapting physical layer parameters to increase throughput and link reliability. In this case, the algorithm will define the next modulation coding scheme (MCS) profile based on error correction amplitude (ECA), signal-to-noise ratio (SNR), current MCS, and quality of service (QoS) target. The implemented solution is based on reinforcement and machine learning techniques and employs low complexity neural networks on the link adaptation procedure. This approach has proven to improve the data rate by defining a suitable modulation scheme for the link.

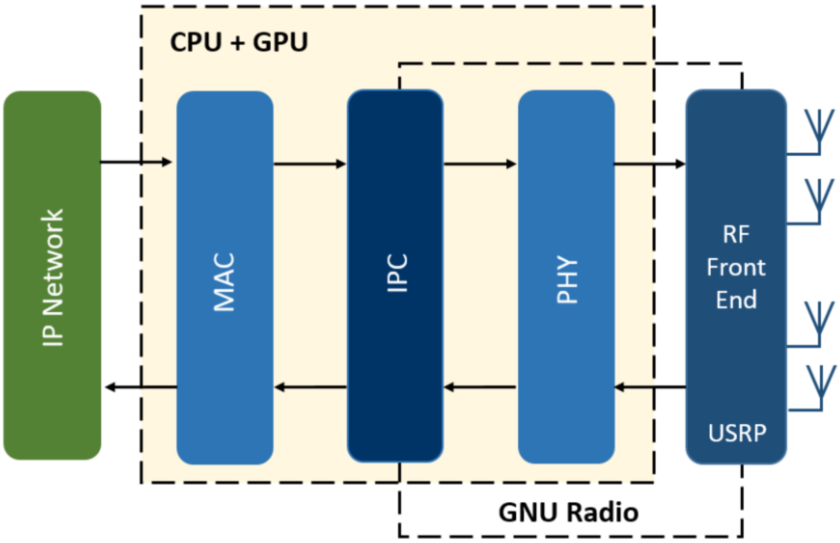

Figure 5: Block diagram of the multiuser transceiver layers.

The Brazil 6G Project proposes the demonstration of a 6G communication platform, showing its operation in real-time. This section describes the main hardware and software components that have been used in the development of the 6G transceiver.

3.2.2. Hardware Description

The main platform for implementing the 6G transceiver physical layer functions is based on SDR, using general purpose processor (GPP) and the GNU Radio [5] framework. Such an approach allows for high flexibility, where different radio components can be used by modifying the code. This characteristic provides the possibility to dynamically change radio settings during the communication. Moreover, SDR is a very low-cost option when compared with dedicated hardware solutions, also delivering a fast development time. Table 1 describes the main hardware characteristics used for the transceiver implementation.

Table 1: Transceiver's hardware characteristics.

Hardware Element	Characteristics
CPU	Intel® Xeon® Gold 5220, 3.9GHz 18 Cores/36 Threads, 64 GB of RAM
GPU	Nvidia® Geforce™ RTX 3070 8GB 5888 cuda cores
SDR	National Instruments USRP 2954R
System Sample Rate	30.72 MHz

3.2.3. Software Environment Description

The operating system used for the prototype is Canonical Ubuntu 20.04 (Focal Fossa). The kernel version is v5.13, once this is the minimum requirement for the video card compatibility. GNU radio modules are written in Python and C/C++ languages. Acceleration is necessary for real-time operation. Thus, libraries, such as Numba [6] (Python), and techniques, such as single instruction multiple data (SIMD) and Volk library [7] (C/C++), are used.

The transceiver includes an Nvidia GeForce RTX 3070 graphics card to increase processing power for AI algorithms. This component is used as a general purpose graphics processing unit (GPGPU) to improve the performance of machine learning algorithms, i.e., TensorFlow [8], whether used for training or inference. Applications that facilitate their use are bundled, such as Keras [9]. Other tools are also used to support visualization and acceleration, such as TensorBoard and the Accelerated Linear Algebra (XLA) compiler, which optimizes TensorFlow calculations.

Some of the main tools and libraries employed in central processing unit (CPU) and graphics processing unit (GPU) processing are listed in Table 2.

Table 2: Transceiver Libraries.

	Library	Version	Source
CPU	GNU Radio	3.9.2	https://github.com/gnuradio/gnuradio.git
	Volk	2.5.0	https://github.com/gnuradio/volk.git
	AFF3CT	2.3.5	https://github.com/aff3ct/aff3ct.git
	USRP	4.1.0	https://github.com/EttusResearch/uhd.git
GPU	Tensorflow	2.7.0	https://www.tensorflow.org/install/source\#gpu
	Nvidia Driver	510.47	https://www.nvidia.com/Download/driverResults.aspx/186156
	CUDA	11.6	https://developer.nvidia.com/cuda-downloads
	cuDNN	8.4.0	https://developer.nvidia.com/cudnn

3.3. Planned extensions

The Brasil 6G transceiver stands out for its ability to modify implemented functions and incorporate new features into the system. Some planned actions that will be modified/included in the device are:

- Changing the spectrum allocation technique from FDD (Frequency Division Duplex) to TDD (Time Division Duplex) to increase the spectral efficiency of the system.
- Replacing the USRP 2954R device with the BladeRF device to reduce the transceiver costs.
- Integrating Reconfigurable Intelligent Surfaces (RIS) in high-frequency scenarios to increase coverage.

