

## Poster presentation (GJWS7-P01)

### 5G PRISM: A Distributed Network Measurement System

Niklas Beckmann, Niels König, Robert Schmitt

5G PRISM is a distributed network monitoring and measurement system. It can do distributed load testing, stress tests, baseline monitoring and more. The system itself is device independent. We will present the system itself, as well as some results of a large scale measurement campaign conducted at Fraunhofer IPT (more than 100 devices in total).

## 5G PRISM – A Distributed Network Measurement System

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**Fraunhofer IPT**  
**5G PRISM**  
Performance & Reliability Insight

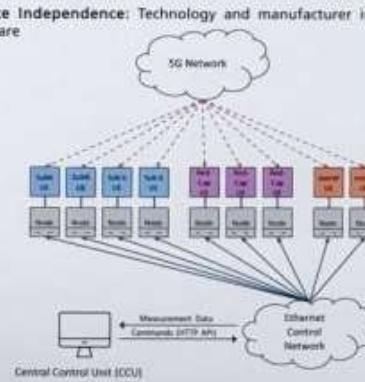
### 5G PRISM – 5G Performance & Reliability Insight System for Mobile networks

SG PRISM is a flexible measurement framework designed for the automated coordination of complex performance test campaigns across distributed nodes in private 5G campus networks.



#### Key Measurement Capabilities and Features

- Radio Metrics: Continuous monitoring of RSRP, RSRQ and SINR directly from the UEs
- Network Capacity: Distributed uplink/downlink throughput testing via central content/iperf3 server
- Quality of Service (QoS): Precise assessment of latency, jitter and packet loss
- Time-to-Attach (TTA): Automated modem resets to measure the duration until full IP connectivity is restored
- Data Integrity: All measurement and control data via a separate control network
- Graphical User Interface: Easy to use GUI to monitor the network and get live result plots
- Device Independence: Technology and manufacturer independent software



**Large Scale Measurement Campaign at 5G Industry Campus Europe**

A comprehensive measurement campaign was conducted using 60x Sub-6 GHz, 40x RedCap, and 20x mmWave devices. The evaluation quantifies industrially critical KPIs, such as Time-to-Attach (TTA) and resource fairness, in a realistic production shopfloor.

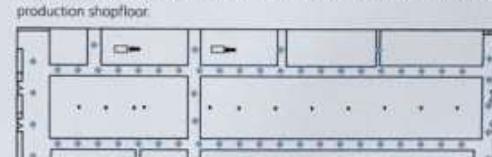


Fig. 2: Sub-6 GHz Device Distribution at Fraunhofer IPT/5G-ICE

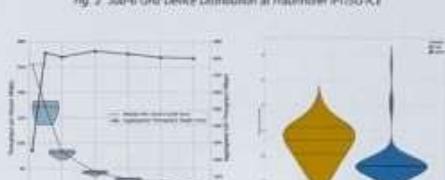


Fig. 3: DL Scaling & Fairness Graph (left); TTA sequential and parallel (right)

#### Resource Fairness & Network Entry

- Throughput Scaling: The aggregated cell throughput remains stable at saturation, while individual throughput follows a  $1/N$  distribution
- Scheduling Fairness: Negligible variance between individual nodes proves the high efficiency of the 5G SA scheduler even at a maximum density ( $N = 60$ )
- TTA Performance: Sequential attachment (blue) shows a deterministic median of  $\sim 0.7s$ . Under massive parallel attaches, the median shifts to  $\sim 0.9s$  with increased variance due to RACH contention and signaling queues

#### Conclusion

- SG PRISM successfully orchestrates massive-scale measurement campaigns without affecting 5G air interface integrity
- Private 5G networks demonstrate high robustness and fairness under extreme device densities
- The generated dataset provides a benchmark for future Industry 4.0 network characterization

5G PRISM is one of four European research projects under the Joint Undertaking for Intelligent Networks and Services (JUINS) and was funded over 2.5 years by the „Joint Undertaking for Intelligent Networks and Services“ (JUINS) under Horizon Europe grant number 101098614.

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**Fraunhofer IPT** **ERICSSON** **5G INDUSTRY CAMPUS EUROPE**

# Poster presentation (GJWS7-P02)

## Bandit Formulations for Hybrid Band Wireless Networks

Sherief Hashima, Kohei Hatano RIKEN/AIP

Hybrid band communications emerged as a good solution to meet exponentially growing bandwidth demands. Optimal link selection using the best channel in those systems is a difficult problem to formulate due to the dynamic nature of communication. This problem is formulated as a bandit problem where the Transmitter (TX) is the player, and the bands/channels are the arms. Finally, the rewards are the throughput, cost is the energy consumption.

### Bandit Formulations for Hybrid Band Wireless Networks

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**EA-Randomized Upper Confidence Bound (RUCB)-MBS Algorithm**

RUCB randomizes the confidence interval, and selects the most ideal arm by substituting the exploration parameter by a random variable  $Z_t$ , where  $Z_1, \dots, Z_T$  are i.i.d sampled from Gaussian distribution.

$$a_{RUCB-MBS}(t) = \arg \max_n \{\bar{\psi}_n(t-1) + Z_t \sqrt{\frac{2 \ln t}{M_{n,t-1}}} - \frac{\kappa_0}{\Xi_{1,n}(t)}\}$$

where  $\bar{\psi}_n(t)$  denotes the average throughput obtained from the transmission band  $n$  until time  $t$ .  $M_{n,t-1}$  refers to the number of times  $n$  has been picked until time  $t$ .

**EA-Kullback-Leibler UCB (KLUCB)-MBS Algorithm**

KLUCB calculates the bounded Kullback-Leibler divergence of the average reward of each arm, and the arm characterized with the maximum divergence parameter is played

$$a_{KLUCB-MBS}(t) = \arg \max_n \left\{ \sup \left\{ \mu_n(t) \in (0, 1) : d(\bar{\psi}_n(t), \mu_n(t)) \leq \frac{f(t)}{T_{n,t}} \right\} - \frac{\kappa_0}{\Xi_{1,n}(t)} \right\}$$

where,  $f(t) = \log t + 3 \log(\log t)$  and  $d(\mu_1, \mu_2) = 2(\mu_1 - \mu_2)^2$ .

**EA-RUCB/KLUCB-MBS Algorithm steps**

At each round  $t = 0, 1, 2, \dots, T$ .

- Try each band  $n$  once in the first  $t = N$  trials and update the source remaining energies:  $\Xi_{1,n}(t) = \Xi_{1,n}(t-1) - \frac{P_{n,t} t}{W_{max} \cdot \eta_{min}}$ .
- While  $\Xi_{1,n}(t) > \Xi_{1,n}$  for any  $n \in N$
- Choose the most appropriate channel index  $a_{R/KLUCB}^*(t)$  for transmitter-receiver using EA-(R/KL)UCB-MBS.
- Obtain  $\bar{\psi}_{a_{R/KLUCB}}^*(t) = \frac{W_t T_{a_{R/KLUCB}}(t)}{D(t) + T_{a_{R/KLUCB}}(t)}$
- Update Parameters

**Multi armed Bandits (MABs)**

Player simultaneously tries to explore new arms (exploration) and optimize their choice based on the current knowledge (exploitation) to maximize his reward

**System Model**

How to perform smart and online optimization of heterogeneous channels assignment to D2D nodes in highly dynamic conditions (i.e., varying distance, different channel/link models, energy, and type of blocking)?

