D1.1

Use case-driven specifications and technical requirements and initial channel model

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Abstract	This deliverable reports on the results of Task 1.1, providing an inventory of interactive use case specifications, representative deployment scenarios, technical requirements and KPIs for the four focus domains. D1.1 includes the initial channel model based on existing measurements and models. It reports on the particular investigation of the origin of latency in wireless applications.
Keywords	Use cases, technical requirements, deployment scenarios, channel model, cell-free operation

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Executive Summary

This is deliverable 1.1: "*Use case-driven specifications and technical requirements and initial channel model*". This document describes the results of Task 1.1 (Analysis of interactive use case scenarios and detailed technical requirements), providing an inventory of interactive use case specifications, representative deployment scenarios, technical requirements and KPIs for the four focus domains.

This analysis aims to comprise thirteen representative future interactive use cases enabling new services in the mentioned application domains. The deliverable also includes the initial channel model based on existing measurements and models.

Chapter 2 describes the main use cases identified for the REINDEER project and their respective KPIs. The technical requirements are described in Chapter 3, reporting the functional and quantitative requirements identified, that the infrastructure shall meet. The deployment scenarios are described in Chapter 4 reporting the main deployment opportunities for Radio Weaves (RW) and the use cases identified.

Considering the challenging technical requirements posed by the use cases, Chapter 5 contains a study of the latency requirements for emerging wireless applications. In Chapter 6 guidelines for initial channel models are provided, based on existing measurements and models related with Task 1.2 (Characterization and modelling of propagation environments).

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Chapter 1 Introduction

The REINDEER project develops a new wireless infrastructure, "RadioWeaves" (RW), consisting of a fabric of dispersed electronic circuits and electromagnetic surfaces that collectively function as a massive, distributed resource offering hyper-diverse connectivity, positioning, wireless power transfer (WPT) and computational capabilities. This architecture brings the capabilities of multi-antenna systems to a next level upon the foundations of cell-free massive MIMO systems and is based on large intelligent surfaces, which can be integrated into walls and furniture present in the different deployment scenarios meeting the challenges of new interactive, real-time and real-space applications.

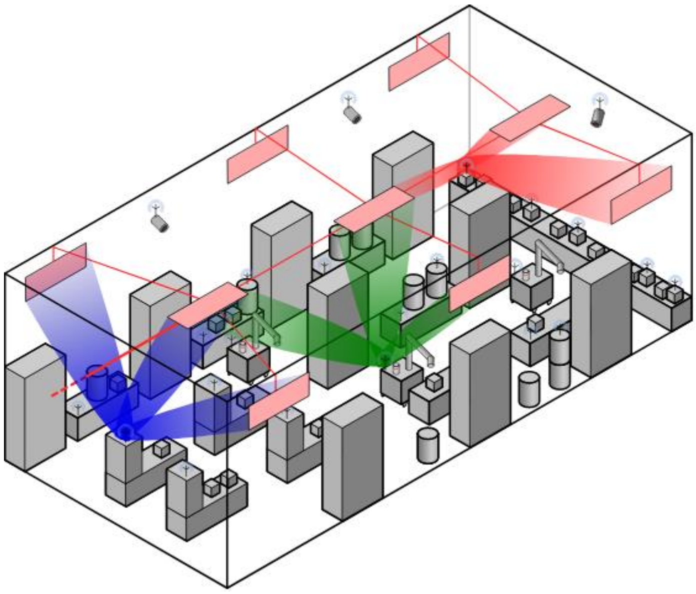


Figure 1: RW infrastructure sketch with antennas integrated into the environment bringing them closer to the devices and increasing spatial diversity for higher capacity and reliability

Future applications in the field of industry, healthcare and entertainment will depend on wireless connectivity to provide resilient interactive experiences with uninterrupted availability both in time and location, with unnoticeable dislocation between virtual and real elements. We focus on four main application domains, where RW becomes more relevant to drive REINDEER innovation:

(A) **Adaptive robotized factories, warehouses, retail and logistics**: In future factories, warehouses, and logistics, applications will critically rely on wireless connectivity, requiring zero-outage and imperceptible latency communication. Manufacturing and industrial settings are typically highly reflective and feature many blocking objects. Future interactive applications in these environments will hence face a combination of challenging requirements.

(B) **Immersive entertainment for crowds of people:** The future connectivity infrastructure needs to offer a capacity that can be scaled up to support a very high number of individual video services and with enhanced user experiences, to be offered in places where crowds gather, far beyond the capabilities current and emerging wireless networks. This occurs in large and, typically, relatively open spaces such as stadiums, festival grounds, or large halls and auditoriums.

(C) **Human-machine interaction in care environments, hospitals and assisted living:** Future human-oriented applications will need to provide intuitive experiences for people interacting with robots and objects in their environment. The people-friendliness of the experiences is therefore extremely important, including both the reliability of the application and the aesthetic of the integration of the infrastructure in the environment.

(D) **Home automation and smart home systems:** Our homes are becoming increasingly connected and automated and we foresee this trend reaching a new level of sophistication with the help of energy-neutral devices, which allow for extremely dense deployments of sensors and actuators with no maintenance. Entertainment options at home are also expanding with the advent of virtual reality. In this domain, we need to meet performance requirements while keeping costs low so that products are accessible to consumers.

On top of communication, RW will feature a new range of intelligent services through capabilities that are inherent to its architecture. Deploying large and distributed electromagnetic surfaces will lead to unforeseen spatial resolutions that will enable precise localization even with a limited bandwidth. In contrary to conventional beamforming, the emitted radio signals will be largely uncorrelated everywhere, except at desired focal points. This paves the way for WPT at unprecedented power levels, while keeping the overall electromagnetic exposure low in the vicinity. Both localization and WPT, offered as services from the infrastructure, will ultimately open the doors for novel location-aware applications and the operation of new generation of highly capable energy-neutral devices.

1.1 Objective of the document

This deliverable reports on the results of Task 1.1 (Analysis of interactive use case scenarios and detailed technical requirements and initial channel model) that aims to analyse the needs of the innovative interactive applications and representative use case scenarios, and translates the specifications of the use cases into detailed quantitative technical requirements to drive the R&D in the project.

In this way, this document defines the representative deployment scenarios, technical requirements, inventory of interactive use case specifications and key performance indicators (KPIs) for the main application domains of the project.

This analysis comprises thirteen representative future interactive use cases, enabling new services in the four focus application domains. The specifications characterise typical spatial characteristics of the environment and include both the nature and the amount of active and energy-neutral devices envisioned in the application. The technical requirements are detailed quantitatively and apply to both performance and complexity. The requirements include numbers of devices, links and simultaneous service levels to be supported.

The deliverable reports on the particular investigation of the latency requirements from wireless applications. It also includes the initial channel model based on existing measurements and models related with T1.2 (Characterization and modelling of propagation environments).

1.2 Structure of the document

The structure of the document can be summarized in the following way:

- Chapter 1, Introduction: contains an overview of the project and the objectives of this deliverable.
- Chapter 2, Use cases: describes the main use cases identified for the REINDEER project and their respective KPIs.
- Chapter 3, Technical requirements: describes the functional and quantitative requirements identified that the infrastructure shall meet.
- Chapter 4, Deployment scenarios: describes the main deployment opportunities for RW and use cases identified.
- Chapter 5, Latency in wireless applications: contains a study of latency requirements for emerging wireless applications.
- Chapter 6, Initial channel model: outlines a channel model framework for RadioWeaves based on the COST 2100 channel model and its massive MIMO extension.
- Chapter 7, Summary and conclusions: provides an overview of the main learnings and conclusions in this deliverable.

1.3 Terminology

This section describes the main definitions relating to the concepts exposed in the document.

1.3.1 Scenarios

The scenarios are the environments with specific characteristics where the RW technology is expected to be deployed and provide connectivity, under the framework of the REINDEER project, and the corresponding use cases identified.

The description of these scenarios involves sketching typical high-level ground plans for the environments, specifying dimensions and typical objects and materials encountered in these environments. In addition, this document describes the RW deployment opportunities within each scenario.

1.3.2 Technical requirements

Technical requirements must be considered to successfully implement the use cases and services. The technical requirements will be detailed not only with functional requirements describing functionalities and services, but also with the quantitative requirements which describe the specific values of RW performance coming from the KPIs imposed by use cases and services.

General functional and quantitative requirements that the system shall accomplish to have an adequate performance are further detailed in this document.

1.3.3 Use cases

The use cases describe the sequence of interaction and services provided to the users in a specific environment by means of the RW infrastructure. Thirteen specific use cases are analysed, identifying the needs for innovative interactive applications within the four defined applications domains.

1.3.4 Key Performance Indicators

Key performance indicators (KPI) are the relevant measurable values for evaluating RW performance. These values establish thresholds and optimal values that the infrastructure shall cover to support the use cases with adequate performance.

1.3.5 Services

A Service represents a specific functionality provided by the infrastructure to cover the functional requirements of use cases. These services can imply additional KPIs that the infrastructure shall meet to be considered successfully implemented.

Chapter 2 Use cases

This chapter presents an overview of the main use cases that have been defined. These selected use cases are those relevant for each of the application domains defined in Chapter 1, giving a wide variety of applications which have not only a considerable economic impact by improving and making industrial processes more efficient, but also a social impact by covering other scenarios related to health, people care and entertainment, both in massive environments and at home. For this, it is always important to identify the needs of society, taking into account the state of the art and covering those needs that can go one step further thanks to the technological advances which are achieved with RW. This infrastructure provides technological advantages such as greater availability, location accuracy and the ability to connect massive simultaneous devices.

Table 1 contains a list of the selected use cases as well as the application domains that they are covering. Each of the uses cases is described in detail together with the required system performance indicators (technical requirements). It will be listed the main functional requirements for each of the use cases and the main challenges that the use case impose to the system.

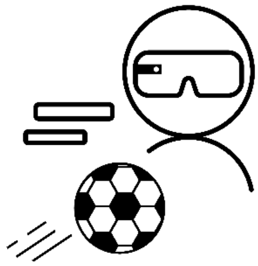
Use case ID	Use case name	Application domain			
		A	B	C	D
1	Augmented reality for sport events		X		
2	Real-time digital twins in manufacturing	X			
3	Patient monitoring with in-body and wearable sensors			X	
4	Human and robot co-working	X		X	
5	Tracking of goods and real-time inventory	X			
6	Electronic labelling	X			
7	Augmented reality for professional applications	X		X	
8	Wander detection and patient finding			X	
9	Contact tracing and people tracking in large venues		X	X	
10	Position tracking of robots and UVs	X			
11	Location-based information transfer		X	X	
12	Virtual reality home gaming			X	X
13	Smart home automation			X	X

Table 1: Use cases list and their corresponding application domains

The different use cases have been classified using two different approach. The first one considering the similarities in the functionalities that they are providing, and the second approach, making cluster of use cases with similar technical challenges that should be addressed to meet with the identified KPIs. These two classifications will be described at the end of the chapter.

2.1 Use cases description and KPIs

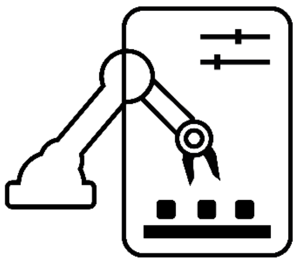
2.1.1 Augmented reality for sport events

General description			
Name/ Icon	Augmented reality for sport events		
Description	Augmented reality for sport events provides a new concept of providing real-time information to the users, creating a map of the surrounding area, localization of relevant players or objects, and real-time information. Players wear low power sensors which provide real-time data to a central server, multiple sensors input are combined and processed to offer different statistics to the user, e.g. position of users, speed, health constants, colour maps, tracking record, highlights replay etc. The users can consume this real-time information, interacting with their augmented reality devices, selecting the content or statistics that they want to see in each moment of the match. The augmented reality devices consist on the smartphones of the users, that using their camera and an app which connect to the central server, can visualise the most relevant content according to their interest. In addition to the sport-related information, the user will be able to access to information systems where they could visualise the location of different interest areas, e.g. restaurants, exits, bathrooms, stairs, etc.		
Scenario	Stadiums and sport event locations		
Application domain	Immersive entertainment for crowds of people		
Geographic scope	Indoor and outdoor		
Technical requirements			
Attribute	**Description**	**KPI**	**Comments**
Spectrum	Carrier frequency	5GHz or 2.4GHz	Highest frequencies shall be more suitable for broadband communications
Traffic model	Maximum number of simultaneous devices	100000 AR devices 50 low power sensors	The highest sport event has a capacity for up to 100.000 person.
	User Experience data rate	Up to 5 Mbps	For video HD streaming, statistics information updates require lower data rates.
	Uplink/Downlink ratio	Mostly DL	
UE	Mobility	Up to 10 m/s for sensors Walking speed for AR devices	High mobility for players. Spectators will move by walking speed.
	Accuracy	<0.5 m	

System	Reliability	99.9%	
	End to end Latency	<20 ms	[3GPP3]
	Traffic volume density	10 Mbps/m^2	50000 m^2 of stadium bleachers. Maximum traffic density considering all the users connected simultaneously downloading HD streaming video. Typical values will be less stringent.
Functional requirements			
Functional requirements	• The system shall process the data collected from the passive devices and provide it in a proper manner to the AR reality users. • Gather information and statistics from the sensors • Users will be able to see information and statistics in real-time with an augmented reality application using their mobile phones and the camera or any other compatible AR device • The system can provide localisation service to show the relevant information according the position of the different players.		
Technical challenges addressed			
Challenges	• Massive number of simultaneous connections, high traffic volume/sum rate. • Necessity to cover higher mobility speeds for sport events where the players are usually reaching up to 10m/s • Deployment in wide open areas. Larger coverage is needed compared with pure indoor deployments • Low latency required for a good VR quality experience		
Security	The main security requirements for this use case are confidentiality, authentication and user access control referring to the raw information shared by the sensors to the cloud where the data is processed. For the processed data that are accessed by the AR users, the security requirements are less stringent, being the most important: data integrity, non-repudiation and privacy.		