3.4. Exhibitor

The Brasil 6G Project is coordinated by Inatel and funded by the Brazilian government, with the collaboration of several Brazilian universities, research institutes, and companies such as: RNP (Rede Nacional de Ensino e Pesquisa), Advantech, UFG (Universidade Federal de Goiás), UNISINOS (Universidade do Vale do Rio dos Sinos), UFSC (Universidade Federal de Santa Catarina), UFPA (Universidade Federal do Pará), UFC (*Universidade Federal do Ceará),* UFU *(Universidade Federal de Uberlândia),* UNICAMP *(Universidade Estadual de Campinas*), Instituto de Pesquisas Eldorado, UFRJ *(Universidade Federal do Rio de Janeiro),* and CPQD *(Centro de Pesquisa e Desenvolvimento em Telecomunicações).*

3.5. Contact information and references

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- one6G summit 2023 [10]
- one6g youtube channel [11]

4. DEMO #2

6G Healthcare: Integrating New Network Approaches in Medical Robotics Applications

4.1. Abstract

The COVID-19 pandemic highlighted two fundamental and threatening bottlenecks: The increasing shortage of medical staff and a backlog in the development of telemedicine for basic examinations. To address these challenges, the tele-diagnostics framework which we developed in the BMBF-funded research project ProteCT (Protection against the Coronavirus through Telemedicine) allows medical staff to examine patients from a safe distance and explores the possibilities of medical check-ups performed with the help of a sensitive robotic arm.[1]

Even after the pandemic, there are still many medical applications in which telemedicine can create added value. For instance, before a surgery in a specialized center can take place, patients must make multiple journeys to the clinic for pre-checks and diagnostics. After surgery, follow-up appointments and wound control are usually necessary. For people living far away or in rural areas, this is associated with a lot of traveling effort. A telerobotic diagnostic examination system could help reduce this effort for patients.[2]

On an architectural level, this in turn requires a decoupling of patient and physician side and a more powerful and flexible network infrastructure, as a direct cable connection between the two modules is no longer feasible. New network approaches such as 6G can meet the requirements of data security, low latency and high data rates necessary for such a telerobotic system. With envisioned 6G capabilities like in-network computing and intelligent data routing, it can even enable the flexible and redundant processing of resource-intensive, intelligent applications within the network itself.[3]

Besides their promising use in telemedicine, emerging robotic applications can play a key role in supporting medical staff in many other areas of the hospital. In operating rooms (ORs), robots can perform assistive tasks in the form of robotic scrub nurses or circulating nurses. [4,5,6] On patient wards, mobile robotic platforms could help by performing logistics tasks or assisting nurses.

To maximize the benefit for the healthcare system, a holistic approach is necessary to make use of synergies between all these medical robotic systems. For this, it is essential to develop a fully interconnected environment within the hospital. 6G as a powerful wireless access technology can help to integrate the different robotic applications in hospitals, hereby enabling the development of truly intelligent novel healthcare applications.

[1] Fuchtmann, J., Krumpholz, R., Berlet, M. *et al.* (2021). COVID-19 and beyond: Development of a comprehensive telemedical diagnostic framework. International Journal of Computer Assisted Radiology and Surgery, 16(8), 1403–1412. https://doi.org/10.1007/s11548-021-02424-y

[2] Berlet, M., Fuchtmann, J., Krumpholz, R. *et al.* (2024). Toward telemedical diagnostics—Clinical evaluation of a robotic examination system for emergency patients. DIGITAL HEALTH, 10, 20552076231225084. https://doi.org/10.1177/20552076231225084

[3] Kolb, S., Jurosch, F., Kröger, N. *et al.* (in press). 6G in Clinical Applications: Integrating New Network Approaches in Healthcare. *Current Directions in Biomedical Engineering*.

[4] Bernhard, L., Amalanesan, A.F., Baumann, O. *et al.* Mobile service robots for the operating room wing: balancing cost and performance by optimizing robotic fleet size and composition. *Int J CARS* 18, 195–204 (2023). https://doi.org/10.1007/s11548-022-02735-8

[5] Kuluru, M., Sirasala, S., Jammalamadaka, *et al.* (2021) Collaborative Robot as Scrub Nurse. *Current Directions in Biomedical Engineering*, vol. 7, no. 1, pp. 162-165. https://doi.org/10.1515/cdbme-2021-1035

[6] Wagner, L., Kolb, S., Looschen, C. *et al.* (2023) Versatile end effector for laparoscopic robotic scrub nurse. *Int J CARS* 18, 1589–1600. https://doi.org/10.1007/s11548-023-02892-4

4.2. 6G use cases and key technologies

The presented demonstrator shows the robotic examination module of the telerobotic diagnostics framework, enabling a physician to remotely perform physical examinations on patients. The design of the examination cabin enables a complete routine medical check-up – from temperature, and blood pressure measurements, oxygen saturation and otoscopy, to robotic ventral and dorsal auscultation, tapping and abdominal palpation. It further includes the capability for oropharyngeal inspection and throat swab taking. The bilateral teleoperation system enables bidirectional haptic interaction between the examining physician and the patient using two robotic arms coupled via joint-based mapping. The system architecture is visualized in Figure 6.[7]

To enable the spatial decoupling of the demonstrated system, the connecting network must provide reliable, ultra-low latency connections for huge amounts of data to match the performance of a direct LAN connection. As the use of medical images for diagnostics requires high resolutions and high color depth, the available bandwidth must enable the integration of multiple high-quality streaming channels. At the same time, there must be a high synchronicity between image streams and robotic control commands to allow an efficient physician-patient contact and enable a remote examination comparable to one on-site. Using the 6G key feature of in-network computing will allow the development of more flexible systems at the end user side, as many computationally intensive processes can be offloaded. Combined with intelligent data routing, the use of distributed robotic architectures within the network can provide an increase in performance as well as reliability.[8] This approach is what we are aiming to implement within the BMBF-funded research project 6G-life. Overall, the emerging features envisioned in 6G shall enable a push in telerobotic technologies and medical robotics in general.

