Wireless

VERIFYING JCAS PERFORMANCE IN THE 6G LANDSCAPE

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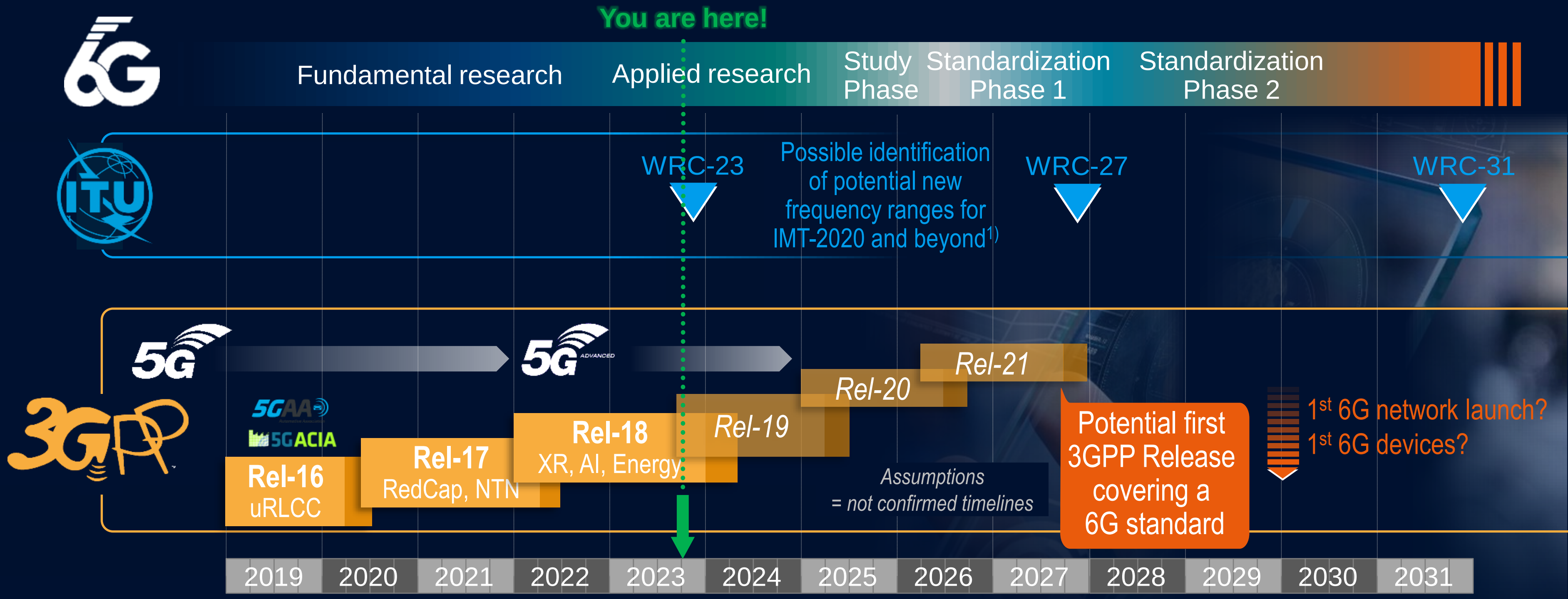
ROHDE&SCHWARZ

Make ideas real

AGENDA

- Introduction
- Communication and sensing/radar roots
- Use Cases
- Non-cellular technology based sensing
- 5G-Advanced to 6G evolution
- JCAS architectures and waveforms
- JCAS testing approaches
- Take aways

FUTURE STANDARDIZATION AND REGULATORY ROADMAP



1) *IMT-2020 systems are called 5G*

RESEARCH AREAS FROM A T&M PERSPECTIVE

THz communicatio and “FR3”

Joint communication & sensing

rtificial Intelligence a d Machine Learning

Reconfigurable Intelligent Surfaces

Photonics, Visible Light Communication

Multiple access, new waveforms, channel coding

Ultra-massive MIMO

New network topologies, distributed computing

Full-duplex communication

Security & Trustworthiness

A high-level overview on all these research areas is provided in one of our [#THINKSIX](#) video. Don’t miss it!