**Problem Formulation**

Select the optimal band that achieves maximum throughput and low energy consumption.

$$\arg \max_{i,j} \sum_{i=1}^m \sum_{j=1}^{n_i} x_{ij} \mathbb{E}(\psi_{ij}(t))$$

s.t.

$$\Xi_{Tx,0}(t) > \Xi_{th}, \forall s \in \{\text{transmitting nodes}\}$$

$$\sum_{i=1}^m n_i \geq N$$

$$\sum_{i=1}^m \sum_{j=1}^{n_i} x_{ij} = 1, \quad x_{ij} \in \{0, 1\},$$

where  $m$  and  $n_i$  denote the number of heterogeneous frequency bands and the number of channels in band  $i$ , respectively.  $N$  indicates the total number of available channels across all the bands.  $\psi_{ij}(t)$  indicates the throughput in bps of the transmitter-receiver link at time  $t$  utilizing channel  $j$  of band  $i$ .

**Blocking formula:**  $\text{Blocking loss [dB]} = \beta_s + \alpha_s \log(1 + \frac{c_s}{100})$

\*M. Balan et al. "Multi-band vehicle-to-vehicle channel characterization in the presence of vehicle blocking," IEEE Access, 2019.

**Simulation Results**

Comparison of RUCB-MBS and KLUCB-MBS against UCB-MBS, TS-MBS at distinct distances and different blocking types (no, small, large blocking).

**Average throughput comparison of EA-RUCB-MBS, EA-KLUCB-MBS algorithms Vs distinct distances at different blocking scenarios**

Energy Efficiency (EE) comparison vs distinct distances of no, small, and large blocking situations.

**Summary & Future work**

- Hybrid RF/VLC optimization problem is formulated using MAB schemes
- We propose EA-RUCB-MBS algorithm that outperforms the original UCB and TS implementations.
- EA-RUCB-MBS exhibits slow convergence, we developed another variant of UCB, referred to as EA-KLUCB-MBS that exhibits faster convergence
- Future work includes regret analysis and multiplayer extensions

# Poster presentation (GJWS7-P03)

## Integrated Sensing and Communication in Coherent Passive Optical Networks

Laurenz Ebner (Fraunhofer HHI), Juan L. Moreno Morrone (Fraunhofer HHI), Johannes K. Fischer (Fraunhofer HHI)

Integrated sensing and communication (ISAC) has attracted significant attention due to its potential to exploit the usage of existing optical fibers simultaneously for high-speed data transmission and distributed sensing, while minimizing modifications to deployed communication infrastructure. Especially distributed acoustic sensing (DAS) has gained momentum, because of its ability to spatially resolve external forces. Besides optical network monitoring, applications in urban areas for DAS include both traffic and structural health monitoring and surveillance of water flow and seismic activities. This work investigates distributed fiber sensing for passive optical networks in urban areas.

## Integrated Sensing and Communication in Coherent Passive Optical Networks

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### Motivation

Integrated sensing and communication (ISAC) has attracted significant attention due to its potential to exploit the usage of existing optical fibers simultaneously for high-speed data transmission and distributed sensing, while minimizing modifications to deployed communication infrastructure. Especially distributed acoustic sensing (DAS) has gained momentum, because of its ability to spatially resolve external forces [1]. Besides optical network monitoring, applications in urban areas for DAS include both traffic and structural health monitoring and surveillance of water flow and seismic activities [2]. The passive architecture of optical urban access networks is particularly well suited for distributed fiber sensing due to the absence of in-line optical amplification modules, which require complex bypass techniques to enable DAS.

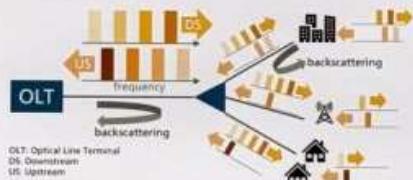


Fig. 1: Coherent Passive Optical Network (PON) with Digital Subcarrier Multiplexing and Time-Frequency Division Multiple Access (TFDMA)

### Coherent Passive Optical Networks

Coherent transmission is a strong contender for next-generation Passive Optical Networks (PON), expecting to offer service rates up-to 200 Gbps. Discussions for very high speed PON (VHSP) are on-going within ITU-T SG15 Q2 [3]. Besides single-carrier coherent PONs, digital subcarrier multiplexing coherent PON [4] employing time-frequency multiple access (TFDMA) is a promising system architecture [5]. Several low-rate users may share a digital subcarrier, while demanding users such as enterprise customers may be assigned with more than one subcarrier, making the scheme highly flexible and efficient. Such an architecture is also suitable to exploit techniques for **integrated communication and sensing**. At the end of 2023 ITU-T also launched a work item on distributed fiber optic sensors, which also includes access networks and has been integrated into the studies VHSP.

### Distributed Acoustic Sensing and Communication

Integrating DAS into coherent transceivers for PON enables simultaneous data transmission and urban environment monitoring using existing fiber infrastructure, without additional sensing hardware. While prior work demonstrated WDM-based communication and sensing using separate devices [6], incorporating DAS directly into the optical line terminal (OLT) further improves cost efficiency and integration.

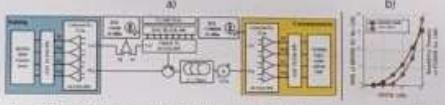


Fig. 2: Experimental verification of the sensing to telecom power ratio (SPTR) in the downstream link. a) Setup b) Sensing SNR and induced penalty on the communication signal from the sensing subcarrier. Note: COMM = 4x8 Gbit PDM-QPSK, SENSE = 500 Mbit PDM BPSK.

### The functionality of a coherent ISAC transceiver is described as follows:

- A DAS probe is digitally multiplexed at the spectral edge of the downstream communication subcarrier and jointly transmitted through the feeder fiber.
- The probe interrogates the fiber by exploiting Rayleigh scattering in the silica fiber, where a small fraction of the optical signal is backscattered toward the optical line terminal (OLT) in response to vibration events.
- The backscattered DAS signal is jointly received with the upstream communication subcarrier.
- The sensing signal is digitally demultiplexed, processed, and analyzed to extract vibration information.

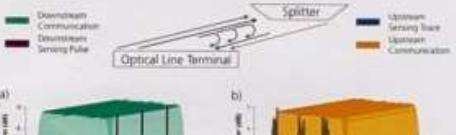


Fig. 3: ISAC in a Coherent PON Transceiver showing a) Down- and b) Upstream communication subcarriers and a) sent and b) received sensing signal in the spectral gap in the OLT.