Figure 6: : Telerobotic diagnostics framework. (1) Medical history and vital parameter assessment. (2) Robotic oral cavity inspection and swab sampling. (3) Bilateral multifunctional teleoperation system. (4) Safety hatch for additional manual diagnostics, e.g. blood sampling.[9]

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[7] Naceri, A., Elsner, J., Tröbinger, M. *et al.*, (2022) Tactile Robotic Telemedicine for Safe Remote Diagnostics in Times of Corona: System Design, Feasibility and Usability Study. *IEEE Robotics and Automation Letters*, vol. 7, no. 4, pp. 10296-10303, doi: 10.1109/LRA.2022.3191563.

[8] Kolb, S., Madden, A., Kröger, N. *et al.* (manuscript submitted for publication). 6G in Medical Robotics: Development of Network Allocation Strategies for a Telerobotic Examination System. *Int J CARS.*

[9] Fuchtmann, J., Krumpholz, R., Ostler D. *et al.* (2021). New Method for Surgical Diagnostics—A Robotic Telemedical Approach. Surgical technology international, 39, 28–33. https://doi.org/10.52198/21.STI.39.SO1498

4.3. Planned extensions

The networking concepts planned for the telerobotic examination platform can also be transferred to other medical robotics applications in the hospital. Mobile robots in particular can benefit from aspects of the network-based distributed control, as it allows the development of smaller platforms. In crowded hospital environments, that is an important feature. Furthermore, the energy consumption of mobile platforms can be reduced, leading to longer possible system runtimes.

Probably the greatest benefit of integrating new network approaches in medical robotics applications, however, is the ability to plan, coordinate and orchestrate various robots in a holistic sense, maximizing synergies between systems and enabling the automation of many complex processes in a strongly human-dependent and often insufficiently interconnected environment.[10] Provided that the network can offer sufficient reliability, security and performance, we believe that this approach could lead to a transformation of healthcare in total.

4.4. Exhibitor:

Research Group MITI, University Hospital rechts der Isar, TUM School of Medicine and Health, Technical University of Munich

Acknowledgements: The presented work was originally developed within the BMBF-funded research project ProteCT (project identification number: 16SV8568) and is currently being expanded upon in the BMBF-funded project 6G-life (project identification number: 16KISK002).

4.5. Contact information and references:

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- Sven Kolb: sven.kolb@tum.de
- one6G summit 2023 [10]
- one6g youtube channel [11]

[10] Jurosch, F., Kröger, N., Kolb, S. *et al.* (manuscript submitted for publication). 6G Networks for the Operating Room of the Future. *Prog. Biomed. Eng.*

5. DEMO #3
VR Robots

5.1. Abstract

Revolutionizing the control of robotic systems by building a human robot interface which is intuitive and accurate. Extend Robotics demonstrates intuitive human robot interface which provides seamless connection between humans and robot using minimal hardware and with negligible latency. This kind of interface provides easy adoption of robots at affordable cost which is crucial for large scale deployment of robots in society and for industrial purposes.

The Advanced Mechanics Assistance System (AMAS) from Extend Robotics turns a real robot into a physical avatar with fully immersive remote workspace and 3D vision. Features such as added depth perception, flexible viewing angles, intuitive gesture control, ability to integrate with any third party ROS based robots and automation copilot make the system extremely versatile with unlimited scalability and customization options.

Figure 7: AMAS immersive workspace and 3D vision

We envision that it will unlock huge potential in for industrial applications, starting from hazardous areas to everyday tasks where robots will need to be trained and managed by human operators remotely. As we integrate the system into complex applications, 6G technology will be essential to maintain the seamless remote connection especially in areas where multiple robots are deployed. 6G could provide even lower latency, higher bandwidth, and further computation support from within the network.

5.2. 6G use cases and Key Technologies

A robotic arm (weight ~approximately 7.5 Kg) to be controlled through VR headset and gesture joystick control. High precision remote control e.g. for dangerous applications everywhere on Earth and in Space. AMAS VR Software lets you physically control robotics arms remotely over the internet, using intuitive gestures in an immersive 3D environment.

Figure 8: Immersive 3D VR for Robotics

Figure 9: high precision remote control by AR VR

UR5 robotic arm was used for the demonstration at the one6g summit 2023. Furthermore, supports the solution xArm6 robotic arms and the TIAGo mobile robotic system from PAL robotic.

5.3. Planned extensions

Extending Human Capability Beyond Physical Presence. Safer, Faster and Cheaper Remote Physical Workforce, with Metaverse, Robotics and Artificial Intelligence.

5.4. Exhibitor:

Extend Robotics Ltd, UK https://www.extendrobotics.com/

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- Azmat Hossain, Business Development Director : Azmat.Hossain@extendrobotics.com
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- one6G summit 2023 [10]
- one6g youtube channel [11]

6. DEMO #4

Intelligent Robot (MELISAC) Empowered by 6G Native AI and ISAC

6.1. Abstract

The robot MELISAC (Machine Learning Integrated Sensing And Communication) is a research testbed of the intelligent dual-arm-robot empowered by 6G technologies. It can leverage both Terahertz signal and optical signal for sensing objects with high resolution. The Terahertz signal can be used for data transmission in the sense of ISAC (Integrated Sensing And Communication). This allows MELISAC to perceive the world around it in a highly detailed and accurate way, and to communicate with other devices and humans in real time. It is also powered by a large language model (LLM), which gives it the ability to understand and respond to natural language. LLM has also the capability to generate control date for the robot [12]. Unfortunately is the reliability of the generated code not sufficient for complex tasks in the context of human machine cooperation. In our demo we added pre-defined API for the low level control of the robot actions. The demo will show you how MELISAC can use these unique capabilities to perform a variety of tasks.

Used components: LLM advanced reasoning, LLM for robotic, Visual-language model, THz ISAC, Semantic based object detection, intend based programming of 6G robot.

