Qualcomm

What's the role of sensing for next-generation wireless networks?

Integrating sensing with communications for enhanced system efficiencies and new user experiences

@QCOMResearch

Agenda

ONE

Sensing is an emerging wireless capability that can unlock exciting new use cases and business opportunities

TWO

Integrating sensing and communications can drive new wireless system efficiency and valuable cellular services

THREE

The path to 6G integrated sensing and communications (ISAC) starts with 5G Advanced study on wireless sensing

FOUR

We are pioneering foundational wireless sensing research, accelerating the physical and digital convergence

Sensing can unlock exciting new opportunities

AN EMERGING WIRELESS CAPABILITY

The sensors economy is experiencing rapid growth and transforming various industries

Global sensor market is expected to reach $300.5 Billion by 2029[1]

Growing at a CAGR of 8.9% (2024-2028)[1]

Consumer electronics

SMARTPHONES

Equipped with various sensors like accelerometers, gyroscopes, and ambient light sensors to enhance user experience

SMART HOME DEVICES

Sensors in smart thermostats, security systems, and lighting control contribute to energy efficiency and home automation

Automotive

ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS)

Sensors such as lidar and cameras are crucial for functions like adaptive cruise control and lane-keeping assistance

ELECTRIC VEHICLES (EVS)

Battery management systems rely on temperature and voltage sensors for optimal performance and safety

Industrial

INDUSTRIAL AUTOMATION

Sensors are used in machinery to monitor performance, predict maintenance needs, and improve efficiency

ENVIRONMENTAL MONITORING

Sensors track air quality, temperature, and humidity, aiding in maintaining optimal working conditions and regulatory compliance

Healthcare

WEARABLE SENSORS

Devices like smartwatches and fitness trackers monitor vital signs and activity levels

REMOTE PATIENT MONITORING

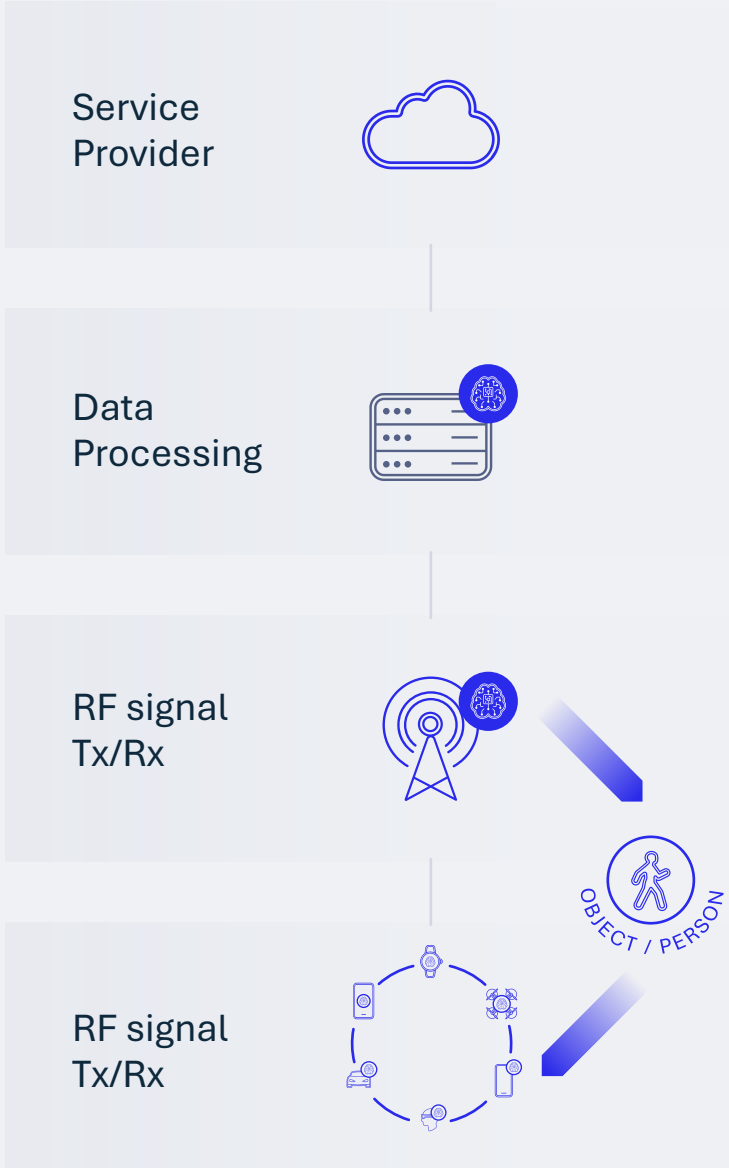
Sensors enable continuous monitoring of patients' health, reducing the need for hospital visits

1. https://www.bccresearch.com/market-research/instrumentation-and-sensors/sensors-technologies-markets-report.html

Wireless sensing

To utilize radio frequency (RF) signals from a wireless system to gain insights into the environment

Object does not contain active electronics or support device positioning



Types of wireless sensing use cases include:

Presence detection and recognition

Motion and gesture recognition

Activity monitoring

Environmental monitoring

Vital signs

Localization

Occupancy counting

Fall detection

Sleep tracking

Intrusion detection

Data collection

Wireless networks are connecting virtually everyone and everything around us

Cost-effectiveness

Growing wireless support in new devices beyond smartphones, e.g., XR, laptops, IoT, and more

Scalability and flexibility

Wireless connectivity is a key enabler of easy addition, removal, and maintenance of sensors

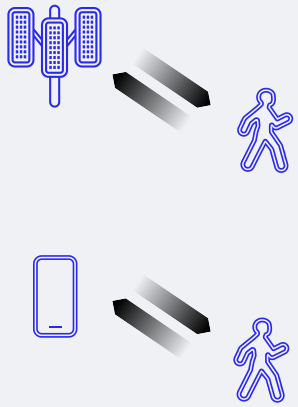
Real-time data

Wireless data transmission opens door to real-time data collection from sensors

Massive scale and broad reach

Wireless sensing is a new type of sensor that can expand the capacity of the sensor economy

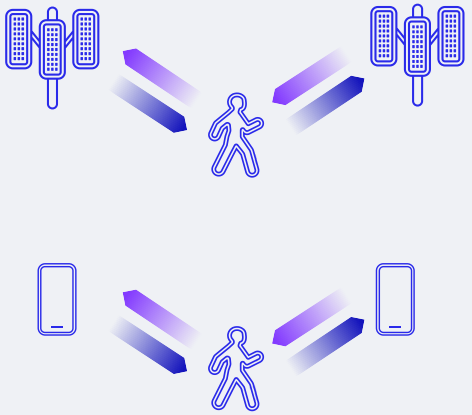
Wireless sensing offers flexible operation modes for different use case scenarios



Monostatic

NETWORK-ONLY
AND DEVICE-ONLY

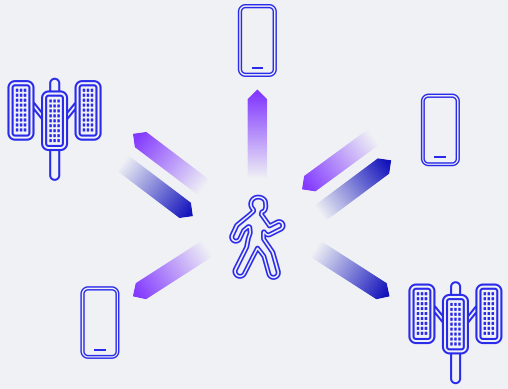
Sensing transmitter and receiver are co-located in the same entity



Bistatic

NETWORK-ONLY
AND DEVICE-ONLY

Sensing transmitter and receiver are located in different entities



Multistatic

NETWORK AND DEVICE
COLLABORATION

Multiple sensing receivers capture reflected signals from one or more sensing transmitters

Drone detection and tracking

Automotive detection and tracking

Immersive XR

Automated guided vehicles (AGVs) detection and tracking

Digital twins

Pedestrian and obstacle monitoring on roads / railways

Weather monitoring

Health monitoring

Home intruder monitoring

Improving network performance and efficiency

Wireless sensing can support a variety of use cases across industries

Globally standardized technologies can provide the best support for wireless sensing

To exploit synergies with their strengths (e.g., reach, bandwidth) and capabilities (e.g., communications)

Cellular (e.g., 5G)

Globally adopted for wide-area communications with ubiquitous coverage

Supports wide-bandwidth spectrum in both licensed and unlicensed bands

5G already enhances GPS by supporting device positioning with active electronics for localization and mapping

Wi-Fi

Globally adopted for wireless local area networking (WLAN), ubiquitous for indoor spaces