Table 2: Use case 1. Description and KPIs

2.1.2 Real-time digital twins in manufacturing

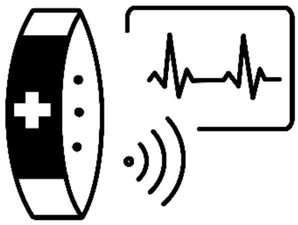
General description		
Name/ Icon	Real-time digital twins in manufacturing	
Description	Digital twins [MF1] are a new technology for Industry 4.0, in which processes, machines, or even entire factories are mirrored in the digital domain by creating a virtual copy of the physical entity and synchronising the state between the digital and physical twins. The digital twin is typically hosted in a	

	cloud or edge data centre (private or public) and can be used to monitor manufacturing processes in real time, simulate potential changes before implementing them in the physical twin, and add enhanced functionality such as improved control [PS1], intrusion detection [FA1], and other security features [CG1]. In this use case we focus on digital twins used for monitoring and control of real-time processes. This requires bidirectional communication between the digital and physical twins, in order to replicate the physical twin's state in the digital domain, as well as to send control signals and other updates from the digital twin to the physical one. This requires extremely high reliability, as lost packets may affect the correct functioning of the physical machines and lead to damage or even threaten the safety of human operators. In cases where positioning is used, this should be very accurate in order to ensure multiple machines or robots can interact at high speed and with high precision. The latency requirements for this use case are also stringent. Control loop periods for industrial processes can in general be as low as hundreds of microseconds, however here we will target processes with a latency requirement of no lower than 1 ms. This nonetheless covers a wide range of factory and process automation instances.		
Scenario	Factories		
Application domain	Adaptive robotized factories, warehouses and logistics		
Geographic scope	Indoor		
Technical requirements			
Attribute	**Description**	**KPI**	**Comments**
Spectrum	Carrier frequency	2.4 GHz or 3.8 GHz	ISM band if it is an unlicensed site, 3.8 GHz if operated by a provider with a license
Traffic model	Maximum number of simultaneous devices	20-100 / m^2 [MG1]	Mixture of low power sensors and machines
	User Experience data rate	1 Mbps	
	Uplink/Downlink ratio	Both UL and DL	
UE	Mobility	Low/none for sensors Up to 10 m/s for robots	
	Accuracy	10 cm	
System	Reliability	>99.999%	Five nines for process automation, nine nines for factory automation [MG1]
	End to end Latency	1 ms – 50 ms	We focus on real-time control. Some processes require even lower latency but we target those that work with 1 ms or higher.
	Traffic volume density	20 Mbps / m^2	High density devices tend to have lower data rates (sensors and actuators), so we use the lower device density estimate
Functional requirements			

Functional requirements	• Mirroring of the state of individual machines up to the entire factory in the digital domain (local or remote cloud) in real time. • Interaction between the digital and physical domains (digital twin acting on the physical twin). • State of the plant and control signals synchronised between the physical and digital twins in real time. • For safety purposes: (vehicle & person) Collision warnings; policy monitoring
Technical challenges addressed	
Challenges	Extremely high reliability and low latency High accuracy positioning Massive number of simultaneous devices and high traffic volume High mobility for some devices
Security	This use case requires a high level of security in several aspects. Data integrity, authentication, and user access controls are the most important aspects as breaches in these can affect the safety of human operators in the worst case. Availability is critical for financial reasons as shutting down a production line even briefly is extremely expensive. Confidentiality is also needed to protect sensitive business information, and non-repudiation to provide confidence in quality assurance processes (may even be needed for certification depending on the particular industry). Privacy is less important for this use case.

Table 3: Use case 2. Description and KPIs

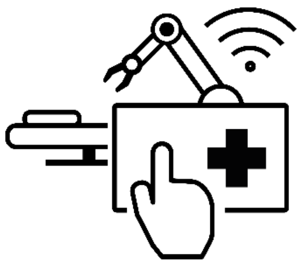
2.1.3 Patient monitoring with in-body and wearable sensors

General description			
Name/ Icon	Patient/Resident monitoring with in-body and wearable sensors		
Description	RW can offer the possibility to monitor patients in hospitals, retirement homes, care homes, etc. using in-body and wearable sensors from all device classes. This allows healthcare staff to collect and process monitoring data from a remote location, which can make healthcare more efficient and better. More information can be obtained about the health status of a patient and the work package of the staff is reduced ensuring that they can focus on the care itself. Patients can also be sent home more quickly with certain sensors, which ensures that the hospital occupancy can decrease more quickly, and means that there is more capacity in the hospital itself.		
Scenario	Hospitals, care homes		
Application domain	Human-machine interaction in care environments, hospitals and assisted living		
Geographic scope	Indoor		
Technical requirements			
Attribute	**Description**	**KPI**	**Comments**

Spectrum	Carrier frequency	2.4 GHz, 868 MHz, 5 GHz	Depending on the sensor, 3.8 GHz possible with provider
Traffic model	Maximum number of simultaneous devices	10s of devices per patient, max 2 patients per m²	
	User Experience data rate	100 bps – 1 Mbps	Mostly single-variable signals (e.g. heartrate, oxygen level), sensing rate seconds to minutes
	Uplink/Downlink ratio	Mostly UL	
UE	Mobility	1 m/s	Patients walking
	Accuracy	< 1m	
System	Reliability	99.99 %	Reliable delivery of alarms
	End to end Latency	< 200 ms	Most data delay-tolerant, even critical alarms on the order of seconds or more
	Traffic volume density	kbps/m² – 10 Mbps/m² µW/m²- mW/m²	(compared with Bluetooth values [SM1]) Power density highly dependent on used sensors and amount of sensors
Functional requirements			
Functional requirements	• Continuously collect data from sensors either worn by the patient or located inside their body, for monitoring by automated systems or medical staff • Low-energy cost to maximise battery life • Some devices may rely on energy harvesting to communicate • Position accuracy high enough to support: 1) in/out bed; 2) in/out bathroom; 3) In front of door (wander prevention) • Target cost < 10 eur/resident; < 10 eur/ m² (infrastructure) • Remote sensing for respiration monitoring (potential extension)		
Technical challenges addressed			
Challenges	Low-energy communication, low-energy positioning, high traffic density volume		
Security	confidentiality, authentication, availability, privacy, user access controls		

Table 4: Use case 3. Description and KPIs

2.1.4 Human and robot co-working

General description		
Name/ Icon	Human and robot co-working	

Description	Already today humans and robots cooperate on tasks in many settings, especially in industrial environments, and this trend is expected to continue and expand in the future. Examples of human and robot co-working include: a surgeon operating on a patient with the help of a high-precision robot operating lasers or other tools; therapeutic robots interacting with patients and carers in hospitals and care homes; autonomous vehicles transporting goods in warehouses and cooperating with human workers; and stand-alone robots or automated industrial machines working alongside human operators in smart factories. A key requirement is maintaining the safety of the human workers, especially in cases where the robots move at high speed and/or operate dangerous tools such as lasers, cutting blades, or welding torches. For this reason, reliability and accurate positioning are critical for this use case. Very low latency may also be needed for some cases, especially those in industrial settings. Since the operation of the robots typically needs to be backed by intelligent algorithms for image processing, navigation, and sensor fusion, this processing must be coordinated with the communication between the robots and the backend such that the needed information arrives at the right time. Relatively high traffic volumes can be needed in cases where complex sensor data such as video streams need to be processed.		
Scenario	Factories, operating theatres		
Application domain	Adaptive robotized factories, warehouses and logistics (manufacturing tasks), Human-machine interaction in care environments, hospitals and assisted living (robot-assisted and remote surgery)		
Geographic scope	Indoor and outdoor		
Technical requirements			
Attribute	**Description**	**KPI**	**Comments**
Spectrum	Carrier frequency	2.4 GHz or 3.8 GHz	Depending on if it is licensed or unlicensed
Traffic model	Maximum number of simultaneous devices	10 devices per task, 1 device / m^2	
	User Experience data rate	5 Mbps	Assuming multiple video streams. If other types of sensors are used, the needed data rate will be lower
	Uplink/Downlink ratio	Both UL and DL	
UE	Mobility	Stationary	
	Accuracy		
System	Reliability	99.999%	
	End to end Latency	1 ms	Depends on the robot, needs to be fast enough to ensure safety of human workers and accuracy of surgery
	Traffic volume density	5 Mbps / m^2	
Functional requirements			

Functional requirements	• Collect sensor data from internal and external (to the robots) sensors, send it to a backend for processing, and return control data to allow robots and humans to cooperate in performing tasks • Ensure safety of human workers in the event of errors or disturbances (e.g. shut down or stop the robots) • Ensure accuracy in performing the task
Technical challenges addressed	
Challenges	High reliability, low latency, coordination of communication and processing, high accuracy positioning
Security	The main security aspects for this use case concern safety of human workers. In particular, data integrity, authentication, and user access controls are needed. Availability can also be a safety concern if downtime is long enough: how long this is depends on the type of robot but in manufacturing even a brief downtime could be a safety issue as robots may operate at high speeds. In care settings, privacy and confidentiality may be important, depending on the specific data involved (whether it is possible to infer health or other private information about patients from the data).

Table 5: Use case 4. Description and KPIs

2.1.5 Tracking of goods and real-time inventory

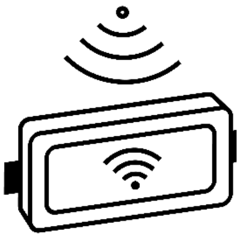
General description					
Name/ Icon	Tracking of goods and real time inventory				
Description	RW technology enables evolution in the field of logistics and supply chain. Typically, the companies have manual control on the logistics and supply chain, creating inefficiencies and bottlenecks that can be further improved by new wireless access technology. With improved positioning accuracy and reliability across a massive number of devices, it is possible to have real-time information on the status of each single item of the supply chain, helping with inventory management with a precise location and identification status of the goods, which open new possibilities to make decisions with this information in a real-time basis according to the needs that arise when the users/robots interact with the goods.				
Scenario	Warehouses, sales floor, hospitals				
Application domain	Adaptive robotized factories, warehouses and logistics Human-machine interaction in care environments, hospitals and assisted living				
Geographic scope	Indoor				
Technical requirements					
Attribute	**Description**	**KPI**			**Comments**
		Warehouses	**Sales floor**	**Hospitals**	

Spectrum	Carrier frequency	868 MHz, 2.4 GHz, 3.8 GHz or 5 GHz			Preferably higher frequencies, which provide better positioning capabilities. Frequencies depends on the possibility to use licensed bands
Traffic model	Maximum number of simultaneous devices	- 1000s of passive or low-power tags (10s per m2) - 10s of human or robot workers	- 10000s of passive or low-power tags (100s per m2)[1] - 50s customers and store personnel	100 per m2 [1] of passive or low power tags	[1] Maximum density estimated for the most stringent areas, assuming that very small objects are bundled together in a box
	User Experience data rate	<1 Mbps			[3GPP3] Maximum data rates for process automation, typical location update messages have small payload
	Uplink/Downlink ratio	Mostly UL			
UE	Mobility	Up to 10 m/s for robots	Up to 2 m/s	Up to 3 m/s	Mostly stationary except for goods being moved by customers / users / personnel
	Accuracy	Better than 0.1 m			
System	Reliability	99.9%			Higher reliability could be required for critical applications in hospitals
	End to end Latency	< 1 s for static or low mobility scenarios < 100 ms for highest speed			[3GPP1]
	Traffic volume density	10 $Mbps/m^2$	100 $Mbps/m^2$	100 $Mbps/m^2$	Maximum traffic density considering the densest areas and the maximum expected data rates for process automation
		$\mu W/m^2$- mW/m^2			Power density highly dependent

			on the specific sensors and the sensors density in the scenario
Functional requirements			
Functional requirements	• Determine and monitor the location of each individual item both in static position and in motion • Allow users (humans or robots) to access and interact with item tracking data • Low-power or passive tags for items, possibly using energy harvesting to communicate • The dimensions of the tag must be correct to fit a small object		
Technical challenges addressed			
Challenges	• Massive number of devices for positioning, and low-energy communication • Large amount of simultaneous connections • Accurate positioning and high mobility support • High reliability (for critical environment such an hospitals) • Need to cover higher speed mobility (up to 10 m/s) (for warehouses with vehicles moving faster)		
Security	The main security requirement for this use case are authentication and user access controls of the data, because most of the data can be related to sensitive information and should be accessed only by authorized staff.		

Table 6: Use case 5. Description and KPIs

2.1.6 *Electronic labelling*

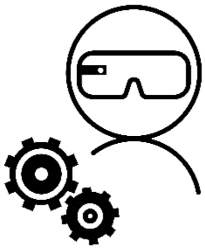
General description		
Name/ Icon	Electronic Labelling	
Description	Electronic labels are used to display dynamic information (e.g. pricing) for items on sales floors, in warehouses, etc. Typical display technologies are e-paper or LCDs, allowing current devices to operate on batteries for several years. RW offer the potential advantages of an energy-neutral design – allowing to get rid of the battery – and accurate location information, which is a desired feature for location-based information services. This use case is an excellent example, where WPT and accurate localization are utilized by a huge number of energy-neutral devices. It is required to design protocols and algorithms that support all three services simultaneously, i.e. power transfer, localization, and communication. Real-time information may be less relevant, considering that the labels are typically attached to static shelves, but a change of position should be detected within several seconds. Alternatively to the electronic labels, energy-neutral sensor nodes will make for a similar scenario.	

