VTT

Integrated Sensing and Communication in 6G

Turning networks into platforms for real-world awareness

Contents

Introduction: From connectivity to awareness

Mobile networks have always been designed to connect people, devices and systems. With 6G, they are evolving into something more: platforms that can also understand the physical world around them.

Integrated Sensing and Communication (ISAC) brings sensing capabilities directly into the radio network. The same signals used to transmit data can also detect movement, locate objects and interpret environmental conditions. This shifts networks from passive carriers of information into active observers of their surroundings.

In essence, ISAC in 6G enables continuous, infrastructure-scale awareness of the physical environment while delivering connectivity.

The implications are significant. Instead of deploying separate sensor systems, organisations can extract environmental intelligence directly from communication infrastructure. This opens the door to new services, new business models and entirely new ways of interacting with physical environments.

ISAC is not just a feature. It represents a broader shift from connectivity to awareness.

About this white paper

This white paper explores ISAC as a practical capability for 6G systems, with a focus on real-world deployment, system-level implications and business relevance.

It is designed for:

- Industry leaders and decision-makers evaluating future network capabilities
- Technology developers and system architects working on 5G-Advanced and 6G
- Researchers and ecosystem partners shaping next-generation wireless systems

This white paper offers:

- A clear understanding of what ISAC enables beyond traditional connectivity
- Insight into where ISAC creates tangible business and operational value
- A view of key system-level trade-offs and technical constraints
- An overview of how ISAC evolves from single-node solutions to networked capabilities
- Guidance on the main challenges and opportunities for real-world adoption

1. What ISAC enables

ISAC introduces a new capability layer to wireless networks: the ability to observe and interpret the physical environment.

While many of these capabilities are already being explored in research and early pilots, their full impact will emerge as ISAC becomes embedded into future 6G systems.

Over the coming years, networks are expected to evolve from data transmission platforms into distributed sensing systems, extending their role from connectivity to real-time environmental awareness and decision support.

From a business perspective, ISAC represents a platform shift rather than a single technology feature. As sensing becomes embedded into networks, new value chains begin to form, bringing together connectivity providers, equipment vendors, system integrators and application developers to deliver sensing-enabled services. These services span areas such as smart mobility, industrial automation, safety-critical monitoring and digital twins, aligning closely with emerging industry and standardisation directions for 6G.

This evolution creates several fundamental shifts.

1.1. Networks become distributed sensors

Base stations and connected devices can detect objects, motion and changes in the environment, including targets that are not connected to the network.

In this shift, connectivity is complemented by spatial, situational and contextual intelligence. Sensing is integrated natively into radio access technologies, enabling the network to observe and interpret its surroundings.

1.2. Environmental awareness becomes part of the network

ISAC embeds sensing into existing communication infrastructure, reducing the need for dedicated sensor systems.This reduces deployment complexity while expanding coverage, allowing environmental awareness to be delivered as part of the network itself.

1.3. Real-time sense–classify–react loops

Sensing is not only about collecting data. The value lies in how quickly that data can be interpreted and acted upon. ISAC enables fast, local decision-making at the network edge.