6.2. 6G use cases and key technologies

Human-robot collaboration is one of the highlighted use cases in [1] and Invalid source specified.. Human – robot interaction was addressed in the one6g white paper Invalid source specified. by the use case "H2R: Collaborative robots in industrial environments" and "R2H: Service Robots for Healthcare assistance". [4]

The major capabilities

6.2.1. Natural language interaction: free chatting

MELISAC can understand and respond in natural language. This allows users to interact with MELISAC in a natural and intuitive way, without having to learn any special commands or programming languages for the control of the robot. Visitors are welcome to ask any kind of questions and discuss with MELISAC. A very knowledgeable LLM model is integrated with the audio sub-system with the voice recognition and the text-to-speech capabilities. The user can talk with MELISAC on any topics: technologies, art, travel, history and food, etc. Furthermore, the LLM generates instructions for the robot behavior and task execution.

6.2.2. Hidden object detection: The shell game

MELISAC can use its 6G ISAC capability to sense the object and surrounding environment. This can be used for a variety of applications, such as quality inspections, autonomous navigation and obstacle avoidance. Thanks to the nature of sub-THz frequency band, even hidden objects can be detected inside or behind of objects with sub-centimeter level of accuracy. For the demo, we designed a game which is played between the robot and the user. The game master hides one object insides of cups. The visitor has to guess the color of the cup where the object is inside.

MELISAC robot introduce the rules of the game and guides the visitor step by step thanks to the power of the used LLM (Large Language Model) inference.

A sub-THz ISAC module operates in 140GHz band with 8 GHz channel bandwidth is mounted on one of the robot arms which performs a linear scan of the table for the detection of hidden objects. Postprocessing of the monostatic sensing detects the existence of locates hidden object and where it is placed on the table.

Recorded data of the THz scan is available for one6g members on the TODSI (Trusted Open Data Sharing Initiative) platform from one6g WG4.

6.2.3. Reasoning for human-robots collaboration

The LLM enables that MELISAC can reason the human's essential needs based on the indirect information captured during the chatting. The Robot is used to give suggestion to the visitor e.g. regarding the drinks available and suitable to fulfil the wishes of the visitors. Example: "I want to drink something and get energy boost". MELISAC will suggests to take a coke and take it from the shelf. Example 2: MELISAC will serve a glass of water if the visitor is asking somehow: "I'm thirsty and want to drink something healthy."

6.2.4. Digital Twin

Fusion of different types of on-board sensors and radio sensing to build an immersive digital twin. The fusion of the reconstructed shape of the robot with the information provided by the ToF camera feed is shown on the screen as depicted in Figure 10. The position of the objects e.g. the cups is determined by a VLM (Vision Language Model) system and instructs the robot controller.

Figure 10: MELISAC LLM and ISAC platform

6.3. Planned extensions

MELISAC is an extendable research platform, which means that it can be easily modified and upgraded to support new features and applications. We believe that MELISAC has the potential to revolutionize the way we interact with robots, and we are excited to see what new and innovative applications the research community can develop for it.

6.4. Exhibitor:

Huawei Munich Research Center

6.5. Contact information and references:

- https://www.huawei.com/en/
- one6g TODSI: https://shared.one6g.org/f/51831
- one6G summit 2023 [10]
- one6g youtube channel [11]

7. DEMO #5

Ultrafast Sub-Terahertz Point-to-Point Wireless Link for 6G Fronthaul Communications

7.1. Abstract

We have demonstrated 12.5 Gb/s transmission in the sub-THz frequency band by using 6.25 GBaud QPSK signal. The flexible testbed allows for real-time processing to generate and demodulate wide band IQ-signals, but also to research and develop sub-components of the system such as up- and down-converter. In this demo, the signal quality is evaluated in terms of bit error rate and constellation diagrams of the actual link. The demonstration is the result of a cooperation between Keysight and Karlsruhe Institute of technologies.

7.2. 6G use cases and key technologies

The key technology allowing for such high-wide band signal generation and demodulation is the Keysight Universal Signal Processing Architecture (USPA). It is a modular, flexible and re-usable real-time prototype hardware platform, with unique combination of high-speed data converters and open FPGA access. The data-converters (>64 GS/s, 22 GHz 3dB-bandwidth of the DAC, 38 GHz 3dB-bandwidth of the ADC) are based on UltraFastSiGe technology for best signal quality achieving ENOB ≥ 4.5 up to 22 GHz. The high-performance Xilinx Ultrascale+ FPGAs give the ability to run customers application software. In addition, the driver infrastructure and SDK (python / HDL) make it possible to integrate FPGAs and/or extension boards on demand.