### Application Scenarios & Outlook

Optical sensing techniques based on phase-domain reflectometry and Rayleigh backscattering have proven successful in many fields, including seismic wave detection, road traffic, rail traffic and infrastructure monitoring. In addition, state-of-polarization (SOP) sensing is a technique that estimates vibrations in the fiber by analyzing variations in the received Stokes parameters. Although its application as a standalone method is limited due to the lack of spatial resolution of vibration events, SOP sensing can be effectively integrated with backscattering-based distributed acoustic sensing (DAS) and functions as a complementary extension to enhance the overall sensing performance. The analysis and feature extraction of DAS data is a promising application for machine learning. These methods enable automatic detection and classification of different types of vibration events and support predictions for various applications, enhancing overall network monitoring. The **SUSTAINET-innovate** project will extend its investigation to these options while mainly focusing on joint communication and sensing using coherent passive optical network (PON) transceivers, with the objective of enhancing network monitoring and control, improving network robustness, and increasing overall operational reliability.

Figure 4: Project logos and funding information. It includes the German Federal Ministry of Education and Research (BMBF) logo, the CELTIC-NEXT logo, and the SUSTAINET innovate logo. It also includes the text "Funded by" and "Bundesministerium für Bildung, Forschung, Technologie und Raumfahrt".

References:

- [1] N.L.E. et al., "Distributed fiber sensor network using telecom cables as sensing media: technology advancements and applications invited," *J. Opt. Commun. Netw.*, 14, 481-488 (2022).
- [2] J. L. Ebner, et al. "Urban sensing using existing fiber-optic networks," *Nature Communications*, 16, 1-20 (2021).
- [3] I.D. Agius, et al. "Progress on Very High Speed PON in PON," 2025 Optical Fiber Communications Conference and Exhibition (OFC), San Francisco, CA, USA, 2025.
- [4] G. Kotsopoulos, et al., "Coherent LDWDM PON with joint subcarrier reposition in OLT," *Opt. Express*, 22, 16879-16886 (2014).
- [5] Z. Zhou, et al., "Flexible Coherent Optical Access: Architectures, Algorithms, and Demonstrations," *J. Lightw. Technol.*, vol. 42, no. 8, pp. 1193-1202, Feb. 2024.
- [6] C. Duan, et al., "From coherent systems technology to advanced fiber sensing for smart network monitoring," *Journal of Lightwave Technology*, 41, 4 (2023), 1054-1063.

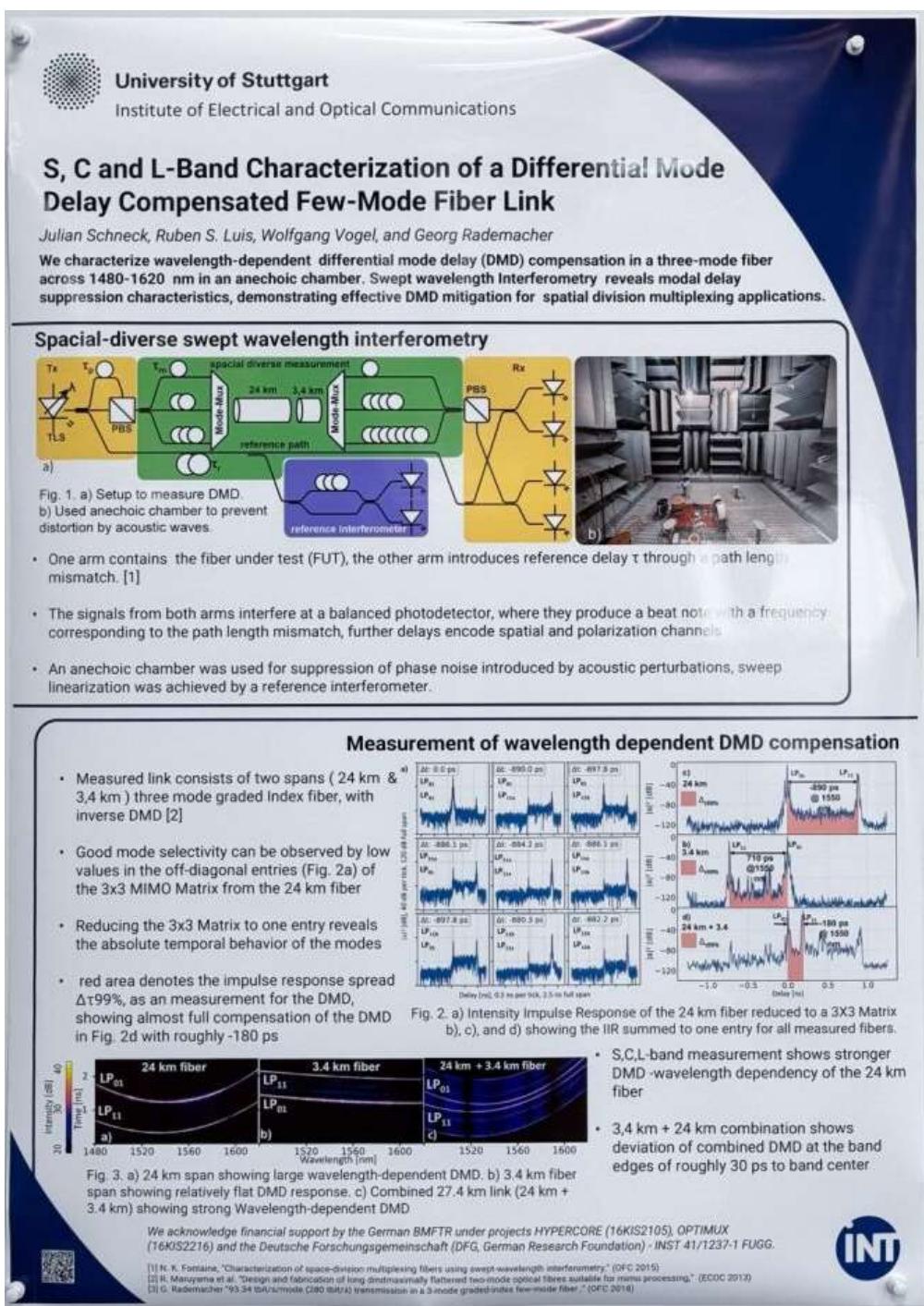
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## S, C and L-Band Characterization of a Differential Mode Delay Compensated Few-Mode Fiber Link

Julian Schneck (University of Stuttgart), Wolfgang Vogel (University of Stuttgart), and Georg Rademacher (University of Stuttgart)

Spatial division multiplexing (SDM) in few-mode fibers offers a promising pathway to overcome the capacity limits of single-mode transmission systems. However, differential mode delay (DMD)—the temporal separation between propagating modes—poses a significant challenge, causing inter-modal interference and limiting transmission reach. Effective DMD compensation is therefore critical for realizing practical SDM links. In this work, we characterize wavelength-dependent DMD compensation in a three-mode fiber across the extended wavelength range of 1480–1620 nm. Measurements were conducted in an anechoic chamber to minimize environmental perturbations. Using swept wavelength interferometry, we quantify modal delay suppression characteristics and demonstrate effective DMD mitigation strategies applicable to next-generation SDM systems.



## Towards AFDM-ISAC for Next-Generation Communications

Naoya Kumakura (Keio Univ.), Ryoya Saito (UEC), Koichi Adachi (Keio Univ.), Haris Gacanin (RWTH Aachen Univ.)