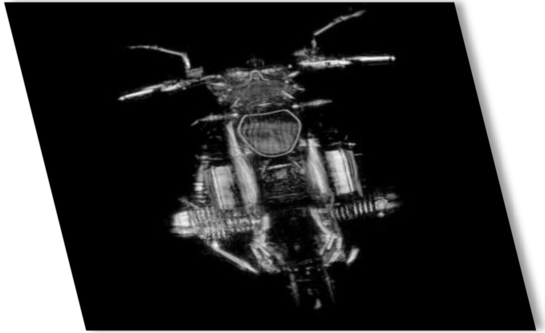
JCAS RESEARCH LANDSCAPE

WHERE WE ARE COMING FROM
SENSING AND COMMUNICATION HAVE A LONG (SEPARATE) HISTORY

Communication

2G, 3G, 4G, 5G

Imaging



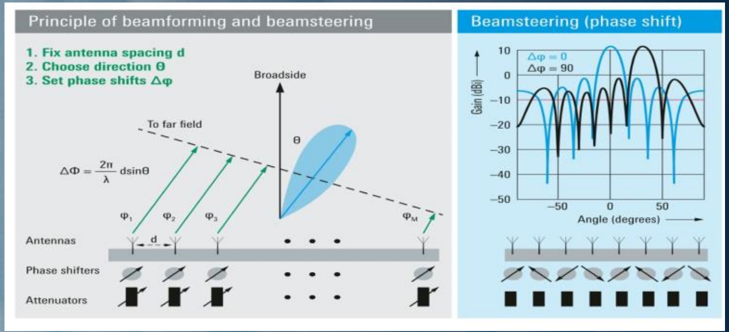
Proprietary

Automotive

FMCW, chirps, …

RADAR AND COMMUNICATION COMMONALITIES

Hardware



Processing

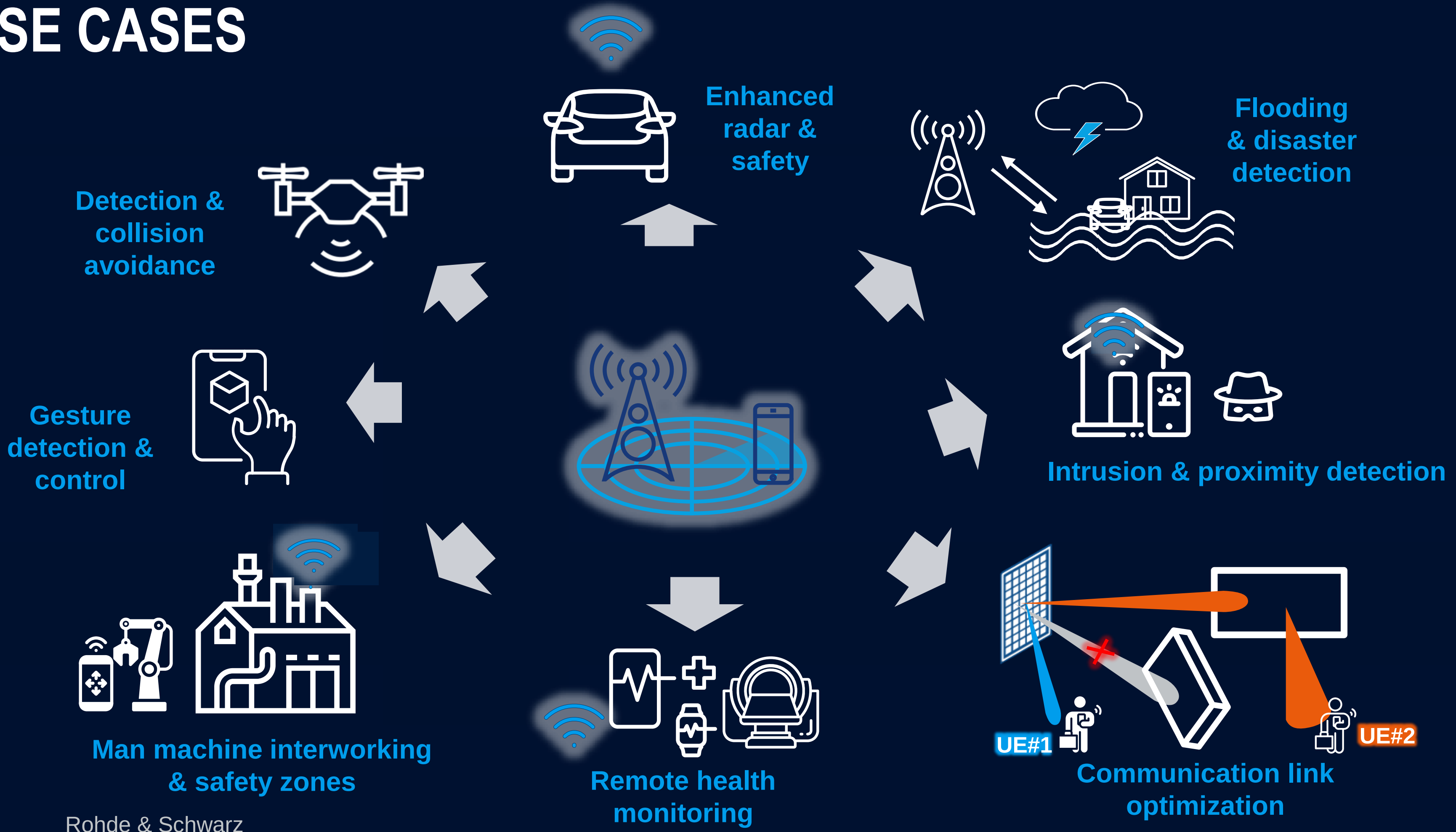
Phased array antennas and beamforming are widely used

Both benefit from high bandwidth in higher frequency ranges (FR2 and 70 GHz)

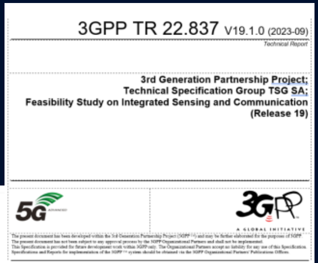
Estimation techniques (channel or target) are important

Both benefit from recent increased trends on machine learning

USE CASES


Enhanced radar & safety
Flooding & disaster detection
Detection & collision avoidance
Gesture detection & control
Intrusion & proximity detection
Man machine interworking & safety zones
Remote health monitoring
UE#1
UE#2
Communication link optimization

USE CASES
3GPP AND EXAMPLE RESEARCH PROJECT


3GPP TR 22.837 V19.1.0 (2023-09)
Technical Report

3rd Generation Partnership Project;
Technical Specification Group TSG SA;
Feasibility Study on Integrated Sensing and Communication
(Release 19)

Scenario	Sensing service category	Sensing service area	Confidence level [%]	Accuracy of positioning estimate by sensing (for a target confidence level)		Accuracy of velocity estimate by sensing (for a target confidence level)		Sensing resolution		Max sensing service latency [ms]	Refreshing rate [s]		
				Horizontal [m]	Vertical [m]	Horizontal [m/s]	Vertical [m/s]	Range resolution [m]	Velocity resolution (horizontal/ vertical) [m/s x m/s]				
Object detection and tracking	1 (use cases 5.1; 5.13 – level1)	Object to be detected indoor: Human, object to be detected outdoor: UAV	95	10	10	N/A	N/A	10 NOTE 2	10 NOTE 3	1000	1	5	2
	2 (use cases 5.13 – level2, 5.6, 5.14)	Object to be detected outdoor: Human, UAV	95	5	5	N/A	N/A	10 NOTE 2	10 NOTE 3	1000	1	5	5
	3 (use cases 5.2, 5.7, 5.10, 5.11, 5.12, 5.23)	Factory (100m2), crossroad, highway, railway [air] NOTE 4 Object to be detected: Animal, Human, UAV, Vehicle	95	1	N/A	1 NOTE 5	N/A	1 NOTE 5 NOTE 8	1 x 1 NOTE 9	100 NOTE 6 1000 NOTE 10	0.1 NOTE 11	2	2

- ► 32 use cases in TR 22.837
  - – Includes consolidated potential KPIs
- ► KomSens 6G
  - – 11 uses cases clustered into
    - – Sensing-aided communication
    - – Public safety
    - – Smart logistics
    - – Smart factory
    - – Smart city
    - – Weather-related sensing

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KOMSENS 6G

NON-CELLULAR SOLUTIONS ADDRESSING SOME USE CASES

Wi-Fi sensing has bee successfully demonstrated on the market for several years, but the current Wi-Fi standard does not specify any sensing specific features.