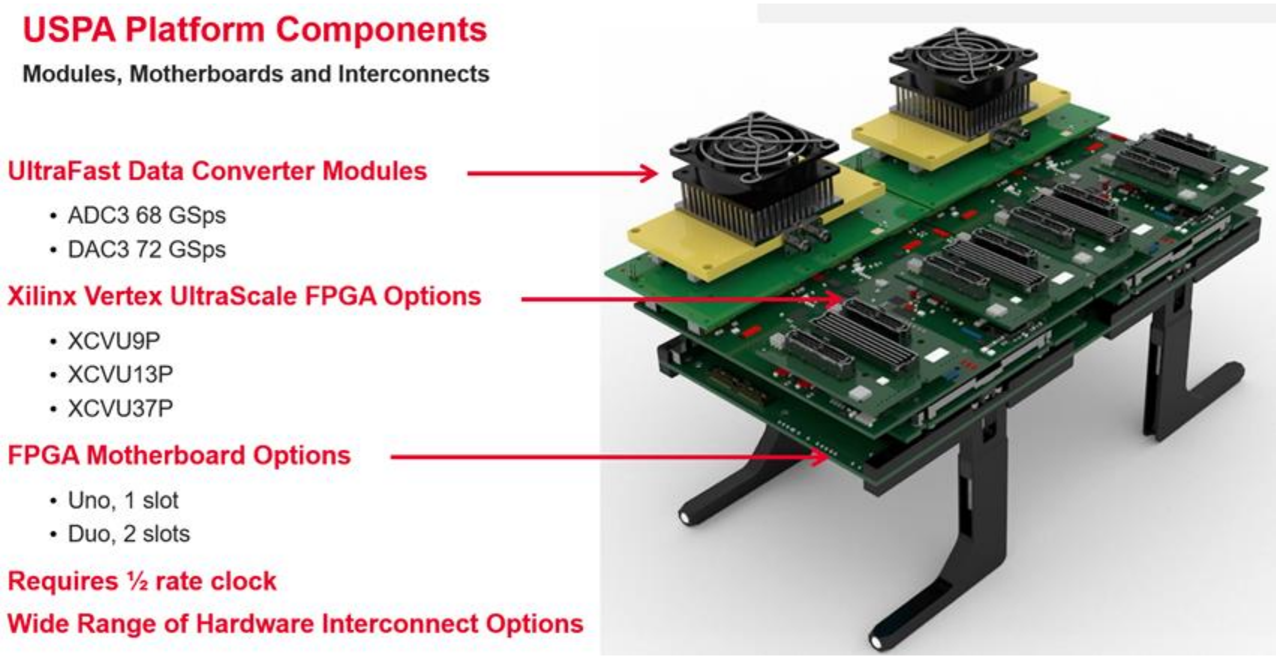

Figure 11: USPA Platform Components

KIT has provided the single carrier baseband digital signal processing for the point-to-point link, the RF front-ends and the lens needed to form a narrow beam targeting to the receiver unit as depicted in Error! Reference source not found..

Higher data rate transmission of 16 Gbps has been already demonstrated with the same setup over 48 m distance. During the One6G summit a link distance of 4 m has been successfully demonstrated.

A sub-THz transmission at record data rate of 200 Gbit/s over 52 m long indoor link at a carrier frequency of 300 GHz has been also demonstrated by exchanging the transmitter front-end with an optoelectronic signal up-converter and keeping the same all-electronic intradyne down-converter based on a GaAs mm-Wave integrated circuit and same USPA platform for IQ-data generation and demodulation.

Wide-band signal transmission in sub-THz point-to-point links using optoelectronic signal generation is a promising approach towards high-capacity mobile fronthaul in6th-generationmobilenetworks.

Figure 12: Sub-THz transmission setup: transmitter (left) and receiver (right).

7.3. Planned extensions

Further development in sub-components and digital-signal processing algorithms.

7.4. Exhibitors:

Keysight and Karlsruhe Institute of Technology (KIT)

7.5. Contact information and references:

- Fabio Pittala, Horst Hettrich (Keysight)
- Joel Dittmer, Patrick Matalla, Sebastian Randell (KIT)
- one6G summit 2023 [10]
- one6g youtube channel [11]

8. DEMO #6

Beyond 5G localization in 3GPP-compliant scenario

8.1. Abstract

This demo shows real-time simulations of beyond 5G localization fully compliant with 3GPP specifications and environments [13], in both microWaves (FR1) and mmWaves (FR2), with possibility to fuse different types of measurements. A menu-driven GUI enables to select environments, frequency range, bandwidth, and type of measurements according to 3GPP specifications [14].

8.2. 6G use cases and key technologies

Location awareness is a key enabler for a myriad of applications in beyond 5G (B5G) wireless networks, including autonomy, smart environments, assets tracking, internet-of-things (IoT), and Industrial-Internet-of-things (IIoT) [15]. However, fulfilling the localization performance requirements is challenging due to the complexity of the wireless environments for different applications and verticals. This demo demonstrates the effectiveness of SI-based localization [16] in indoor environments via fully 3GPP-compliant simulations. In particular, SI-based localization is able to effectively learn the environmental impairments via machine learning, providing a probabilistic representation of the relationship between radio measurements, user equipment position, and contextual information. The SI-based approach for localization enables overcoming the performance limitations of conventional localization algorithms currently deployed on commercial 5G networks [16]. Figure 13 shows the graphical user interface for the B5G localization demo.

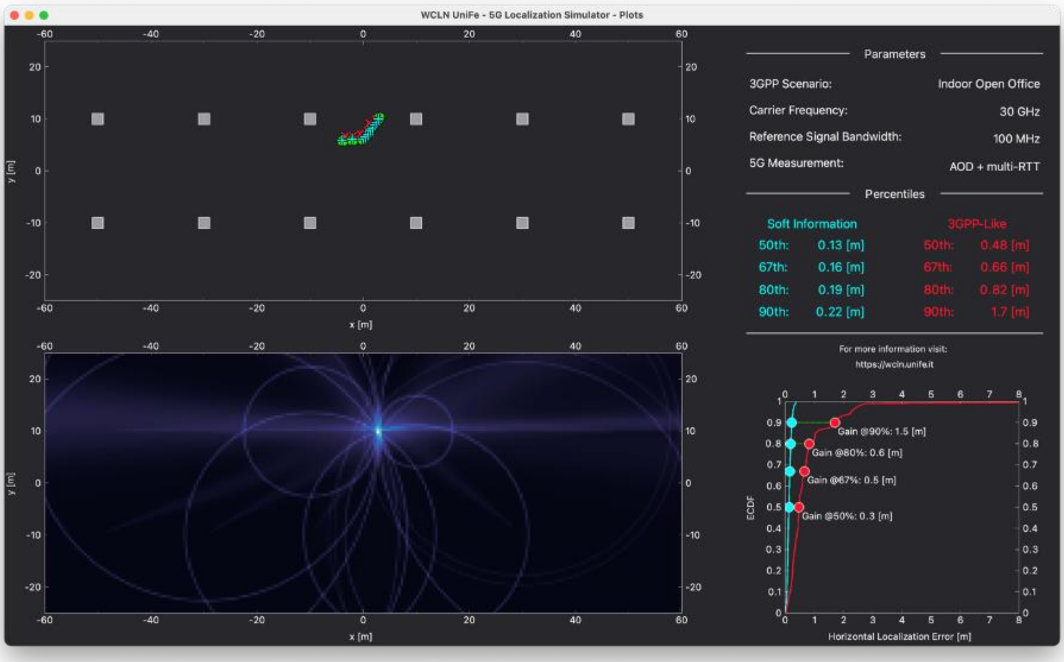

Figure 13 Graphical user interface of the B5G localization demonstration platform.