Scenario	Warehouses, manufacturing, workshops, sales floors		
Application domain	Adaptive robotized factories, warehouses and logistics		
Geographic scope	Indoor		
Technical requirements			
Attribute	**Description**	**KPI**	**Comments**
Spectrum	Carrier frequency	ISM 2.4 GHz or 5 GHz	Due to the special protocol needs, this use case may rather use the ISM bands.
Traffic model	Maximum number of simultaneous devices	10000+ passive labels; peak device density 50/m3; average density 20/m2	Need to provide power for communications and display updates
	User Experience data rate	Low but could be extended towards video	
	Uplink/Downlink ratio	Mostly DL; uplink needed for ACK	
UE	Mobility	Mostly stationary, but mobile	
	Accuracy	Better than 0.5 m	Positioning to create 3D map of items for human interaction
System	Reliability	99.999% w.r.t. display updates 99% for accurate positioning	Dynamic pricing requires high reliability; not time critical; ARQ can be used
	End to end Latency	> 10 mins. or more (for display updates) < 10 s for position updates< 1 s for real-time human interaction	
	Traffic volume density	23 kbps Estimated net power 12 µW/ESL □ mean net power density is 0.24 mW/ m^2; peak net density 0.6 mW/ m^3	Transmission of a 24bit, 1080p image to 20 devices per m^2 with 2 updates per day. A small 2.9” e-paper display requires 400 mWs/update within 15” [WS1]; makes 1 Ws/ESL/day at 2 updates/day
Functional requirements			
Functional requirements	• Passive design of labels to avoid use of batteries • Accurate positioning for creating 3D map of scenario for human inter-action • Accurate positioning for WPT; reciprocity-based beamforming can be used for WPT		
Technical challenges addressed			
Challenges	• Large amount of simultaneous connections • Massive number of energy neutral devices		

	• Accurate positioning • High reliability
Security	Encryption is needed to avoid unauthorized access to devices.

Table 7: Use case 6. Description and KPIs

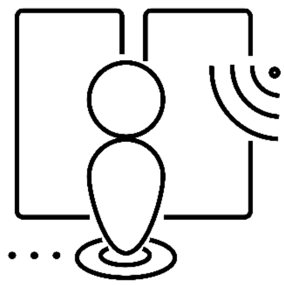
2.1.7 Augmented reality for professional applications

General description			
Name/ Icon	Augmented Reality for Professional Applications		
Description	Augmented reality empowered by energy-neutral display devices such as very light-weight AR-goggles or contact lenses for professional environments such as health care, maintenance, or manufacturing AR glasses need to implement a wide range of functionalities, including at least high-resolution displays, cameras for tracking the environment and the eye movement, and high performance processors for the image processing, while requiring light-weight und ultra-low-power designs for wearability and usability. Those requirements have been prohibiting mass-market adoption till date. This use case illustrates how RW can ease the implementation issues of such AR devices. In particular, it is envisioned (i) to off-load the demanding video-processing to the edge computing infrastructure of RW, exploiting its low-latency, high-data-rate communication links, (ii) to provide power for the AR device using WPT, and (iii) to exploit high-accuracy, real-time positioning to support the AR applications. The use of radio weaves may therefore reduce the cost and complexity of AR devices. However, the initial high cost of the RW infrastructure hints at initial use cases within professional sectors rather than entertainment.		
Scenario	Manufacturing, workshops, hospitals, care environments		
Application domain	Adaptive robotized factories, warehouses and logistics; Human-machine interaction in care environments, hospitals and assisted living		
Geographic scope	Indoor		
Technical requirements			
Attribute	**Description**	**KPI**	**Comments**
Spectrum	Carrier frequency	ISM 2.4 GHz or 5 GHz; 3.5 GHz	
Traffic model	Maximum number of simultaneous devices	< 10 per 100 m^2	
	User Experience data rate	Video streams for uplink and downlink 45 Mbps compressed	Uplink video for environment and eye tracking; compressed data rate is for *perceptually transparent* 1080p@50fps streams

		< 3 Gbps uncompressed	
	Uplink/Downlink ratio	Both need cons. rate; estimated 80% for downlink video	
UE	Mobility	< 2 m/s	
	Accuracy	Better than 0.1 m	Positioning and orientation estimation for video augmentation
System	Reliability	99%	Occasional, short outages are tolerable
	End to end Latency	< 10 ms for real-time human interaction	
	Traffic volume density	4.5 $Mbps/m^2$	Compressed data for *perceptually transparent* 1080p@50fps streams
Functional requirements			
Functional requirements	• High-rate uplink and downlink to off-load video processing to the infra-structure • WPT for energy-neutral design of devices • Accurate positioning for video-information augmentation		
Challenges addressed	• WPT • Accurate, real-time positioning • Real-time processing at edge computing resources • Low-power / energy-neutral design with high UL/DL rates		
Security	Security requirements are less stringent; comparable to UC1: data integrity, non-repudiation and privacy.		

Table 8: Use case 7. Description and KPIs

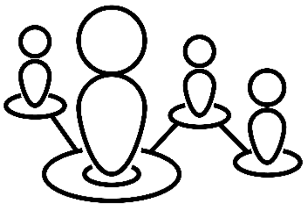
2.1.8 Wander detection and patient finding

General description		
Name/ Icon	Wander Detection and Patient Finding	
Description	In health and care environments positioning technology can assist providers to focus on care by enabling wander detection and prevention and patient finding. This gives patients or residents more freedom of movement with a lower risk of accidents. A typical case is when someone suffering from dementia is wandering off which could be a dangerous situation for this person. Receiving an alert, closing doors remotely and the knowledge of the position of this person can completely solve this problem. The privacy of this person must still be guaranteed, which means that this system may not be applicable in every room (e.g. personal room).	
Scenario	hospitals, care environments	

Application domain	Human-machine interaction in care environments, hospitals and assisted living		
Geographic scope	Indoor		
Technical requirements			
Attribute	**Description**	**KPI**	**Comments**
Spectrum	Carrier frequency	2.4 GHz, 868 MHz,	Depending on the used technology
Traffic model	Maximum number of simultaneous devices	1 device per patient, maximum 2 patients per m^2	
	User Experience data rate	< kbps	Small messages, low data rate, update rates every several seconds, also depending on used technique
	Uplink/Downlink ratio	Mostly UL	
UE	Mobility	< 7 m/s	Sprinting speed
	Accuracy	1 m	
System	Reliability	99.9 %	
	End to end Latency	< 1 s	
	Traffic volume density	< 2 kbps/m² 100 µW/m²	Traffic density [DD1], same comment as above (difficult to define) Power density: [BC1, DD1]
Functional requirements			
Functional requirements	• Determine and monitor the location of each patient both in static position and in motion • Allow staff to access and interact with the tracking data • Low-power or passive tags needed that can easily be worn by a patient without being bothered by it		
Technical challenges addressed			
Challenges	• Low-energy positioning • Higher speed mobility (up to 7 m/s) • Large environment with many individual rooms		
Security	confidentiality, authentication, availability, privacy, user access controls		

Table 9: Use case 8. Description and KPIs

2.1.9 Contact tracing and people tracking in large venues

General description		
Name/ Icon	Contact Tracing and People Tracking in Large Venues	
Description	With the recent outbreak of the Covid-19 virus and maybe other illnesses in the future, precise contact tracing could enable companies or events to log unsafe contacts within the company walls and give insights for optimized measures and employee safety. This system can also be used to track people in large venues such as airports, exhibition centres, shopping malls, museums, etc. For example, it is possible to monitor how busy it is in certain places, which offers the opportunity for crowd management. Other options are visitor profiling and search and navigate applications. In this application, the privacy of the individual must also be taken into account, as not everyone wants to be tracked. To do this, for example, passive tags can be used, as these are also economically more interesting. RW offers the possibility to address a large number of tags in a dense environment, which may be necessary in this case.	
Scenario	factories, events, schools, hospitals, care environments, large (public) venues	
Application domain	Immersive entertainment for crowds of people; Human-machine interaction in care environments, hospitals and assisted living	
Geographic scope	Indoor and outdoor	

Technical requirements			
Attribute	**Description**	**KPI**	**Comments**
Spectrum	Carrier frequency	2.4 GHz, 868 MHz,	Depending on the used technology
Traffic model	Maximum number of simultaneous devices	< 2 per m^2	
	User Experience data rate	< kbps only for positioning > 1 Mbps for navigation	Low data rate possible (small messages), update rates every several seconds, also depending on used technique
	Uplink/Downlink ratio	Mostly UL	
UE	Mobility	< 2 m/s, very exceptional up to 10 m/s	Walking (2 m/s) Sprinting (10 m/s)
	Accuracy	< 1 m	
System	Reliability	99.9 %	
	End to end Latency	< 1 s	

	Traffic volume density	< 2 kbps/m^2 only for positioning, otherwise > 2 Mbps/m^2 100 µW/m^2 (only positioning)	If the device is also used for navigation, there is a good chance that a battery is present
Functional requirements			
Functional requirements	• Provide the option to record contacts between persons, both in static position and in motion • Real-time updates; more than 1 update every 2 seconds • If necessary, it must be possible to use the data to avoid more spread after contamination • Low-power or passive tags needed that can easily be worn by a person without being bothered by it • Privacy must be taken into account, positioning is preferably done on the user equipment (UE) device for privacy reasons; Sharing location data is only by user choice		
Technical challenges addressed			
Challenges	• Situations possible with the need for a large amount of (passive) tags and simultaneous connections • Low-energy positioning and communication • Large environment with many individual rooms • Many fast moving people • Privacy concerns		
Security	confidentiality, authentication, availability, privacy, user access controls		

Table 10: Use case 9. Description and KPIs

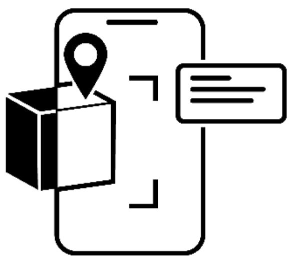
2.1.10 Position tracking of robots and UVs

General description		
Name/ Icon	Position Tracking of Robots and UVs	
Description	In adaptive robotized factories and Industry 4.0 more and more robots and Unmanned Vehicles (UVs) are entering the factory floor and warehouses. The knowledge of the position of these nodes can improve plant floor productivity, increase warehouse visibility and optimize field and supply chain operations. On reconfigurable factory floors tracking the position of equipment will be essential. Typically robots and UVs, or even Unmanned Aerial Vehicles (UAVs) are equipped with a battery implying that these devices can be used as a class 4 and 5 device. This application requires a low latency if both the location must be known and, if necessary, control signals must be sent in real time to moving objects.	
Scenario	factories, hospitals, care environments	
Application domain	Adaptive robotized factories, warehouses and logistics	

Geographic scope	Indoor		
Technical requirements			
Attribute	**Description**	**KPI**	**Comments**
Spectrum	Carrier frequency	2.4 GHz, 868 MHz 3.8 GHz	Depending on the used technology
Traffic model	Maximum number of simultaneous devices	< 100 per m^3	
	User Experience data rate	Up to 10 Mbps	Defined by 3GPP (controls included) [FA2] [TA1]
	Uplink/Downlink ratio	Both, more UL	Control signals can be applied via the downlink
UE	Mobility	< 10 m/s	
	Accuracy	Better than 0.1 m	
System	Reliability	99.9999 %	Defined by 3GPP [FA2]
	End to end Latency	< 10 ms	
	Traffic volume density	50 Mbps/m^2	
Functional requirements			
Functional requirements	• Determine and monitor the location of the robots or UVs both in static position and in motion • Offer the possibility to derive optimizations from the data • Low-power devices needed for small robots or UVs		
Technical challenges addressed			
Challenges	• High positioning accuracy • Higher speed mobility than expected • High density of devices possible and traffic volume • Low latency desired • High reliability		
Security	authentication, availability, user access controls, non-repudiation		

Table 11: Use case 10. Description and KPIs

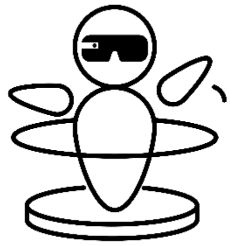
2.1.11 Location-based information transfer

General description		
Name/ Icon	Location-based Information Transfer	
Description	Information can be given to people depending on where they are. In museums or events people can get information about the road to follow, the object they are standing in front of, the nearest toilet, the best evacuation route in case of	

	emergency etc. For example, visitors can receive a bracelet that monitors their position in relation to an object. Once in the presence of the object, they can get information (sound, video), whether or not via a smartphone or other device. Everything could also be done from a smartphone with additional electronics. Other commercial applications can be found, for example in retail to give information of certain products, where position tracking tags are attached to products as they can change places. For example, active information can be provided in connection with allergies and food products. With this application, devices from all classes can be used depending of economic reasons or availabilities (such as a smartphone). Furthermore, the privacy of the user must also be taken into account.		
Scenario	hospitals, care environments, museums, schools, events, public places, retail		
Application domain	Immersive entertainment for crowds of people; Human-machine interaction in care environments, hospitals and assisted living		
Geographic scope	Indoor and outdoor		
Technical requirements			
Attribute	**Description**	**KPI**	**Comments**
Spectrum	Carrier frequency	2.4 GHz, 5 GHz	868 MHz and , 3.8 GHz also possible
Traffic model	Maximum number of simultaneous devices	< 10 per m^3	Assuming to put a tag on both the object and the person/smartphone
	User Experience data rate	Video streams for downlink possible (10 Mbps)	
	Uplink/Downlink ratio	Mostly DL	
UE	Mobility	< 2 m/s	walking
	Accuracy	Better than 0.5 m	
System	Reliability	99 %	Reliability may be lower for some use cases
	End to end Latency	< 1 s	In emergency situations
	Traffic volume density	50 Mbps/m^2	
Functional requirements			
Functional requirements	• High-rate downlink for video streaming • Low-power or passive tags needed that can be put on an object to get information from • Accurate Positioning and tracking of the person or smartphone must be possible		
Technical challenges addressed			
Challenges	• Situations possible with the need for a large amount of tags • Low-energy positioning and communication • Possibility for high data rate video streaming		
Security	confidentiality, authentication, availability, privacy, user access controls		