Beyond communications, also used for indoor localization systems, often combined with inertial measurement units (IMU) for enhanced accuracy

Ultra-wide band (UWB)

Offering wide-bandwidth communications and positioning services

Adopted in automotive use cases (e.g., secure keyless entry and passive presence detection), as well as high-precision asset tracking for industrial and smartphone applications

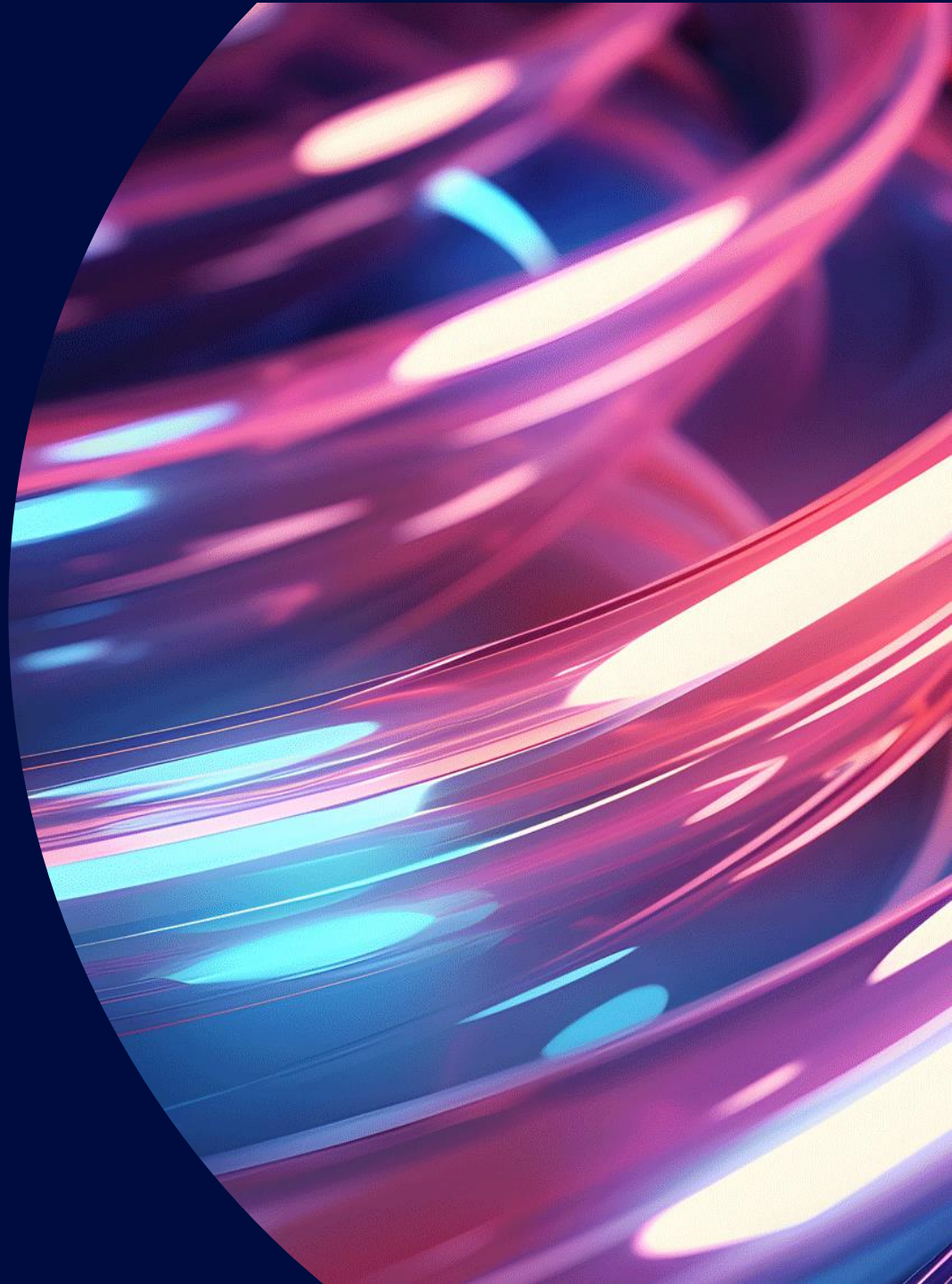
Bluetooth

Globally adopted for short-range, low-power personal area networking (PAN)

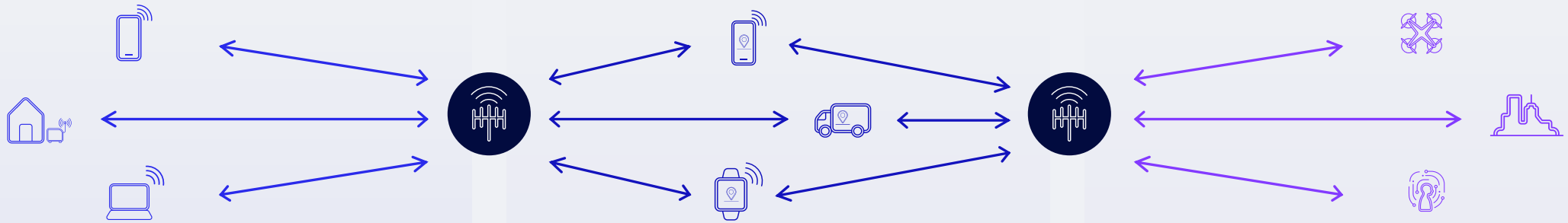
Utilized for proximity estimation, often in conjunction with other sensors like IMUs

Integrating sensing with communications

TO DRIVE NEW WIRELESS SYSTEM EFFICIENCY
AND VALUABLE CELLULAR SERVICES



Next-generation wireless can bring exciting opportunities beyond communications



Wireless communications

Main use case today, for the exchange of information (i.e., voice, data) in wide-area and local settings.

Continued technology evolution is connecting new devices, use cases, and verticals — backbone of sustained digital economy growth.

Wireless positioning

Value-add services using the same infrastructure, for tracked devices with active electronics (i.e., modem).

Many positioning techniques are already supported (e.g., DL-TDOA, RTT, AoA/AoD) by various global standards (e.g., 5G Rel-16+).

Wireless sensing

Next frontier of environmental awareness, for objects without active electronics (e.g., foliage, building, people).

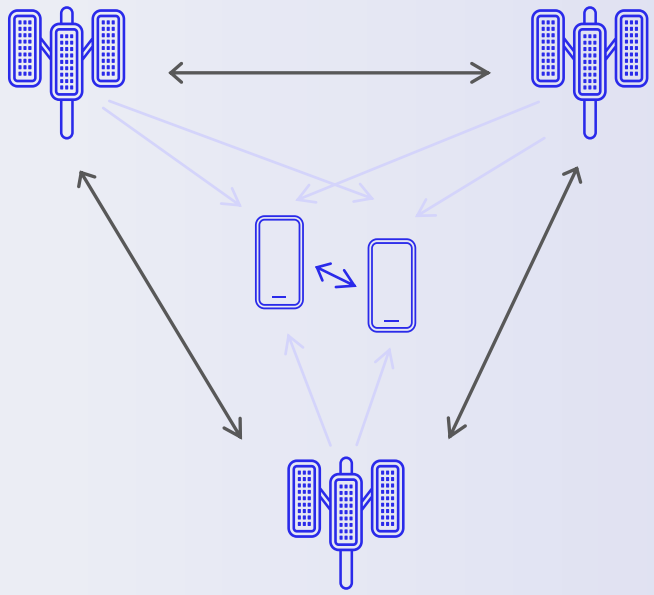
Many approaches and flexible operation modes that bring benefits to diverse applications — an innovative research area for what's next.

