7th Fed4FIRE+ Open Call

“enabling Hybrid beAmforming and Massive Mimo through lEaRning”

HAMMER

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FEC 10

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CONCEPT – MOTIVATION & OBJECTIVES

CONCEPT & MOTIVATION

Concept:

Design, development & evaluation of an experimentation engine for hybrid beamforming & non-conventional massive MIMO enabled through DL & data analytics

Motivation:

- 5G NR already integrates cloud, VNF & RAN functionalities to meet demanding objectives
- Beyond 5G requirements demand: 1. Non-conventional massive MIMO systems supported by DL networks 2. Advanced beamformers with learning mechanisms hosted on mobile edge

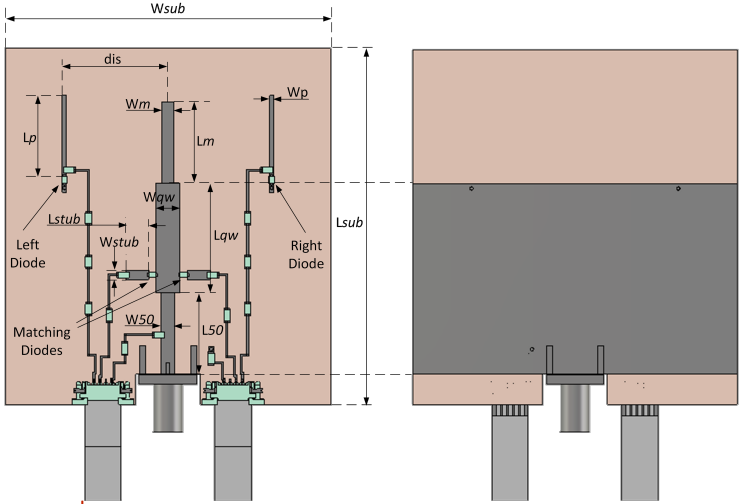
OBJECTIVES

- Hybrid beamforming over SDR resources from Fed4FIRE+ & a MUPAR antenna provided by UPRC
- DL schemes for channel estimation on mobile UE & beamforming deployed over FED4FIRE+ computational resources
- Sandbox for link optimization tests & a REM service as VNF using the USRPs mounted on robots of FED4FIRE+ testbeds
- Measurement collection service as VNF, real-time monitoring app & a GAN for the development of proactive beamformer
- Integration of HAMMER to FED4FIRE+

Experiment Description – Hardware Elements

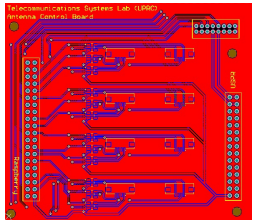
ESPAR Antenna Element

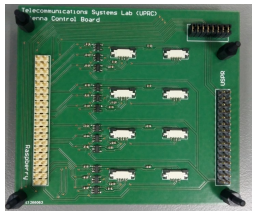
- printed monopole ESPAR at 3.5 GHz (one active element – two parasitic elements)
- compact size, low complexity, low cost
- pattern reconfigurability (PIN diode switching)
- switched impedance matching network

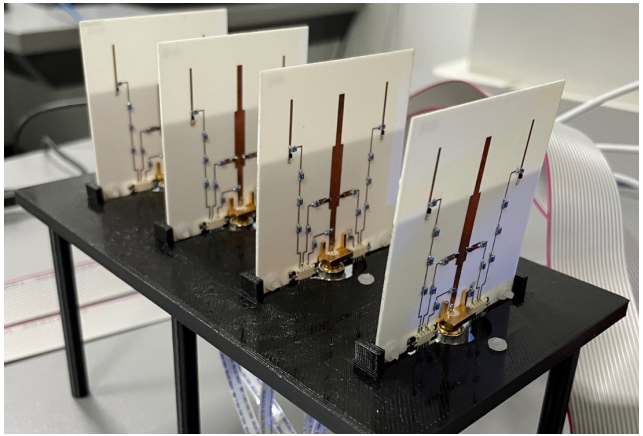


MuPAR Antenna System

- four ESPAR elements in series (stacked parallel configuration) – 42.8mm distance
- 3D-printed plastic table (transparent in EM waves)
- generation of three patterns (one bidirectional, two directives) + beamscanning through phase shift
- controlling translation board (voltage drop to 0.9V)