Table 12: Use case 11. Description and KPIs

2.1.12 Virtual reality home gaming

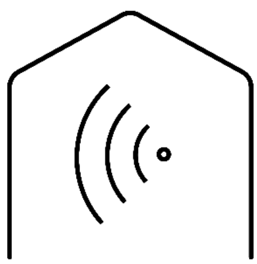
General description		
Name/ Icon	Virtual Reality Home Gaming	
Description	In recent years, virtual reality has become a growing trend within video gaming, both in private homes on consoles and PC, and in dedicated venues that provide VR gaming experiences. In this use case we focus on home use. Virtual reality gaming typically makes use of a headset, for example those made by Oculus, HTC, and Sony (for Playstation), along with handheld controllers. Other accessories are available, such as omnidirectional treadmills to provide a sense of movement, and motion sensors that attach to various parts of the body. Because of the possibility of experiencing motion sickness, latency is a key concern in VR gaming. A common movement paradigm in current games is teleportation, that is, the player is static (within a small area) but can instantaneously teleport from place to place within the game world. However, even with the use of such techniques, players can still experience simulator sickness if there is too much delay or jitter in seeing the response to smaller movements, for example moving their head, or moving their body in place. In-game performance can also be affected by too much delay or jitter, especially for certain genres of games such as shooters or fighting games. In terms of other requirements, high data rates may be needed if the virtual reality headset is connected wirelessly to a separate gaming console or PC that performs graphics processing and then streams high definition video to the headset.	
Scenario	Home (standalone villa, townhouse, or apartment).	
Application domain	Smart home	
Geographic scope	Indoor	

Technical requirements			
Attribute	**Description**	**KPI**	**Comments**
Spectrum	Carrier frequency	ISM bands, preferably 5 GHz	
Traffic model	Maximum number of simultaneous devices	1 device / m^2	This includes VR headset(s), gaming console or PC, controllers etc. One player with 3-4 connected devices per 4 sqm.
	User Experience data rate	150 Mbps	Several UHD video streams (one per eye, so two per player) plus game data. Video streams could be over the internet or local (from console/PC to VR device)

	Uplink/Downlink ratio	Both, mostly DL	
UE	Mobility	< 2 m/s	User may move around within a small area, but not move from place to place
	Accuracy	Better than 0.1 m	Accuracy depends on if we include gesture recognition, and if so what kind (e.g. gestures with fingers vs. entire arm)
System	Reliability	99%	
	End to end Latency	< 1 ms for VR and haptic controls, < 100 ms for other game data	VR needs low latency to avoid motion sickness
	Traffic volume density	50 Mbps / m^2	Only headset and console/PC require high data rate, so it is not data rate x number of devices.
Functional requirements			
Functional requirements	• Smooth streaming of ultra-high definition video alongside haptic control data, with minimal or no motion sickness • Several players supported at once • Online play supported, including for game types requiring high precision (of control) and low latency, such as FPS and fighting games. • Hardware cost reasonable for home users		
Technical challenges addressed			
Challenges	• High traffic volume/sum rate • High peak rate • Low latency • Real-time processing, edge computing support • High positioning accuracy		
Security	Security is not a major concern for this use case, however players' privacy should be protected and confidentiality of players' personal and payment data should be ensured. Authentication and user access controls may be needed to provide parental controls to keep inappropriate content from children. Breaches in availability may lead to negative user experiences but are otherwise not critical for this use case.		

Table 13: Use case 12. Description and KPIs

2.1.13 Smart home automation

General description		
Name/ Icon	Smart Home Automation	

Description	A proliferation of products have appeared on the market in recent years, offering to automate all aspects of users' homes, including lighting, security cameras, locks, fire alarms, vacuum cleaners, watering systems for the garden, heating and cooling, and entertainment in the form of connected speakers and TVs. Home assistants such as Google Nest and Amazon Alexa have also been developed that are able to control this proliferation of home automation devices via voice commands. Current devices use a range of IoT protocols, most notably WiFi, ZigBee and Z-Wave, and Bluetooth, including Bluetooth low energy (BLE). For home automation sensors and actuators, data rates and latency are generally not major obstacles, however for battery powered devices energy usage can be of concern. While covering the existing types of devices is not overall a challenging use case for RW, doing so at a price point attractive to home users may be more difficult. In addition to this, the use of energy neutral devices coupled with RW opens up new opportunities for home automation. An array of small, cheap sensors and actuators that do not require a power source but can instead harvest energy wirelessly from a RW array allows for home sensors to be deployed at a new scale. For example, relatively dense arrays of energy neutral sensors could be deployed throughout the home to provide a three-dimensional map of quantities such as temperature, light, sound, and air quality, thus opening the possibility for smarter and more seamless actuation. This also relies on the localisation and high accuracy positioning capabilities of RW, possibly also coupled with an environment learning backend.		
Scenario	Home (standalone villa, townhouse, or apartment).		
Application domain	Smart home		
Geographic scope	Mostly indoor, some outdoor		
Technical requirements			
Attribute	**Description**	**KPI**	**Comments**
Spectrum	Carrier frequency	ISM bands: 5 GHz (maybe 2.4 GHz)	Higher frequencies will positively impact the positioning accuracy as well and may help to reduce the size of passive (i.e., energy-neutral) nodes.
Traffic model	Maximum number of simultaneous devices	5 device / sqm (non-energy-neutral) Up to 100 / sqm (energy-neutral)	20 square metres for a studio apartment up to say 200 square metres for a family villa
	User Experience data rate	50 kbps	50kbps for the highest data rate devices, e.g. security cameras. Most will use less, i.e. infrequent sensor updates and commands to actuators
	Uplink/Downlink ratio	Mostly UL for data	For positioning and WPT the DL energy may be bigger.
UE	Mobility	0 m/s	For tracking a person and adjusting lights and/or music volume, walking speed (<2m/s) may be sufficient.

	Accuracy	Better than 0.1 m for 3D mapping of a sensed quantity.	The required positioning accuracy depends on the chosen frequency.
System	Reliability	99%	
	End to end Latency	100 ms	Most home sensors can tolerate more than this but some, e.g. security cameras, may need a lower delay at times (when actively streaming) Adaptive scheduling of energy transfer may be implemented for devices requiring much energy at certain times.
	Traffic volume density	< 1 kbps / m^2	Depends on the device mix.
Functional requirements			
Functional requirements	• Connection of smart home sensors and actuators, e.g. security systems, fire alarms, smart lights, smart appliances, watering systems and monitors for gardens • 3D mapping of a sensed quantity (e.g., temperature, light, sound volume, humidity, air quality) through a combination of positioning and sensing with a large deployment of energy-neutral sensor nodes • Low energy usage • Hardware cost reasonable for home users • Environment learning		
Technical challenges addressed			
Challenges	• Low-energy communication • Low-energy positioning • Energy-neutral devices • WPT • “Massive” number of devices • High position accuracy		
Security	The most important concern for this use case is privacy as it concerns the operation of people’s homes. Tied to this, confidentiality of sensor and actuator data should be provided. Authentication and user access controls should be implemented to prevent unauthorised operation of home appliances, security systems, etc.		

Table 14: Use case 13. Description and KPIs

2.2 Use cases classification

Analysing the thirteen use cases listed before, it was detected that some use cases show similarities, considering the technical challenges the system has to overcome to implement the use cases and also considering the intrinsic functionalities of the applications that the use cases are based on.

Therefore, use cases have been classified into functional families, providing an overview of the whole range of applications we are covering, as well as by technical challenges which give us a quick insight about the main clusters of use cases which are dealing with similar technical challenges.

2.2.1 Functional classification

Three main families have been identified among the thirteen uses cases:

- **Location-based information applications**: this family of use cases include applications whose main functionality is relying on positioning and tracking position of connected devices. This functionality provides the infrastructure the capability to provide relevant information to users according to their position in space.
- **Monitoring and real-time applications**: the use cases gathered in this family are relying on real-time operation and the possibility of monitoring different processes or states that are collected, most likely, with low energy or zero energy devices.
- **AR/VR applications**: extended reality applications have been growing in the last years, becoming an important trend for social and economic applications. This family gathers use cases where VR/AR functionality is in focus, connecting unnoticeably virtual elements with the real world.

Each use case have been classified in one of the categories, according to its main functionality, Table 15 shows which use cases pertain to each category:

Location-based information systems and services	Monitoring and interaction in real time	AR/VR services
• Tracking of goods and real-time inventory (5) • Electronic labelling (6) • Wander detection and patient finding (8) • Contact tracing and people tracking in large venues (9) • Position tracking of robots and UVs (10) • Location-based information transfer (11)	• Real-time digital twins in manufacturing (2) • Patient monitoring with in-body and wearable sensors (3) • Human and robot co-working (4) • Smart home automation (13)	• Augmented reality for sport events (1) • Augmented reality for professional applications (7) • Virtual reality home gaming (12)

Table 15: Use cases application type classification

It is important to note that although the use cases have been classified into one of the families, they can share similarities with any of the other families. This concept is illustrated in Figure 2, which shows the three use cases families by means of three hexagons and the intersections of the hexagons show use cases which have similarities not only with the family it belongs to, but also with any of the other families, depending on the functional requirements that it has.

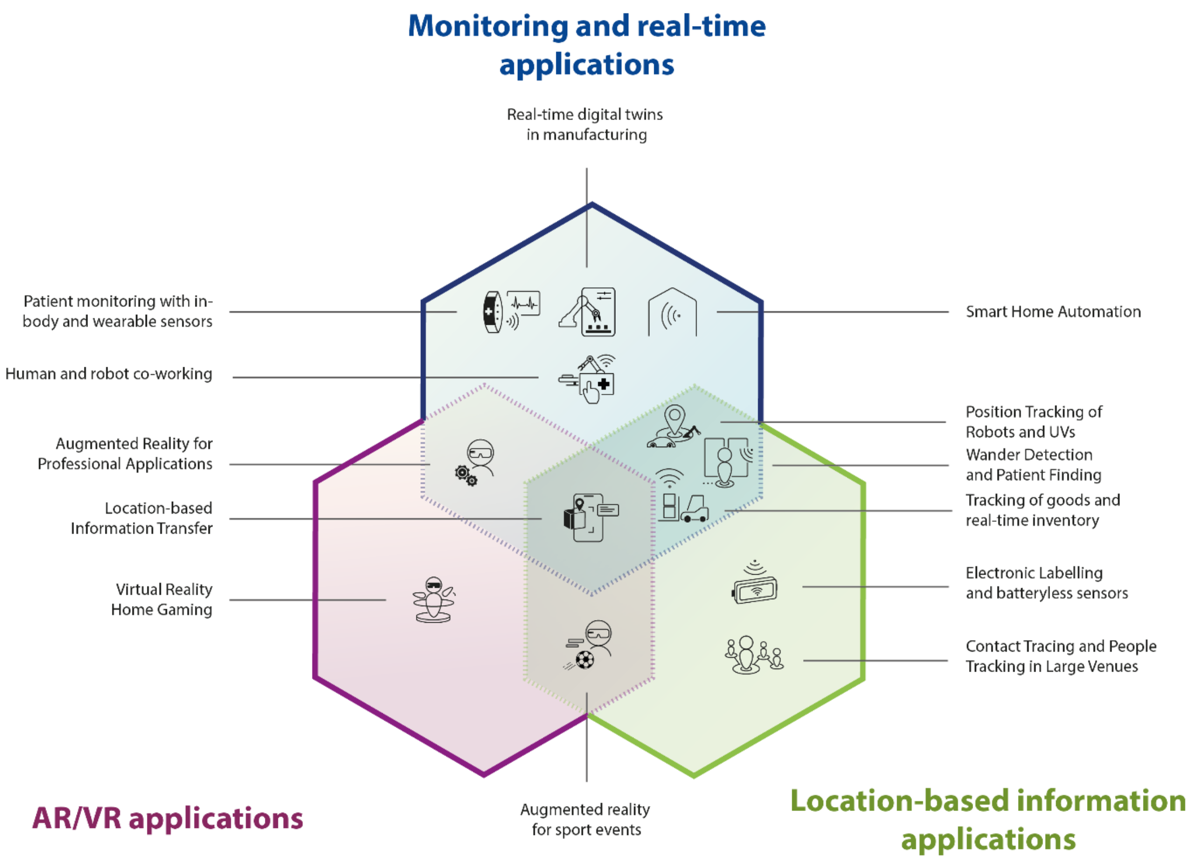


Figure 2: Use cases application type classification

2.2.2 *Challenges classification*

From the use cases KPIs several representative technical challenges have been identified. The list contains all the technical requirements which are more demanding for each use case considering its KPIs:

A. Massive number of devices/connections
B. High traffic volume/sum rate
C. High peak rate
D. Higher mobility speeds (up to 7-10 m/s)
E. Deployment in open or complex environments
F. High reliability
G. Low latency
H. High positioning accuracy
I. Low-energy communication
J. Low-energy positioning
K. Energy-neutral devices and WPT
L. Real-time processing, edge computing support

Use case ID	Use case name	Technical challenges											
		A	B	C	D	E	F	G	H	I	J	K	L
1	Augmented reality for sport events	X	X		X	X		X					
2	Real-time digital twins in manufacturing	X	X		X		X	X	X				

Use case ID	Use case name	Technical challenges											
		A	B	C	D	E	F	G	H	I	J	K	L
3	Patient monitoring with in-body and wearable sensors		X							X	X		
4	Human and robot co-working						X	X	X				
5	Tracking of goods and real-time inventory	X			X		X		X	X	X	X	
6	Electronic Labelling	X				X	X					X	
7	Augmented Reality for Professional Applications			X				X	X	X		X	X
8	Wander Detection and Patient Finding				X	X					X		
9	Contact Tracing and People Tracking in Large Venues	X				X				X	X		
10	Position Tracking of Robots and UVs	X	X	X	X		X	X	X				
11	Location-based Information Transfer	X	X	X						X	X		
12	Virtual Reality Home Gaming		X	X				X	X				X
13	Smart home automation	X							X	X	X	X	

Table 16: Use cases. Challenges identified

From the previous list it is possible to locate several of the technical challenges to each of the use cases. This can be depicted in the next table:

Cluster 1	Cluster 2	Cluster 3	Cluster 4
High traffic volume, low latency	*High reliability, low latency, high mobility*	*Low energy devices, massive number of devices, high accuracy positioning*	*Mobility, complex environments, positioning, low energy*
• Augmented reality for sport events (1) • Augmented reality for professional applications (7) • Virtual reality gaming (12)	• Real-time digital twins in manufacturing (2) • Human and robot co-working (4) • Position tracking of robots and UVs (10)	• Tracking of goods and real time inventory (5) • Electronic labelling (6) • Smart home automation (13)	• Patient monitoring with in-body and wearable sensors (3) • Wander detection and patient finding (8) • Contact tracing and people tracking in large venues (9) • Location-based information transfer (11)

Table 17: Use cases challenges classification

This part of the study shows similarities that use cases may have, making it possible to create clusters of use cases sharing technical challenges. Thereby providing input to WP2 when dimensioning the network depending on the characteristics of the use cases which are intended to be covered. Not all the challenges would be present at the same time, so it is possible to adapt the infrastructure depending on the use cases intended to be implemented.

