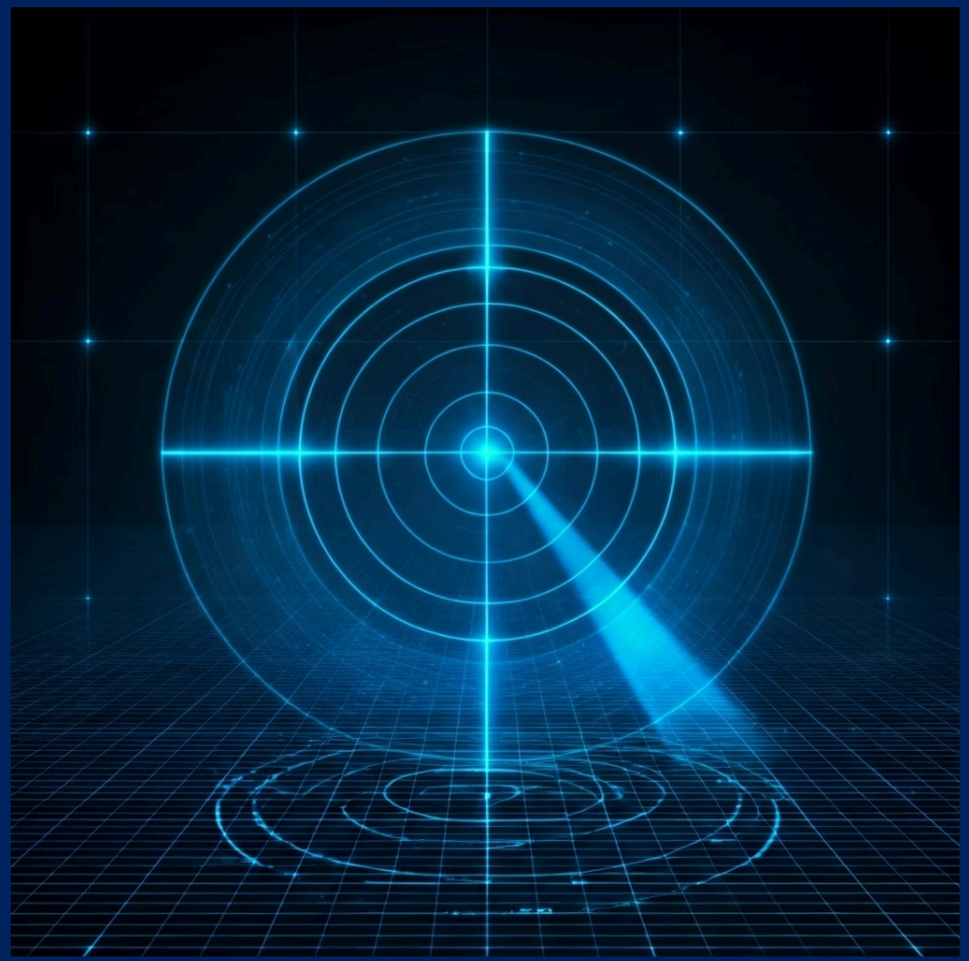
INTEGRATED SENSING AND COMMUNICATIONS (ISAC)

Adding spatial sensing capabilities to existing communications infrastructure, enabling networks to detect passive objects not connected to the network.

WHAT IS ISAC?

ISAC adds sensing as a native function of communication networks, allowing network nodes to perform both communication and sensing tasks while enabling efficient spectrum sharing.

Sensing refers to extracting information about the physical environment—such as shape, size, location, and velocity of objects—using radio signals transmitted and received by network infrastructure and user equipment.



Unlike current location capabilities (e.g., for e911), ISAC can detect passive objects not connected to the network, similar to radar technology.