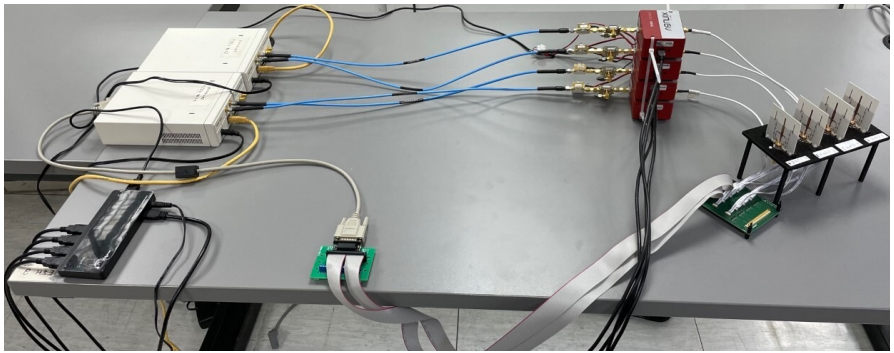


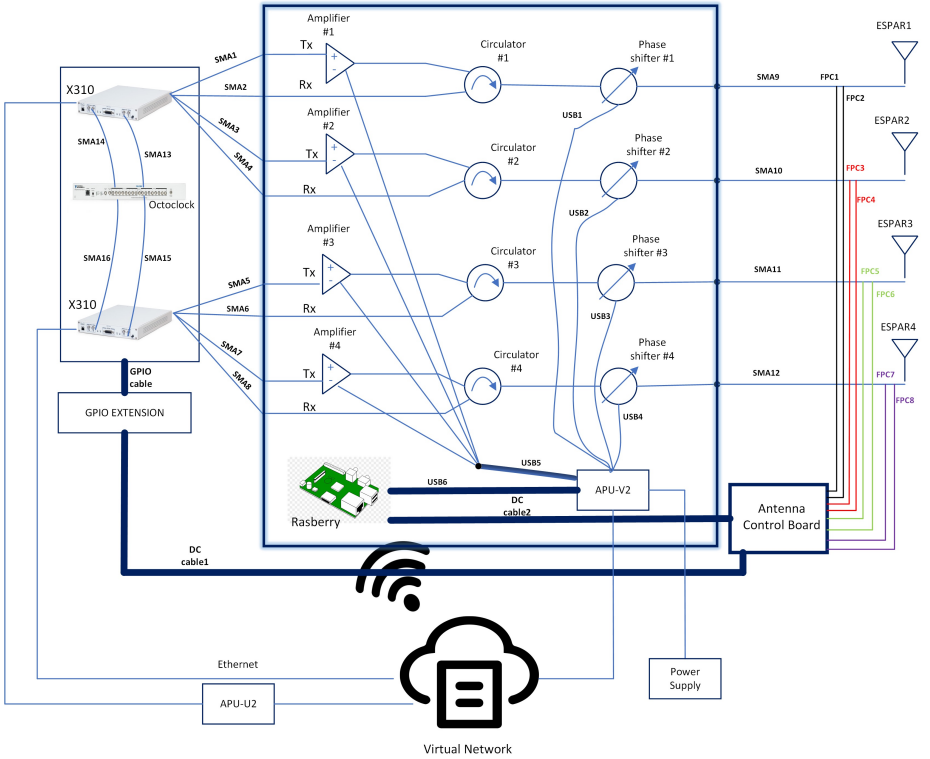


Experiment Description – Hardware Elements

THE HAMMER SDR TRANSCEIVER

a) two Ettus X310 USRPs with the OctoClock
b) RF-box containing all the microwave RF components (phase shifters, amplifiers, circulators, splitters)
c) MuPAR antenna system
d) peripheral components (controlling translation board, GPIO extension, networking hub, RF cables, networking cables, FFC DC cables etc.)