Cluster 1: Augmented and Virtual Reality:

The first cluster contains the AR and VR use cases, sharing as their primary requirements the large traffic volume and high sensitivity to delay or latency which are essential for an adequate user experience quality.

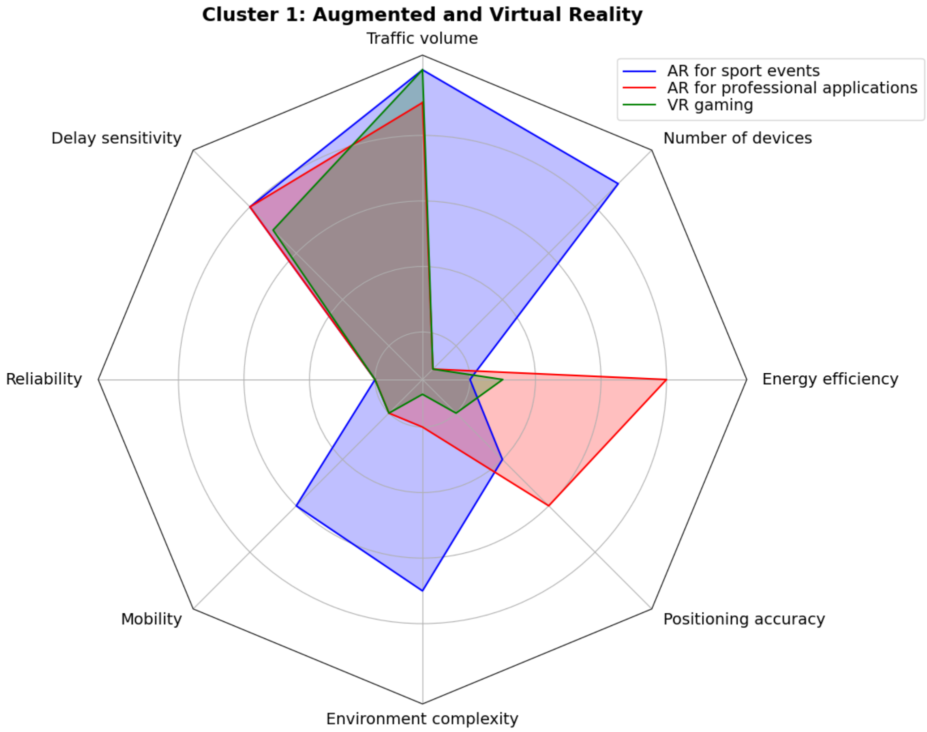


Figure 3: Challenges cluster 1. Augmented and virtual reality

Cluster 2: Robots and Industrial Systems

The second cluster largely corresponds to the ultra-reliable and low-latency communication application class in 5G, with an emphasis on reliability and delay sensitivity. However, for the new 6G use cases, we also see a demand for mobility support and positioning accuracy which makes the cluster more complex, gathering many challenges into the same group of use cases.

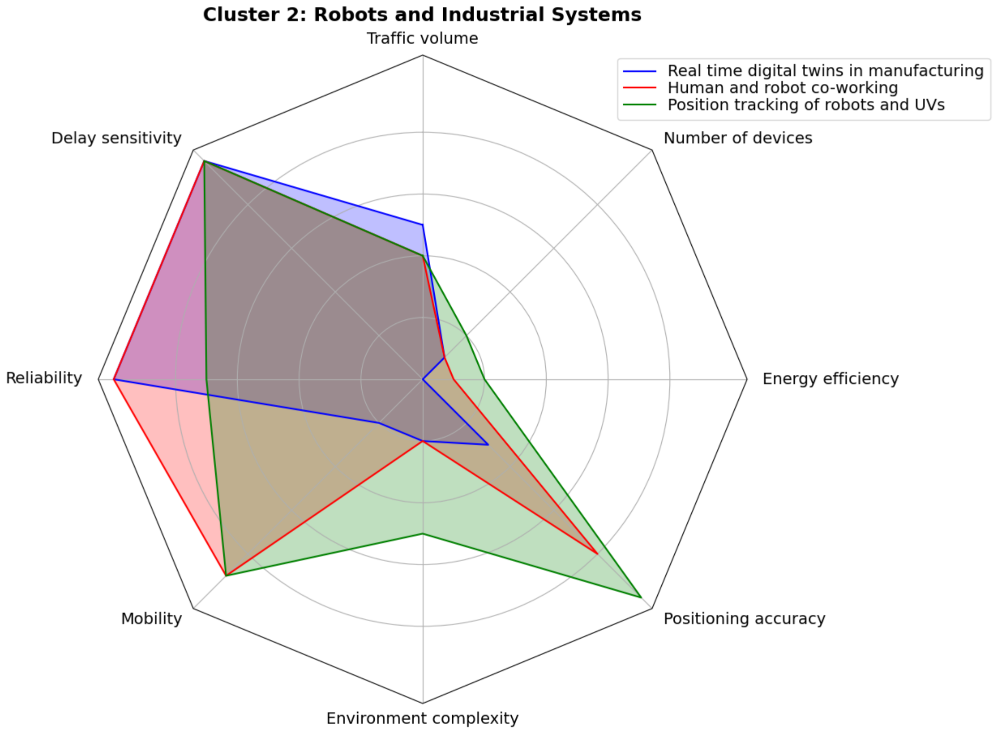


Figure 4: Challenges cluster 2. Robots and industrial systems

Cluster 3: Massive Positioning and Sensing

The third cluster concerns massive positioning and sensing, with use cases that make heavy use of large numbers of energy-neutral devices and their accompanying need for a high degree of energy-efficiency, consisting mainly of class 1 and class 2 devices.

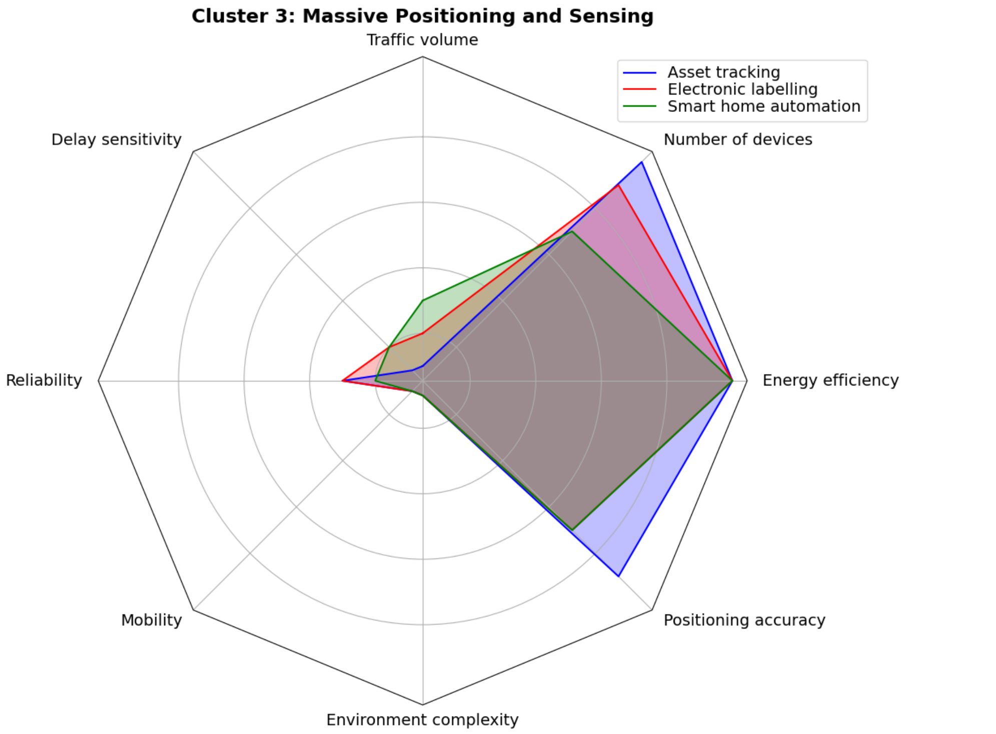


Figure 5: Challenges cluster 3. Massive positioning and sensing

Cluster 4: Tracking and Location Based Services

Finally, the fourth cluster is related with those use cases where there is a high degree of mobility, often in complex environments with a strict requirement on positioning accuracy to provide location-based services.

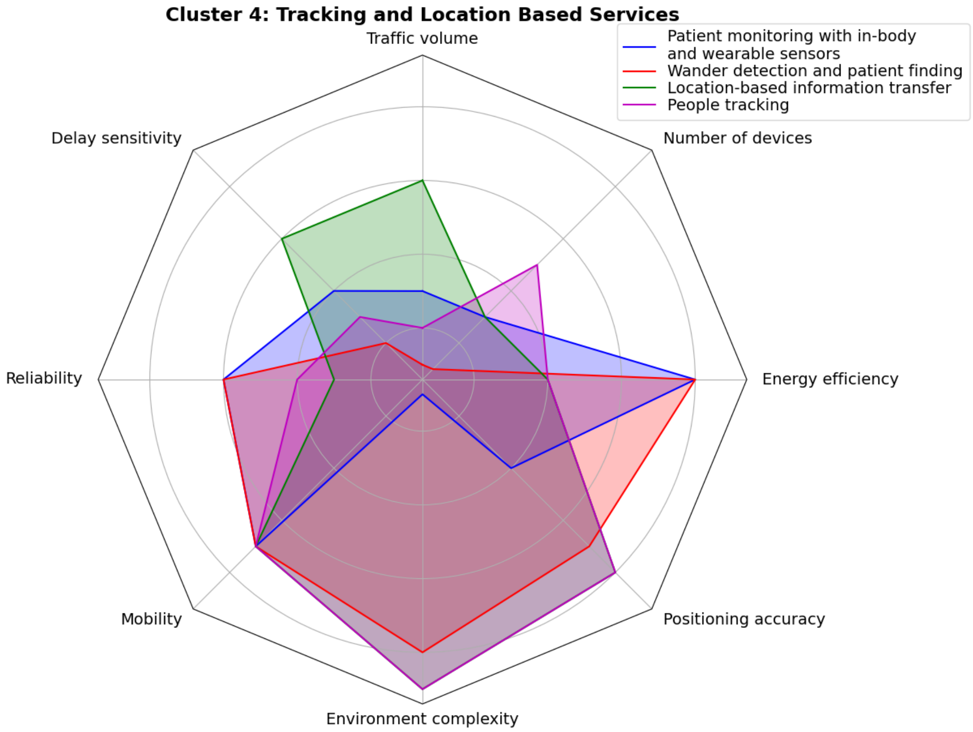


Figure 6: Challenges cluster 4. Tracking and location-based services

Chapter 3 Technical requirements

The RW infrastructure needs to meet a set of technical requirements in order to serve future interactive applications. We classify devices used in the foreseen applications into five classes based on their functional capabilities and power needs. Furthermore, we divide the technical requirements into functional requirements, explaining the general technical features demanded by those applications, and quantitative requirements, that cast those demands into KPIs and ultimately specify the necessary physical structure of RW.

3.1 Device classification

This section defines different device classes that are expected to be encountered when investigating requirements for different use cases and the targeted device classes with their specific computational capabilities. The five classes range from energy-neutral devices without any computation capabilities in (Class 1) to externally powered devices with substantial computation capabilities (Class 5) with a grading in between.

Class 1:

Energy-neutral devices, e.g., tags for tracking objects, that are supplied with RF energy through WPT. In the uplink, information is transmitted via backscatter communication only.

Class 2:

Energy-neutral devices, with the capability of energy-storage and low power needs that only use backscatter communication in the uplink. A typical example could be an in-body sensor.

Class 3:

Battery-powered devices charged through mains-power or energy-neutral devices with energy storage charged wirelessly via WPT, with moderate functional capabilities, capable of actively transmitting radio signals. Energy-neutral AR glasses are a representative example of this device class.

Class 4:

Battery-powered, mobile end-user devices with significant energy-storage, computation, and communication capabilities (e.g., smartphones, VR goggles, etc.).

Class 5:

Mains-powered devices that are effectively not limited by energy constraints and have substantial computation and communication capabilities. Big machines and (stationary) production robots are typical examples.

3.2 Functional requirements

The RW infrastructure will meet a range of functional requirements that are demanded through various use cases.

RW enables **wireless connectivity** with high throughput and ultra-reliable low latency through its distributed infrastructure, where a paradigm-shift is made towards cell-free, user-centric system architectures. Massive machine type communications (mMTC) will be achieved through wirelessly powered energy-neutral devices capable of backscatter modulation in the uplink.

Various use-case scenarios will leverage on the important feature of **localization and tracking**, enabling interactive and more immersive user-experiences, tracking of people and goods in real-time and the reliable, autonomous navigation of UAVs. The respective localization and tracking requirements vary among the different device classes: Devices of classes 1 and 2 need to be located via backscattered signals. Class 2 devices will mostly be static, while Class 1 devices may potentially be mobile (e.g., tags attached to people or goods). Devices of classes 3 through 5 may use active communication, potentially dedicated to localization uses. Class 3 and Class 5 devices will mainly be static, nevertheless, localization is desired for mapping the device locations, while Class 4 devices are typically mobile. Class 4 and Class 5 devices will possibly feature on-device localization processing.