Wireless network owners/operators can offer integrated services — possible new revenue streams for the ecosystem

DL: Downlink; TDOA: time difference of arrival; RTT: Round-trip time; AoA: Angle of arrival; AoD: Angle of departure;

Leveraging wireless positioning to design efficient wireless sensing

Wireless positioning



Multi-technology metrics

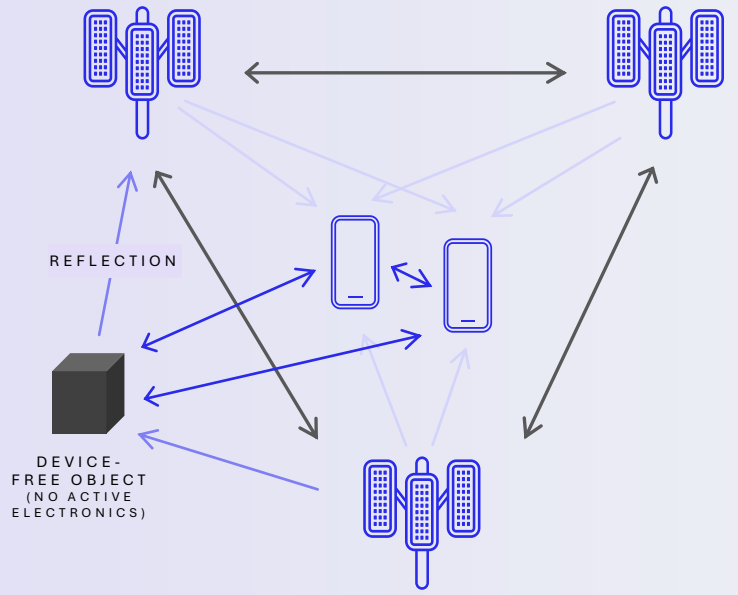
Timing of arrival of multipath

RSRP/reflection coefficient

Angle of arrival/departure

Synchronization error

Wireless sensing



SUPPORTING TECHNOLOGIES CAMERA RADAR LIDAR AI/ML

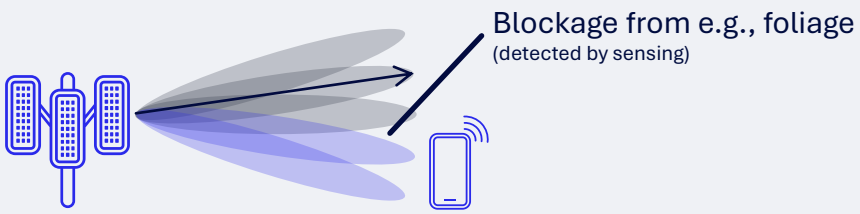
RSRP: reference signal received power; LIDAR: light detection and ranging

Exploring the synergistic relationships between sensing and communications

SENSING-ASSISTED COMMUNICATIONS

Sensing can bring tangible performance improvements to wireless communications

Sensing can deliver heightened environmental awareness, to potentially improve communication system performance (e.g., latency, power consumption). For example, detected blockage allows the system to proactive streamline the channel feedback process, as priority can be given to other paths without blockage.



REDUCED # OF
CANDIDATE BEAMS NEEDED

COMMUNICATIONS-ASSISTED SENSING

Wireless communications can efficiently scale sensor footprint and use cases

Wireless coverage deployed for wide-area communications is nearly ubiquitous. In addition to using the network to connect different sensors (e.g., temperature, light), wireless sensing can further enrich our understanding of the environment for a wide range of use cases (e.g., automotive, smart cities).

WIRELESSLY CONNECTED SENSORS USING SAME
COMMUNICATIONS NETWORK

Integrated support for sensing and communications brings new wireless system efficiency

ISAC

Integrated Sensing and Communications

Deployment efficiency

A single system supporting both capabilities can maximize hardware reuse (e.g., RF, general compute) and allow for efficient scaling (e.g., add new sensing capability easily)

Spectrum efficiency

Closely coordinated spectrum utilization for sensing and communication improves overall efficiency, reduce interference, and avoid the need for separate allocations

Energy efficiency

Combined system design can yield new efficiencies by sharing power and processing resources between sensing and communication tasks, in addition to new synergistic efficiency achieved

Scalability and flexibility

Creating value for new wireless applications that require both high-performance communication and sensing (e.g., ADAS, industrial automation, and more)

INTEGRATING COMMUNICATIONS, SENSING, AND MORE

The upcoming 6G platform provides a timely opportunity for broader ISAC adoption

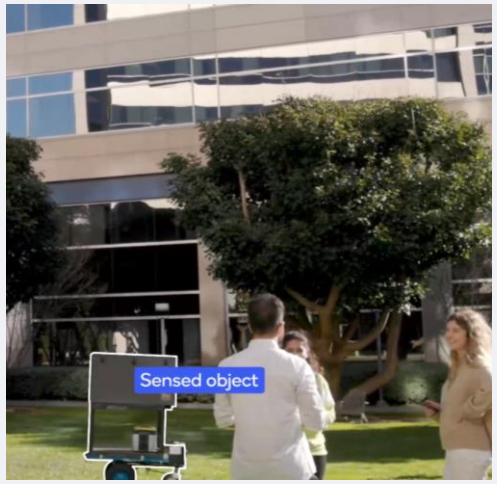
Arriving around 2030 to fuel next decade of wireless technology innovations

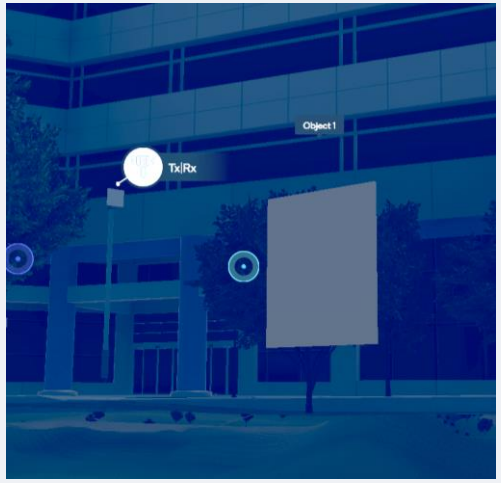
Native system architecture, including next-generation air interface, will be designed to efficiently support services beyond communications

Services such as wireless sensing and precise positioning will be integrated to the communication platform from the outset

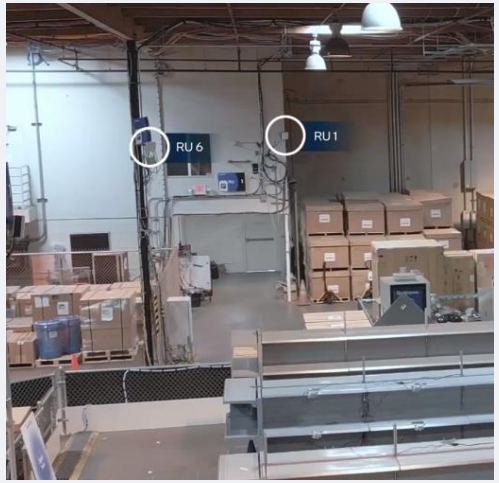
Wireless sensing enables efficient creation and sustained accuracy of digital twins

OUTDOOR





INDOOR



Scalable digital twin network creation

MATERIAL IDENTIFICATION

Allow more accurate modeling of the environments

AUTOMATED CREATION

Sensing, AI/ML and computer vision can automate the digital twin network creation