We evaluate the impact of peak-to-average power ratio (PAPR) reduction technique on the ambiguity function (AF) of affine-frequency division multiplexing (AFDM)-integrated sensing and communication (ISAC), which is a promising candidate for the future wireless communication systems.

### Towards AFDM-ISAC for Next-Generation Communications

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#### Background

- BSG/6G systems operate under high mobility, high carrier frequencies, and wide bandwidths, leading to linear time-variant (LTV) channels.
- Conventional multicarrier waveforms (e.g., OFDM) lose subcarrier orthogonality in high-Doppler scenarios, resulting in severe inter-carrier interference (ICI).
- Affine Frequency Division Multiplexing (AFDM) leverages delay-Doppler domain sparsity to ensure reliable transmission over LTV channels.



Figure 1: Concept of the LTV channel

#### Waveform Comparison Between AFDM, OCDM, and OFDM

##### Waveform Characteristics

- OFDM assumes a time-invariant channel; however, Doppler spread breaks subcarrier orthogonality, leading to ICI.
- OCDM employs fixed chirp-based spreading, which provides limited diversity gain over LTV channels.
- AFDM utilizes the affine Fourier transform with tunable chirp parameters to control delay-Doppler coupling.

##### Chirp Parameter Design

- Chirp parameters determine the symbol mapping in the delay-Doppler domain.
- Proper parameter selection aligns the transmitted signal with the LTV channel characteristics.

##### Diversity Properties

- AFDM can achieve full diversity over LTV channels with appropriate chirp parameters.
- OFDM and OCDM generally fail to guarantee full diversity in high-Doppler scenarios.

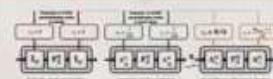


Figure 2: Modulation diagram (Left: OFDM, Center: OCDM, Right: AFDM) [5].



Figure 3: Waveform comparison (Left: OFDM, Center: OCDM, Right: AFDM)

#### Performance Evaluation

##### BER vs. SNR

- AWGN channel: AFDM, OCDM, and OFDM exhibit identical BER performance.
- LTI channel: AFDM and OCDM exhibit identical performance, while OFDM achieves only linear diversity gain.
- LTV channel: AFDM outperforms OCDM due to the chirp parameter design, whereas OFDM fails to maintain reliable communication.

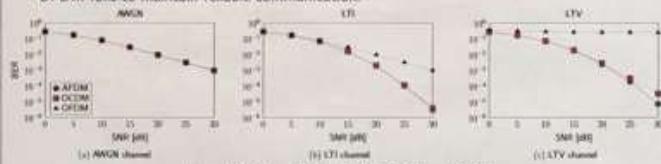


Figure 4: BER vs. SNR for AFDM, OCDM, and OFDM

##### PAPR Reduction

- Typical PAPR reduction methods, such as selected mapping (SLM) [2] and grouped pre-chirp selection (GPS) [3], are applied to AFDM.

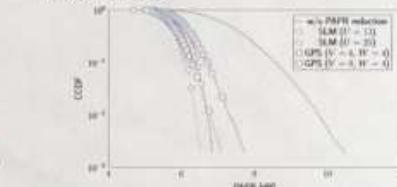


Figure 5: Comparison of PAPR performance between GPS and SLM

#### AFDM-ISAC Waveform Design

##### Auto-Ambiguity Function (AAF) Analysis

- The AAFs of OFDM, OCDM, and AFDM are compared to evaluate their sensing performance.
- OFDM exhibits a dominant correlation along the Doppler axis, limiting the Doppler resolution.
- OCDM shows a strong delay-Doppler correlation.
- AFDM achieves a highly concentrated AAF around the origin, enabling superior delay-Doppler resolution [4].

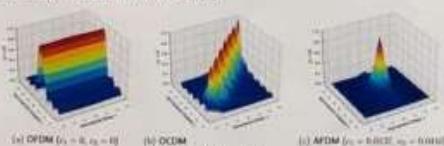


Figure 6: Comparison of AAFs for OFDM, OCDM, and AFDM

##### Impact on AAF-based Sensing Metrics

- PSR (Peak to Sidelobe Ratio) / ISLR (Integral Sidelobe Ratio)
- Due to fundamentally different mechanisms, a strictly fair comparison of PAPR reduction capabilities between SLM and GPS is non-trivial.
- SLM introduces random phase rotations, which results in a significant degradation of sensing metrics.
- In contrast, GPS adjusts chirp parameters without significantly altering the waveform structure, thereby preserving the AAF characteristics.

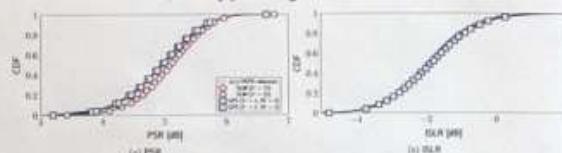


Figure 7: Comparison of PSR and ISLR

#### References

- A. Rizani, N. Kauri, and M. Kountouris, "AFDM: A Full Diversity Next Generation Waveform for High Mobility Communications," Proc. IEEE ICC Workshop, 2021.
- R. Bäuerl, R. Fischer, and J. Huber, "Reducing the PAPR of multicarrier modulation by selected mapping," Electron. Lett., 1996.
- H. Yau et al., "PAPR Reduction With Pre-Chirp Selection for AFDM," IEEE Wireless Commun. Lett., 2025.
- H. Yau et al., "Ambiguity Function Analysis of AFDM Signals for Integrated Sensing and Communications," IEEE J. Sel. Areas Commun., 2025.
- H. S. Rao et al., "AFDM for 6G: Properties, Features, and Challenges," arXiv preprint arXiv:2507.21704, 2025.

#### Acknowledgement

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# Identifying Non-Controlled Vehicles via MPC Trajectory Tracking for Outdoor Channel Modeling of 6G Integrated Sensing and Communication

Nopphon Keerativoranan and Jun-ichi Takada from Institute of Science Tokyo, Ainur Ziganshin and Christian Schneider from Technische Universität Ilmenau

Accurate channel characterization for 6G Integrated Sensing and Communication (ISAC) requires high-fidelity digital twins that account for dynamic outdoor environments. A major challenge in this domain is the presence of "non-controlled" traffic—vehicles lacking ground-truth positioning data—which complicates the validation of ray-tracing simulations against measurement data.

This poster presents a methodology to detect, track, and geo-locate these non-controlled vehicles using only Multipath Components (MPCs) extracted from channel sounder measurements. We employ a two-stage Recursive-RANSAC algorithm that first detects consistent linear trajectories within processing windows and subsequently stitches them over time using Hungarian-based pairing. Experimental validation compares the tracked MPCs extracted from channel measurements at 2.53 GHz (using both SAGE and RIMAX estimators) with reference trajectories extracted from video footage, demonstrating that the reconstructed trajectories align with physical road geometries.