The technical specifications of RW will enable unprecedented **WPT** capabilities: The distributed architecture and operation of RW panels in the array near-field allows to coherently focus radiated power at desired focal points, reaching high power levels at the positions of remote devices, while being largely uncorrelated elsewhere. This allows to keep the overall exposure to electromagnetic radiation low in the environment of the RW panels while enabling the operation of energy-neutral devices at exceptionally high power levels. This will eventually allow operation of massive amounts of battery-less devices with a virtually unconstrained lifespan as well as enabling a new generation of energy-neutral devices with high computational and functional capabilities.

The RW infrastructure will also implement powerful **sensing** capabilities: Environmental awareness is achieved through mapping the environment and its channel properties. Objects and people can be localized and tracked passively (i.e., without being tagged by a dedicated device), which can be exploited for detecting intruders or distance bounding for secure access.

Edge processing will be leveraged by the distributed architecture to off-load the computational burden from individual devices and supply them with storage resources, while achieving ultra-low latencies. Eventually, it allows the realization of a range of services through RW, e.g., video processing for low power AR/VR devices, serving as infrastructure for federated learning, position estimation and tracking, as well as environment mapping.

3.3 Quantitative requirements

The use cases defined in Chapter 2 impose different technical requirements on the RW infrastructure. The individually defined use cases show a range of KPIs that not only define the needs of RW, but can be seen as ultimate requirements that have to be met by any 6G infrastructure in order to serve the defined use cases.

As **carrier frequencies**, the ISM bands around 900 MHz, 2.4 GHz and 5 GHz will be targeted primarily. For several indoor use cases, the licensed bands around 3.5 GHz are considered, if they are available for use.

The **device density**, i.e., the number of devices per unit area in $1/m^2$, is predicted to range up to 100 for use cases where a massive number of devices are deployed. This is the case in the field of logistics, where large numbers of goods are tracked, or in Industry 4.0 environments where many processes and machines are digitally monitored and unmanned vehicles (UVs) or robots have to be tracked and orchestrated. A massive deployment of energy-neutral sensors, combined with the positioning abilities of the RW infrastructure, will enable simultaneous acquisition and three-dimensional mapping of a sensed quantity (e.g., temperature or humidity). This enables cost-effective, battery-less and, therefore, sustainable monitoring of a sensing quantity and its spatial distribution, which may be of interest for future smart homes.

A high **maximum number of devices** that have to be served simultaneously is demanded by those use cases having either a high device density or a large coverage area as, for instance, use cases 1 and 9, where large venues have to be covered.

For many use cases, the **user experience data rate** lies below 10 Mbps, where a massive number of devices may be served, but individual devices (e.g., sensors or electronic shelf labels) have no need to communicate large amounts of data. The situation is different for use cases where one (see use case 11) or several (see use case 12) video streams to a single user device have to be accomplished simultaneously. Use case 7 may need the highest user experience data rate by far: The proposed infrastructure will enable the operation of energy-neutral AR glasses by shifting the energy-hungry computations associated with AR to the RW infrastructure. This leaves AR glasses at a very low energy consumption, but also limits their computational capabilities, such that the captured video has to be streamed either uncompressed (3000 Mbps) or compressed at a low compression rate (45 Mbps) to the infrastructure.

Use cases with either a few devices communicating at a high data rate (see use cases 11 and 12) or use cases communicating at a low data rate with a massive amount of devices (see use cases 5, 6, 10 and 2) exhibit a high **traffic volume density**, i.e., a high data rate provided per unit area in $Mbps/m^2$. The former of these dominantly show download traffic, while upload traffic is dominant among the use cases of the latter group, involving tracking of people and goods.

Two KPIs address the positioning capabilities of RW: The **mobility** of any device is largely divided among the use cases into walking speed (2 m/s) and driving speed (10 m/s). Furthermore, we target a **positioning accuracy** of 0.1 m for many of the defined use cases which will be achieved through exploiting both the available bandwidth and the ultra-large aperture of the RW panels.

To supply energy-neutral devices with power wirelessly imposes requirements on the WPT capabilities of the infrastructure. Being battery-less, massive numbers of these devices may be permanently integrated in the environment (see use cases 6 and 13) without maintenance costs, but a high **power density**, i.e., RF power available to harvest per unit area in mW/m^2, has to be provided to power them up.

The operation of UVs in Industry 4.0 environments (see use case 10 and use case 5) demands the highest **reliability**, or lowest packet loss rate, respectively, of the envisioned use case scenarios [FA2]. Use cases involving process automation demand a packet loss rate smaller than 10^{-5} (see use cases 2 and 4) [MG1]. Furthermore, these use cases may demand maximum latencies as low as 1 ms.

The KPIs for each use case are outlined in Table 18, where the numbering of the use cases is defined as in Chapter 2:

1. Augmented reality for sport events
2. Real-time digital twins in manufacturing
3. Patient monitoring with in-body and wearable sensors
4. Human and robot co-working
5. Tracking of goods and real-time inventory
6. Electronic labelling
7. Augmented reality for professional applications
8. Wander detection and patient finding
9. Contact tracing and people tracking in large venues
10. Position tracking of robots and UVs
11. Location-based information transfer
12. Virtual reality home gaming
13. Smart home automation

Key Performance Indicator	Use Case												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Carrier frequency (GHz)	2.4 5+	2.4 3.8	0.9 2.4 5+	2.4 3.8	0.9 2.4 3.8 5+	2.4 5+	2.4 3.8 5+	0.9 2.4 3.8 5+	0.9 2.4 3.8 5+	0.9 2.4 3.8 5+	2.4 5+	5+	2.4 5+
Device density (per m^2)	2	100	2	1	100	20	0.1	2	2	100	10	1	100
Maximum number of simultaneous devices	10k	1000	20	10	50k	10k	10	50	10k	500	100	2	10k

Key Performance Indicator	Use Case												
	1	2	3	4	5	6	7	8	9	10	11	12	13
User experience data rate (Mbps)	5	1	1	5	<1	≪1	45 / 3000	<1	1	10	10	150	0.5
Dominant traffic direction	DL	Both	UL	Both	UL	DL	DL	UL	UL	UL	DL	DL	UL
Mobility (m/s)	10	10	1	0	10	2	2	7	2	10	2	2	0
Positioning Accuracy (m)	0.5	0.1	1	-	0.1	0.5	0.1	1	1	0.1	0.5	0.1	0.1
Reliability (packet loss)	10^{-3}	10^{-5}	10^{-4}	10^{-5}	10^{-3}	10^{-5}	10^{-2}	10^{-3}	10^{-3}	10^{-6}	10^{-2}	10^{-2}	10^{-2}
End to end latency (ms)	20	1	200	1	100	1000	10	1000	1000	10	1000	10	100
Traffic volume density (Mbps/m²)	10	20	10	5	<100	<0.1	4.5	<1	2	50	50	50	0.1
Power density (mW/m²)	-	-	<1	-	-	0.25	>10	0.1	0.1	-	-	-	0.25

Table 18: Key performance indicators for each use case.

3.4 System Services

The system services that provide the corresponding backbone for the use cases are the **infrastructure for federated learning** allowing for cooperation between different devices and the distribution of computation resources. **Environment mapping** and **localisation and tracking** provide the background for all position related use cases and applications, while **edge processing and storage** is essential to achieve a low latency where required and save bandwidth by storing data close to the sources without unnecessary transmissions. Each service needs to tackle specific technical challenges detailed in Chapter 2 which is highlighted in the table below. The services are analysed in terms of the importance of performance characteristics such as delay sensitivity and energy efficiency shown in Figure 7.

Table 19 lists the services and their affiliation with the respective application domains defined in Chapter 1 as well as the technical challenges that were already defined in Chapter 2:

M. Massive number of devices/connections
N. High traffic volume/sum rate
O. High peak rate
P. Higher mobility speeds (up to 7-10 m/s)
Q. Deployment in open or complex environments
R. High reliability
S. Low latency
T. High positioning accuracy
U. Low-energy communication
V. Low-energy positioning
W. Energy-neutral devices and WPT
X. Real-time processing, edge computing support

Service ID	Service name	Application domain				Technical challenges											
		A	B	C	D	A	B	C	D	E	F	G	H	I	J	K	L
1	Infrastructure for Federated Learning Over Wireless Communications	X		X		X	X		X					X			X
2	Environment Mapping	X	X	X	X				X	X			X				X
3	Localisation and tracking	X	X	X	X	X			X	X		X	X		X		X
4	Edge Processing and Storage	X	X	X	X	X	X	X			X	X					X

Table 19: System services list and their corresponding technical challenges and application domains

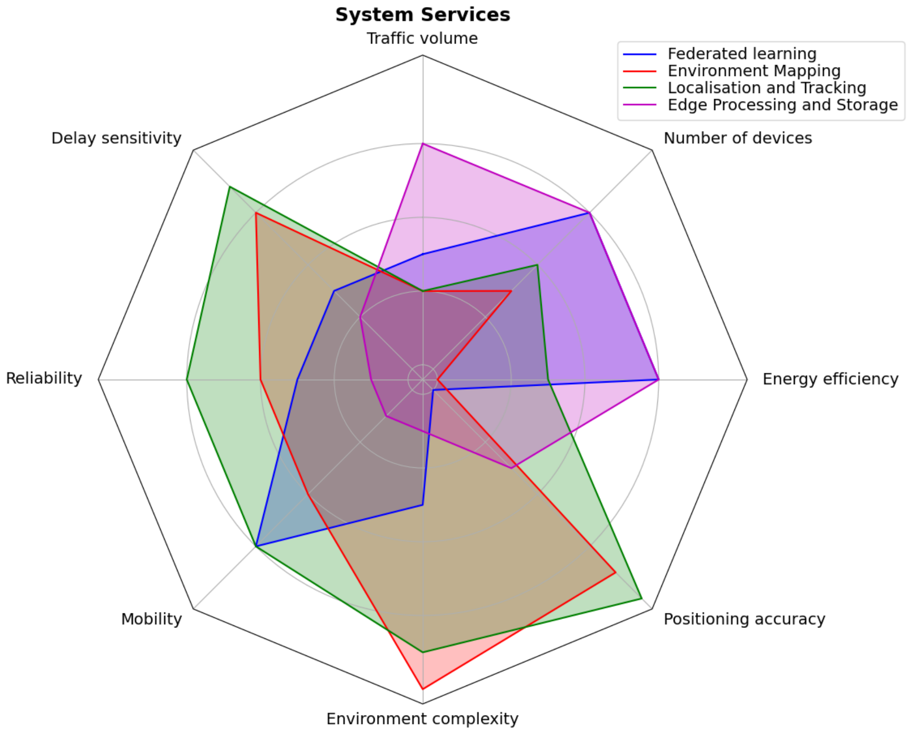


Figure 7: System services and corresponding importance of performance characteristics.

3.4.1 *Infrastructure for federated learning over wireless communications:*

General description	
Name	Infrastructure for federated learning over wireless communications
Description	Federated learning is a form of distributed learning where multiple agents collaborate in training a global model that is stored at a central parameter server. The agents have access to private training data, but these data are not shared with the server: only the gradient updates computed based on the local data are shared. Federated learning enables applications such as face detection/recognition and next-word prediction without compromising the user privacy or consuming bandwidth/battery power. Information from different sensors can be processed without communicating the real data. Developing infrastructure to support federated learning is essential.

Scenario	Privacy-sensitive data traffic. Consider for example, a network of camera-equipped devices that have access to video streams or recordings (e.g., in a public area), and where these streams must not be shared with anyone, yet the network should be able to use them to learn a global model. Another example is in text prediction, where a network of devices wants to jointly learn a language model with each device having access to text written by its user; however, these texts themselves must not be shared with anyone. Further examples are natural language processing (including language modeling and sentiment learning), autonomous vehicles that adapt to their environment (i.e., traffic models can be learnt without receiving the actual movement of the vehicles), health risk management with wearable devices (i.e., learning behavior models without knowing data from specific patients), smart homes learning models based on local training by sensors located at homes or surveillance applications.		
Application domain	A, C		
Geographic scope	Indoor and outdoor		
Technical requirements			
Attribute	Description	KPI	Comments
Spectrum	Carrier frequency	< 6 GHz	
Traffic model	Maximum number of simultaneous devices	~100	rough estimate, emerging applications may have much higher requirements
	User Experience data rate	-	the connection between rate and user experience is very indirect for this use case
	Uplink/Downlink ratio	0.5	potentially higher if multicasting is used on downlink (all agents receive the same model)
UE	Mobility	Indoor: < 2 m/s Outdoor: up to 110 km/h	
	Accuracy	-	
System	Reliability	99 %	not critical
	End to end Latency	-	not critical
	Traffic volume density	125 kbits/s/m^2 for low end scenario 1 Mbit/s/m^2 for high demand scenarios	These numbers correspond to 1/8 device per m^2, 1 million parameters per sec for low end scenario and 8 million parameters for high demand scenarios
Functional requirements			
Functional requirements	• Each UE should be capable of doing local learning. It should be able perform required computations within predetermined time limits. Battery should be capable to support the power requirements. • Servers/APs should be able to update the model quickly by processing the updated information received from distributed nodes.		
Technical challenges addressed			
Challenges	• Real-time processing and edge computing support		

	• Support large number of devices. • Higher mobility speeds to support vehicular networks. • Low-energy communication at the UEs to save battery
Security	Privacy and confidentiality are main issues, as eavesdropping could facilitate deep gradient leakage techniques, compromising the confidentiality of agent's private training data.