Fine Ranging

Bluetooth LE CA
Wi-Fi 802.11az/bk

Life Sensing

Wi-Fi 802.11bf
UWB 802.15.4ab

Google sleep sensing

Murata child detection

Verizon home aware

Gesture control

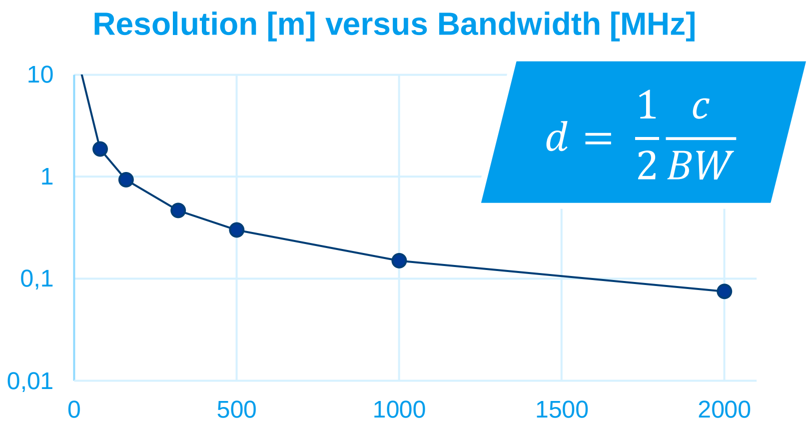
THE WI-FI SENSING PLAYGROUND AND MOTIVATION

- Privacy protection no pictures, no video
- Works in dark or low -light environments
- Can see trough material/housing
- Able to detect fine moves or even heart beats

IEEE 802.11bf was formed to use Wi-Fi sensing to estimate **range, velocity, or motion** of objects in an area of interest

Targets:

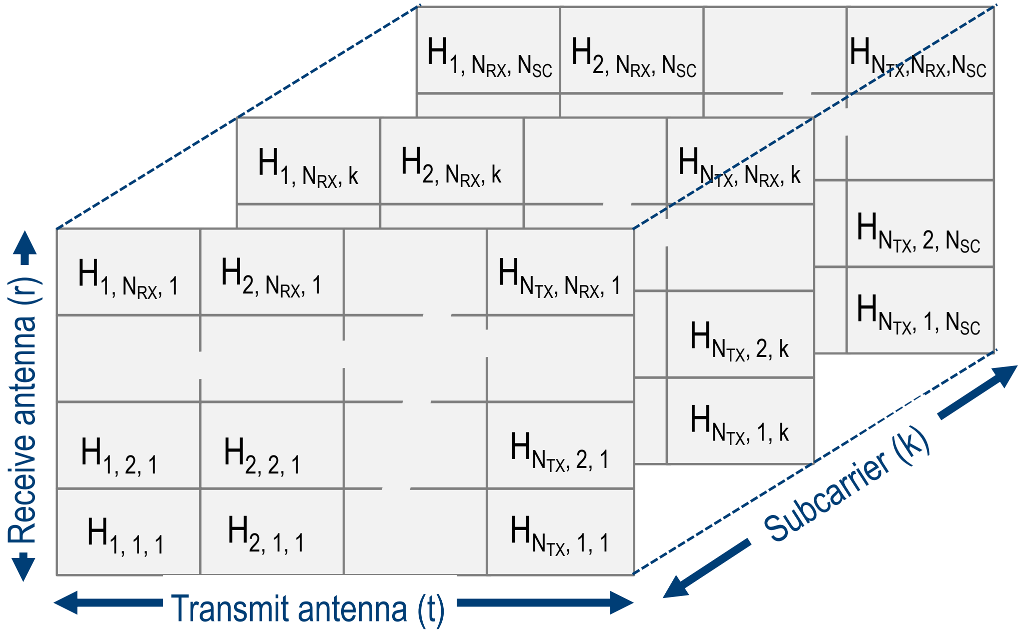
- Enable interoperability of sensing device from different vendors
- Define interfaces for sensing applications to request/obtain sensing measurements
- Reduce sensing overhead
- Allow for sensing applications to obtain sensing measurements with greater consistency and control



$$d = \frac{1}{2}\frac{c}{BW}$$

SENSING MEASUREMENT REPORT

CHANNEL STATE INFORMATION (CSI)



N_{TX} number of transmit antennas [0…8]

N_{RX} number of receive antennas [0…8]

N_b number of bit per CSI value [0: 8bit, 1:10bit]

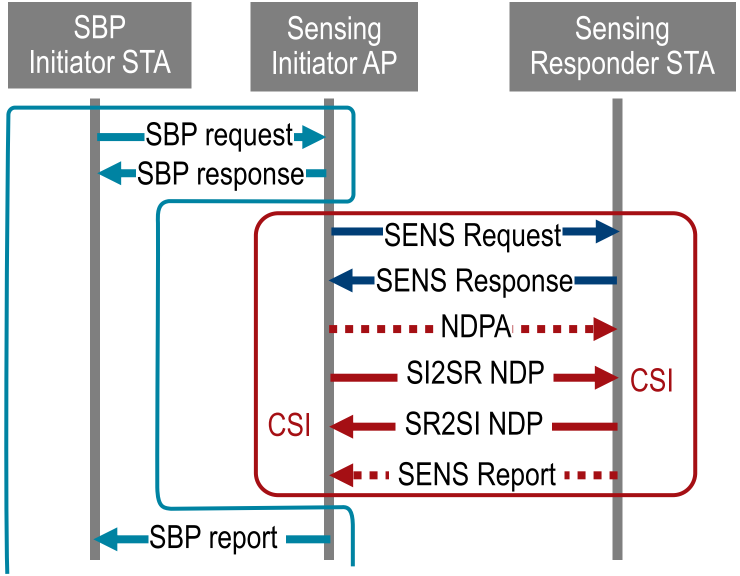
N_g Subcarrier grouping [4, 8, 16]