## Identifying Non-Controlled Vehicles via MPC Trajectory Tracking for Outdoor Channel Modeling of 6G Integrated Sensing and Communication

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and Jun-ichi Takada<sup>1</sup>

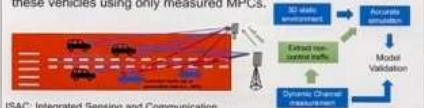
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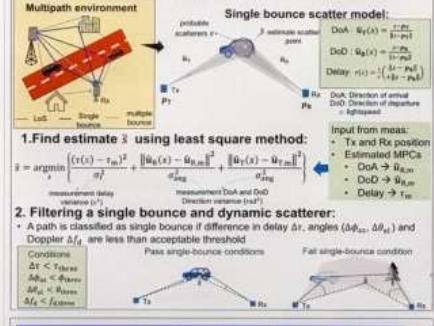
### 1. Introduction

- 6G ISAC demands accurate digital twins for deterministic and dynamic modeling, e.g., ray tracing (RT), evaluated via channel meas.
- The Challenge:** MPCs include reflections from moving objects; validating them traditionally requires matching to visual 3D data.
- The Gap:** Obtaining ground truth for "non-controlled" traffic is difficult, especially in video Non-Point-of-View (NPOV) zones.
- The Objective:** Investigate capability of tracking and geo-locating these vehicles using only measured MPCs.



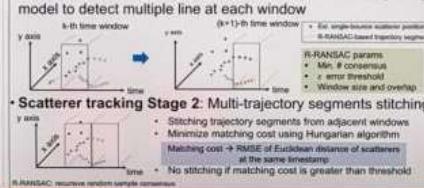
### 2. Estimation of Dynamic Single-bounce Scatterers

Goal: Estimate scatterer for each multipath component assuming single-bounce



### 3. Two-stage Recursive-RANSAC Dynamic Scatterer Tracking

- Assumption:** local linearity and sparseness of dynamic single-bounce scatterers
- parameters for tracking:** scatterer position vs time window
- Scatterer tracking Stage 1:** R-RANSAC [1] w/ linear trajectory model to detect multiple line at each window



- Scatterer tracking Stage 2:** Multi-trajectory segments stitching
  - Stitching trajectory segments from adjacent windows
  - Minimize matching cost using Hungarian algorithm
  - Matching cost  $\rightarrow$  RMSE of Euclidean distance of scatterers at the same timestamp
  - No stitching if matching cost is greater than threshold

### 4. Measurement Scenario and Extracted MPCs

#### Channel sounder setting

parameter	value
Center Frequency	2.53 GHz
Bandwidth	20 MHz
# array elements (dual polarized)	8 horizontal
Delay, AoA, AoD, Doppler complex path weight	2 vertical
Sampling time	4 ms
Measurement time	80 s



Scenario: Dynamic outdoor near roundabout

### 5. Results and Discussion

Estimated dynamic single-bounce scatterers (top left subfigure)

- Most likely vehicles: trajectories along the road behind Rx and half of roundabout

#### Estimated trajectories

- Only partial trajectories of vehicle were tracked
- 12 vehicular trajectories were partially detected out of 23 retrieved from video footage
- Common detected segments are right side of Rx and a roundabout corner (near LoS)
- Segment of Truck1 beyond reference were seen



#### Single-bounce and tracking setting

parameter	value
Window size	1 s
Overlapping size	0.89 s
$\epsilon$ error threshold	3 m
Min. # consensus	13 samples ( $\sim 0.5$ sec)
Segment stitching threshold	3 meters
Standard deviation of meas. parameters	$\sigma_t = 10$ ns $\sigma_{ang} = 5^\circ$
Dynamic single-bounce threshold	$\tau_{thres} = 10$ ms $\theta_{thres} = 10^\circ$ $\phi_{thres} = 30^\circ$ $\rho_{thres} = 5$ Hz

Overall estimated single-bounce scatterer estimate (top left), and 3 samples of estimated vehicle trajectories from MPCs in comparison with visual-based geolocation references

### Conclusion

- Proposed framework can estimate single-bounce scatterer of vehicle motion
- Due to rich multipath and estimation techniques, not all MPCs of entire trajectory was estimated, resulting in the partially reconstructed of vehicle trajectories
- Partial trajectories can be used to reconstruct/exclude MPCs of non-control traffic at certain time window

### References

[1] F. C. Hellwig, N. Aoyagi, and P. W. Smith, "Development and Analysis of Recursive-RANSAC for Multiple Scatterer Estimation," *IEEE Trans. Signal Process.*, vol. 65, no. 19, pp. 4945–4955, Feb. 2017.

[2] R. Thoma, M. Lachhab, and A. Suttor, "RIMAX: A Channel Model for Vehicle-to-Infrastructure Channel Modeling," in *Proc. 16th International Conference on Wireless Communications and Signal Processing (WCSP)*, 2022, pp. 1–6.

## Simplified Vehicular Scattering Models for Integrated Sensing And Communication: A Bistatic Radar Cross Section based Study

Karthik Subhash Jayasree (Institute of Science Tokyo), Nopphon Keerativoranan (Institute of Science Tokyo), Junichi Takada (Institute of Science Tokyo)

This work investigates the suitability of simplified vehicular models for Integrated Sensing and Communication (ISAC) systems.

Multiple simplified geometric models based on cuboids and curved cuboids are generated using the physical dimensions of a real vehicle, namely the VW Sharan. The bistatic radar cross sections of these models are computed using full wave electromagnetic simulations using the multilevel fast multipole method. To evaluate the scattering behavior, both radar cross section and received power responses of the simplified models are compared against those of the full scale VW Sharan model at an operating frequency of 2.1 GHz. The comparative analysis shows that the modified two curved cuboid model provides the closest approximation to the scattering characteristics of the VW Sharan car.

**Simplified Vehicular Scattering Models for Integrated Sensing And Communication : A Bistatic Radar Cross Section based Study.**

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**Institute of SCIENCE TOKYO**  
 Federal Ministry of Research, Technology and Sports  
 TAKADA Lab.  
 5G-ICAS4Mobility

**1. Introduction**

**Integrated Sensing and Communication (ISAC):**

- Combines the concept of communication and sensing into a single system [1].
- Enables object detection using existing communication infrastructure.

**ISAC Channel model:**

- Hybrid channel model [1]:

**Deterministic Multi Scattering Centre Target model [1]:**

- Each target is represented by several multiple scattering centres.
- Need for MSC model in ISAC:**
  - Conventional methods rely on complex EM simulations to compute the scattering fields.
  - MSC models are suitable for large scale ISAC applications.
- Research Gap:** MSC based models for typical sensing targets (Vehicles, Humans etc.) is underdeveloped and insufficiently validated.
- Research Goal:** To model a vehicle using deterministic MSC model for ISAC applications.
- Challenge:**
  - Identification of MSCs directly from a real car is challenging.
  - Scarcity of accurate car models.
- Objectives of this work:**
  - Model a car using simplified geometric structures.
  - Evaluate modeling accuracy and assess error due to simplification.

Actual Car → Simplified vehicular model → Validation of simplified model → MSC extraction and modeling

**3. Simulation**

- Bistatic RCS of simplified models are generated using the multilevel fast multipole method (MLFMM) in Ansys HFSS.
- The Bistatic RCS ( $\sigma$ ) of Simplified models are compared to that of VW Sharan.