HOW ISAC WORKS

SIGNAL TRANSMISSION

Radio base stations transmit signals that reflect off objects in the environment

SIGNAL RECEPTION

Reflected signals are received by the same station (monostatic) or different stations (bistatic/multistatic)

SIGNAL PROCESSING

Comparing transmitted and reflected signals to detect objects and their properties

KEY USE CASES

INDOOR APPLICATIONS

- AGV detection in factories
- Human motion recognition
- Crowd size estimation
- Senior care monitoring

PUBLIC SAFETY

- Emergency search & rescue
- Disaster risk monitoring
- Health hazard detection

OUTDOOR APPLICATIONS

- Drone detection
- Traffic monitoring
- Environmental sensing
- Emergency vehicle routing

NETWORK ENHANCEMENT

- Sensing-aided communications
- Context-aware services
- Improved spectrum efficiency

ECONOMIC VALUE

1 NETWORK AS A SENSOR

Adds sensing capability to the network, providing cost, scale, and coverage benefits over standalone sensor solutions

2 SENSING-AS-A-SERVICE

Transforms the communication network into a sensing platform, often integrating complementary sensor data through sensor fusion

3 SENSING FOR COMMUNICATIONS

Uses environmental awareness to optimize network operations, such as handover and beam management

TECHNICAL CAPABILITIES

KEY SENSING METRICS

Range Error	Accuracy of distance measure
Velocity Error	Accuracy in speed estimation
Angle Resolution	Direction discrimination
Detection Probability	Likelihood of correct detection
False Alarm Rate	Likelihood of false detection

FACTORS AFFECTING PERFORMANCE

- Pulse train bandwidth
- Carrier frequency
- Transmit energy
- Antenna gain
- Target radar cross section (RCS)

Higher frequencies allow detection of smaller features but have shorter range. Wider bandwidth provides better resolution.

TECHNICAL CHALLENGES

WAVEFORM CO-DESIGN

Reconciling differing priorities of communication (throughput, latency) and sensing (resolution, detection)

MUTUAL INTERFERENCE

Managing shared use of spectral, temporal, and spatial resources between sensing and communication

DYNAMIC ENVIRONMENTS

Adapting to constantly changing RF conditions due to mobility and physical obstructions

PERFORMANCE TRADE-OFFS

Balancing sensing accuracy with communication capacity in real-time

SECURITY & PRIVACY

Addressing concerns about surveillance and sensitive information revealed through sensing

STANDARDIZATION

Developing comprehensive frameworks for hardware compatibility and interoperability

FUTURE DIRECTIONS

1

2025

6G standardization efforts commence with ISAC as a foundational element

2

3GPP RELEASES 19-21

Progressive advancement of ISAC technology in 5G-Advanced evolution

3

2030

Expected 6G deployment with mature ISAC capabilities

Research focus areas include AI-enhanced signal processing, reconfigurable intelligent surfaces (RIS), and cross-layer optimization to harmonize the often-conflicting demands of communication and sensing.

FIGURE 2.1 SENSING WITH RADAR TECHNOLOGY AT TRANSMITTER (RADIO BASE STATION)