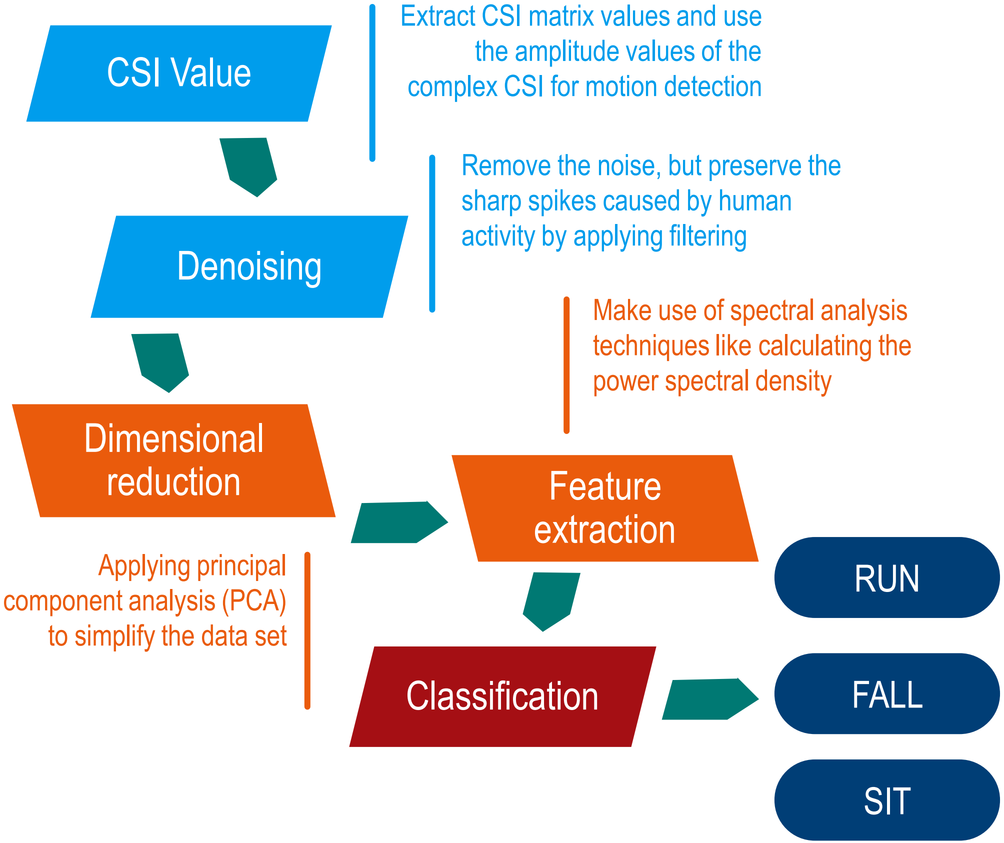
N_{SC} number of subcarriers

Channel width	N_g	N_{SC}
20 MHz	4	64
	16	20
40 MHz	4	122
	16	32
80 MHz	4	250
	16	64
160 MHz	8	252
	16	128

