# Project Overview

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| Project name, short and extensive | **INSTINCT (Joint Sensing and Communications for Future Interactive, Immersive, and Intelligent Connectivity Beyond Communications)** |
| Name of Coordinator, Company of coordinator | **Padmanava Sen (Barkhausen Institut gGmbH)** |
| Technical Manager | **Angeliki Alexiou (University of Piraeus - Research Center)** |
| Start date-End date of the project | **January 2024 – December 2026** |
| Website | http://instinct-6g.eu/ |
| LinkedIn account | https://www.linkedin.com/company/eu-instinct/ |
| YouTube account | https://www.youtube.com/channel/UCJTnxxFO1QQFr9MEPVyWOIg |
| Verticals concerned (see list below) | Wireless Communication Technologies and Signal Processing, Joint communication and sensing |
| List of partners | Barkhausen Institut, University of Piraeus - Research Center, Bosch, Aalto University, Fraunhofer HHI, Greenerwave, NEC Laboratories Europe, Institut National de Recherche en Informatique et Automatique, Institut National des Sciences Appliquées de Lyon, i2CAT Foundation, Oulu University, Centralesupelec, Telefónica Innovación Digital (TID), Telefónica (TSA) |

Contributors in this Newsletter: Researchers in the consortium

(Prepared by Mehrab Ramzan and Nelly Pistorius)

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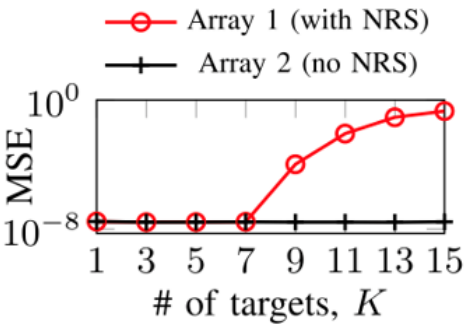
# Papers and Results in January – July 2026

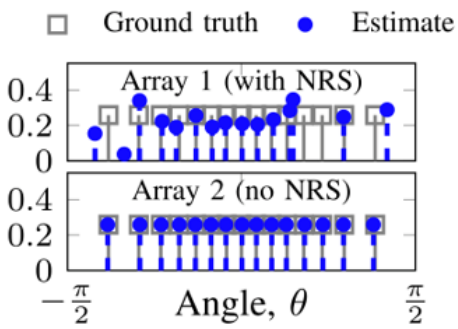
**1.** Convergence of Wireless Sensing & Communication for Industrial Manufacturing

Dr. Alexander Artemenko from Bosch served on the Industrial Panel on the 22nd International IEEE Conference on Factory Communication Systems (WFCS 2026)

The convergence of wireless sensing and communication, known as ISAC, promises to be a cornerstone of future industrial automation—offering enhanced perception for mobile robots, improved human-machine collaboration, and streamlined asset tracking. However, the initial excitement is now meeting the pragmatic realities of the factory floor. The primary hurdle to deploying ISAC at scale is the gap between its theoretical potential and the lack of well-defined, application-driven requirements from the industrial sector. This talk will explore how we can move beyond fragmented research by focusing on specific, high-value industrial use cases. We will discuss the need for a collaborative effort between technology providers and factory operators to define the precise performance, safety, and security metrics required to turn ISAC from a research concept into a robust, value-generating tool for cyber-resilient manufacturing.

**2.** R. Rajamäki and P. Pal, "On the Impossibility of Lossless Waveform Rank Reduction for Certain Redundant Arrays," in IEEE Signal Processing Letters, vol. 33, pp. 2220-2224, 2026, doi: 10.1109/LSP.2026.3695827