Towards near real-time digital twin network

DYNAMIC ENVIRONMENT CHANGES

Requires continued update of the digital twin network

NEAR REAL-TIME CREATION

Requires efficient sensing data generation to create the digital twin network

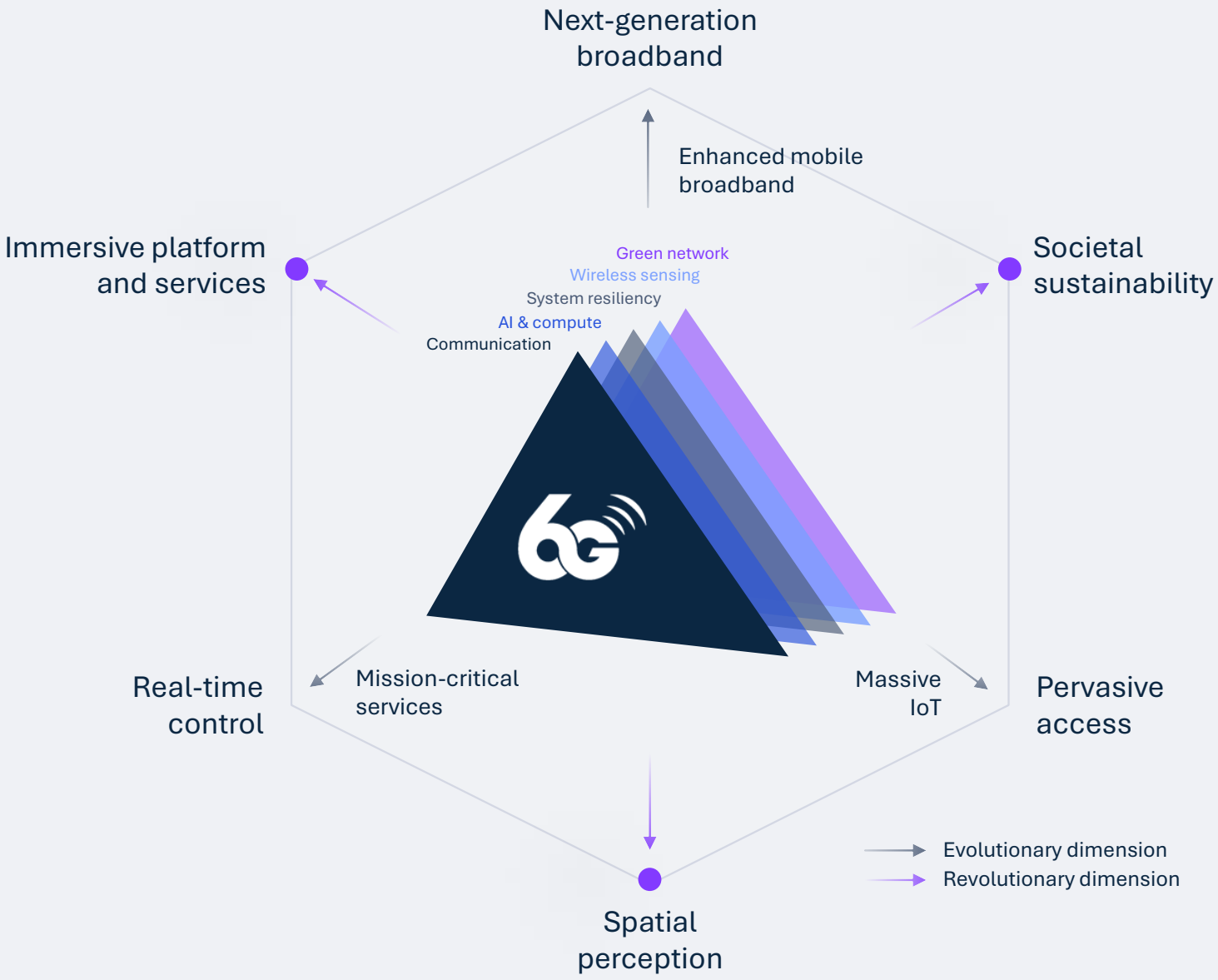
Closed-loop operation with wireless system

REFINEMENT OVER TIME

Accuracy of the modeling can be improved with data measurement from the device

OUR VISION FOR THE NEXT-GEN WIRELESS

Wireless sensing is a new 6G system capability that will fuel a wide range of new and enhanced use cases



Wireless sensing complements all other envisioned 6G system capabilities

Wireless sensing +

Communications

Sensing-assisted communication leverages sensing data to improve communication services and operations.

EXAMPLES INCLUDE

- Radio resource management
- Beam management
- Mobility management procedures

AI and Compute

AI can enhance wireless sensing to adapt in real-time to changing environments and requirements, making them more resilient and efficient.

AI algorithms can process the vast amounts of wireless sensing data, enhancing the accuracy and reliability of sensing tasks.

System Resilience

Wireless sensing capability can allow real-time monitoring of the environment, enabling quick detection of potential threats or disruptions.

Wireless sensing can be incorporated into anti-jamming techniques, improving networks' resilience against intentional attacks.

Green Network

Wireless sensing network can share hardware and network resources between communications and sensing function, reducing overall cost and improving spectral efficiency.

Targeting a wide range of bands for 6G ISAC system design

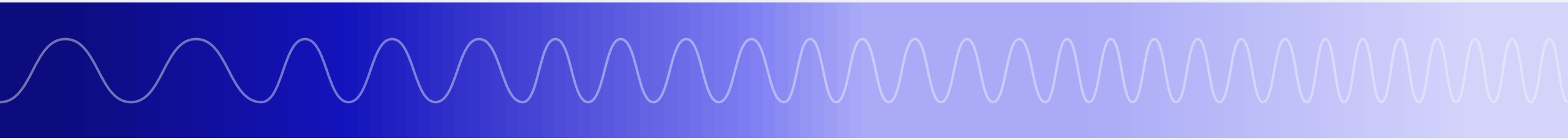
LOW BANDS
below 1 GHz (~20 MHz BW)

MID BANDS
1 — 7 GHz (~100 MHZ BW)

UPPER MID-BANDS
7 – 24 GHz (~500 MHz BW)

mmWAVE BANDS
24-71 GHz

SUB-THZ
above 100 GHz



Lower frequencies with narrower bandwidths offer better long-range detection and penetration but with reduced resolution

Bandwidths up to ~100 MHz are available

New 6G spectrum bringing additional wide-area capacity for communications and sensing

6G spectrum bringing additional local-area capacity for communications and sensing

Higher frequencies with wide bandwidths provide excellent precision

Dense deployment
Provides multi-cell visibility, enhancing system's spatial resolution and coverage

Wide channel bandwidth
Improves ability to detect rapid object changes or movements

Advanced beamforming
Offers better resolution and accuracy for detecting small objects

ISAC will be a key 6G technology

Wireless sensing can unlock the full potential of the sensor economy

Combining sensing with communications can enhance wireless efficiency and enable new, valuable services

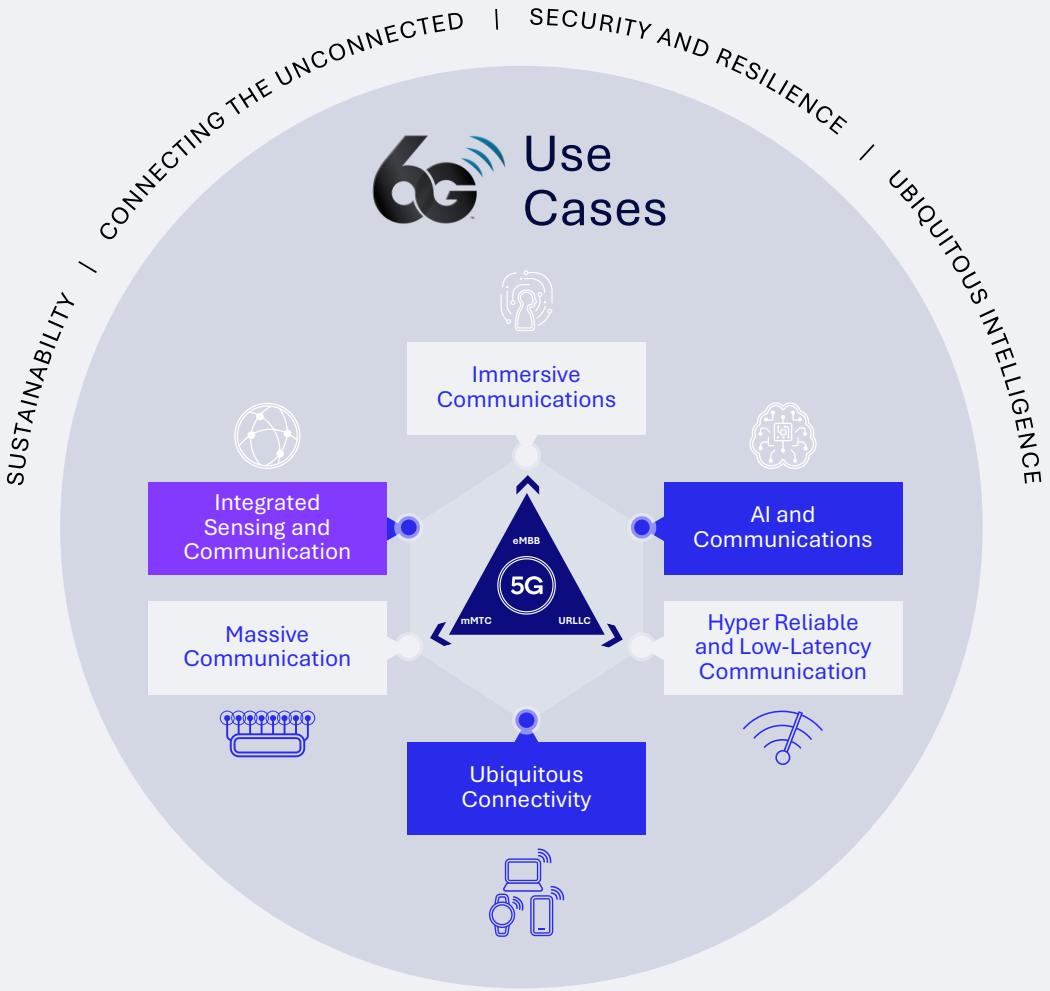
6G is the next unified wireless platform designed from the outset to deliver integrated services including communications, sensing, and more