Experiment Description – Software Elements

SDR Control
Remote Radio Head
&
Beam Switching/
Antenna Control

Phase Shifter Control Service

SDR UE
Measurement Report
Mobility (Robots)

HAMMER "Cloud"

C-RAN
Architecture
VNFs
Three levels of beamforming

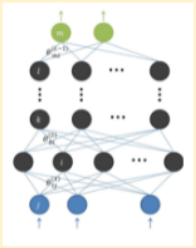
Measurement coordinator and analyzer

Data Collection and Management VNF

influxdb

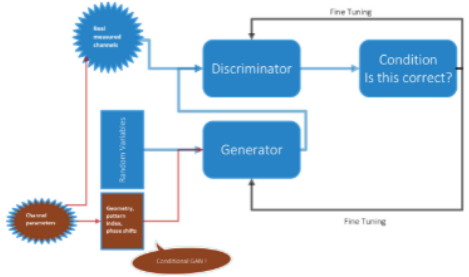
Base Band Unit -
Waveform design
Signal Analyzer
VNF

Convolutional DNN VNF



Visualization and Monitoring VNF

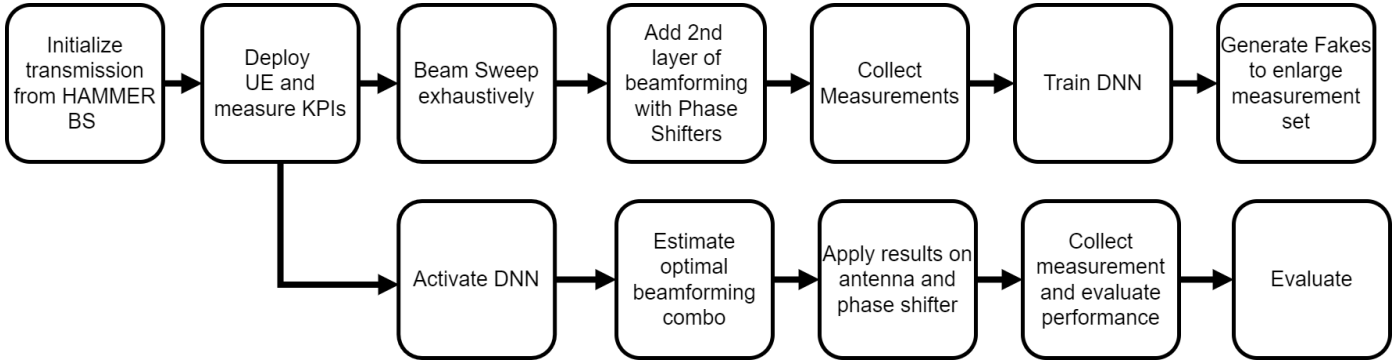
Generative Adversarial Network

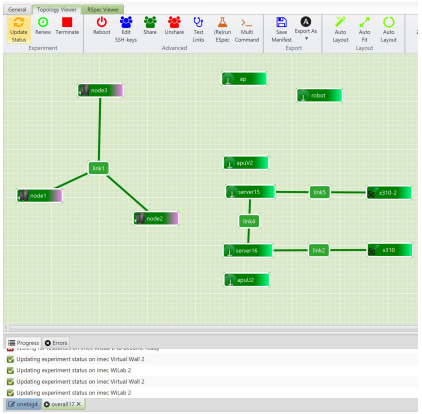


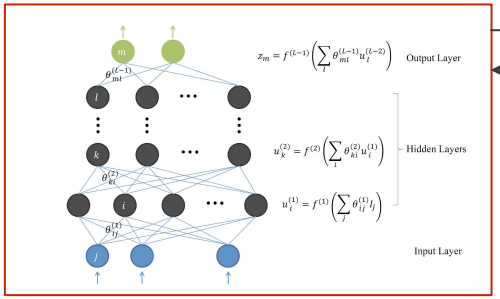
VARIOUS LAYERS OF DEVELOPMENT

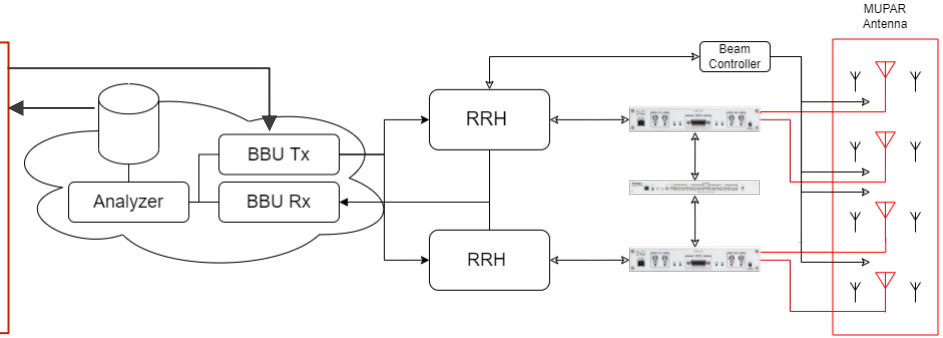
Complete experiment setup

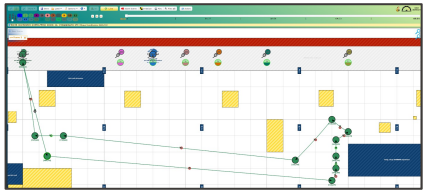
TWO STAGES: TRAINING VS TESTING