Observation Plane: Along YZ plane  
 Car Model: Perfect conductor  
 Frequency: 2.1 GHz  
 Material: Perfect conductor  
 Excitation: Plane wave  
 Incident wave: -z direction  
 Polarization: x-polarized

**4. Results and Discussions**

Three simplified models (Cuboid, M2CCub, MM2CCub) are compared with the actual car model (VW Sharan) in terms of scattering characteristics.

**Angular RCS Comparison:**

**Angular ACF Comparison:**

**5. Conclusion**

- Simplified Cuboid models are adequate for forward and backward scattering scenarios.
- Proposed MM2CCub model accurately captures the scattering behavior of VW Sharan across all the regions.
- These simplified models can serve as a basis for applying MSC-based approaches in future research.

**6. References**

[1] W. Yang et al. "Integrated Sensing and Communication Channel Modelling and Measurements: Requirements and Methodologies Toward 6G Standardization," in IEEE Vehicular Technology Magazine, vol. 19, no. 2, pp. 22-30, June 2024.  
 [2] S. J. Myint, C. Schneider, M. Röding, G. Del Gatto, and R. S. Thomä, "Statistical analysis and modeling of vehicular radar cross section," in Proc. 13th European Conf. on Antennas and Propagation (EuCAP), Krakow, Poland, Mar. 2019.

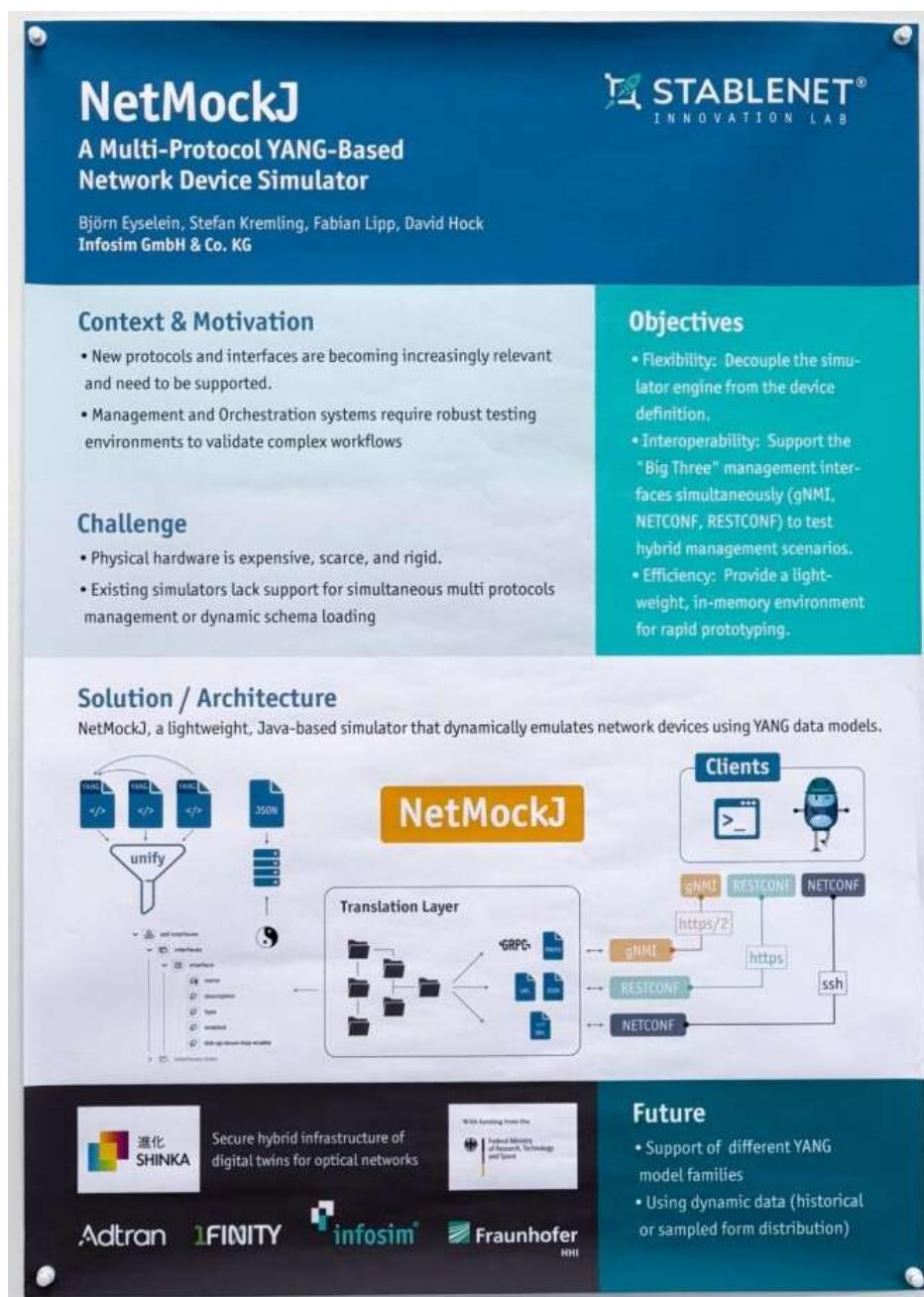
## Poster presentation (GJWS7-P08)

### NetMockJ: A Multi-Protocol YANG-Based Network Device Simulator

On site presenters: David Hock, Infosim & Fabian Lipp, Infosim - Additional authors: Björn Eyselain, Infosim & Stefan Kremling, Infosim

We present NetMockJ, a network device simulator developed as a Proof of Concept (PoC) within the SHINKA project, funded by the BMFTR. In the context of Beyond 5G and 6G, where network functions are increasingly softwarized, flexible testing environments for Management and Orchestration (MANO) systems are essential. NetMockJ enables the simulation of network devices by dynamically loading YANG data models to define their structure and state.

The simulator maintains a unified internal data store, exposed simultaneously via three industry-standard interfaces: gNMI, NETCONF, and RESTCONF. This multi-protocol approach allows researchers to validate orchestration workflows across different management paradigms within a single, lightweight environment, bypassing the need for physical hardware. As a functional prototype, NetMockJ serves as a tool for accelerating research and prototyping in next-generation network management and experimental automation scenarios.



# Poster presentation (GJWS7-P09)

## Channel Modeling for ICAS vehicular applications

Maximilian Lübeck (FAU Erlangen-Nürnberg)

Integrated sensing and communication (ISAC) for vehicular applications has attracted significant attention due to its potential to improve traffic safety and enhance spectral efficiency. To enable reliable system design and performance evaluation for vehicular applications, an accurate understanding and modeling of the time-varying characteristics of vehicular ISAC channels are essential. A dynamic sensing channel model is proposed for vehicular ISAC scenarios, based on 3D Ray tracing simulations conducted at mmWave frequencies in intersection scenarios. An improved multipath-component-distance (MCD) threshold-based cluster identification and tracking algorithm for sensing channel is proposed, which groups the multipath components (MPCs) contributed from the same target vehicles or surrounding buildings into clusters and subsequently tracks their evolution over time. To model the dynamic evolution process of channel, parameters characterizing the birth-to-death behavior of clusters are investigated. These include the cluster survival duration, initial (birth) point, number of born clusters and cluster evolution in the delay, azimuth and Doppler domains, which constitute a dynamic model for the outdoor vehicular ISAC channel.