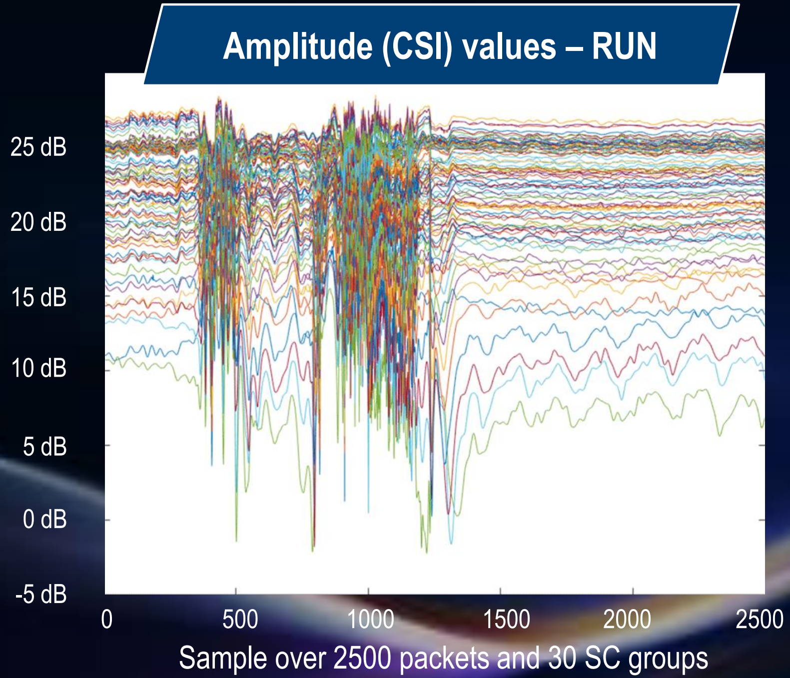
PRINCIPLE PROCEDURES

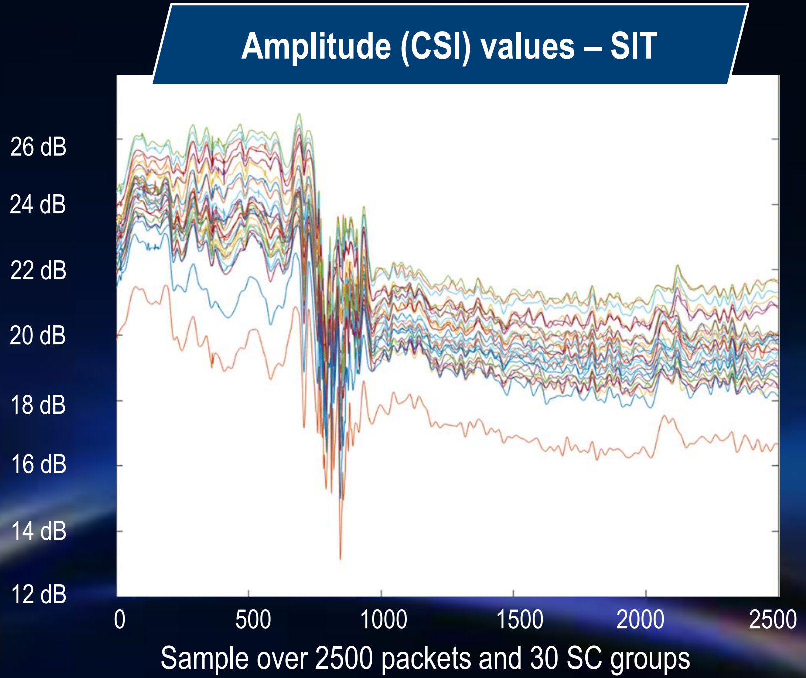
Procedure specified in Wi-Fi 802.11bf





CSI AMPLITUDE DATA FOR DIFFERENT MOTION ACTIVITIES





Device free human activity and fall recognition using WiFi channel state information (CSI); Neena Damodaran, Elis Haruni, Muyassar Kokhkharova & Jörg Schäfer, Springer CCF Transactions on Pervasive Computing and Interaction volume 2, 2022 see https://rdcu.be/c0IQN

JCAS EVOLUTION FROM 5G ADVANCED TO 6G

2023

5G NR Rel18 SA

- Ranging based services and sidelink positioning

2024/25

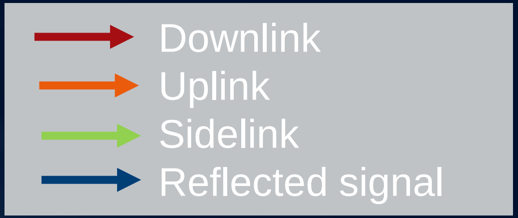
5G NR Rel19 RAN

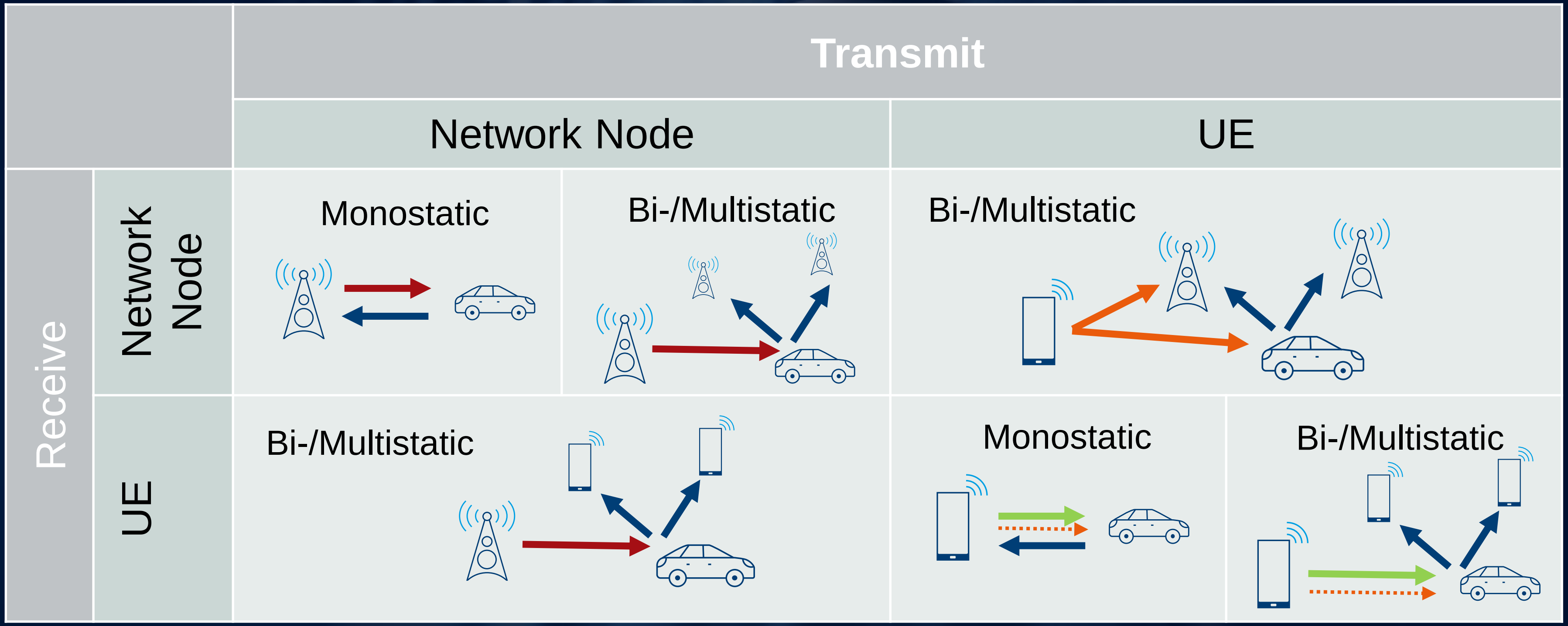
- ISaC use case selection (based on TR 22.837)
- Channel modelling details for sensing (modelling of targets, RCS, …)

> 2027

6G joint / integrated communication and sensing

SENSING ARCHITECTURES





PROS AND CONS OF SENSING ARCHITECTURES

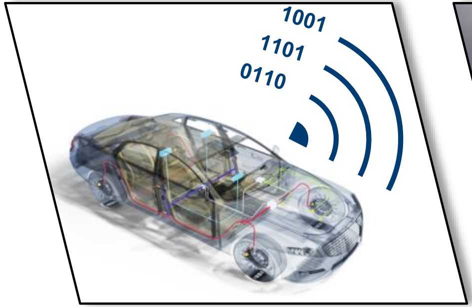
Some key differences can be perceived between multi-static and monostatic approaches:

- **Multi- and Bi-static**
  - Big advantage: Existing infrastructure can be reused (no full duplex is required). However, this architecture requires information transfer between nodes/devices.
  - Note that the sensing accuracy is impacted by clock/timing offsets between base stations and/or devices.

- **Monostatic**
  - Requires full duplex operation adding complexity and cost to available implementations.
  - However, all data is available at the sensing transmitter node.