8.3. Planned extensions

The probabilistic approach of SI-based localization natively enables the extension of the algorithm to different types of data including radio access technology (RAT)-independent, (e.g., information from accelerometers, Wi-Fi, ultra-wideband systems, etc.), and RAT-dependent (e.g., other measurements from the 5G network such as channel impulse response (CIR) metrics and blockage intelligence (BI) [17]).

8.4. Exhibitor:

WiLab at CNIT and WCLN Lab at University of Ferrara

8.5. Contact information and references:

- Video available: wcln.unife.it/technology-readiness/
- one6G summit 2023 [10]
- one6g youtube channel [11]

9. DEMO #7

Multi-target tracking and classification via MIMO radar at mmWaves

9.1. Abstract

Tracking and classification (e.g., identification and activity recognition) of targets are keys enablers for next generation wireless network applications, including fragile assistance, public safety, and smart factories. In fact, the 3rd Generation Partnership Project (3GPP) is considering use cases and services, for integrated sensing and communication (ISAC), which require to localize and classify targets that are non-collaborative (i.e., not equipped with any device).

This demo demonstrate a real-time system developed for tracking and classifying multiple targets moving in complex wireless environments (e.g., indoor environments) using a single MIMO radar operating at mmWaves. In particular, the system proposes machine learning-based clutter mitigation and target detection to reduce the severe clutter and the multipath propagation that affect reflected waveforms in harsh propagation conditions. Given a set of detections the proposed approach performs: (i) multi-target tracking (MTT) relying on a soft-decision data association and (ii) classification employing a deep neural network.

9.2. 6G use cases and key technologies

Device-free sensing considers non-collaborative targets and relies on reflected waveforms affected by clutter and multipath, especially in complex wireless environments. High-accuracy tracking and classification are enabled by the development of algorithms for clutter mitigation and multiple targets detection, localization and class inference. In fact, the harsh propagation conditions of complex wireless environments lead to high probability of false-alarms and miss-detection. The system we developed consists of an offline phase for environmental learning, and an online phase for estimation of both position and class of multiple targets at each time instant. The system has been shown operating in real-time during the One6G Summit 2023 employing a single MIMO radar operating at 77 GHz with 2 transmitting antennas, 16 receiving antennas, and 1 GHz of bandwidth. The targets position estimation rate was of 10 estimates per second and the classification rate was of 1 classification per second. Fig. … shows the block diagram of the developed system to track and classify multiple targets in a complex wirelesse environment. The multiple targets detection, tracking, and classification are described in the following.

Multi-target detection is performed via machine learning. Specifically, in the offline phase we collect measurements without targets in the environment to infer the clutter distribution. Then, we define a specific threshold for each positional measurement collected during the online phase. By employing radars at mmWaves, multi-measurements are collected for each target due to the high resolution of the device. We perform clustering to obtain a set of single value positional estimates given by the cluster centroids.

Multi-target tracking is performed recursively, which is referred to as Bayesian filtering. In particular, Bayesian filtering consists in (i) a prediction step, which aims to infer the target position relying on a motion model, and (ii) an update step, which enhances the prediction by considering all the measurements collected. A challenging aspect in device-free sensing is the data association, i.e., the combinatorial problem to associate measurements to targets. Soft-decision data association is promising to achieve high accuracy tracking in complex wireless environments due to the high presence of false alarms and miss-detection. The proposed system employs the joint probabilistic data association filter (JPDAF) to complete Bayesian recursion via soft-decision data association.

Multi-target classification is performed via deep learning. In particular, tracking allows to collect specific signal features (e.g., Doppler shifts) over time from a received waveform for each considered target. The system employs signal features collected as classification metric to distinguish between humans and robots. Neural networks are promising to achieve high-accuracy classification relying on the offline training phase. The proposed system leverages data augmentation to generalize the training, in order to achieve high accuracy classification using training data collected in a different environment from the experimental one.