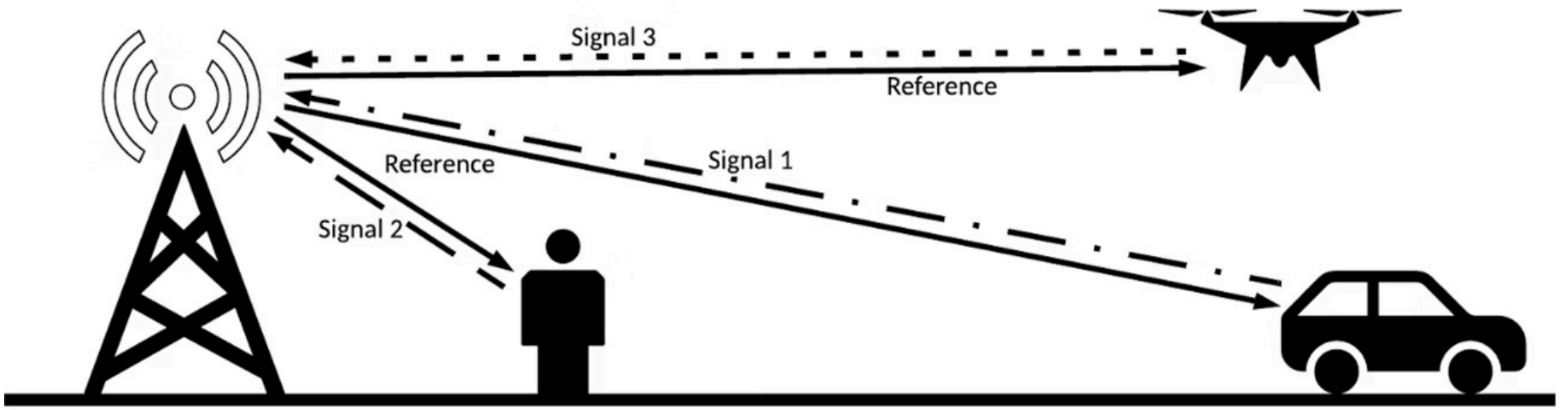


FIGURE 2.2 SENSING WITH EXTERNAL DEVICE (OTHER RADIO BASE STATION OR SENSOR)

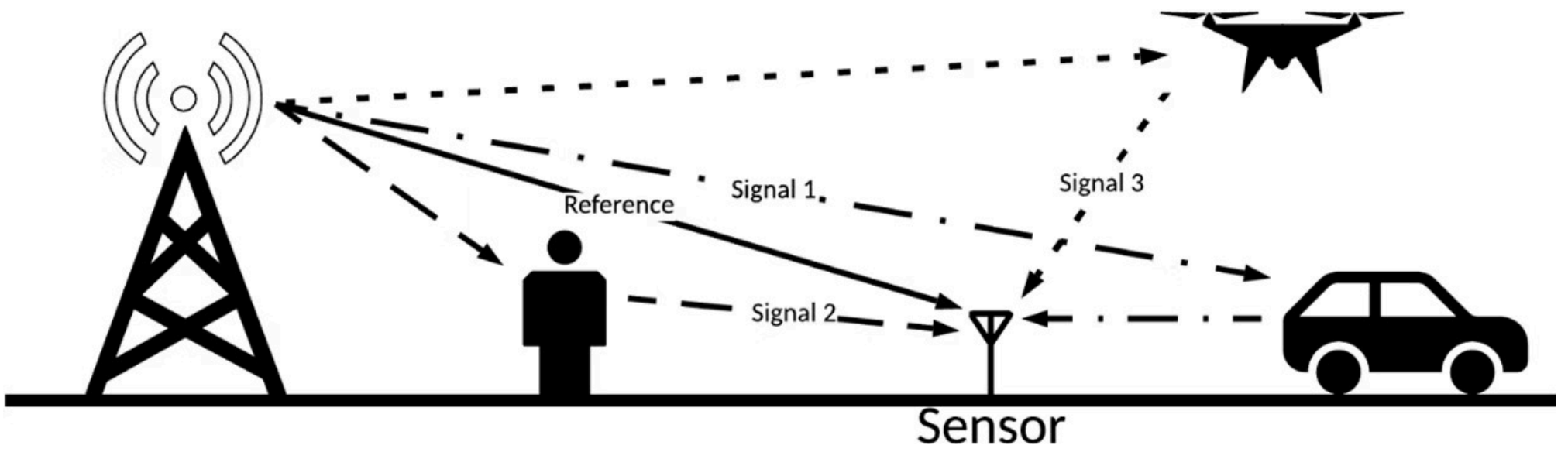
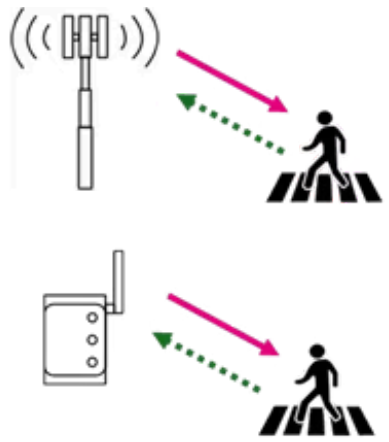
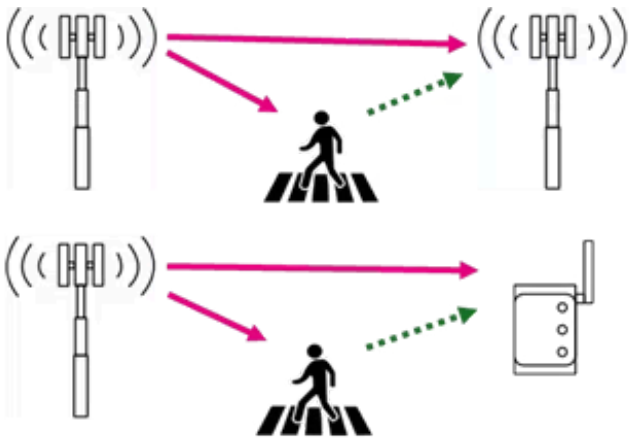