WAVEFORMS
TWO ENTRY POINTS FOR EVOLUTION

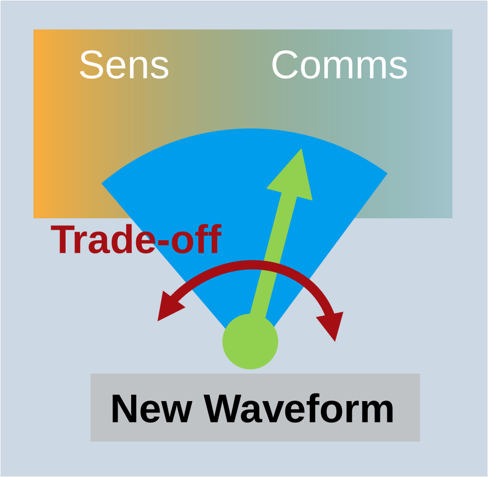
Radar centric



PMCW, FMCW, …

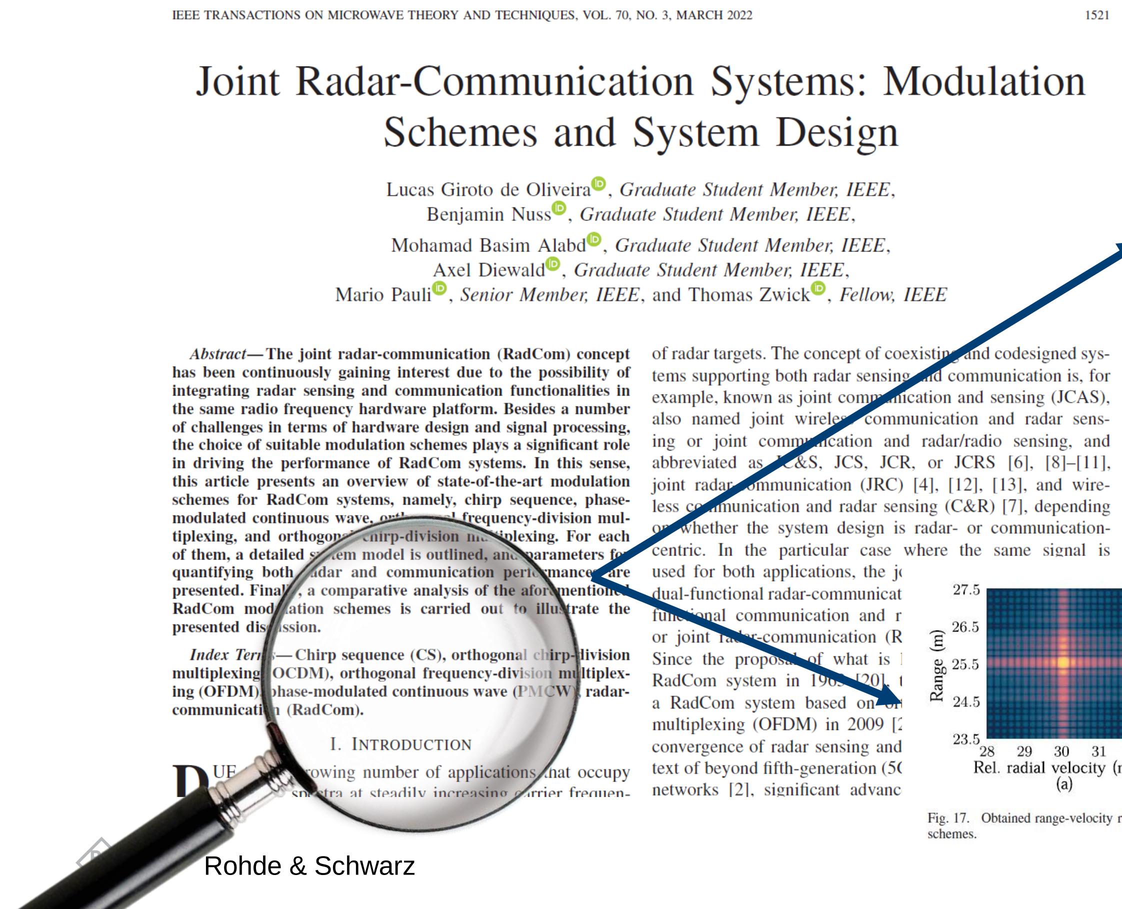
Communication centric

OFDM



Can we find an adaptable waveform, that allows tuning towards sensing or communication performance on a per use case basis?

EXAMPLES OF WAVEFORM RESEARCH



IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 70, NO. 3, MARCH 2022 1521

Joint Radar-Communication Systems: Modulation Schemes and System Design

Lucas Giroto de Oliveira, *Graduate Student Member, IEEE*, Benjamin Nuss, *Graduate Student Member, IEEE*, Mohamad Basim Alabd, *Graduate Student Member, IEEE*, Axel Diewald, *Graduate Student Member, IEEE*, Mario Pauli, *Senior Member, IEEE*, and Thomas Zwick, *Fellow, IEEE*

Abstract—The joint radar-communication (RadCom) concept has been continuously gaining interest due to the possibility of integrating radar sensing and communication functionalities in the same radio frequency hardware platform. Besides a number of challenges in terms of hardware design and signal processing, the choice of suitable modulation schemes plays a significant role in driving the performance of RadCom systems. In this sense, this article presents an overview of state-of-the-art modulation schemes for RadCom systems, namely, chirp sequence, phase-modulated continuous wave, orthogonal frequency-division multiplexing, and orthogonal chirp-division multiplexing. For each of them, a detailed system model is outlined, and parameters for quantifying both radar and communication performance are presented. Finally, a comparative analysis of the aforementioned RadCom modulation schemes is carried out to illustrate the presented discussion.

Index Terms—Chirp sequence (CS), orthogonal chirp-division multiplexing (OCDM), orthogonal frequency-division multiplexing (OFDM), phase-modulated continuous wave (PMCW), radar-communication (RadCom).