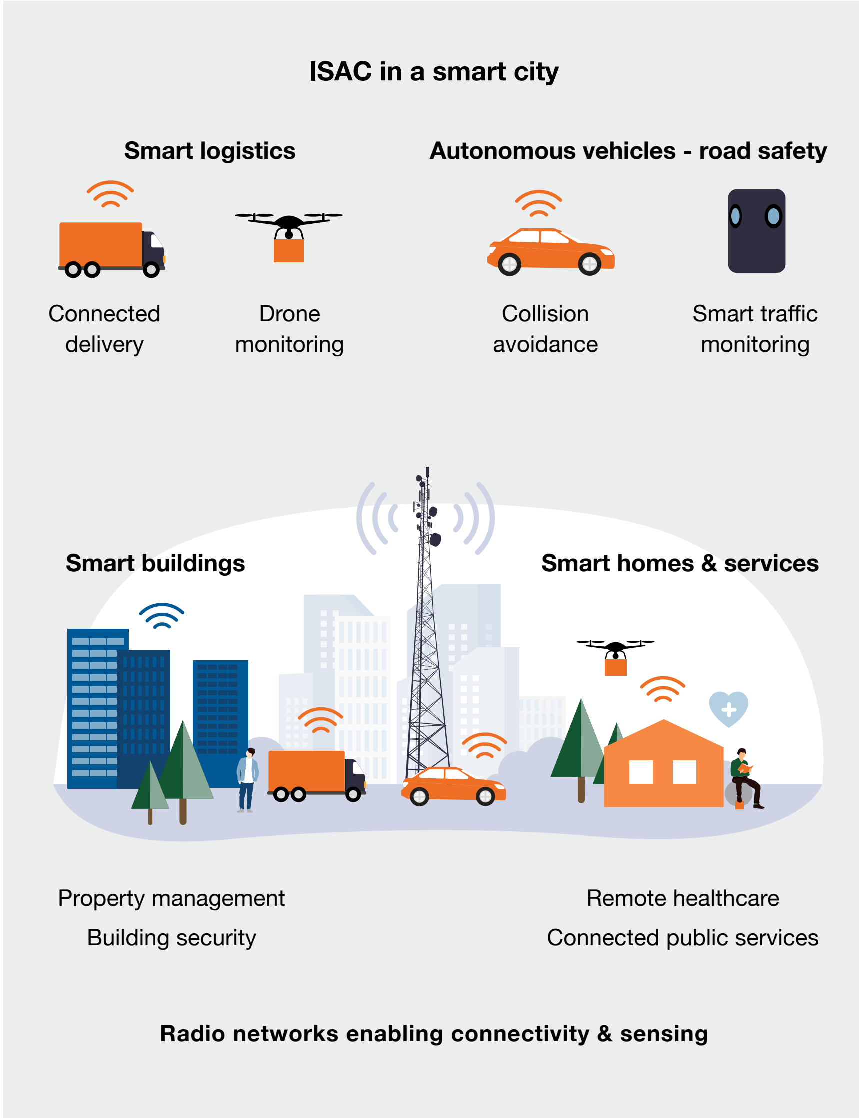
1.4. One infrastructure, multiple roles

The same network can support communication, sensing and decision-making simultaneously. This enables more efficient use of spectrum, hardware and energy.

1.5. New service layers emerge

ISAC makes it possible to deliver sensing as a service, creating new revenue streams based on environmental intelligence rather than connectivity alone.

Together, these shifts redefine what mobile networks are and what they can do.



2. Where value is created

ISAC creates value wherever real-time awareness of the physical environment improves decision-making, safety or efficiency. It is seen as a key step towards more intelligent, perceptive networks that can support next-generation applications across industries.

ISAC is already recognised as a foundational capability for 6G by major industry and standardisation bodies, including ITU, 3GPP and ETSI.

2.1. Defence and public safety

ISAC enhances situational awareness in security-critical environments by enabling detection of drones, vehicles and human movement using existing network infrastructure, including non-cooperative targets that are not connected to the network.

This supports:

- Monitoring of sensitive areas and critical infrastructure
- Faster and more informed emergency response
- Detection of unauthorised or unexpected activity

By combining sensing and communication in the same system, ISAC enables rapid delivery of actionable information where it is needed the most, supporting mission-critical operations.

2.2. Mobility and airspace

ISAC enables networks to detect and track drones, vehicles and other moving objects, including non-cooperative targets.

This supports:

- Airspace monitoring and drone detection
- Collision avoidance and safer autonomous navigation
- Traffic flow optimisation and incident detection

By extending perception beyond onboard sensors, networks can complement vehicles and autonomous systems with broader environmental awareness and improved coordination.

2.3. Industry and logistics

In industrial environments, ISAC supports:

- Detection of blockages and obstacles
- Tracking of assets and material flows
- Continuous updates to digital twins

This improves reliability, safety and efficiency in automated processes and robotics, particularly in dynamic or partially observable environments.

2.4. Smart infrastructure and cities

ISAC can turn existing infrastructure into a sensing layer for urban environments:

- Monitoring congestion and crowd movement
- Detecting abnormal events or safety risks
- Supporting infrastructure planning and optimisation

This allows cities and operators to move from reactive to proactive management.