Paving the path to 6G integrated sensing and communications

5G ADVANCED STARTS THE STUDY TO SUPPORT WIRELESS SENSING

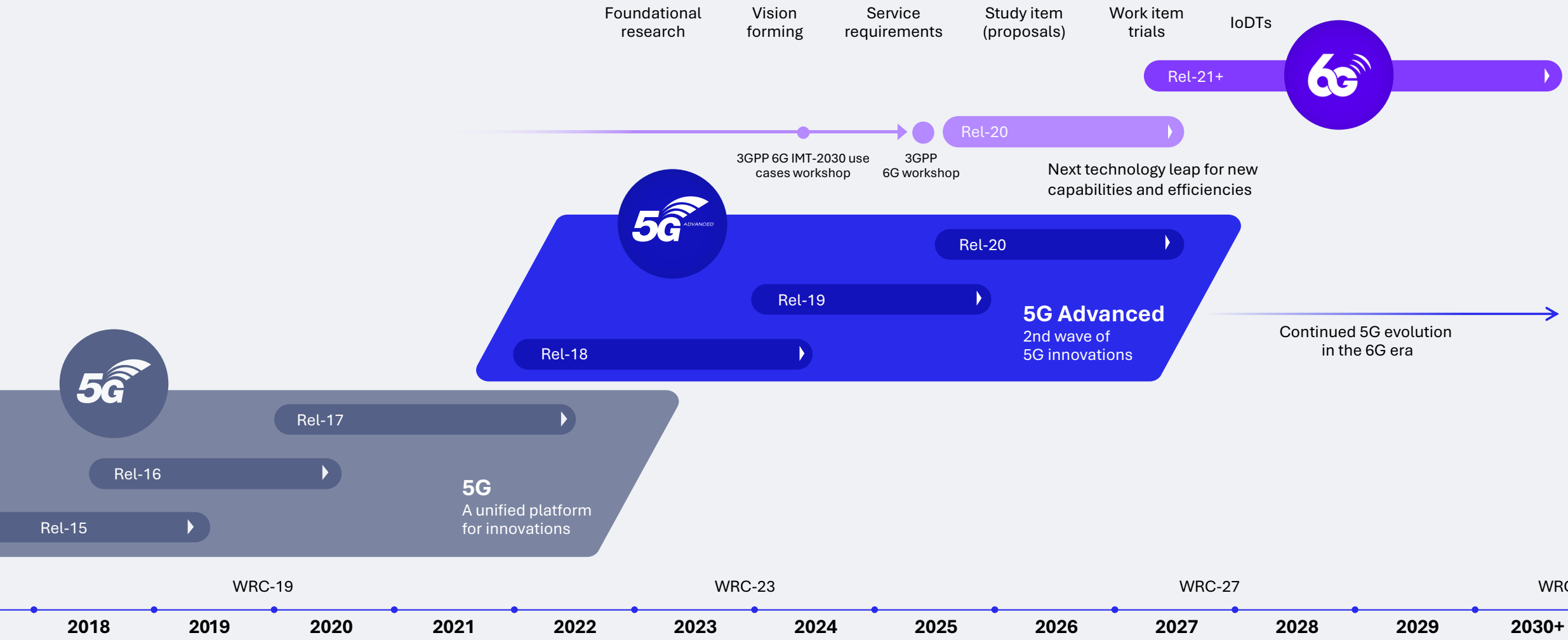
Integrated sensing and communication is an essential part of the 6G vision

ITU-R's IMT-2030 usage scenarios and capabilities

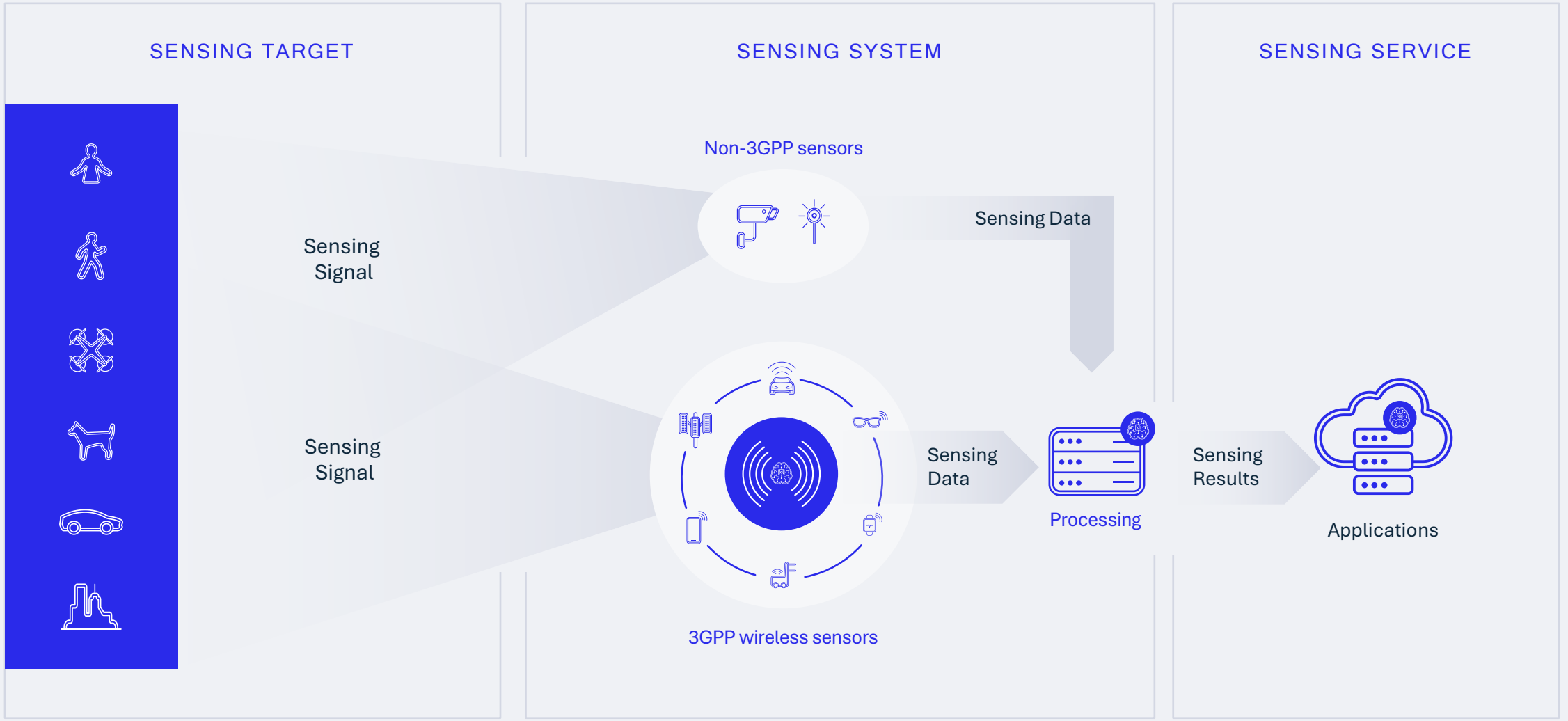


Source: ITU-R's IMT towards 2030 and beyond (https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2030/Pages/default.aspx)

Leading the 5G Advanced evolution toward 6G



3GPP Release 19 starts the study of wireless sensing as a network service



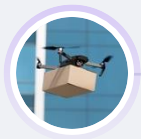
3GPP Release 19 Study

Channel modeling for integrated sensing and communications

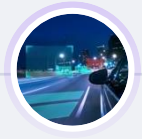
Primary focus on 0.5 — 52.6 GHz, scalable to 100 GHz

Identify deployment details of the selected use cases

Define channel modelling details, e.g., modelling of sensing targets and background environment (radar cross-section, mobility, clutter/scattering patterns) and spatial consistency



Unmanned aerial vehicles (UAVs)



Automotive vehicles

Objects creating hazards on roads / railways

Weather monitoring

Humans indoors and outdoors

Automated guided vehicles (AGVs)

MULTIPLE USE CASES AND SENSING MODES TO BE EVALUATED IN THIS STUDY PROJECT

TRP monostatic

UE monostatic

TRP-UE multistatic

UE -TRP multistatic

TRP-TRP multistatic

UE-UE multistatic

Source: 3GPP TR 22.837

General operation and charging

Provide sensing services to detect and track objects and their environment.