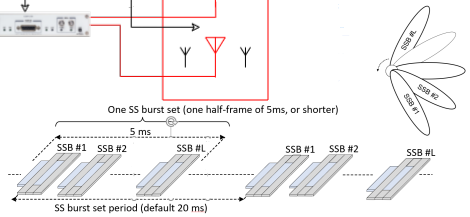






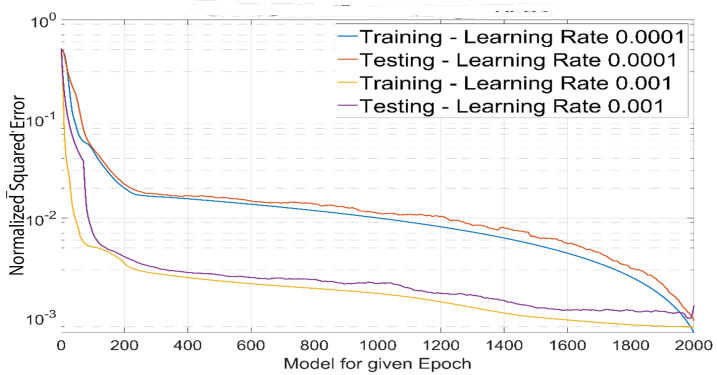






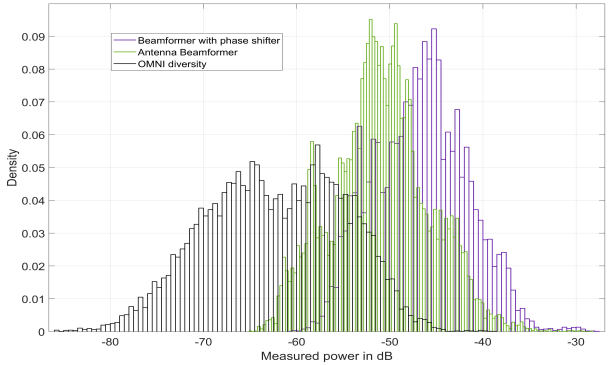
HAMMER Technical Results – Beamformer (1)

DNN MODEL FOR BEAMFORMING: PERFORMANCE IN TERMS OF NSE



- At 2000 epochs, NSE < 0.001 → small deviation from optimum
- Higher learning rate → faster convergence BUT 2000 epochs are needed for convergence
- Performance testing set < training set BUT degradation < 10%
- DNN CAN BE USED for beamforming & optimum performance will asympotically be approached

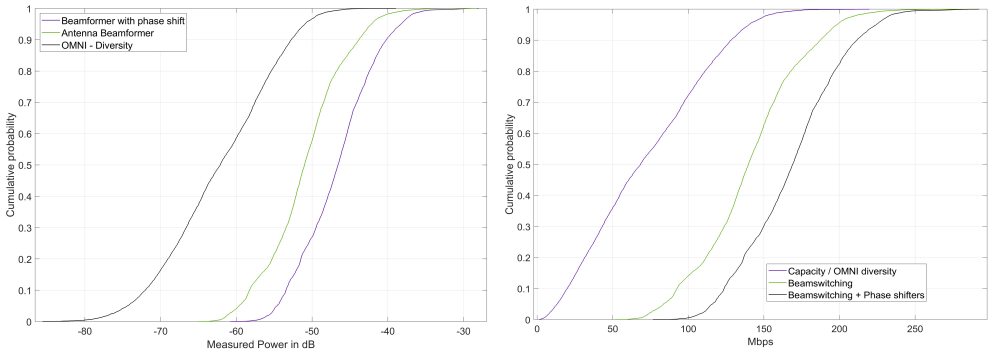
LIVE BEAMFORMING: PDF OF THE RECEIVED POWER



- Analog beamforming → improve reception
- Performance improvement using phase shifters & antenna with NO extra active elements & RF ports
- It seems that phase shifts outperform in beamforming significance the antenna → more elaborate antenna design