**6G-ICAS4Mobility**  
Channel modeling for ICAS vehicular applications  
Guojin Zhang, Norman Franchi and Maximilian Lübeck  
ELITEs Institute for Smart Electronics and Systems, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU)

### Motivation and Goals

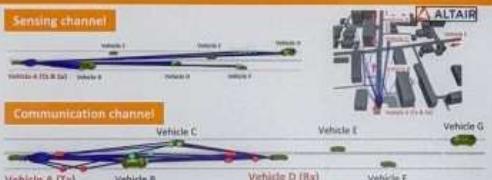
The integrated communications and sensing (ICAS) system is expected to be implemented in intelligent transportation systems (ITSs), significantly enhancing safety while reducing traffic congestion and accident rates.

- Waveform design for ICAS systems in various dynamic scenarios.
- Development of concepts for the ICAS-related extension of the 3GPP channel model, as well as the implementation and validation of the extended 3GPP channel model.
- Develop a Geometry-Based Channel Model based on simulations in highway scenarios.
- Analyze the correlation and different properties of time-varying ICAS channels, i.e. Sharing degree (SD).
- Validate Dual-Link MIMO channel measurements using Ray-tracing tools.
- Propose a dynamic statistical channel model to capture the time-varying properties of high-mobility ICAS channels, based on simulations in intersection scenarios.

### Intersection & Highway Scenarios

Parameter settings	
Frequency	2.53 & 77 GHz
Tool	Altair WinProp
Velocity	Vehicle A: 110 km/h Vehicle B: 80 km/h Vehicle C: 115 km/h Vehicle D: 120 km/h
Antenna	Tx: Radar antenna $G_{max} = 17.37$ dBi Beamwidth: $20^\circ$ (V), $30^\circ$ (H) Sze & Rx: Omnidirectional antennas
Time	12s

**Sensing channel**



**Communication channel**

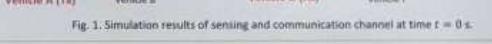


Fig. 1: Simulation results of sensing and communication channel at time  $t = 0$  s.

### Geometry-Based Channel Model

- Multipath-components distance (MCD)-threshold clustering method for both sensing and communication channel.
- Group the multipath components from the same interaction points or objects.
- For sensing channel, MCD between paths  $i$  and  $j$ :
$$MCD_{i,j} = \sqrt{MCD_{i,i} R^2 + MCD_{j,j} R^2 + MCD_{i,j} R^2}$$
- For communication channel:
$$MCD_{i,j} = \sqrt{MCD_{i,i} R^2 + MCD_{j,j} R^2 + MCD_{i,j} R^2}$$

where  $MCD_{i,j}$  is delay domain,  $MCD_{i,i}$  is angular domain, and  $MCD_{i,j}$  is Doppler frequency domain.

- Cluster level parameter: intra-cluster delay, angular, and Doppler spread.
- Sharing degree [SD]—power ratio of the sharing clusters in communication and sensing channel.
- Cluster evolution within their lifetimes in delay, angular and Doppler domains.
- Survival duration  $t_s$ —initial (birth) point:  $t_0, \Phi_0, \Psi_0$ .
- Number of born clusters at each snapshot  $N$ .

### Dual-Link MIMO Channel

**Validation- Dual-Link MIMO Channel Measurements**

- Measurements conducted by TU Ilmenau, in roundabout scenarios, at the frequency bands of 2.53 GHz and 20 MHz bandwidth.
- Simulation: Varying antenna config. (characteristics, mounting positions)
- Compare statistical parameters between measured and simulated data, including path loss, large-scale parameters (delay spread, angle spread, Doppler spread), shadow fading.

- Tracking algorithm: track the trajectory of the paths contributed from the same scatterer points at different time.
- Channel characteristics:
  - Lifetimes (Birth to death process of the target and clutter in time-varying channel);
  - Initial power and delay positions of the tracking trajectory;
  - Dynamic variations within their lifetimes, i.e. power decay.

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## Poster presentation (GJWS7-P10)

### Radio Channel Characterization for ICAS (Channel4ICAS)

Christian Schneider

This work presents a joint German-Japanese research effort focused on radio channel characterization for Integrated Communications and Sensing (ICAS). Serving as an extension to the BMBF-funded 6G-ICAS4Mobility project, the effort aims to study the aspects of sensing and security in automotive communications. Key objectives include acquiring and analyzing high-resolution multi-link MIMO channel measurements in various frequency bands, validating state-of-the-art ray-tracing tools, and developing concepts for the extension of 3GPP channel models for use in simulations. Furthermore, channel analysis and modeling results are used to study optimal waveform design, to evaluate ICAS resource allocation as well as parameter estimation algorithms. The project aims for a holistic understanding of radio channels for ICAS, supporting demands in next-generation vehicular networks and strengthening German-Japanese research activities.

**Project Overview**

The Radio Channel Characterisation for ICAS project serves as an extension to the ongoing BMBF-funded 6G-ICAS4Mobility project. The German and Japanese research partners within the project extension aim for:

- Perform & share novel multi-link MIMO ICAS channel measurements
- Evaluate ray-tracing tools for ICAS applications
- Characterize automotive ICAS channels in multiple frequency bands
- Develop concepts for extending existing 3GPP channel models
- German-Japanese co-operation in ICAS standardisation and research.

**Focus and Collaboration**

ICAS Modelling and Characterisation	ICAS Channel Measurements	Ray Tracing Simulations	PHY Coding and Encryption	Waveform Design	High-resolution Path Estimation
Partners: FAU, TU Ilmenau, SciTokyo	Partners: TU Ilmenau, Tottori Uni.	Partners: DENSO, FAU, SciTokyo TU Ilmenau, BOSCH	Partners: DENSO	Partners: FAU	Partners: TU Ilmenau, Tottori Uni.

**WP 1: Channel Measurements in FR1**

**Objectives**

- Planning and execution of dual-link MIMO automotive channel measurements
- Post-processing, provisioning and dissemination of measurements
- High-resolution multipath parameter estimation

**WP 2: Channel Analysis & Modelling**

- Characterisation of multi-path behavior in urban automotive ICAS
- Validation of existing channel simulation (ray-tracing) tools for ICAS applications
- Integration of channel data into a 3D simulation environment
- Concepts and implementation for GBSCM or hybrid extension of 3GPP channel models
- Investigations into the effect of antenna characteristics and positions on sensing

**WP 3: Data-based Evaluation**

**Objectives**

- Optimized sensing wave-form design considering realistic channel and environment behavior (with results from WP1 and WP2)
- Development of physical layer (PHY) coding and encryption using CSI or sensing results

**Collaborating Partners**

FAU  TECHNISCHE UNIVERSITÄT  
ILMENAU  INSTITUTE OF  
SCIENCE TOKYO  DENSO  BOSCH 

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## Poster presentation (GJWS7-P11)

### Digital Twin Federation for All Photonic Networks

Fraunhofer HHI

The German–Japanese project SHINKA investigates a secure platform for the cross-border and cross-network integration of digital twins. The project aims to establish an ecosystem for the design, control, and optimization of high-speed photonic networks. To this end, SHINKA develops an architecture in which multiple digital twins map the physical network infrastructure and are interconnected via a common management and federation layer. Standardized interfaces ensure compatibility with diverse applications. The project plans to experimentally demonstrate a secure data exchange platform and validate the ecosystem across interconnected testbeds in Germany and Japan.