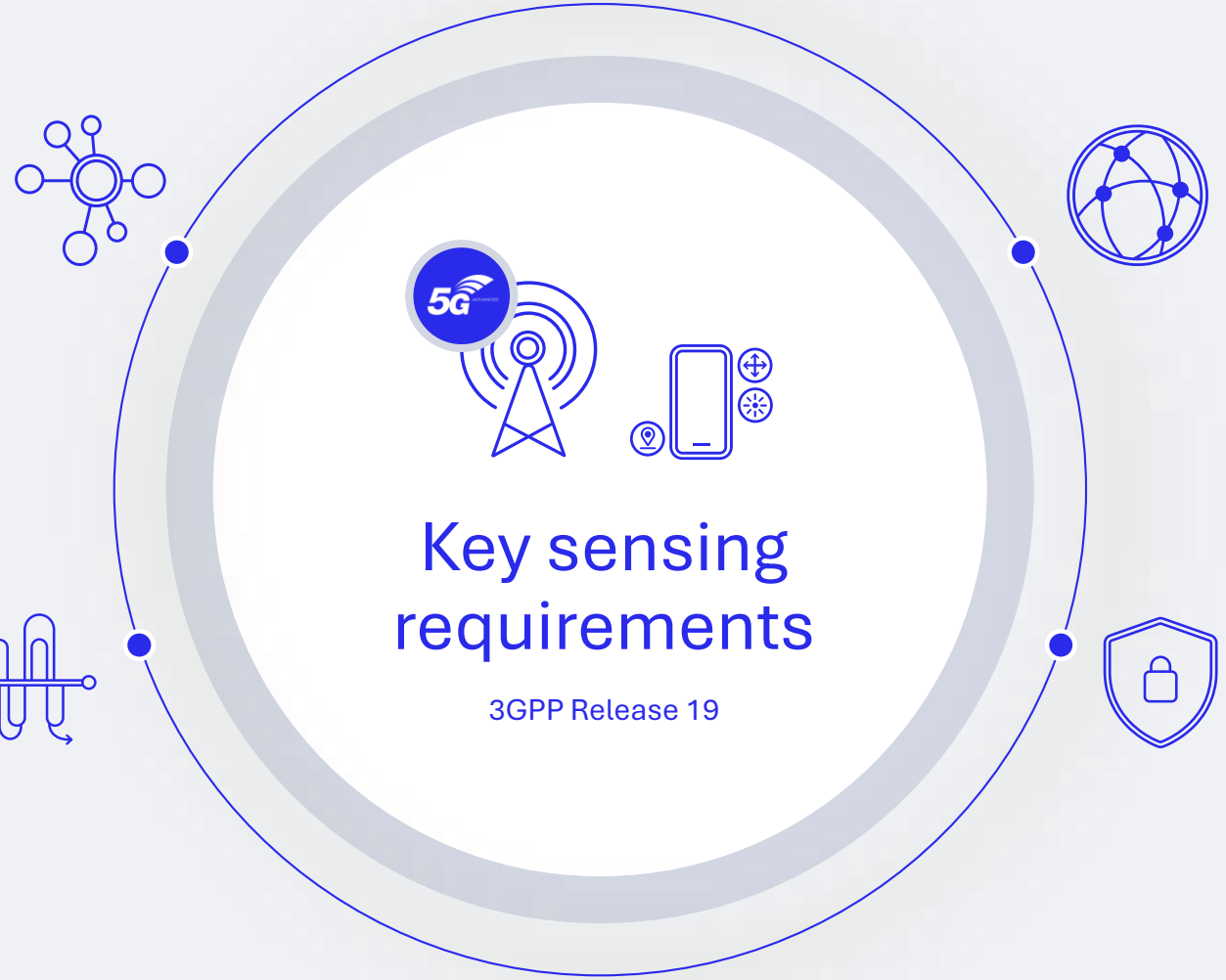
Collect 3GPP sensing data and provide service in a target area using transmitters and receivers.

Support sensing service charging, including sensing KPIs and duration.

Configuration and authorization

Configure and authorize sensing transmitters and receivers based on parameters like location, time, and accuracy.

Ensure licensed spectrum is only used within network coverage and operator control.



Network exposure

Securely report sensing results from both 3GPP and non-3GPP data to trusted 3rd parties based on specific requested conditions.

Provide secure means for sensing services request and receive results based on parameters like refresh rate and location.

Security and privacy

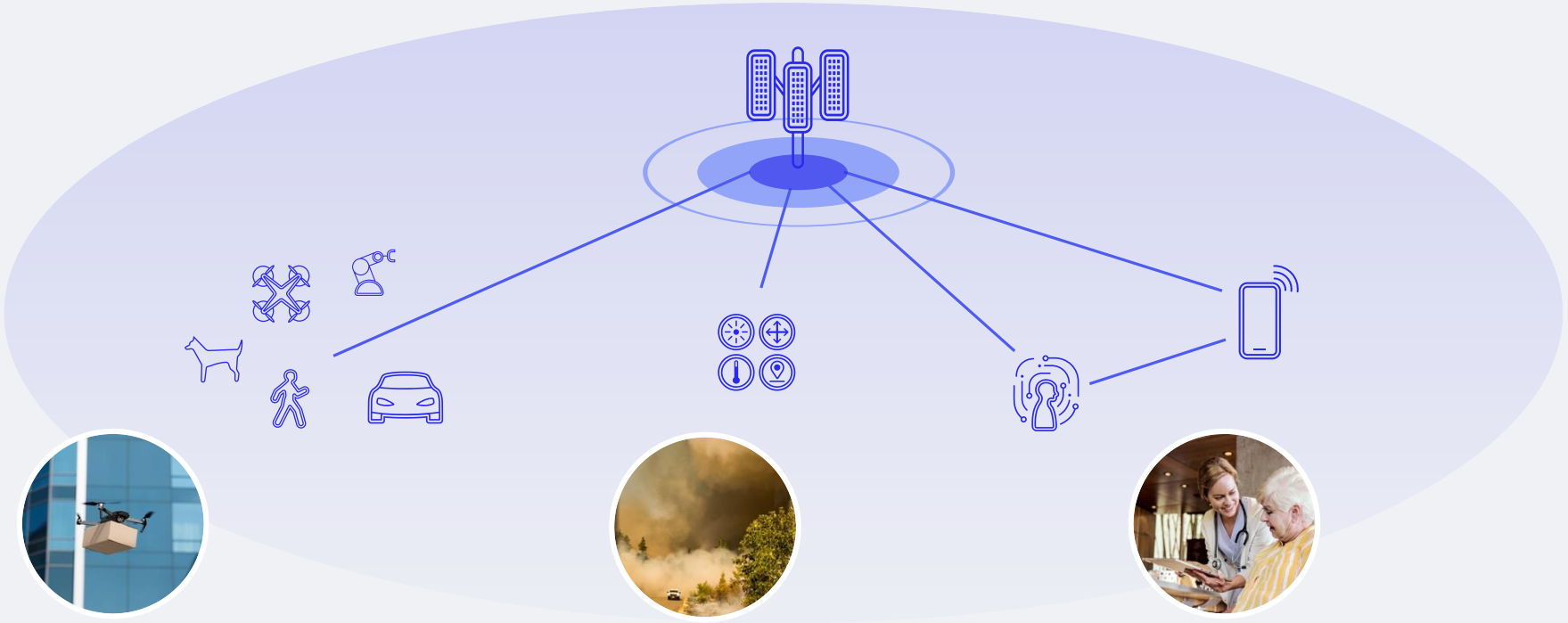
Support encryption, integrity protection and data privacy.

Ensure compliance with regulation and user awareness.

Limit exposure of sensing results to authorized 3rd parties only.

3GPP wireless sensing enables advanced object detection with robust security, flexible configuration, and seamless communication network integration

Source: 3GPP TS 22.137



Object detection and tracking

Indoor and outdoor detection of humans, UAVs, animals, AGVs and vehicles

Environmental monitoring

Indoor and outdoor environment monitoring (e.g.: rainfall, flooding)

Motion monitoring

Indoor monitoring of human motions and activities such as sleep and sports monitoring, and human hand gesture recognition