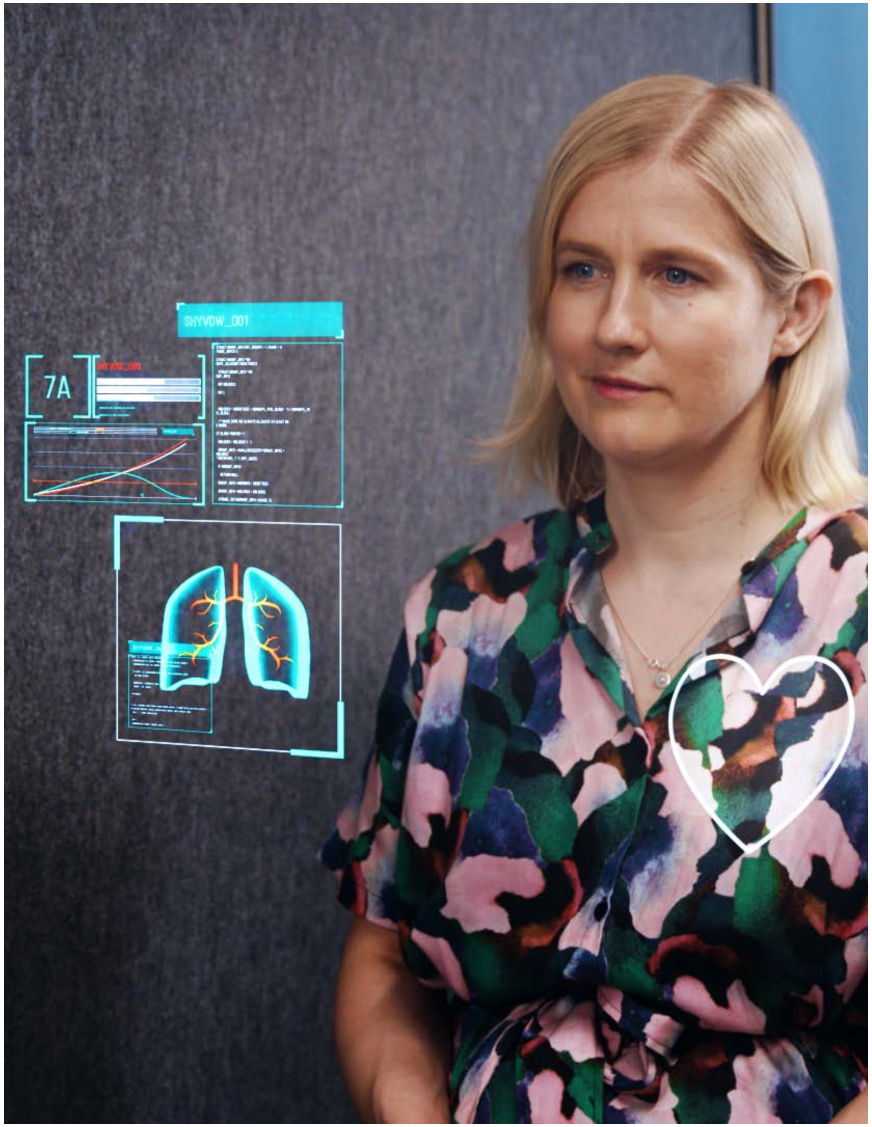
2.5. Human-centric sensing and healthcare

ISAC enables non-contact sensing of human activity and vital signs:

- Monitoring movement and presence
- Detecting micro-motions such as breathing
- Supporting assisted living and healthcare applications

These capabilities can be integrated into existing environments without requiring wearable devices.

Across all domains, the common driver is the same: better decisions through real-time environmental awareness.



3. Enabling technologies for 6G ISAC

Delivering ISAC in real-world systems requires careful balancing of multiple technical and system-level factors. The key question is not whether sensing is possible, but how to integrate it efficiently into communication systems.

3.1. Spectrum and performance trade-offs

A key challenge in ISAC is balancing communication performance with sensing accuracy.