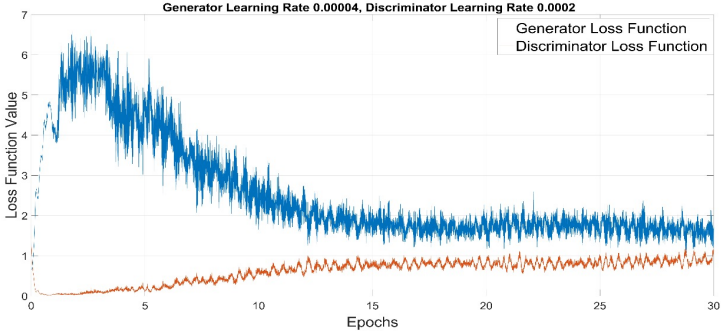
HAMMER Technical Results – Beamformer (2)

LIVE BEAMFORMING: CDF OF THE RX POWER & CHANNEL CAPACITY



- Beamforming gain > 15 dB vs OMNI reception at 50% & additional 5dB beamforming gain
- Performance degradation compared to real optimal parameter set < 10%
- At the 20% percentile, capacity is tripled! Phase shifters adds approx. 20% at the achieved capacity
- The trained model → near-optimum performance with no need of exhaustive search or elaborate search at RX for beamforming parameter selection