FIGURE 2.3 SENSING MODES



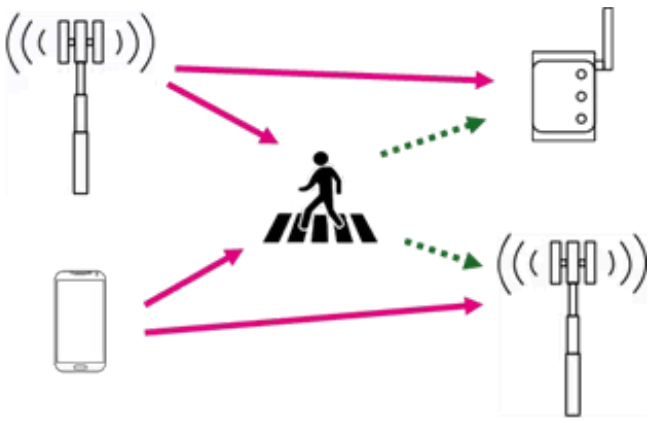
Mono-static

The sensing transmitter and receiver are co-located in the same entity: a network cell, or a device. In ISAC, nominally this is a radio base station.



Bi-static

Sensing transmitter and receivers are in different entities. In ISAC, nominally these are radio base stations.



Multi-static

Multiple sensing receivers capture reflected signals from one or more sensing transmitters. In ISAC, nominally these are radio base stations.

FIGURE 4.1 EXAMPLE ARCHITECTURE FOR ACTIVE SENSING WITH SENSING CAPABILITY IN RADIO AND CORE NETWORK, SENSING-AS-A-SERVICE