One important factor is range resolution: the ability to distinguish between objects that are close together. This improves with wider signal bandwidth, while narrower bandwidth makes it harder to separate targets.

This trade-off is already visible in today's spectrum landscape:

- Sub-6 GHz (FR1) offers wide coverage but limited bandwidth, constraining sensing resolution
- Millimetre wave (FR2 24GHz – 71GHz) enables high-resolution sensing but comes with reduced coverage and more demanding deployment conditions

Between these extremes, the emerging FR3 spectrum (7–24 GHz) offers a potential middle ground, combining moderate bandwidth with more favourable propagation characteristics.

As FR3 is still under study and standardisation, it represents a critical window for industry and research to shape how sensing capabilities are integrated into future 5G-Advanced and 6G systems.

3.2. Waveforms

ISAC depends on waveforms that can support both data transmission and environmental sensing.

Modern wireless communication systems predominantly rely on multi carrier orthogonal frequency-division multiplexing (OFDM) to achieve high spectral efficiency, while trading robustness against power amplifier nonlinearities, phase noise and other hardware impairments. Frequency-modulated continuous-wave (FMCW) radar waveforms, in contrast, are inherently optimised for energy-efficient sensing but lack native data transmission capability.

Hybrid waveform concepts aim to balance these complementary properties.

For high mobility scenarios, modulation schemes operating in the delay–Doppler domain provide improved robustness in fast changing environments, while introducing increased system complexity.

3.3. Antenna systems and massive MIMO

Large antenna arrays are a key enabler of ISAC, shaping both communication performance and sensing capability.

In ISAC, antennas do more than transmit signals: they determine how accurately the network can observe its environment. Factors such as array size, beamforming capability and calibration directly affect the ability to detect, locate and separate objects in space.

As 6G systems evolve toward larger and more advanced arrays, including near-field operation, antenna design becomes a central part of enabling high-resolution, reliable sensing.

3.4. Joint signal processing and machine learning

Sensing performance in ISAC is not only determined by hardware, but also by how signals are processed and interpreted.

Because communication and sensing share the same resources, systems must continuously balance how time, frequency and power are allocated. This is increasingly managed using adaptive methods such as machine learning.

Advanced signal processing and AI enable:

- Improved positioning accuracy through more efficient use of hardware resources
- Reliable detection in challenging conditions
- Classification of objects such as vehicles, drones or pedestrians

Together, these capabilities turn raw radio signals into actionable insight.

3.5. Hardware constraints and system realism

Sensing performance depends heavily on hardware characteristics:

- Antenna design and calibration affect accuracy
- Power amplifiers introduce distortions
- Bandwidth and timing structures limit sensing capabilities

These constraints mean that ISAC must be designed with hardware in mind from the start, not added later as a software feature.

3.6. Edge processing and latency

The value of sensing depends on how quickly data can be used.

Sending raw sensing data to central systems introduces delays and increases energy consumption. Instead, ISAC increasingly relies on edge processing, where:

- Data is interpreted close to where it is generated
- Only relevant information is transmitted
- Decisions can be made in near real time

This enables efficient sense–classify–react operation.

3.7. System-level optimisation

Communication and sensing compete for the same resources: time, frequency, power and spatial capacity.

Optimising these resources dynamically is challenging, especially as requirements change across use cases. This makes adaptive and intelligent resource management a key enabler of ISAC.

4. From nodes to networks

Early ISAC implementations focus on single devices or base stations that combine sensing and communication. The real potential is realised when sensing is extended across the network.

4.1. Networked ISAC

In networked ISAC, sensing is no longer limited to a single node. Instead, multiple network elements work together to observe the environment.

This includes:

- Base stations and access points
- User devices
- Emerging elements such as reconfigurable intelligent surfaces (RIS) and repeaters

These nodes act as both transmitters and receivers, collecting reflections from objects such as vehicles, infrastructure and people.

By combining data across multiple nodes, networks can:

- Improve sensing accuracy through multiple perspectives (multi-static sensing)
- Extend coverage beyond line-of-sight limitations
- Increase robustness in complex and dynamic environments

The result is a shift from isolated sensing to large-scale, distributed environmental awareness, where the network itself becomes a sensing system.