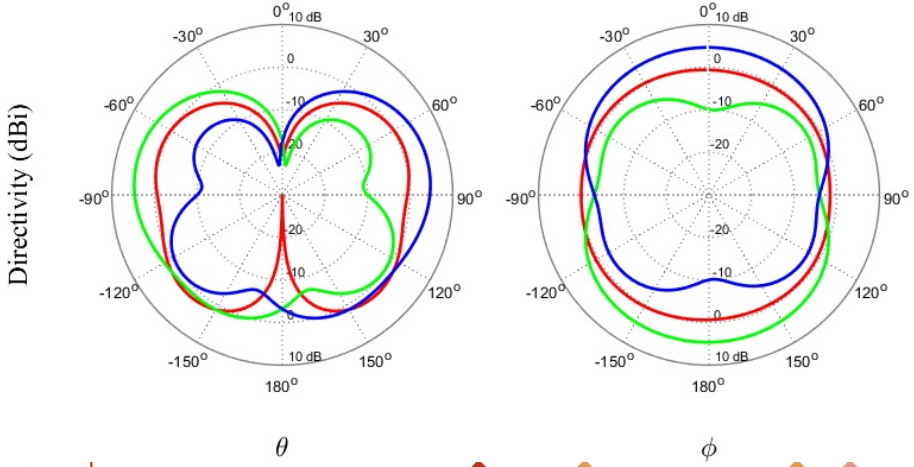
LOSS FUNCTION VALUE OF THE GENERATOR & DISCRIMINATOR OF THE DEVELOPED GAN

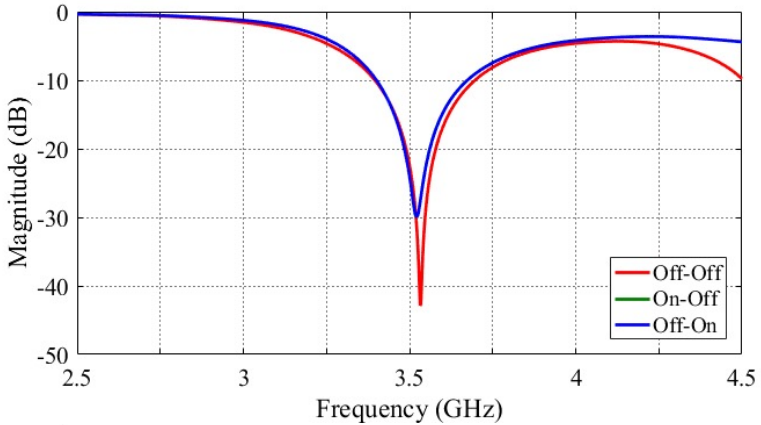


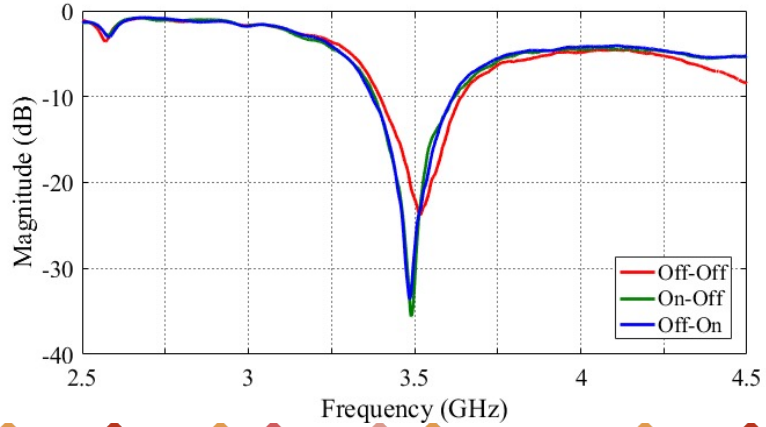
- Convergence between the competitive networks the discriminator & generator → succesful configuration of the network
- Loss function relatively high → alternative network setups may be more effective & efficient
- The generated channels are generally close to the anticipated response for a given environment

HAMMER Technical Results - ESPAR element

- reflection coefficient level better than −25 dB at 3.5GHz for all the operating states of the antenna
- good agreement between simulated and measured S_{11}
- quasi-omnidirectional pattern for the OFF-OFF state
- directional pattern for the ON-OFF and OFF-ON states (5.3 dB gain increase)
- slight upward pattern tilt at the elevation plane (12°)