Table 20: System service 1. Description and KPIs

3.4.2 Environment mapping

General description			
Name	Environment mapping		
Description	Many of the use cases and possibly also the radio infrastructure itself rely on having a map of the physical environment. This includes features such as the dimensions of the room(s), objects and fixtures that can affect the channel quality (e.g., through shadowing) and the locations of the service points[1] (SP). This information can be complemented by a map of channel quality learned over time which can be combined with user mobility patterns to give a prediction of future channel quality to each SP. For applications with mobile users, the environment map allows the system to determine where the user is in relation to important environment features. Environment mapping is especially useful in combination with localisation and tracking, as this gives a complete mobility model for the user devices.		
Scenario	Improved proactive coverage. Consider the scenario of a channel in non-line-of-sight (NLOS) condition. By employing a learned environment model proactive resource allocation is possible for dynamic scenarios where devices move in and out of NLOS. Making use of multipath propagation to reach the device is expected to allow keeping a basic level of connectivity. Base stations that are known to allow no coverage in specific regions can make all of their resources available elsewhere.		
Application domain	All		
Geographic scope	Indoor and outdoor		
Technical requirements			
Attribute	Description	KPI	Comments
Spectrum	Carrier frequency	3.8 GHz, 5 GHz	Higher frequencies can give a more accurate map, but it may be useful to map at each frequency if the environment is combined with learned channel information, as this will differ by frequency band.
Traffic model	Maximum number of simultaneous devices	-	Not relevant, since the map is of the environment itself, not the users.
	User Experience data rate	-	While we do not have a data rate as such, we will instead need some signals to be sent and

[1] Service point is a distributed node capable of serving one or multiple user equipment and applications. RW infrastructure terminology will be further elaborated in deliverable D2.1.

			received by the SPs, similar to positioning for users. How often this needs to be done depends on how quickly the environment changes, e.g. with mobile objects such as vehicles.
	Uplink/Downlink ratio	Both	
UE	Mobility	10 m/s	If there are moving elements in the environment, such as vehicles, the map needs to update as they move.
	Accuracy	0.1 m	Depending on the employed environment model the accuracy might be defined differently compared to agent localisation.
System	Reliability	99%	
	End to end Latency	0.5 s	For moving environments. For static environments this can be much longer.
	Traffic volume density	-	
Functional requirements			
Functional requirements	• Create a map with the locations of SPs, dimensions and shape of the physical space, and objects and other fixtures that are relevant for use mobility and channel quality.		
Technical challenges addressed			
Challenges	• High mobility speeds • Deployment in open or complex environments • High positioning accuracy • Real-time processing and edge computing support		
Security	Security is not a major concern for this service as it does not handle sensitive application data. The main concern is privacy and confidentiality in cases where the layout of the physical environment may be personal or sensitive information, such as in a home, factory, or care environment.		

Table 21: System service 2. Description and KPIs

3.4.3 Localisation and tracking

General description	
Name	Localisation and tracking
Description	An important wireless application complementing communications is localisation and tracking of radio devices. Depending on the device class and possibly the environment model, signal models and motion models for the tracking case, the employed algorithms need to be able to cope with adverse and diverse environment conditions. While localisation generally deals with static devices or at least snapshot-level processing, a change in the environment can lead to strong channel variations and the necessity to exploit NLOS propagation paths or temporarily switch to a different base station. For tracking the device movement introduces changes in the channel requiring

	highly flexible algorithms to ensure that the required quality constraints for specific use cases can be met.		
Scenario	Location-aware transmission of power. Consider an arbitrary environment with either static or dynamic devices requiring data transmission or power transmission. For the static case knowledge of the device location is necessary to power the device, where combination with environment map can improve WPT by exploiting multiple propagation paths. Assuming device movement prediction of motion can enable continuous level of service, e.g., by pre-emptive switching of base stations.		
Application domain	All		
Geographic scope	Indoor		
Technical requirements			
Attribute	Description	KPI	Comments
Spectrum	Carrier frequency	3.8 GHz, 5 GHz	Higher frequencies can give more accurate positions as for the case of environment mapping.
Traffic model	Maximum number of simultaneous devices	1 - 100 per m^3	Depends on the scenario and mobility of the devices. Possible upper limit given by strongly varying channel conditions due to the devices.
	User Experience data rate	-	No actual data rate but rather the number of pilot signals needed for estimation and the frequency of resending these pilots is the key aspect.
	Uplink/Downlink ratio	1	Both are equally important.
UE	Mobility	0 m/s - 10 m/s	Devices can be static or dynamic, depending on device class and environment.
	Accuracy	< 0.1 m	
System	Reliability	99%	
	End to end Latency	1 ms - 1 s	A low latency is required in location critic applications such as automatic access and for UVs.
	Traffic volume density	-	
Functional requirements			
Functional requirements	• Create a map containing mobile device positions relative to the SPs, possibly also including map related quantities that can be estimated without the map such as channel quality.		
Technical challenges addressed			
Challenges	• Massive number of devices • High mobility speeds • Deployment in complex scenarios • High positioning accuracy • High tracking accuracy		

	• Low latency for tracking applications • Low-energy positioning
Security	Security could be a concern regarding broadcasting and storage of user data as well of movement profiles for specific users. Especially devices from Class 1, 2 and 3 will not have computation capabilities. The localisation task needs to be performed at the infrastructure.

Table 22: System service 3. Description and KPIs

3.4.4 Edge Processing and Storage

General description			
Name	Edge processing and storage		
Description	Diverse requirements are expected for latency as well as throughput and bandwidth. Edge processing brings processing elements closer to the data sources allowing to reduce the latency for specific tasks that are vital for a continuous user experience and for other latency critical applications such as UV navigation where latency has a strong influence on safety. With a large number of devices having processing power available, distributed computing allows to further speed up essential computations, allowing highly efficient algorithms for, e.g., environment learning, positioning and tracking. With the requirement for more bandwidth for data transmission, pre-processing can help reduce the actual amount of data that needs to be transmitted. Data storage at the network edge has the advantage of added security and faster access, allowing to keep sensitive data close to the user without storage at a shared data centre or in a cloud storage.		
Scenario	Low Latency Cooperation. Industrial environments that employ coordination in production profit from latency reduction by either sharing computation tasks or allowing network members to perform computations that are only vital to that member on a local level. By collecting pre-processed data system bandwidth can be freed to allow transmission of auxiliary data. Local cooperation between adjacent or directly interacting devices further reduces latency and allows to streamline production by allowing cooperation partners to directly react to needs and requests of direct neighbours.		
Application domain	All		
Geographic scope	Indoor and Outdoor		
Technical requirements			
Attribute	Description	KPI	Comments
Spectrum	Carrier frequency	-	Not critical in general. Reduced bandwidth need allows for less stringent requirements on the used spectrum.
Traffic model	Maximum number of simultaneous devices	1 - 100 per m^2	Devices perform tasks on their own or in small local networks. Rough estimate, can vary depending on the number of EPUs per SP.
	User Experience data rate	-	Not applicable.

	Uplink/Downlink ratio	<1	Not critical.
UE	Mobility	Indoor: < 2 m/s Outdoor: > 10 m/s	
	Accuracy	-	
System	Reliability	99%	
	End to end Latency	< 10 ms	Lower latency can be possible depending on device class.
	Traffic volume density	0.1 – 100 Mbps/m^2	Strongly varies with application
Functional requirements			
Functional requirements	• UEs are required to provide processing power to perform local computations within the required time limits. • APs need to quickly distribute information received from the UEs if not already transmitted locally between neighbouring UEs.		
Technical challenges addressed			
Challenges	• Support for large number of devices • High traffic volume/sum rate • High peak rate • Real-time processing and edge computing support • Low latency support • High reliability • Real-time processing, edge computing support		
Security	Privacy issues can be countered due to local computation of sensitive information without processing in the cloud, or by data encryption performed on the edge.		

Table 23: System service 4. Description and KPIs

Chapter 4 Deployment scenarios

4.1 Deployment characteristics

In this chapter, we describe environments and RW deployment opportunities relevant to use cases presented in Chapter 2 and to technical solutions to be developed in the course of the project. The environments and deployment descriptions are intended to serve as context examples when referring to the different use cases, and illustrations of expected surroundings and conditions encountered. The descriptions may also be used as input to defining environments for technical study scenarios and simulation configurations, but the provided examples are not to be seen as limiting; other environments or specific setups may be invoked in studies, as appropriate.

We present five environment types to support various use case groups and technical challenge clusters. For each environment, the following description components are provided:

- General overview of the environment type
  - High-level description of the setting and distance/areas covered
  - Main device types to be served by RW
  - Typical surfaces for RW mounting
  - Environment-specific deployment aspects
- One representative example with a floor plan figure and details of the surroundings
  - People, machines, and other objects in the environment, including materials, distances, and dimensions
  - Expected device distribution
  - RW deployment opportunities, at least fabric placement and power supply access

A common principle for all presented deployments is that RW is intended to be complementary to a traditional coverage layer (e.g. 4G/5G). In other words, RW does not replace traditional coverage layers and provide area coverage; it provides additional functionality and/or performance boost in areas where such improvements are prioritized. Depending on the scenario, e.g. involving conventional handsets or consumer products with additional functionality, traditional cellular network services may also be provided via RW, where installed.

In all venue types, RW/SP placement choices will generally be selected to minimize blocking probability towards any anticipated device locations, simultaneously subject to esthetic and practical mounting constraints and power availability.

4.2 Environment descriptions

4.2.1 Venue

This environment type refers to contiguous structured areas constituting a large venue, covering distance scales of several tens to hundreds of meters and areas of ~1 000 - 100 000 square meters. Walls, columns, partial ceilings, furniture etc. of diverse materials may be encountered.

Typical to the venue environment is a presence of a large number of people, whereby the RW deployment should support many traditional users using both smartphones and more advanced (e.g. XR) devices, possibly for simultaneous high data rate applications. Additionally, equipment pertaining to the venue (screen or jumbotrons, lighting and automation, etc.) may be served by the RW deployment.

The RW deployment in the venue environment relies on surfaces or fixed supports (walls, ceilings, floors, regularly placed objects) for distributed RW placement.

Examples of venue environments may include sports hall, stadium with open or closed roof, concert hall, convention hall, airport, crowded outdoor area (square), etc.

The venue scenarios may differ significantly in terms of size and the number of devices. For the purposes of technology analysis, we may limit the area scope to mid-sized venues, for example as the example below. If necessary, and to manage complexity, multiple venue installations (e.g. multiple convention halls) may be concatenated to cover a geographically extended area (e.g. a multi-hall convention center). As previously said, there is no ambition for wide-area (network-wide) coverage using RW; such coverage may be ensured by traditional (e.g. centralized macro) coverage layers.

Example: Tennis arena

Characteristic	Description
Layout	Bowl-shaped, not ceiling-covered, may have multiple bleacher levels
Size	90 x 60 m (court area 35 x 20 m)
Device types	Smartphones, XR devices, modems for venue equipment
Number of devices	15 000
Number of people	15 000 (40 rows, avg ~350 persons per row)
Materials	Mix of reflective and absorptive
RW mounting opportunities	Seat backs (~0.5-5 m to devices), bleacher ceilings (~3-10 m)
Power supply availability	External power available at some, but not all, SP locations (not e.g. at all seat backs)

Table 24: Tennis arena, deployment scenario characteristics

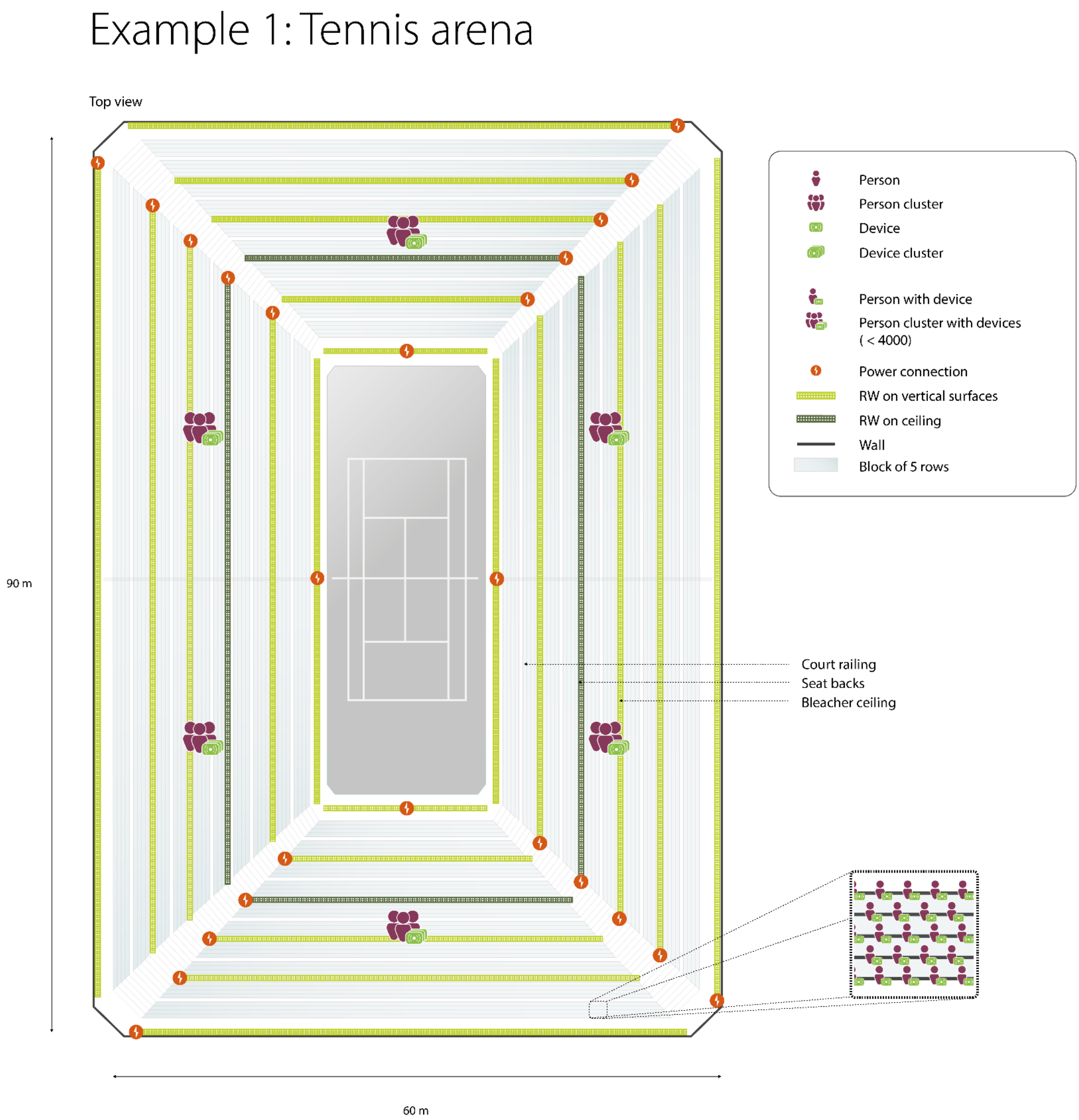


Figure 8: Venue deployment scenario example. Tennis arena

4.2.2 *Manufacturing*

This environment type covers industrial sites, e.g. with automatic production lines or other machinery controlled over cellular/wireless links, including moving machines and unmanned vehicles in environments where people and machines may share same physical space. The distance and area scale are 10s to 100s of meters and 1000s of square meters, respectively. It is typically a highly reflective environment due to a large number of metal objects. Many blockers are present so that quality of traditional site coverage from any central location is poor.