I. INTRODUCTION

DUE to the growing number of applications that occupy spectra at steadily increasing carrier frequen-

of radar targets. The concept of coexisting and codesigned systems supporting both radar sensing and communication is, for example, known as joint communication and sensing (JCAS), also named joint wireless communication and radar sensing or joint communication and radar/radio sensing, and abbreviated as JC&S, JCS, JCR, or JCRS [6], [8]–[11], joint radar-communication (JRC) [4], [12], [13], and wireless communication and radar sensing (C&R) [7], depending on whether the system design is radar- or communication-centric. In the particular case where the same signal is used for both applications, the jo dual-functional radar-communicat functional communication and r or joint radar-communication (R Since the proposal of what is RadCom system in 1963 [20], a RadCom system based on or multiplexing (OFDM) in 2009 [2 convergence of radar sensing and text of beyond fifth-generation (5G networks [2], significant advanc

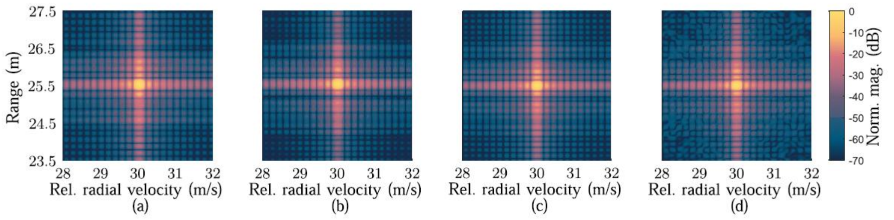
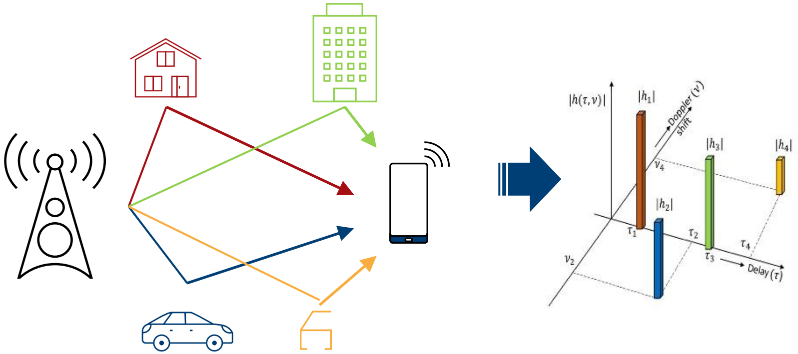


Fig. 17. Obtained range-velocity radar images from measurements with RadCom systems based on (a) CS, (b) PMCW, (c) OFDM, and (d) OCDM modulation schemes.

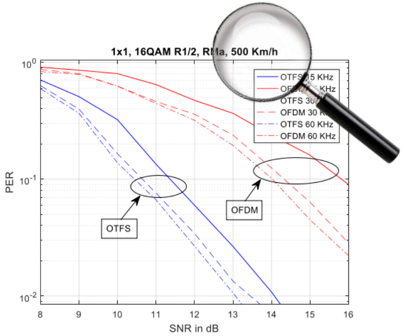
- Detailed work on
  - Chirp sequence (CS)
  - orthogonal chirp-division multiplexing (OCDM)
  - orthogonal frequency-division multiplexing (OFDM)
  - phase-modulated continuous wave (PMCW)

ANOTHER WAVEFORM OF INTEREST
OTFS - ORTHOGONAL TIME FREQUENCY SPACE MODULATION

- For TDM and FDM the signal is localized in time or in frequency → time selective or frequency selective fading
- **Idea: Go to the Delay-Doppler (DD) domain**



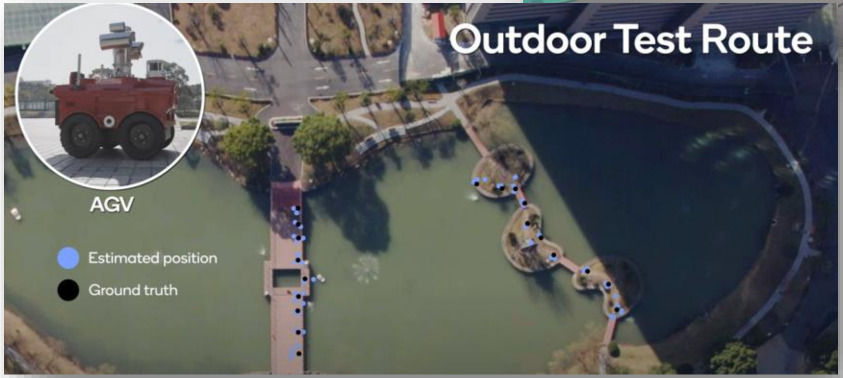
- Doppler Delay Modulation (DDM)
  - Information is carried over DD domain pulse
  - Delay period τ_p ; Doppler period $\nu_p = \frac{1}{\tau_p}$
  - Zac transform z_t, used to transform the DD signal to a TD signal $x(t)$