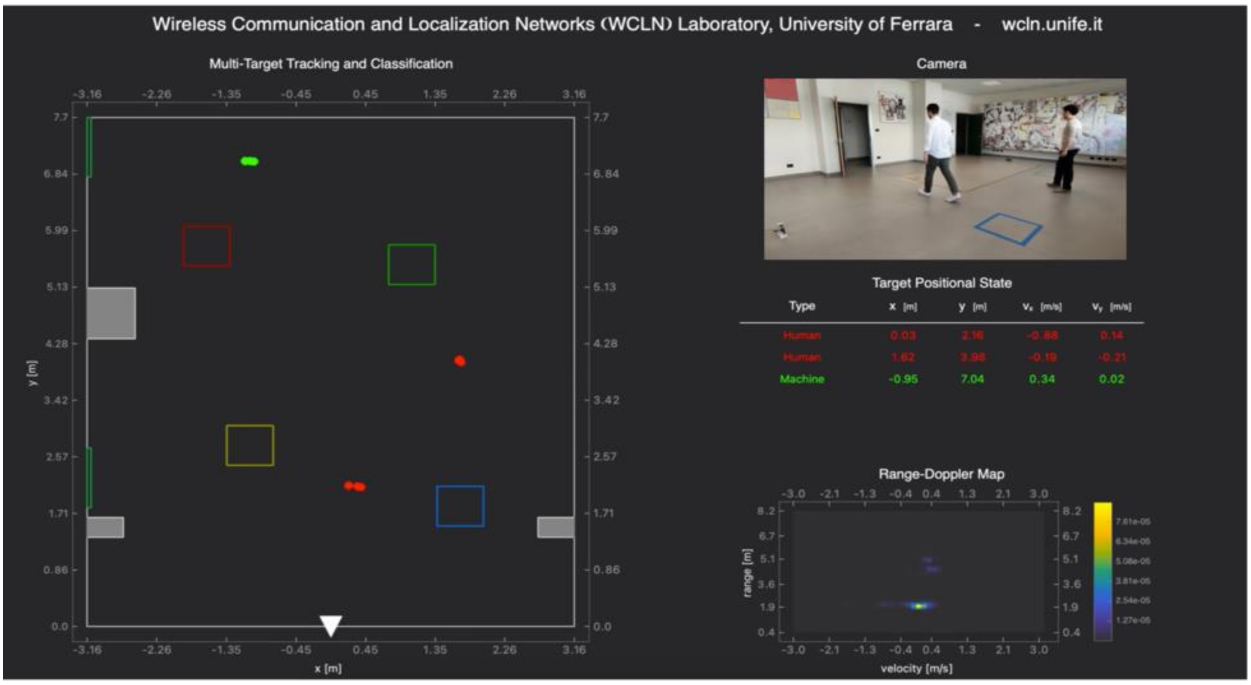

Figure 14 Graphical user interface of the tracking and classification system.

9.3. Planned extensions

Development of signal processing techniques for improving tracking and classification performance and scalability.

9.4. Exhibitor:

WiLab at CNIT and WCLN Lab at University of Ferrara.

9.5. Contact information and references:

- Videos available: wcln.unife.it/technology-readiness/
- one6G summit 2023 [10]
- one6g youtube channel [11]

10. DEMO #8

6G Integrated communication and sensing in sub-THz band with 270 GHz

10.1. Abstract

6G Integrated communication and sensing in sub-THz band with 270GHz based on Huawei baseband / IF boards and R&S frequency up/down converters for H-Band (220 to 330 GHz) [18].

Rohde & Schwarz and Huawei have demonstrated subTHz ISAC with multi-static ranging based on Huawei ISAC prototype and the new R&S high quality up-/Down-converter devices during the one6G summit 2023 in Munich. A VW bus toy car could be moved while the 64QAM ISAC signal was transmitted at 270 GHz RF frequency and stable received.

It was also successfully demonstrated that the in parallel to the OFDM based sensing a 64QAM signal could be reconstruct and a transmission of 10 Gbps.

The FC330ST and FC330SR frequency converters are designed to up and down-convert IF signals to the range from 220 and 330 GHz.

With the integrated IF amplifiers and the additional external accessories (bandpass filters and Tx amplifier) exceptional sensitivity and signal performance can be achieved even in sub-THz frequency range.

10.2. 6G use cases and key technologies

In the industry, we have scenarios where we need to sense and zoom on targeted objects for product quality control and object classification and detection, all this can be achieved by extending low- and mid-band ISAC systems by wireless connected high-band sensing units, while reusing the same existing 6G mobile network architecture and frequency band. This wireless sensing unit will upconvert the received low- and mid-band from the mobile network to the targeted high-band for performing the sensing on the targeted object.

The 64QAM OFDM ISAC signal has been computed by the base band unit and upconverted by the mid-band intermediate frequency unit (IFU). Figure 16 shows the details of the setup with FC330ST (Figure 16) and FC330SR [18] used for the demonstration of bi-static ISAC with concurrent transmission of 10Gbps as displayed on the screen.

Selected capabilities are:

- Support full H-Band (220 to 330 GHz)
- Ultra-wide bandwidth up to 35 GHz
- Integrated IF Amplifier
- Additional accessories (Bandpass filters and Tx PA) available

Figure 16: setup of the demo 8 with multi-static OFDM based ISAC

Figure 15: FC330 down converter

10.3. Planned extensions

The 6G ISAC system is a research platform, it can be extended and optimized to support new capabilities and use cases for sensing and communication. The HUAWEI MRC team is working for developing exciting innovative features and applications.

10.4. Exhibitors:

Cooperation of Huawei Munich Research Center and Rohde & Schwarz Munich

10.5. Contact information and references:

- Huawei Technologies Duesseldorf GmbH, Munich Research Center, Mohamed.gharba@huawei.com
- Rhode und Schwarz GmbH, Munich
- one6G summit 2023 [10]
- one6g youtube channel [11]

11. DEMO #9
Communication Challenges in Tele-Operated Robotics

11.1. Abstract

In Tele-Operated Robotics, i.e. robots controlled from a distance away, numerous difficulties arise with regards to the communication of data. Especially when multiple modalities (e.g. vision, arm control, audio, hand control) are used, there are several data streams each with their own deadlines which needs to be met. This leads us to present the following communication challenge: QoS optimalisation of multiple channels which need lots of bandwidth, at high update frequency, low latency, and synchronicity between the channels.

11.2. 6G use cases and key technologies

Multi-Modal Tele-operated robotics is inherently challenging due to having to handle a multitude of different modalities, not all of which are equally important. Although some smart handling of messages can help with increasing the effective throughput of data, there is still a network at play which will always add latency between sending and receiving.

5G already offers URLLC which aims to provide high reliability and low latency. However, this comes at a trade-off of bandwidth. Multi-modal systems, such as the i-Botics Avatar implementation (see video), require low-latency in combination with reliability, synchronicity, and somewhat high throughput.