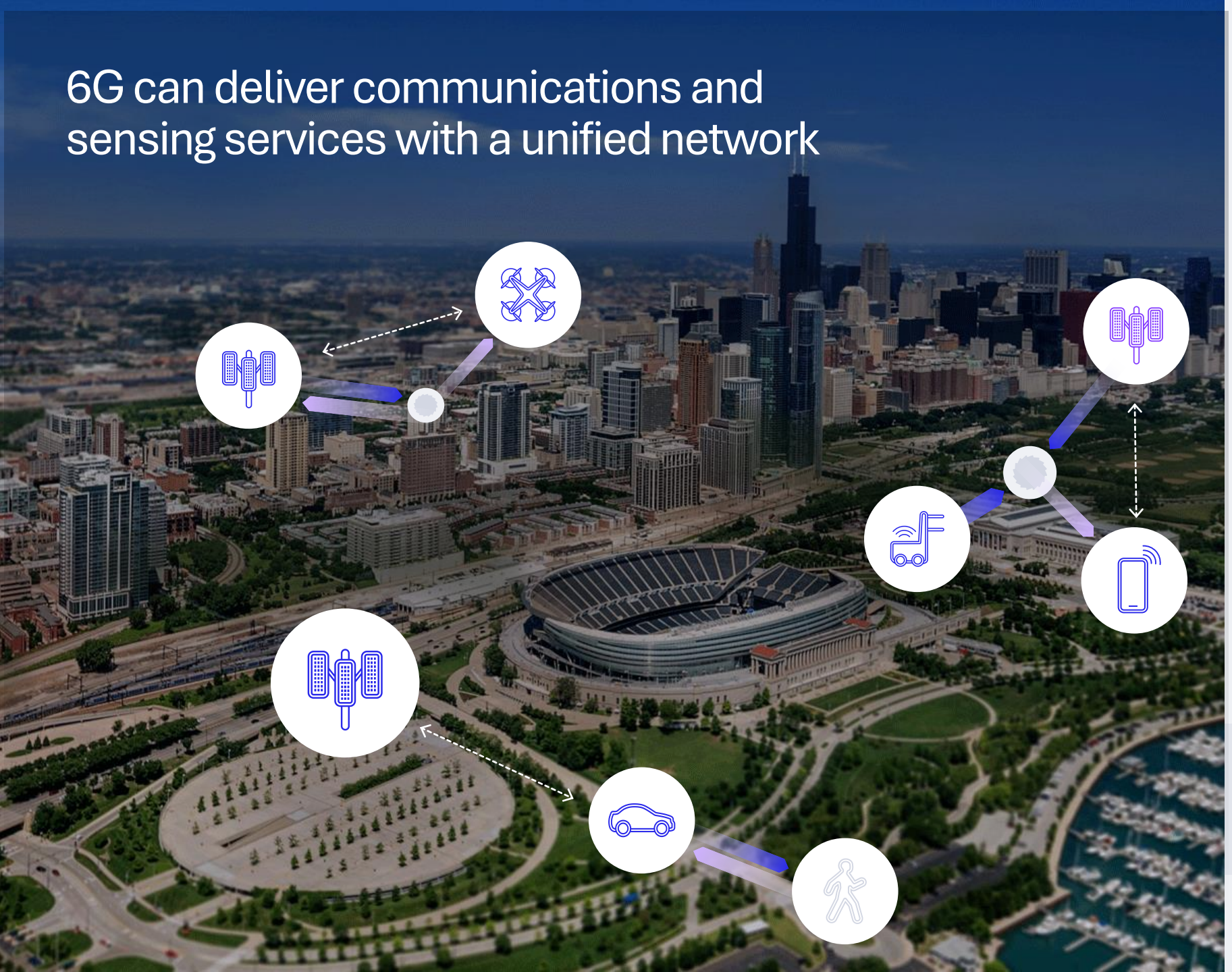
KPIs UNDER STUDY

- Accuracy of positioning estimate
- Accuracy of velocity
- Confidence level
- Sensing resolution
- Missed detection probability
- False alarm probability
- Max sensing service latency
- Refreshing rate

3GPP Release 19 defines sensing scenarios and use cases with specific KPIs for each service category

Source: 3GPP TS 22.137

6G can deliver communications and sensing services with a unified network



5G Advanced Release 19 starts the preparation for 6G ISAC

WIRELESS SENSING SERVICE

Relies on analyzing the transmissions, reflections and scatterings of reference signals

DATA ACQUISITION CAPABILITIES

Acquire environment and objects within information using radio waves to determine distance, shape, size, velocity, and more

OVERALL STUDY SCOPE

Channel modeling

Sensing modes

System requirements

Multiple use cases

KPIs for each use case

LEGEND

Wireless sensing Tx

Wireless sensing Rx

Object

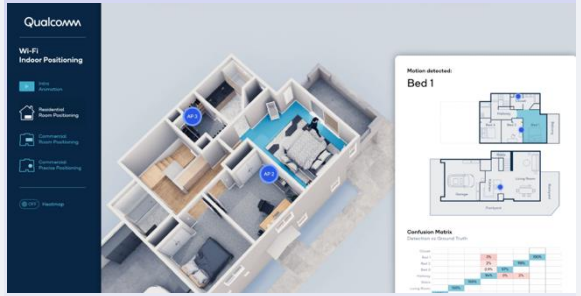
Comm Tx/Rx

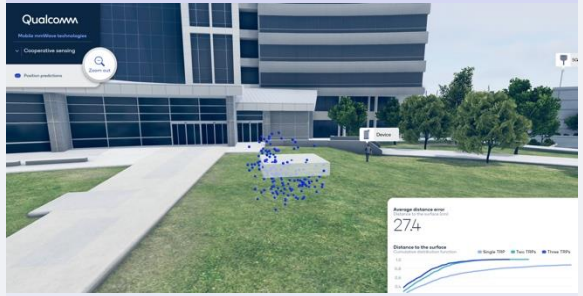
We are pioneering foundational wireless sensing research

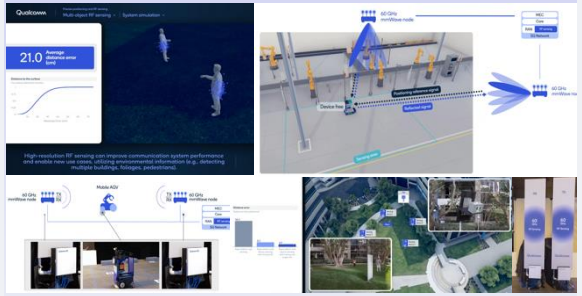
ACCELERATING THE PHYSICAL
AND DIGITAL CONVERGENCE

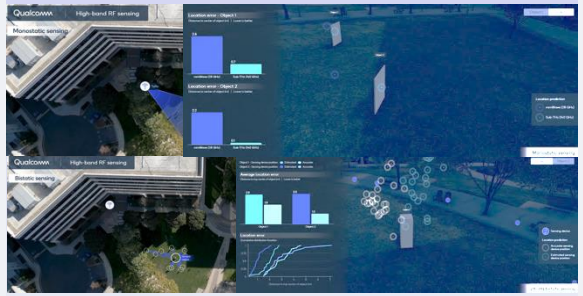
Advancing wireless sensing through cutting-edge research and prototyping

Across a diverse set of wireless technologies, spectrum bands and use cases









Years of foundational sensing research

2021

Wi-Fi (5 GHz)

Indoor human presence and motion detection

2022

5G mmWave (28 GHz)

Outdoor single-object location detection

2023

5G mmWave (28 GHz)

Outdoor multi-object location detection

5G mmWave (60 GHz)

Indoor high-resolution sensing with object detection, localization, and tracking

2024

5G mmWave (28 GHz) & sub-THz (140 GHz)

High-band sensing with material type identification

Continued research towards 6G ISAC

Wi-Fi indoor human presence and motion detection

Wireless sensing system using Wi-Fi to detect a person's position without a device.

Analyzes data from multiple access points and advanced machine learning.

Predicts positions within homes with over 94% accuracy and under one meter error in enterprise settings, effectively tracking movement across different environments.