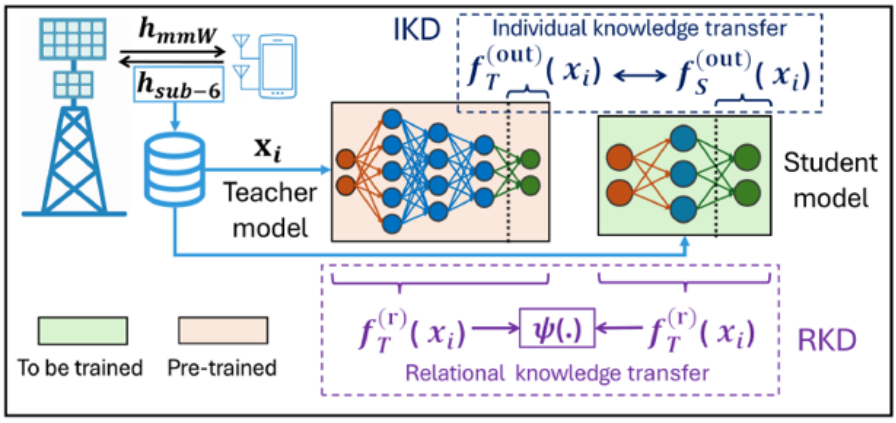




Efficient use of spatio-temporal resources, including sensor arrays and transmit waveforms, is a key challenge in modern MIMO active sensing systems. This paper studies the impact of array redundancy and waveform rank (WR) on active sensing performance. Specifically, we show that parameter identifiability at reduced WR critically depends on subspace properties of the so-called array redundancy pattern. We show that array geometries with identical sum co-arrays can exhibit markedly different identifiability properties at low WR. We derive a novel necessary condition for maximizing identifiability at reduced WR, which reveals that the unfavorable redundancy patterns of certain redundant arrays fundamentally limits their performance. The results yield new insights into resource-efficient sensing systems, motivating redundancy-aware array and waveform design.

**3.** I. van der Werf, R. Rajamäki and G. Leus, "CRB-Optimal Arrays and Waveforms in Active Sensing: Role of Redundancy and Spatial Covariance of Array Geometry," in IEEE Transactions on Signal Processing, vol. 74, pp. 2691-2705, 2026, doi: 10.1109/TSP.2026.3698941.

This paper characterizes the performance limits of optimal array designs using orthogonal and coherent waveforms for both linear and planar arrays. For orthogonal waveforms, we show that the single-target Cramér–Rao Bound (CRB) depends on the sum of the so-called spatial variances of the transmit (Tx) and receive (Rx) arrays, or equivalently, the spatial variance of the sum co-array weighted by the multiplicities of the virtual sensors. This reveals that CRB-optimal geometries are inherently redundant, highlighting a fundamental trade-off between mean squared error (MSE) and identifiability in parameter estimation. Moreover, we derive optimal Tx-Rx sensor allocations given a total sensor budget and show that unequal allocation (favoring the Rx) is optimal even for nonredundant arrays, questioning conventional designs. We extend our results to planar arrays, providing a new general condition that the spatial covariances of the Tx and Rx arrays should satisfy for the optimal waveforms to direct power in the target direction. Additionally, we establish a connection between Diophantine equations and array geometries with equal CRB, along with a constructive method for designing such arrays. Our work provides new guidelines for and insights into optimal array and waveform design with relevance in emerging active sensing multiple-input multiple-output systems.

**4.** S. Tavakolian, N. T. Nguyen, A. Alkhateeb and M. Juntti, "Knowledge Distillation for mmWave Beam Prediction Using sub-6 GHz Channels," ICASSP 2026 - 2026 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Barcelona, Spain, 2026, pp. 22642-22646, doi: 10.1109/ICASSP55912.2026.11461506.




Beamforming in millimeter-wave (mmWave) high-mobility environments typically incurs substantial training overhead. While prior studies suggest that sub-6 GHz channels can be exploited to predict optimal mmWave beams, existing methods depend on large deep learning (DL) models with prohibitive computational and memory requirements. In this paper, we propose a computationally efficient framework for sub-6 GHz channel-mmWave beam mapping based on the knowledge distillation (KD) technique. We develop two compact student DL architectures based on individual and relational distillation strategies, which retain only a few hidden layers yet closely mimic the performance of large teacher DL models. Extensive simulations demonstrate that the proposed student models achieve the teacher's beam prediction accuracy and spectral efficiency while reducing trainable parameters and computational complexity by 99%.

**Academic Outreach:** EXACT-6G School 3- PHY layer techniques and design principles in 6G (UOULU)

Lectures on ISAC: Introduction, dual-functional radar-communications, detection and estimation for ISAC systems, machine learning for ISAC.

**5.** Global Cellular Radio Connectivity: Complexity and Limitations

In recent years, a new wave of virtual mobile operators has emerged, leveraging the radio coverage of a few major network providers to deliver global cellular connectivity. These operators capitalize on network softwarization, virtualization, and eSIM technologies to provide worldwide access.

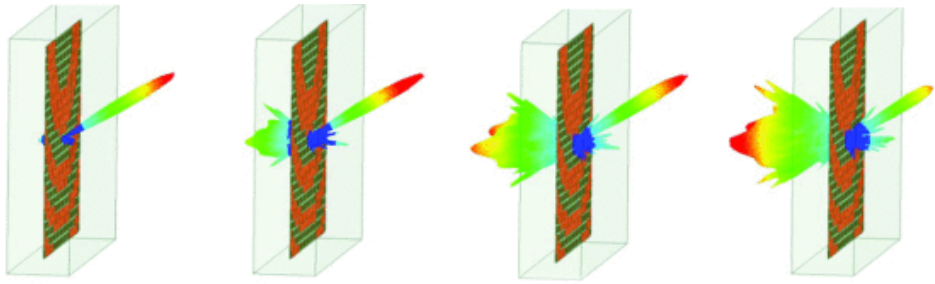
In her keynote, Dr. Andra Lutu from Telefónica Research uncovered the inner workings of this opaque cellular ecosystem and the IP eXchange (IPX) Network,

which interconnects over 800 Mobile Network Operators globally. She discussed how the IPX Network has enabled the rise of Mobile Network Aggregators (MNAs) such as Google Fi, Airalo, and Twilio/KORE, and analyzed the structural and geographic characteristics of IPX traffic.