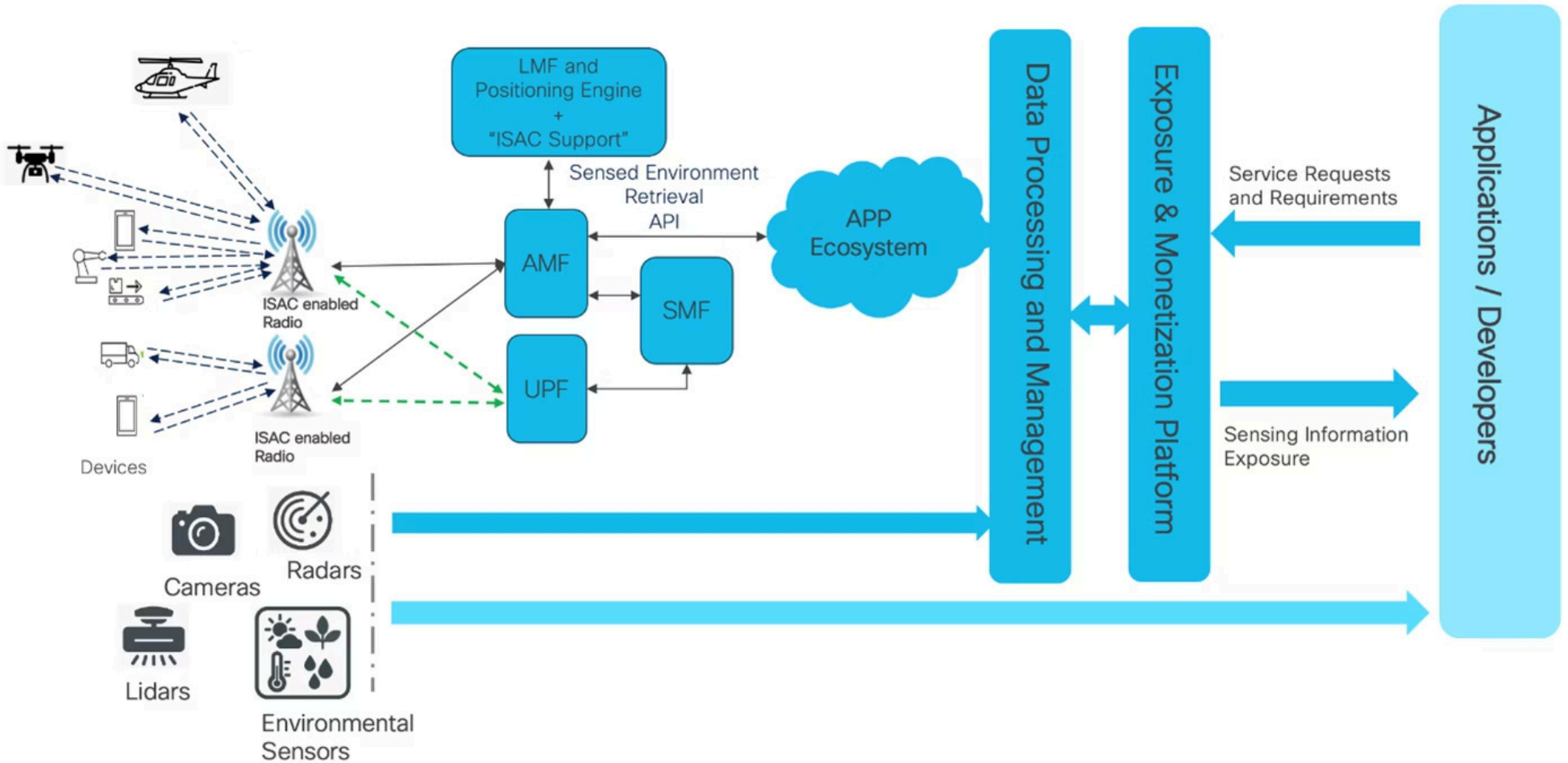


FIGURE 5.1 EXAMPLE OF REFERENCE SIGNALS USED AS PULSE TRAIN INTEGRATED INTO AN OFDM COMMUNICATION SYSTEM

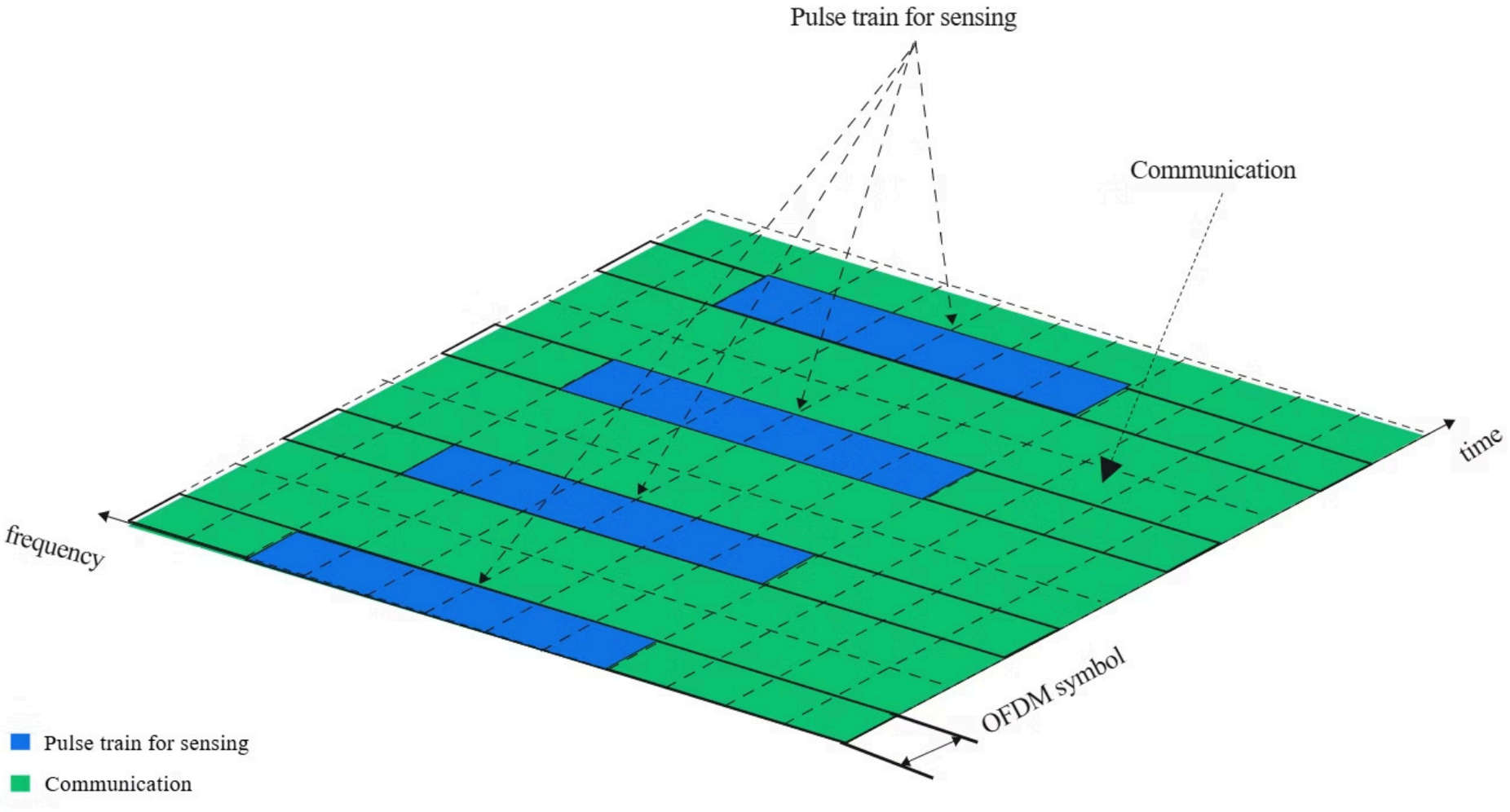


FIGURE 5.2 RANGE-DOPPLER MAP EXAMPLE

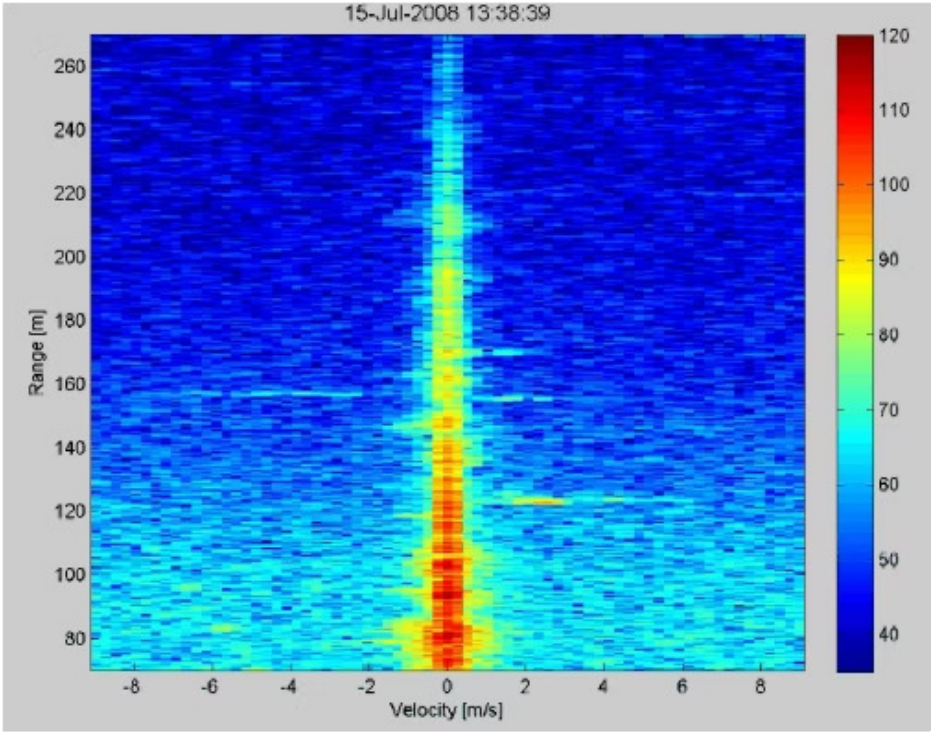


FIGURE 5.3 RANGE-ANGLE MAP EXAMPLE

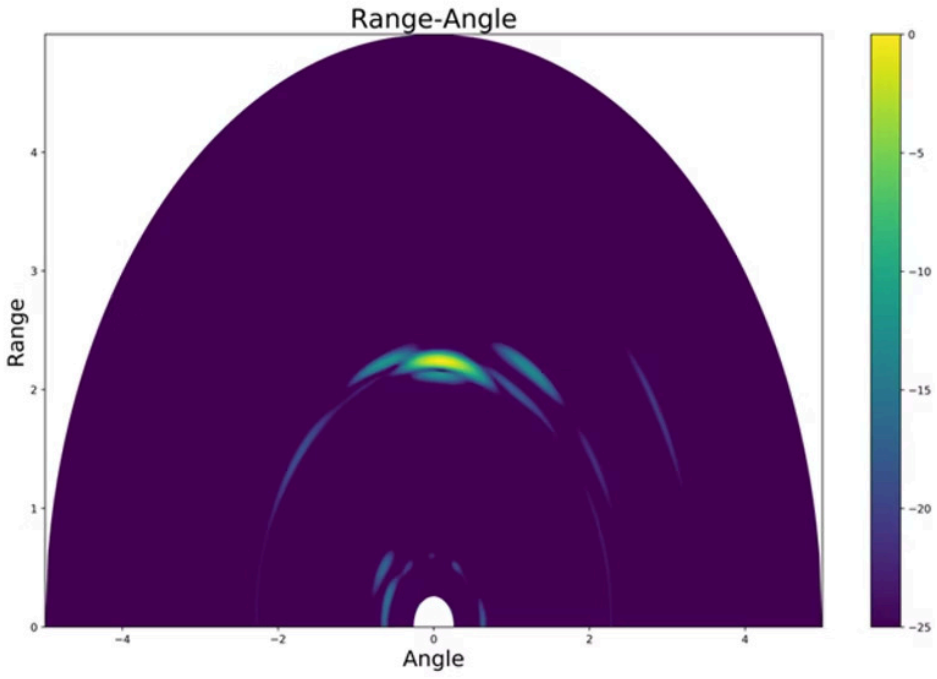


TABLE 3.1 ISAC POTENTIAL USE CASES

Use case	Business potential	Implementation complexity	Notes on implementation complexity
Indoor use cases			
AGV Detection and Tracking in Factories	High	Medium	Reliability and ~10cm location accuracy
Human Motion Recognition	High	Medium	Low-latency indoor sensing and frequent updates
Remotely Controlled Robots for Senior Care	Medium	Medium	Robotic control with moderate sensor feedback; manageable in fixed environments
Body Proximity Sensor	Medium	Low	Simplified sensing, often device-local or edge-assisted
Collaborative Robots (Digital Twin)	High	High	Demands precise synchronization and dense in-factory sensor networks
Resilient Cyber-Physical Systems (R-Caps) in Industrial Worksites	High	High	Complex sensing-communication orchestration with SLAs
Precise Localization for Robot Grasping	High	High	Sub-centimeter precision requires high-resolution sensing and real-time control loops