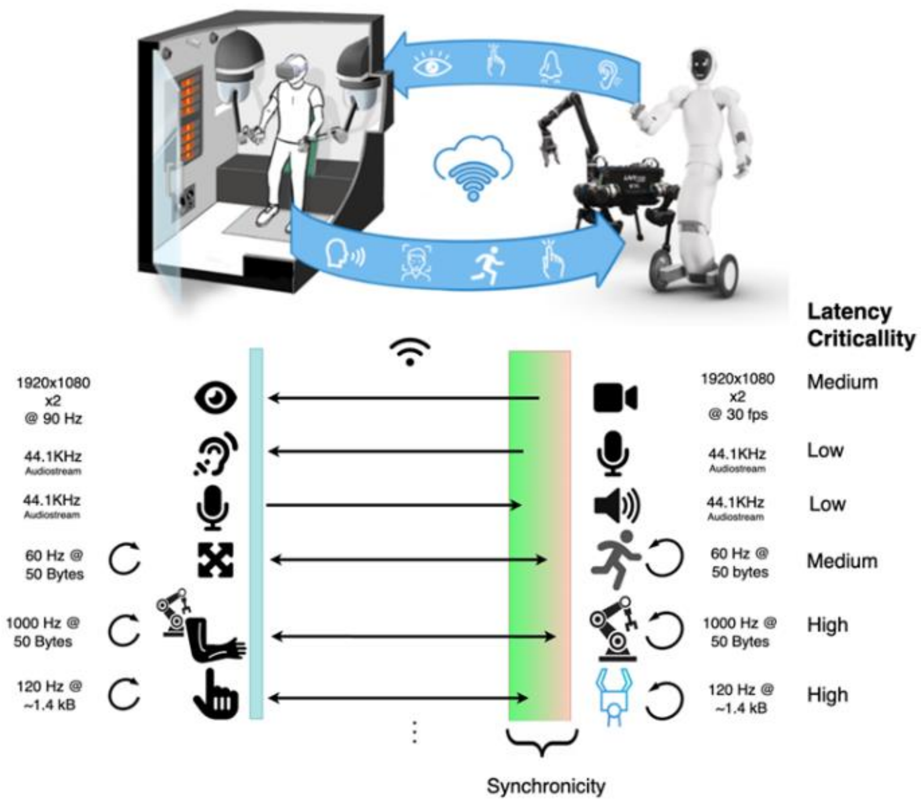

Figure 17: Teleoperation services and requirements

Within a multi-modal control system such as used by the i-Botics avatar, different modalities have different update rates and data volumes. Most of the control of the robotics components, such as base locomotion, arm- and hand-control tend to have small communication requirements, but speed is of importance for safety and transparency[11] of most of these components.

Auditory and Visual information is often larger in size. Although compression techniques exist, these add delay between the sensor recording information and the operator receiving this information. In a Tele-operated system this creates difficulties as this disconnects the operator from the actual state of the robot. For these kinds of data, high through-put and low latency is considered important.

Combining both brings a complex challenge to the system, where low latency is important for all components, but data size varies. Furthermore, some components require information very fast, while others can wait a bit longer (Arm control vs Vision).

Finally, it is preferred that all data sent at a certain time arrives at approximately the same time at the remote site. This is what we call synchronicity, or the equal timing of data. This will improve the experience for the operator. This can be understood as 'reducing input lag' of the system, but between the different sensory modalities.

6G offers higher data rates in combination with lower latency. Furthermore, components as sensing could be used to create a better understanding of the environment around the robot, which is currently often limited to visual data.

Regarding the possibilities of 6G, the high-speed throughput, maybe even low latency end-to-end communication possibilities seem very promising for the high-update frequency communications, such as the control tasks. Furthermore, the sensing capabilities of 6G can help with environment detection of the robot. This would reduce the need for other sensors and their associated date streams.

11.3. Planned extensions

All systems developed within the i-Botics collaboration have the goal to be easily extended with new capabilities by integration of new components.

Within the field of communication, we are hoping to work with communication partners to use the possibilities of 5/6G to optimize user Quality of Service in varying network conditions. We do not have a lot of thorough knowledge about networking, so we are very interested in opportunities regarding this.

Furthermore, we are doing R&D in advanced methods such a Model Mediated Tele-operation to better deal with effects of significant communication delays on operator perception and performance. This means that we use multiple approaches to model the remote environment, both from knowledge-model, and live-model building during runtime

Finally, we are interested in exploring and applying existing methods to improve efficiency and resilience of the communication. Most of our work has focused on using single-mode data networking. We are interested in using existing methods to expand this to multi-mode networking (e.g., 2.4Ghz, 5Ghz Wi-Fi, or including 5/6G).

11.4. Exhibitor

University of Twente / i-Botics

[11] Transparency can be described as how 'clear' the operator can feel the remote site. This is influenced by multiple factors, such as communication speed and what forces are reflected.

11.5. Contact information and references:

- video available: https://www.youtube.com/watch?v=h6nvlPRlVzY
- contact information: Douwe Dresscher d.dresscher@utwente.nl
- one6G summit 2023 [10]
- one6g youtube channel [11]

12. Conclusions

6G is going to become a new mobile radio systems that combines high performance communication and novel solution to sense the environment of antenna systems. One6g association has started to discover new use cases and novel solutions with more than 140 partners from industry and academia.

This whitepaper compiles the achievements of the joint work in one6g in particular with respect to demonstration and proof of concept of promising new use cases enabled by new 6G technologies such like ISAC and AI. In 5G new players has been identified and summaries in the term Vertical. This whitepaper indicates that many of the 6g key technologies are beneficial for many verticals like e-health, agribusiness, and industry. Robotic seems to become one of the main use cases in 6G in particular for applications outside of traditional scenarios like factories. One6g aims to integrate all of the new interest groups and applications at the beginning of the standardization of the 6th generation of mobile radio system.

The annual one6g summit has been utilized to show 9 exciting and outstanding demonstrations in the field of robotic, agriculture, subTHz, Human machine cooperation enabled by AI in particular large language models and XR technologies.

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