Her talk shed light on how the global mobile Internet supports today's IoT landscape and digital mobility and she explored the limitations and future models of next-generation global operators.

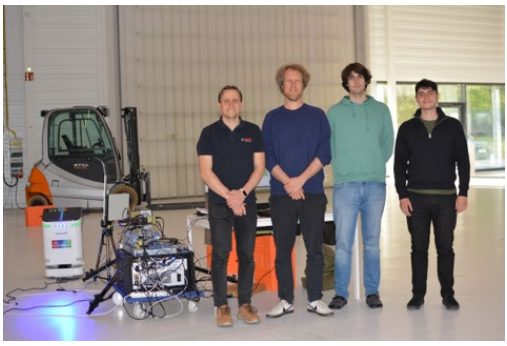
**6.** M. M. Islam, S. Al Nahiyan, P. Sen and M. Ramzan, "Comparative Study of Passive Reflecting Surfaces with Two and Four Quantization Levels: Near-Field, Gain, SLL, and Bandwidth," 2026 17th German Microwave Conference (GeMiC), Karlsruhe, Germany, 2026, pp. 418-421, doi: 10.1109/GeMiC71240.2026.11516454.

In this paper, a comprehensive near-field analysis of the 1-bit and 2-bit quantized passive AMC (PAMC) reflecting surfaces at 6.5 GHz is presented. The evaluation is conducted across different near-field regions by varying the distance (d) between the source (a horn antenna) and reflecting surfaces optimized for reflecting at 30° reflection angle. The performance of the reflecting surface is assessed in terms of gain variance, main-beam stability and changes in the side-lobe levels (SLL) in an HFSS hybrid EM environment (FE-BI). The 1-bit design maintains its main beam direction across the near-field zones. However, gain drops were observed in the close proximity (d<250 mm) and in the far end of the near-field (d>350 mm). In contrast, the 2-bit design demonstrated better beam stability and higher performance in the near vicinity of the reflecting surface. On the other hand, when distance exceeds beyond 250 mm, the 2-bit design fails to preserve the desired beam with significant gain reduction. Due to its finer phase resolution, the 2-bit design showed improved SLL behavior and better gain performance over wider frequency bandwidth. These research findings provide fundamental insights into the near-field behavior of quantized PAMC and highlight critical considerations for optimal deployment of the reflecting intelligent surfaces (RIS) in the future dense 6G networks.



**7**. JCAS demonstration campaign at industrial test facility

Fraunhofer HHI and Bosch performed joint JCAS measurement at the industrial test facility Arena2036 in Stuttgart (20. - 24.04.26).




In an experimental setup, the practical implementation of sensing functionalities for Joint Communication and Sensing (JCAS) in an industrial application scenario was investigated. The objective was to demonstrate the detection of an Autonomous Guided Vehicle (AGV) equipped with a passive reflector using a monostatic 28-GHz phased-array antenna system.

The AGV followed a predefined route with a straight section aligned to the line of sight (LoS) of the sensing setup, ensuring a well-defined trajectory towards and past the sensing system. A corner reflector was mounted on the AGV to enhance the reflected signal.

The recorded data were evaluated using Range-Doppler maps, providing simultaneous information on the target range and velocity. During each pass, the AGV was successfully detected as it entered the sensing area, with its position in range and its corresponding Doppler-induced velocity being clearly observable.

The measurements covered distances of up to approximately 5 m, while the AGV maintained an approximately constant velocity of 0.6 m/s along the predefined trajectory.

These results provide an experimental proof of concept for the sensing capabilities of a 28-GHz phased-array system in an industrial JCAS scenario. The experiment highlights the potential of integrating sensing functionality into future industrial communication infrastructures, where mobile platforms such as AGVs can be simultaneously operated as autonomous transport systems and detected as dynamic objects. The demonstrated approach provides a foundation for further investigations into the joint localization, velocity estimation, and tracking in dynamic industrial environments.

# List of Publications (2026 January - June)

1. Kumar, Y. Vindas and M. Guillaud, **"Doppler-Supervised Channel Charting,"** *ICC 2026 - IEEE International Conference on Communications*, May 2026.