4.2. Distributed and centralised roles

Different parts of the network play different roles in sensing.

At the edge (e.g. radio units and distributed units):

- Time-critical sensing and signal processing take place
- Real-time decisions can be made based on local observations

At more central layers (e.g. central units and core network):

- Data from multiple nodes is combined and analysed
- System-level coordination and optimisation are performed
- Sensing information is made available to applications

This split is essential to balance:

- Latency (fast local response)
- Accuracy (multi-node data fusion)
- Scalability (network-wide coordination)

4.3. Towards perceptive mobile networks

As ISAC evolves, networks move towards a new paradigm:

perceptive mobile networks, where communication and environmental understanding are tightly integrated. In this model, environmental data is continuously collected and interpreted, and insights directly influence network behaviour and applications.

Looking ahead to 2030 and beyond, ISAC is expected to converge with edge computing, AI and distributed intelligence. Together, these capabilities will form the basis for perception-driven networks, where sensing data is processed close to where it is generated and directly influences system behaviour.

This shift enables networks to actively support automation, safety and intelligent system behaviour.

4.4. From architecture to applications

This network-level sensing capability enables a new class of services, including:

- Safer and more coordinated mobility systems
- Industrial automation with real-time environmental awareness
- Continuous monitoring of critical infrastructure
- Digital twins that reflect real-world conditions in real time

In this sense, ISAC is not just a technology feature, it is a platform capability that enables new cost-effective value creation across industries.

5. From concept to deployment

ISAC is moving from research to early real-world implementation. The key challenge is turning promising concepts into reliable, scalable solutions.

This requires:

- Early validation in realistic environments
- Close collaboration across industry and research
- Iterative development from simulation to hardware testing

At VTT, this transition is built on early industrial validation and risk reduction. By combining advanced algorithms, RF and photonic hardware, multi-functional radios, edge intelligence and open testbeds, VTT helps organisations move ISAC from laboratory concepts to deployable solutions.

This includes validating performance, reliability, energy efficiency and regulatory readiness in realistic environments – critical factors for adoption in industrial, defence and infrastructure domains. By bridging theory and practice, ISAC can evolve from a promising concept into a deployable capability that creates real value.

ISAC is also a promising capability for future Non-Terrestrial Networks, particularly in 6G and beyond era, including LEO and HAPS deployments.

VTT is advancing ISAC from research to real-world use

Defence and security: drone detection and control
In the EU PRESERVE project, radar sensing combined with deep learning is used to detect and track potentially hostile drones, supporting the development of ISAC-based security capabilities. Related research examines how ISAC could support drone swarm operations.

Smart infrastructure: understanding human movement
In the Untangling People Flow project, VTT uses radar sensing to monitor human movement in real environments such as indoor spaces and public areas. The data supports development of detection, tracking and prediction algorithms for applications like crowd monitoring and infrastructure planning.

Industrial environments: sensing for digital twins
In the 6GLearn project, VTT develops ISAC-based solutions for detecting and predicting signal blockages in factory environments. By combining real measurements with advanced modelling, these capabilities are integrated into digital twins that support more reliable industrial operations.

Space: sensing beyond the Earth's surface
VTT has explored the use of ISAC for detecting space debris using inter-satellite communication signals, demonstrating how sensing can be embedded into existing communication systems to support space safety.

Healthcare and human-centric sensing
VTT develops non-contact sensing solutions that use radio signals to monitor vital signs such as breathing and heart rate. These capabilities enable continuous monitoring without wearables and can also be applied in security contexts, for example to distinguish between living and non-living objects.

6. VTT offering

VTT – Your R&D partner in ISAC in 6G

VTT supports the development and validation of ISAC solutions across the full innovation cycle from early research to real-world deployment. By combining multidisciplinary scientific and technological expertise, advanced research infrastructure and close collaboration with industry, research and policy makers, VTT helps companies reduce development risk, shorten time to market and scale ISAC solutions into deployable, 6G ready capabilities with clear business impact.