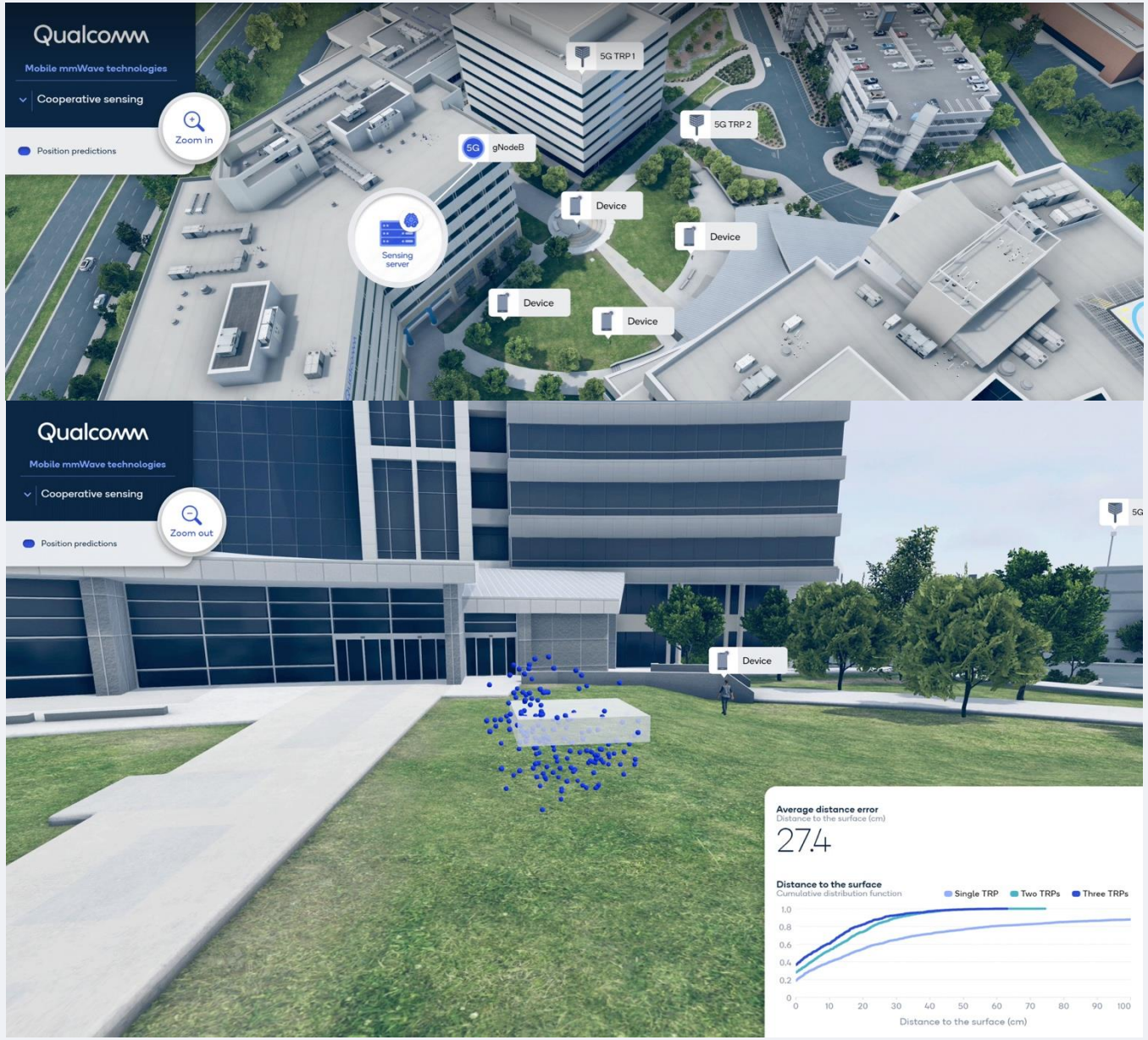
MWCB 2022

mmWave outdoor single-object detection

Based on our comprehensive system simulations in our San Diego campus, utilizing 28 GHz band

Cooperative RF sensing utilizing both network infrastructure (i.e., gNodeBs) and devices (i.e., smartphones)

Simulations showcasing the capability of device positioning and sensing of non-device objects (e.g., rocks, walls) to better understand the physical world to improve the digital experience

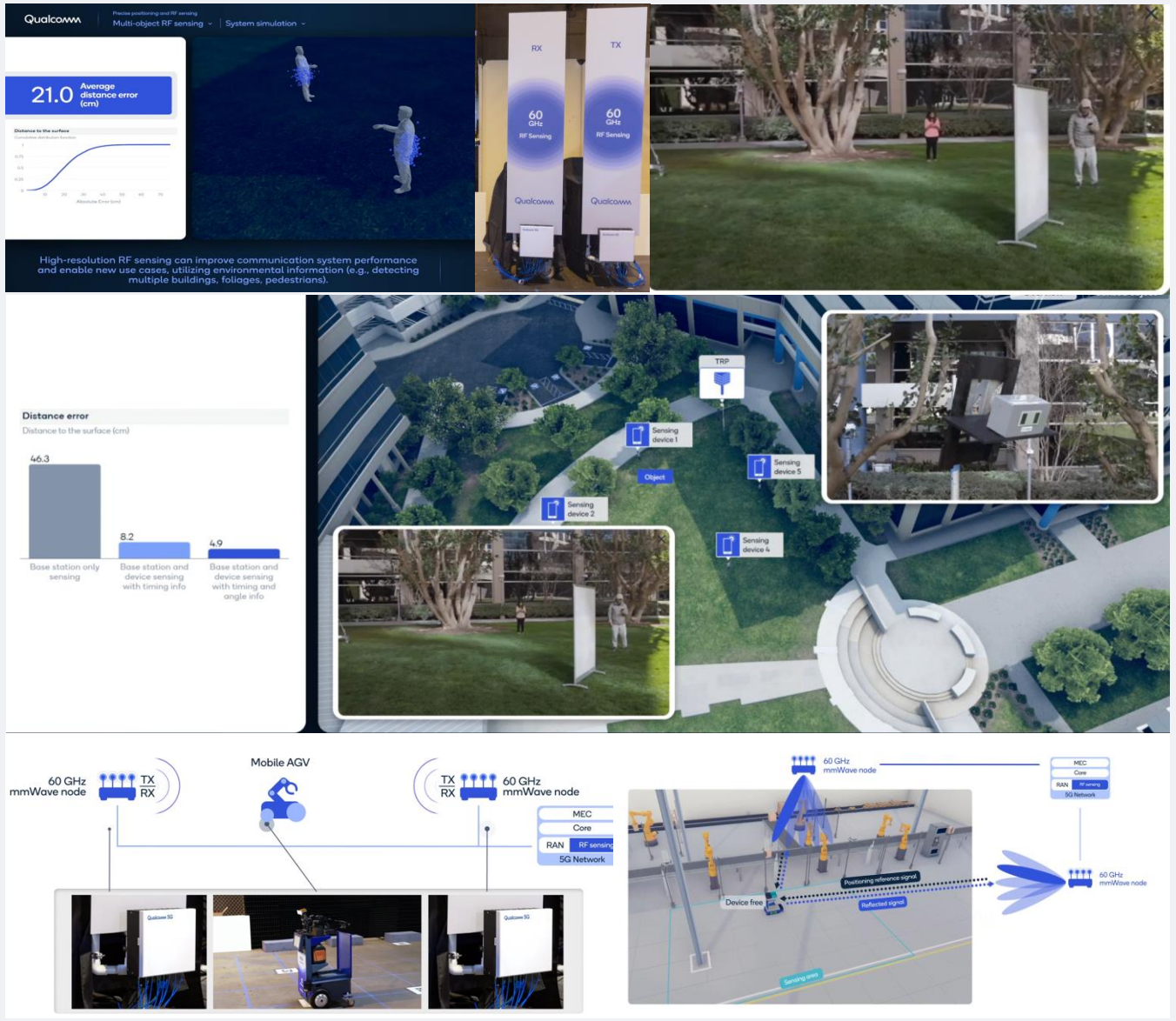


MWCB 2023

Indoor/outdoor multiple object detection

Using our OTA 28 GHz outdoor testbed for “device-free” (i.e., no modem-RF) object detection and 60 GHz indoor testbed for monostatic wireless sensing

Highlighting multiple objects and human bodies successfully detected in the outdoor test network, while the indoor testbed can showcase accurate AGV detection, localization, and tracking



MWCB 2024

High-band wireless sensing

High-resolution wireless sensing for monostatic and bistatic wireless sensing can improve communication system performance and enable new use cases, utilizing environmental information (e.g., detecting multiple buildings, foliage, pedestrians, etc.)

Identifying material type based on measured RF characteristics, useful for building a map of surrounding environment

WE ARE WORKING ON KEY
LONGER-TERM RESEARCH VECTORS

Enabling the path towards 6G

AI-native E2E communications

Data-driven communication and network design, with joint training, model sharing and distributed inference across networks and devices

Scalable network architecture

Disaggregation and virtualization at the connected intelligent edge, use of advanced topologies to address growing demand

Expanding into new spectrum bands

Expanding to THz, wide-area expansion to higher bands, new spectrum sharing paradigm, dynamic coordination with environmental awareness

Air interface innovations

Evolution of duplexing schemes, Giga-MIMO, mmWave evolution, reconfigurable intelligent surfaces, non-terrestrial communications, waveform/coding for MHz to THz, system energy efficiency

Merging of worlds

Physical, digital, virtual, immersive interactions taking human augmentation to next level via ubiquitous, low-power joint communication and sensing

Communications resiliency

Multifaceted trust and configurable security, post quantum security, robust networks tolerant to failures and attacks

When sensing meets communication

Sensing is an emerging wireless capability that can unlock exciting new use cases and business opportunities

Integrating sensing and communications can drive new wireless system efficiency and valuable cellular services

The path to 6G integrated sensing and communications (ISAC) starts with 5G Advanced study on wireless sensing

We are pioneering foundational wireless sensing research, accelerating the physical and digital convergence

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