2. D. J. Bugelnig, F. Lemic, Á. Veres-Vitályos, G. Castillo Gómez-Raya, X. Costa-Pérez and B. Rinner, **"Adaptive Flight Planning for Neural 3D Reconstruction With Low-Altitude UAVs,"** IEEE Internet of Things Magazine, February 2026.

3. L. Rayón Ropero, J. De Laet, F. Lemic, P. Sabater Nácher, N. Nisar Bhat, S. Abadal, J. Famaey, E. Alarcón and X. Costa-Pérez, "Towards Emotion Recognition with 3D Pointclouds Obtained from Facial Expression Images," IEEE Transactions on Affective Computing, January 2026.

4. P. Almasan, S. Bakirtzis, J. Suárez-Varela and A. Lutu, **"From Waves to Graphs: A Ray-Tracing-Inspired Neural Radio Propagation Model,"** IEEE International Conference on Communications Workshops (ICC Workshops), May 2026.

5. R. Rajamäki and P. Pal, **"On the Impossibility of Lossless Waveform Rank Reduction for Certain Redundant Arrays,"** IEEE Signal Processing Letters, 2026.

6. I. van der Werf, R. Rajamäki and G. Leus, **"CRB-Optimal Arrays and Waveforms in Active Sensing: Role of Redundancy and Spatial Covariance of Array Geometry,"** IEEE Transactions on Signal Processing, June 2026.

7. S. Tavakolian, N. T. Nguyen, A. Alkhateeb and M. Juntti, **"Knowledge Distillation for mmWave Beam Prediction Using Sub-6 GHz Channels,"** ICASSP 2026, April 2026.

8. M. M. Islam, S. Al Nahiyan, P. Sen and M. Ramzan, **"Comparative Study of Passive Reflecting Surfaces with Two and Four Quantization Levels: Near-Field, Gain, SLL, and Bandwidth,"** 2026 17th German Microwave Conference (GeMiC), March 2026.

# INSTINCT Dissemination Snapshot

## 📢 At a Glance

A strong series of keynotes, invited talks, workshops, tutorials, panels, and demonstrations showcased INSTINCT's contributions to **ISAC, 6G, wireless connectivity, and reconfigurable RF systems**—engaging research communities, industry, and business stakeholders across Europe and beyond.

## 🎓 Academic & Research Outreach

- **6G Seasonal School 3 on 6G PHY – ISAC** (UOULU)
  *Basics of ISAC Systems*
- **SPS Webinar** (UOULU)
  *Joint Communications and Sensing Hybrid Beamforming Design via Deep Unfolding*
- **IBiDat Seminar** (TID)
  *From National Coverage to Global Platforms: Evolving the Mobile Network Architecture*
- **WONS 2026** (TID)
  Keynote: *Global Cellular Radio Connectivity: Complexity and Limitations*

## 🎤 Keynotes, Panels & Expert Contributions

- **WFCS 2026** (Bosch)
  Invited Talk & Industry Panel:
  *Convergence of Wireless Sensing & Communication for Industrial Manufacturing*
- **EUCNC 2026**
  Panel participation in the ISAC workshop:
  *Demonstrations and Trials*
- **EUCNC 2026** Special Session (UPRC, i2CAT)
  *ISAC – Integrated Sensing and Communications Towards 6G*

## Workshops, Tutorials & Demonstrations

- **EUCNC 2026 Workshop**
  *Second Workshop on Integrated Sensing and Communications Initiatives on the European Research Framework*


- **JC&S Symposium 2026** (BI)
  Tutorial: *Joint Evaluation of Radar and Communication Applications on the Physical Layer: A Deep-Dive into HermesPy*
- **EUCNC 2026 Booth** (INSTINCT partners)
  Demonstrations and presentations on interference mitigation in ISAC, RIS-based sensing and localization, 3DSAR, and urban sensing environments.


## Conferences & Community Building

- **JC&S Symposium** 2026 (BI)
  Organization and TPC Chairing
- **MWC 2026**
  INSTINCT participation and engagement with the global wireless communications ecosystem
- **INSTINCT Architecture Workshop** (NEC)
  Partner workshop advancing the project's system architecture
- **GEMIC 2026** (BI)
  Paper presentation:
  *Comparative Study of Passive Reflecting Surfaces with Two and Four Quantization Levels: Near-Field, Gain, SLL, and Bandwidth*

## ✨ Impact

INSTINCT partners continued to strengthen the project's visibility across research, industry, and business communities, demonstrating the project's expertise in ISAC, 6G connectivity, sensing, and reconfigurable RF technologies and fostering collaboration across the European research and innovation ecosystem.