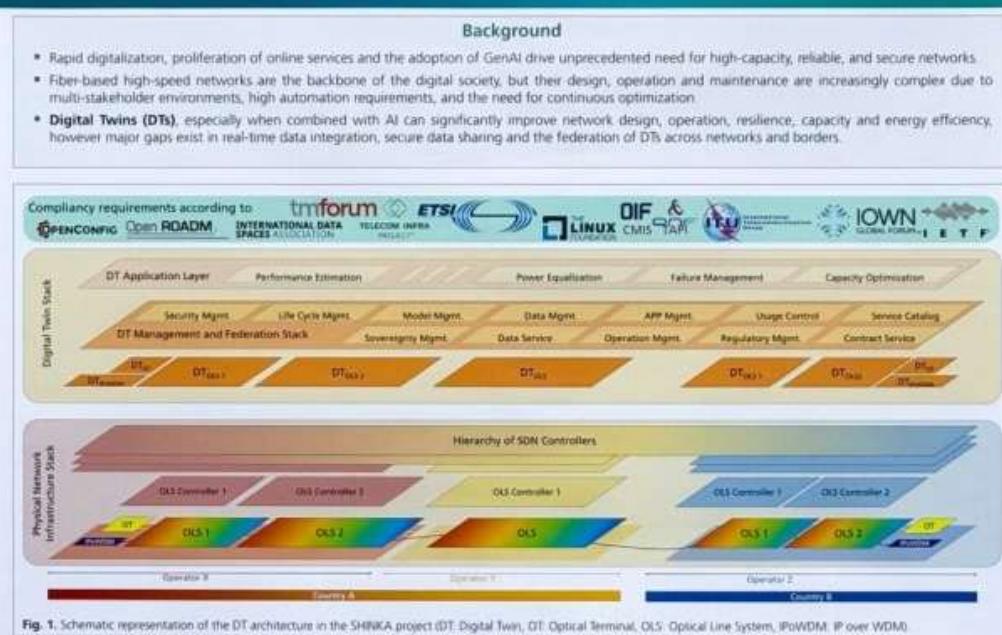


Fig. 1. Schematic representation of the DT architecture in the SHINKA project (DT: Digital Twin, OT: Optical Terminal, OLS: Optical Line System, IPoWDM: IP over WDM).



## Poster presentation (GJWS7-P12)

### Measurement and Analysis of Static and Dynamic ISAC Channels

Christian Schneider

Integrated sensing and communication (ISAC) is set to become a key technology for beyond-5G and 6G networks. In this poster, we present our work on characterising multi-link radio channels for sensing in vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) environments. Our work is based on relevant channel sounding measurement campaigns. Our objectives are to present ISAC datasets that are useful for multi-path propagation analysis, and to study the channel contributions related to static and dynamic objects within the ISAC propagation channel. This is a joint German-Japanese research project involving the Institute of Science in Tokyo, Tottori University, and Technische Universität Ilmenau.

# Measurement and Analysis of Static and Dynamic ISAC Channels

6G-ICAS4Mobility

TECHNISCHE UNIVERSITÄT ILMENAU

Institute of SCIENCE TOKYO

WZL Funding from the Federal Ministry of Research, Technology and the Environment

Förderkennzeichen: 04W19024

## Contribution

**Contribution**

- Measurement of multi-link radio channels in FR1 for Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) for ICAS
- Multipath characterisation for static and dynamic channel contributions (buildings/trees vs. vehicles)
- Extension and parameterisation of Geometry-Based Stochastic Channel Models (GBSCM) for ICAS



**Measured Scenarios of the FR1 ISAC Channel Sounding**

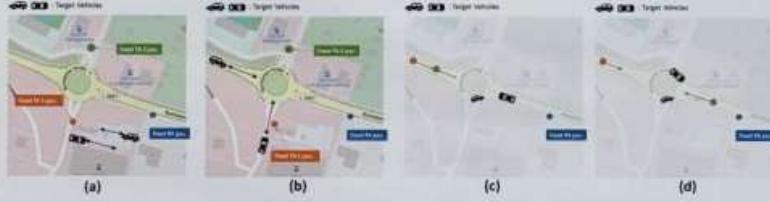


Illustration of scenarios for:  
a) parking lot,  
b) stationary TXs,  
c) dynamic TXs: convoy and  
d) dynamic TXs: opposite.



Automotive Targets



The datasets are publicly available! Contact: christian.schneider@tu-ilmenau.de

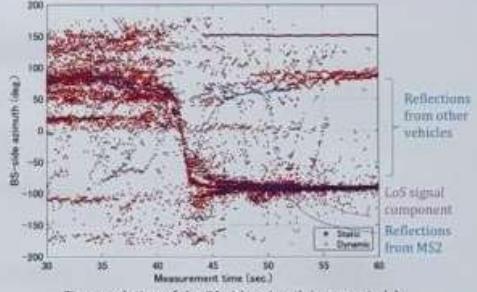
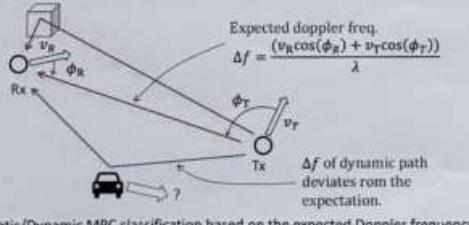
## Estimation of Static and Dynamic Channel Contributions

**Key for accurate ISAC modelling:**

- Characterisation of static and dynamic channel contributions
- Adaptation of estimation and analysis strategy

**Solution:**

- Classify dynamic and static multipath components (MPCs) based on their expected Doppler frequencies,
- Determined from the MPCs' arrival and departure angles and the motion directions of Tx and Rx.



Time evolution of the BS-side azimuth in scenario (c).

**Analysis Results**

- Static MPCs (from static objects such as buildings) and dynamic MPCs (from moving objects such as vehicles) were separately estimated.
- Power ratio of dynamic to static ranged from -35 to -15 dB.

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## Poster presentation (GJWS7-P13)

### Reduction of absorption losses originated from NH bonds in high-Q SiN microring resonators based on low-temperature hot-wire deposition method

Kentaro Furusawa, Tomohiro Tetsumoto, and Norihiro Sekine (NICT)

Microcomb-based signal sources are anticipated to serve as important building blocks in various applications, ranging from telecommunication to sensing in the sub-terahertz frequency range. We have been developing microring resonators in the SiN platform using low-temperature deposition technique, key components in the microcombs. This approach not only eases the device fabrication thanks to the low-stress characteristics, but also paves a way to realize advanced photonic integrated circuits by employing various components available in the other platforms such as photo diodes via hybrid or heterogeneous integration. Recent progress in our device fabrication is presented, including the loaded Q-factors beyond  $10^6$  achieved by reducing the hydrogen content within the SiN films.