Outdoor use cases			
Outdoor Drone Detection	High	Medium	LoS environment
Airborne-based Environmental Sensing	High	Medium	UAV or elevated platform integration; moderate latency sensitivity
Real-time Health Hazard and Disaster Risk Monitoring	High	High	Large-area coverage, coordination with emergency systems, and high reliability
Micro-deformation Sensing	Medium	Medium	Passive or periodic sensing with localized integration
Traffic Throughput and Safety at Intersections	High	High	Edge-based multi-point sensing, timing-critical alerts
Outdoor Healthcare Monitoring	Medium	Medium	Periodic bio-signal sensing, variable environments
Safe & Economic UAV Transport	Very High	High	Requires beyond visual line of sight (BVLOS) support, coordination with airspace systems
Emergency Vehicle Route Planning	High	Medium	Real-time data fusion and coordination; complexity depends on integration depth
High-resolution Topographical Mapping	Medium	Medium	Periodic updates; may leverage existing infrastructure
Mixed use cases			
Emergency Search & Rescue	High	High	Requires edge artificial intelligence (AI), dynamic routing, and resilience to signal loss
AGV in Airports	Medium	Medium	Confined but operationally dense environments
Sensing-aided Communication	Very High	High	Tight integration of sensing data into communication control layers
Remotely Controlled Robots for Senior Citizen Monitoring and Care	Medium	Medium	Combines motion detection with robotic assist in structured settings

TABLE 3.2 ISAC USE CASE COMPARISON

Use case	Operator utility	Community benefit	Business potential
Safe & economic UAV transport	6	6	6
Real-time monitoring of health hazard and disaster risk	5	6	6
Sensing-aided communications	6	5	6
Vison-aided sensing	6	5	6
Emergency search and rescue	5	6	5
Airborne-based sensing for environmental reconstruction	5	5	5
Traffic throughput and safety on road intersections	5	5	5
Collaborative robots based on digital twinning	5	5	5
R-CPS in industrial worksites	5	5	5
Emergency vehicle route planning	4	5	5
Precise localization for robot grasping	4	5	4
Micro-deformation sensing	4	5	4
Body proximity sensor	5	4	4
Human motion recognition	3	5	4
Remotely controlled robots for senior citizen monitoring and care	3	5	4
Outdoor healthcare sensing and monitoring	3	5	4
AGVs travelling in airports	4	4	4
High-resolution topographical maps	4	4	3

TABLE 5.1 KEY METRICS FOR SENSING

Metric	Definition	Units
Range Error	Accuracy of distance measure	m