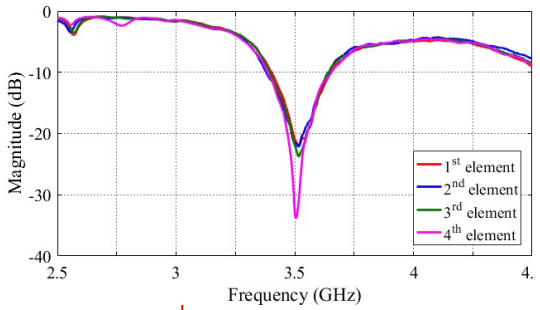


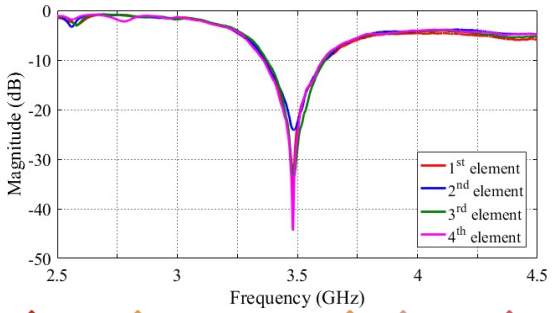


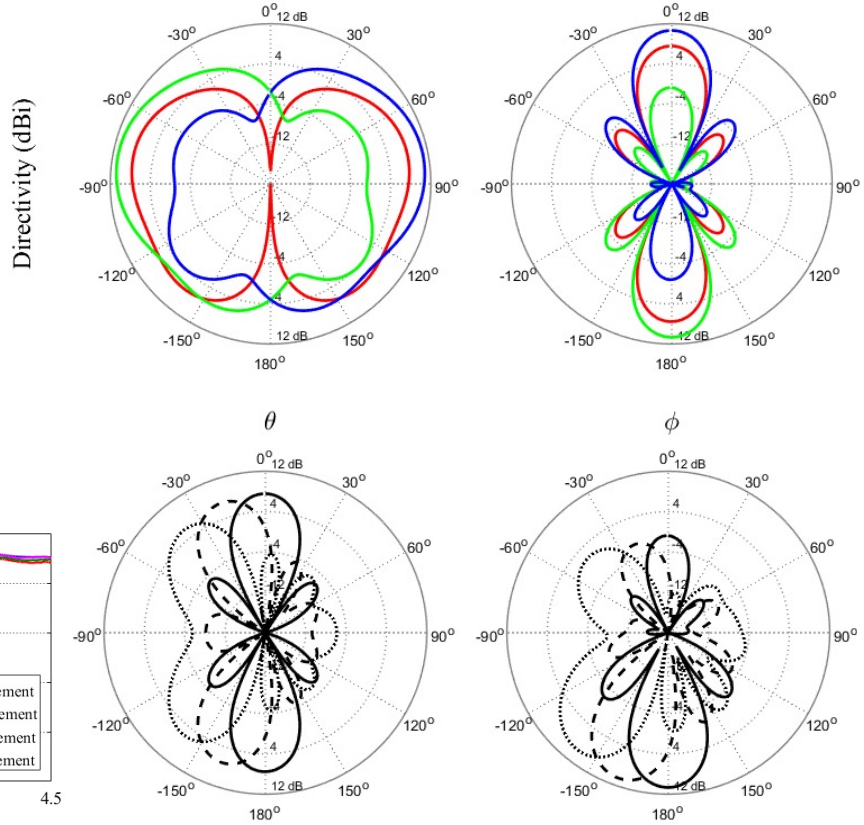


HAMMER Technical Results - MuPAR system

- reflection coefficient level (S_{11}) better than -20dB
- negligible deviations are observed between the elements
- maximum directivity of 8dBi for the OFF-OFF state and 11dBi for the two ON-states (narrowed patterns at the azimuth plane due to the array configuration)
- side lobes more that 10dB lower from the main lobe
- the lobes seem are steered to 28°, 37° and 49° for phase shift 90°, 120° and 150° respectively
- the bidirectional shape (OFF-OFF) offers the ability to simultaneously steer two opposite lobes







Business Impact of the HAMMER Project

Business Impact

- Researchers exhibit a great industrial experience → Convert HAMMER findings to useful industrial products.
- The successful outcome of the experiments can lead to a spin-off transition and the establishment of a promising start-up company.
- Employment of the MuPAR antenna on the BS
  - Compact size, low-cost solution, when compared to the existing conventional expensive antenna systems installed on the BSs.
  - MuPAR antenna features can give a new point of view for the new generation BSs (especially the indoor Base Stations employed in micro/pico-cells) offering a strong economic impact.
  - Hybrid beamforming can be used to decrease the transmission power levels of the BSs, prevent unnecessary broadcasting with omnidirectional fixed patterns and achieve a minimization of the exposure to EM radiation

Business Impact of the HAMMER Project

Impact on Research and Academic Community

- Introduce new findings and technologies into the curriculum
- Present project results to students and university staff in seminars and tutorials
- Initiate / launch new PhD topics in wireless communications, make adjustments to UPRC's current research directions and achieve better cooperation with industrial partners
- Cooperation with distinguished partners from the Fed4FIRE+ consortium will strengthen the UPRC bonds with the applied research and will attract new co-operations
- TSL will enrich its portfolio of SDR implementations and tools
- HAMMER implementation will be provided as open-source and UPRC will be glad to help integrate it – both hardware and software components - into the FED4FIRE+ platform

Business Impact of the HAMMER Project

Perceived Value for TSL (UPRC)

- Gained knowledge in a plethora of scientific fields in wireless communications:
  - hybrid beamforming techniques for 5G/beyond-5G wireless networks
  - deep learning tools upon channel estimation and beamforming schemes
  - radio access performance evaluation and
  - 5G waveform testing
- Access to hardware and software resources, that otherwise could not be exploited due to increased costs.
  - USRPs X310 and the Octoclock device
  - valuable know-how in SDR hardware, radio reconfiguration and inspiring suggestions provided by the patron.
- Cooperation with a prestigious research institute (IMEC – w.iLab.t)

Business Impact of the HAMMER Project

Perceived Value for TSL (UPRC)

- Boost of the TSL Academic Profile
  - increase the scientific impact of the university and establish it as a source of state-of-the-art research
  - conference paper (EUCAP 2022): oral presentation to describe the HAMMER MuPAR antenna system design and results
- Future expansions and new ideas:
  - an advanced beamforming controller design for joint optimization of the Tx and Rx
  - development of advanced deep learning algorithms
  - implementation of alternative MuPAR antenna designs (patches, passive pixels, varactors)
  - development of advanced hybrid beamforming schemes
  - expansion to 6G and mmWave band – employment of RIS technology

FEEDBACK (1)

USED RESOURCES & TOOLS

- Hardware & software resources over **w.iLab.t** and **Virtual Wall** testbed were utilized :
- **jFed**: Mature tool for unlimited remote access over different hardware & software resources.GUI was friendly. No problems occured.
- **Robot Dashboard**: Quite mature platform for driving mobile robots with some of them having USRPs mounted. Sometimes → failure to park/auto-dock robots
- **W.iLab.t inventory**: Well-developed platform for reserving servers, APUs, USRPs, mobile robots, etc. No problems occured.