Capabilities include:

- Development of joint communication and sensing hardware and waveforms
- Prototyping with multi-functional radios and advanced RF platforms
- Testing in realistic environments using open and configurable testbeds
- Integration of edge intelligence and data processing into ISAC systems

Selected focus areas:

- Networked ISAC and distributed sensing architectures
- High-frequency and multi-band operation (including FR3 and beyond)
- Novel algorithms and waveform designs, evaluated via simulations and theory
- AI-driven signal processing and resource optimisation

What this enables for partners:

- Reduced development risk
- Faster transition from concept to prototype
- Access to infrastructure, validation of performance under real operating conditions
- Clear pathways towards scalable deployment
- IP licensing and technology transfers

7. Summary

ISAC extends mobile networks beyond connectivity, enabling them to sense and interpret the physical world.

This shift creates new opportunities across industries, from mobility and manufacturing to healthcare and smart infrastructure. At the same time, it introduces new challenges in system design, coordination and trust.

The next phase of ISAC will be defined by how effectively these challenges are addressed – and how quickly the technology can be translated into real-world solutions.

Interested? Get in touch to explore collaboration opportunities.

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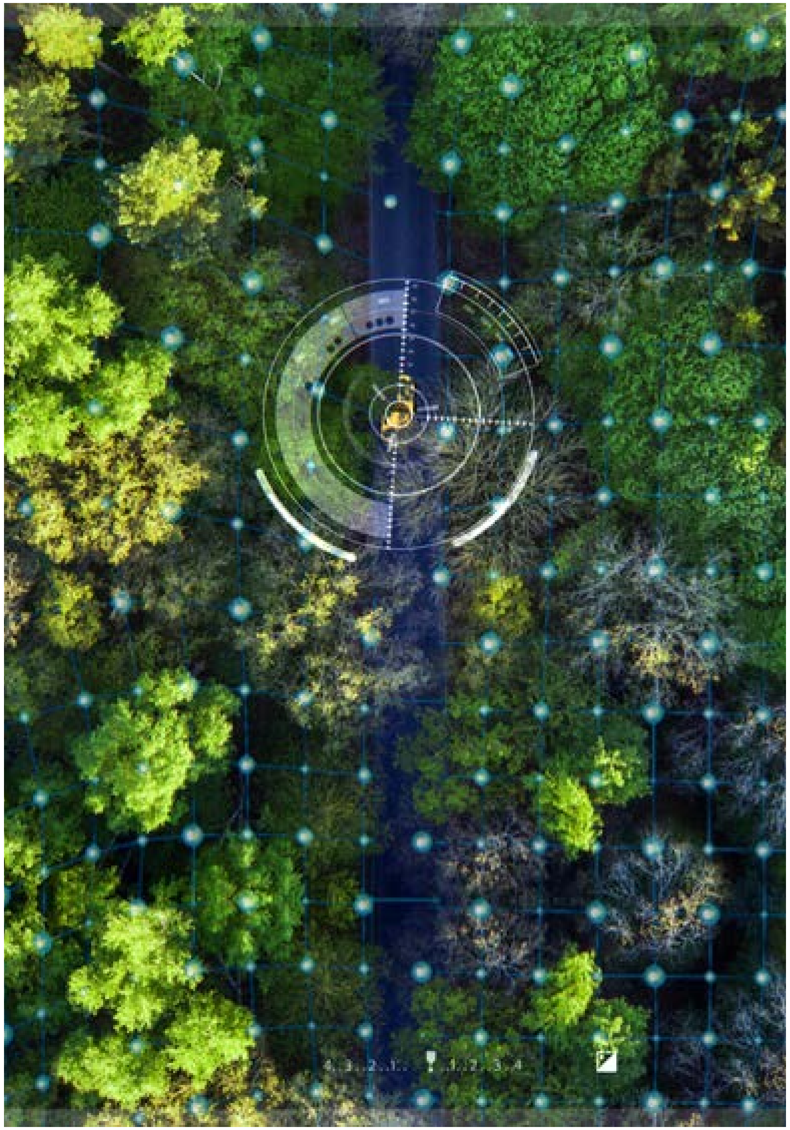

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