Velocity Error	Accuracy in speed estimation	m/sec
Angle Resolution	How well you distinguish direction	Degrees
Detection Probability	Likelihood of correct detection	%
False Alarm Rate	Likelihood of false detection	%
SNR	Signal vs noise in reflections	dB
Field of View (FOV)	Angular area where sensors can effectively detect/observe objects	Degrees (2D), Steradians (3D FOV)

TABLE 5.2 EXAMPLE: SENSING TASKS AND RELATED REQUIREMENTS FOR INDOOR FACTORY AGV

Requirement		Basic sensing tasks		
		Detection	Characterization	Localization
Detectability	$P_{False\ Alarm}$	3%	3%	TBD
	$P_{Detection}$	99%	99%	TBD
Location accuracy	Horizontal	-	-	0.5 m
	Vertical	-	-	0.5 m
Velocity accuracy		-		1 m/s
Latency		100ms		

TABLE 5.3 THEORETICAL ISAC CAPABILITIES

Frequency (GHz)	**3.5**	**24**	**Carrier wave frequency**
Pulse bandwidth (MHz)	15	15	Assumption
Transmit Power (dBm)	45	45	Assumption
Antenna gain (dBi)	20	20	Assumption
Radar cross section (m^2)	1	1	Assumption
Minimum Detectable Signal (dBm)	-94	-94	Assumption, function of bandwidth
Max Detection Range, monostatic (m)	1325	506	From radar equation
Range Resolution (m)	10	10	$\Delta R = c / (2*bandwidth)$
Velocity Resolution (m/s)	0.4	0.0625	$\Delta V = \lambda / 2T$, assuming T = CPI of 100 ms