Ref: R1-1609825, 3GPP TSG RAN WG1 Meeting #86bis, 2016

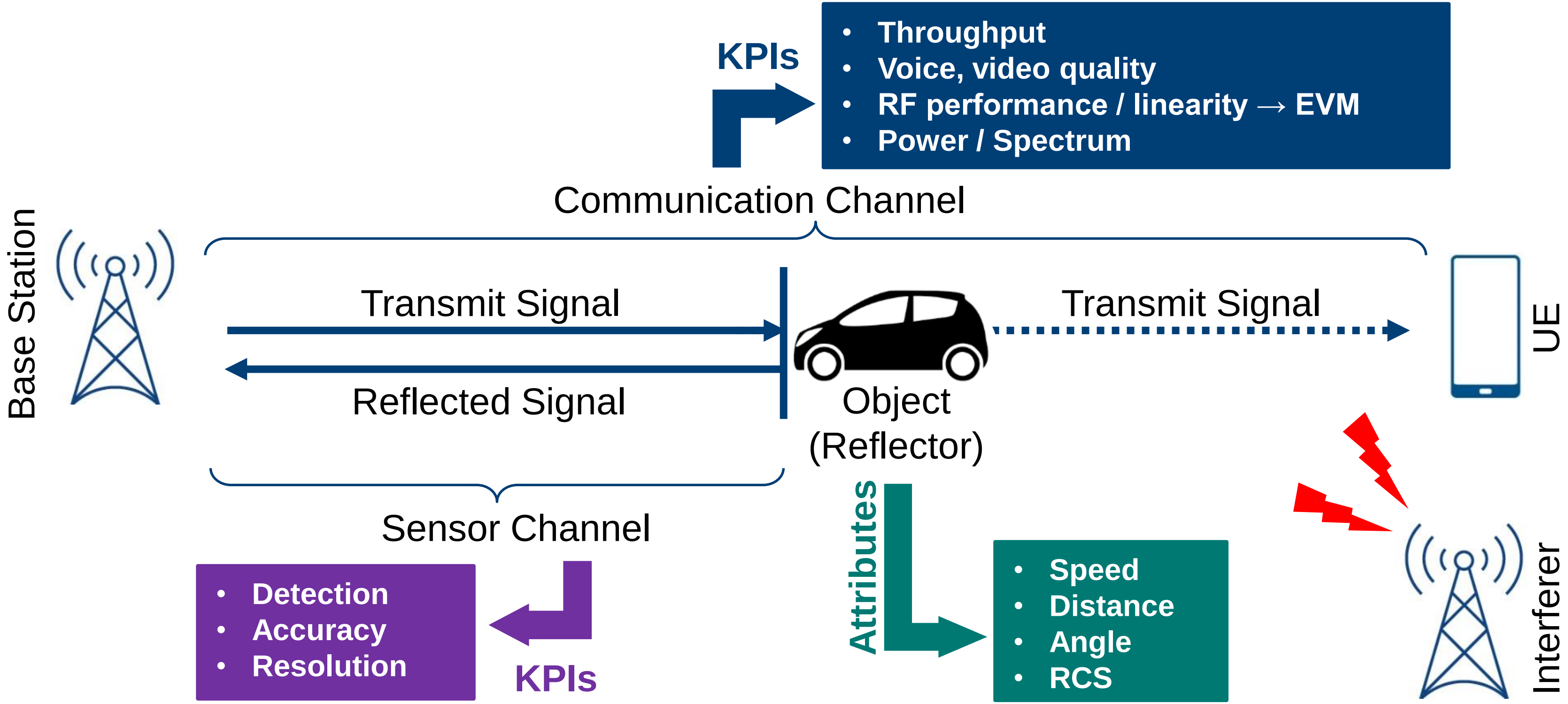
MOBILE WORLD CONGRESS DEMONSTRATIONS FEB 2023

- ► Quite some demonstrators were showcased already based on existing 5G NR FR2 implementation.
- ► Focus on distance and speed estimation of passive objects.



JOINT COMMUNICATION AND SENSING

PRINCIPLE TESTING CONSIDERATIONS



RADAR CROSS SECTION

- **Definition:** Radar cross section is a parameter which describes how much of the incoming radar signal at the object gets reflected back to the radar sensor. **The RCS does not represent the physical size of an object but is rather a virtual parameter**. **Multiply the RCS by the power density of the radar signal at the location of the object to get the signal power reflected to the radar sensor**.

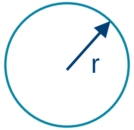
- Many parameters affect the RCS of an object, for example:
  - Geometrical shape of the object, like surfaces, edges or size
  - Material of the object
  - Orientation of the object towards the radar sensor
  - Polarization of the radar transmit antenna and the radar receive antenna
  - Wavelength of the radar signal

RADAR CROSS SECTION
SOME FORMULAS AND NUMBERS

- Under the following assumption, simplified formulas apply
  - Distance >> wavelength (λ) of radar signal

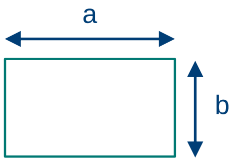
- RCS for an ideal sphere

$$RCS_{max} = \pi \cdot r^2$$



- RCS for an ideal plate

$$RCS_{max} = \frac{4 \cdot \pi \cdot a^2 \cdot b^2}{\lambda^2}$$



- Typical value (76-81 GHz):

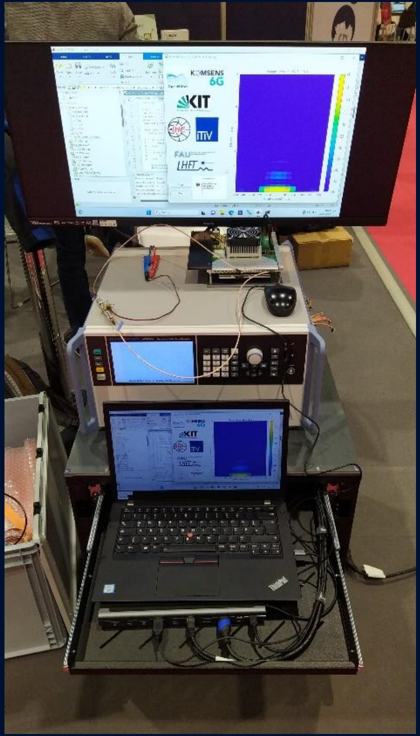
RCS ≈ -5.44 to -7.12 dBm²

ETSI TS 103 789 V1.1.1

- Z. Li, A. Nimr, P. Schulz and G. Fettweis, “Multi-Band Superresolution Multipath Channel Path Delay Estimation for CIR-Based Localization,” in Proceedings of 2nd IEEE International Hybrid Symposium on Joint Communications & Sensing (JC&S 2022), Seefeld, Austria, Mar 2022. DOI:10.1109/JCS54387.2022.9743505
- R. Bomfin, Z. Li, A. Nimr and G. Fettweis, “Experimental Validation of Superresolution Delay Estimation Algorithm Using a 26 GHz Radar Setup,” in Proceedings of 2nd IEEE International Hybrid Symposium on Joint Communications & Sensing (JC&S 2022), Seefeld, Austria, Mar 2022.

TECHNISCHE UNIVERSITÄT DRESDEN

DEMONSTRATION AT EUMW 2023 (BERLIN)



More information at:

https://www.ihe.kit.edu/english/index.php

TAKE AWAYS

Joint / Integrated communication and sensing will enable enhanced and new use cases.

Non-cellular technologies provide initial sensing solutions, while 5G-Advanced specification work has started in 3GPP.

6G aims at an integrated approach for supporting communication and sensing within the same technology.

Sensing performance verification requires additional test methods and procedures.

► **Rohde & Schwarz is actively engaged in this phase of applied research, providing our expertise in test and measurement to make ideas real.**

Find out more

www.rohde-schwarz.com/6G

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Make ideas real