USED RESOURCES & TOOLS

- **SDR components:** Unlimited acess to a wide variety of high-end SDR resources: 1. USRPs (X310, B210, etc.) 2. The Octoclock device. Software (GNU radio, UHD drivers, etc,) was installed!
- **Mobility toolkit**: Robots equipped with radio equipment that can move on-demand and perform measurements.
- **w.iLab.t toolkits :** Most of the tookits was easy to use. Mobile toolkit & “Creating experiment with mobile node” tutorial allowed 1. automated robot driving 2. coordinate extraction. No problems occurred BUT more details about establishing internet access are expected

FEEDBACK (2)

USED RESOURCES & TOOLS

Tutorials & howto's: w.iLabt's tutorials & howto's → easy to follow & detailed. Representative examples to customize based on our needs were also available. No problems occured BUT extensions to the existing tutorials could include:

- Case-focused examples that can be used as a guideline for other similar experiments e.g., "Conducting experiments using X3x00 USRPs and mobile nodes"
- Video tutorials illustrating the procedure of conducting an experiment using different resources (e.g., SDRs, mobile robots etc.) beginning from the reservation phase through the end of the experimentation phase

USED RESOURCES & TOOLS

And some problems…

OpenStack:

- Difficulties occurred on deploying OpenStack through EnOS: 1. EnOS installation problematique due to python libraries incompatibility issues & outdated Ubuntu release 2. The tutorial provided was outdated.
- After several failed attempts → EnOS 6.0.2 was successfully installed on Ubuntu 18.04 LTS manually & "reservation.yaml" file was created.
- Problems on "enos deploy" due to technical difficulties regarding ssh keys were occurred
- Feedback from Virtual Wall → could not find alternative solutions

FEEDBACK (3)

ADDED VALUE OF FED4FIRE+

The most highly valuable components offered by FED4FIRE+ are in order of importance:

- **Diversity of available resources:** Wide diversity of hardware (USRPs X3x0, Octoclock, robots, etc.) & software resources without restrictions that TSL could not afford due to increases costs!
- **Easy, stable, remote access:** Unlimited & uninterruptedly easy access without the need for physical presence
- **Tutorials and documentation:** w.iLab.t provided easy-to-follow documentation & tutorials followed by real experiments
- **Funding** for applied research and innovation!

ADDED VALUE OF FED4FIRE+

Support:

- Opportunity to contact the w-iLab.t support team directly via email and arrangement of telcos for technical discussion. Cooperation was excellent (encouraged to address any issues, quick mail-response, etc.).
- Work with the w.iLab.t team consisting of highly-trained, scientifically-acclaimed researchers & engineers
- TSL & w.iLab.t team share common research directions → easy for w-iLab.t team to get familiar with HAMMER experiment & catch-up with the concept.

FEEDBACK (4)

WHAT IS MISSING

Although not necessary, some small additions/extension suggestions for shorter learning curve - provided as feedback are:

- **Direct integration** of containers and Docker in the testbed environment (put your container directly to work!)
- **Antenna** variety for non-ISM bands
- **Scripts:** Provide fundamental scripts in different programming languages (MATLAB, C++,etc) for enabling 5G experimentation & SDR experiments. Experimenters would strongly be encouraged to improve & extend the initial versions. This ability is missing from Fed4FIRE+ consortium.
- **Integration with other testbeds** (e.g., Grid5000) not through public internet (is it possible?).
- Big data support – especially for storing
- Ways to accelerate experiment initialization for custom images.

SUGGESTIONS FOR IMPROVEMENT

- **Radio Hardware:** Integration of mmWave RF development kits.
- **Software:** More software resources such as LabVIEW could be added
- **Tools:** Tools for real-time monitoring, observing and supervising experiments (possibly through cameras) could also be added
- **Tutorial videos:** Example videos for conducting several fundamental experiments (using mobile nodes, different SDR resources & tools) step-by-step → less technical failures
- **In conclusion, using Fed4FIRE+ was, in general, a very pleasant experience!**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