RW deployment in the environment relies on availability of surfaces or fixed supports (walls, ceilings, floors, regularly placed objects) for distributed RW placement.

The RW deployment should support industrial machines, robots, UVs, etc., moving at speeds 3-15 km/h. It need not be designed/dimensioned for e.g. smartphone traffic, which can be provided by e.g. coverage layers from other networks.

Coverage should be limited to the designated area; it may in fact be desirable to avoid wider coverage for security, safety, and reliability reasons.

Examples of industrial environments include: Automated production facility, automated central storage.

Example: Production hall

Characteristic	Description
Layout	Rectangular, hundreds of static and moving objects
Size	140 m x 70 m, height 15 m
Device types	Modems for industrial equipment, robots, UVs
Number of devices	1 000, ~20 on UVs
Number of people	20
Materials	Reflective
RW mounting opportunities	Ceilings, walls, support columns (~10 m to devices)
Power supply availability	External power available at most RW/SP locations

Table 25: Production hall, deployment scenario characteristics

Example 2: Production hall

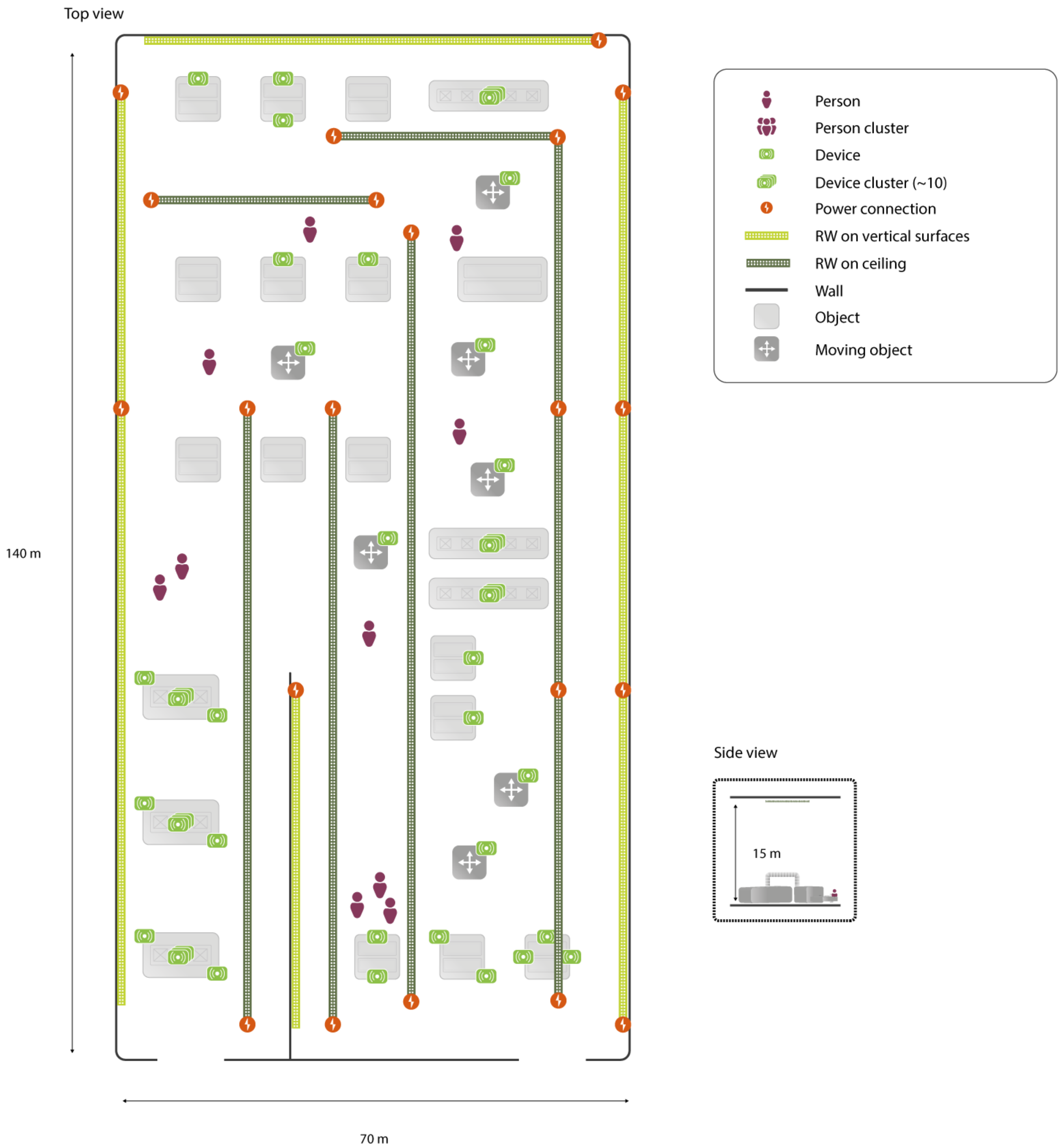


Figure 9: Industrial deployment scenario example. Production hall

4.2.3 Goods and logistics

This environment type covers commercial sites for goods handling where a large number of articles (packages, loose articles, or labeling accessories) are packed densely and need to be located or tracked. The distance and area scale are 10s to ~100s of meters, and a few 1000s of square meters, respectively. Large number of metal shelves are mounted for storing goods. Other equipment and people may be present in the vicinity.

RW deployment in the environment relies on availability of surfaces or fixed supports (walls, ceilings, floors, shelves themselves) for distributed RW placement.

The RW deployment should support equipment for sales support (e.g. electronic price labels), item tracking (e.g. passive RFID-style tags), and/or equipment used for storage management. It need not be designed/dimensioned for e.g. smartphone traffic, which can be provided by e.g. coverage layers from other networks.

Examples of goods storage environment include: warehouse, retail sales floor, distribution center, port. The characteristics may vary, for example, the warehousing environment includes fast moving objects like forklifts, while a retail setting may instead contain a large number of people.

Example: Supermarket sales floor

Characteristic	Description
Layout	Rectangular, mixture of shelves, equipment, and people
Size	60 m x 30 m, 5 m high
Device types	Modems for electronic labels
Number of devices	10 000
Number of people	200
Materials	Mix of reflective and absorptive
RW mounting opportunities	Ceilings, walls, support columns (~1-10 m to devices)
Power supply availability	External power available at some RW/SP locations

Table 26: Supermarket sales floor, deployment scenario characteristics

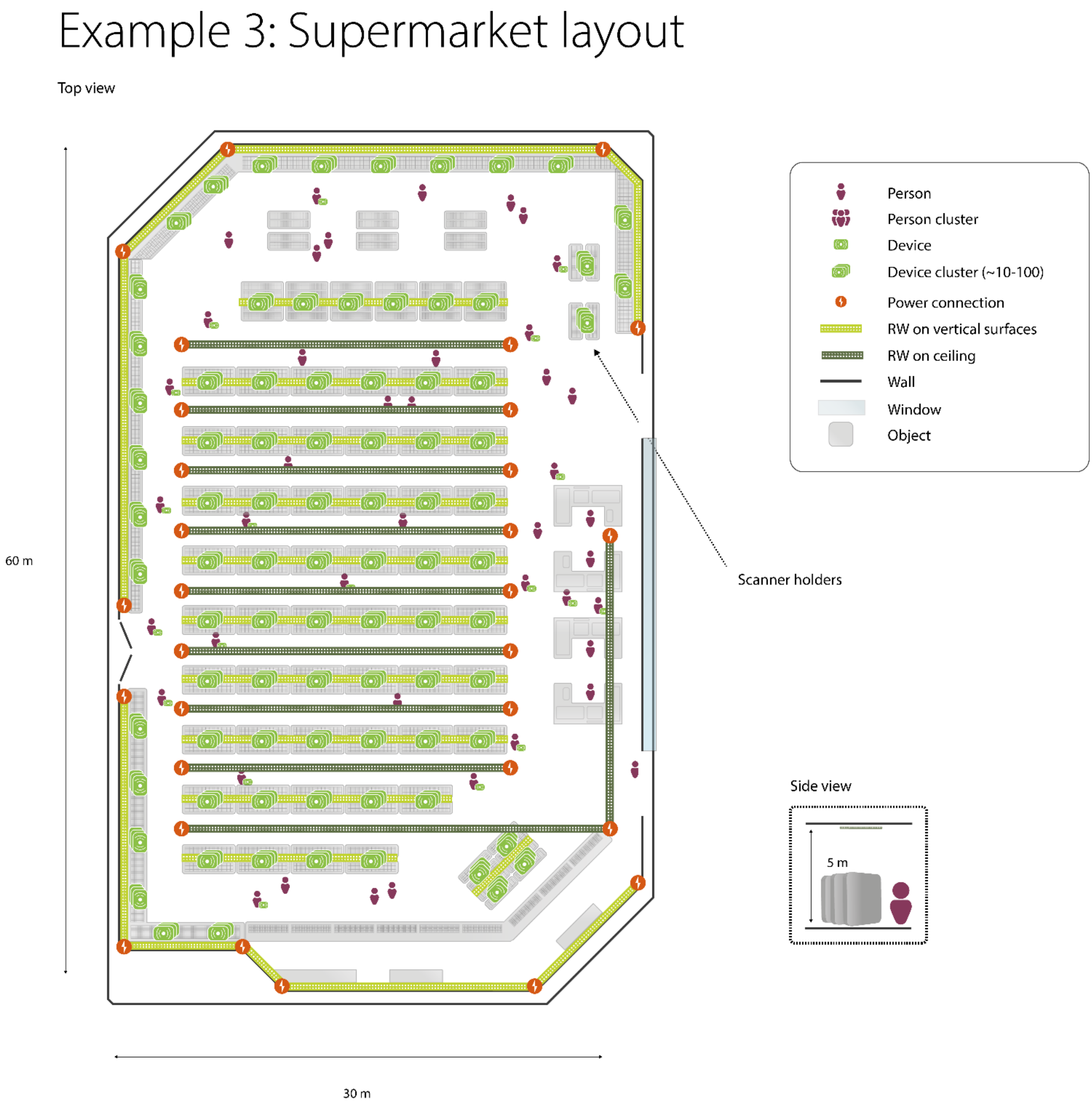


Figure 10: Goods and logistics deployment scenario example. Production hall

4.2.4 Residential

This environment type covers residences configured for home automation and advanced teleservices and entertainment. The distance and area scale are a few 10s of meters and 100s of square meters, respectively. Multiple floors in a house or duplex architecture may be covered. People are present in the environment. Many blockers may exist so that quality of traditional site coverage from any central location is poor.

RW deployment in the residential environment relies on available surfaces (typically walls and ceilings) for distributed RW placement.

The RW deployment should support home automation, entertainment, and other high-performance applications (XR, gaming, etc.) in low mobility scenarios. RW coverage may be limited to a designated area since simultaneous wide area coverage is typically present. High-performance RW coverage should be ensured in most of the residence; it may be permissible to rely on conventional cellular coverage in a low percentage of the area. Traditional smartphone traffic may also be supported by RW, or it may be handled using traditional wide-area coverage layers.

Examples of residential environments include: House, townhouse, apartment.

Example: Large apartment

Characteristic	Description
Layout	Rectangular, single-floor
Size	15 m x 10 m, 2.5 m high
Device types	Embedded home automation devices, high-performance entertainment devices (smartphone, XR glasses, gaming console)
Number of devices	100 automation +10 personal
Number of people	4
Materials	Mix of reflective and absorptive
RW mounting opportunities	Ceilings, walls
Power supply availability	External power available at a few RW/SP locations

Table 27: Large apartment, deployment scenario characteristics

Figure 11: Residential deployment scenario example. Large apartment

4.2.5 *Patient care*

The last environment type covers medical or supervised care facilities with hallway-style or other regularly structured floor plans. The distance and area scale are a few 10s to 50 meters and few 100s to ~1000 square meters, respectively. The environment includes a wide variety of objects, reflective and absorptive, as well as possibly a large number of people. Walls may have high RF isolation and blockers may exist so that quality of traditional site coverage from any central location is poor.

RW deployment in this environment relies on available surfaces (typically walls and ceilings) for distributed RW placement.

The RW deployment should support patient monitoring, patient tracking, and equipment tracking in low mobility conditions. Traditional smartphone traffic via the deployment may also be supported.

RW coverage may be limited to the designated area, however, seamless integration with wide area coverage should be ensured. High-performance and reliable RW coverage should be ensured in the entire area.

Examples of patient care environments include: Hospital, elder care, or other special care facilities.

Note that some individual patient care environments may resemble residential environments, in which case Environment 4 may be invoked.

Example: Hospital floor

Characteristic	Description
Layout	Rectangular, hallway-style
Size	20 m x 75 m, 3.5 m high
Device types	Personal medical equipment, embedded sensors, general medical equipment, smartphones
Number of devices	~300
Number of people	50
Materials	Mix of reflective and absorptive
RW mounting opportunities	Ceilings, walls
Power supply availability	External power available at a most RW/SP locations

Table 28: Hospital floor, deployment scenario characteristics

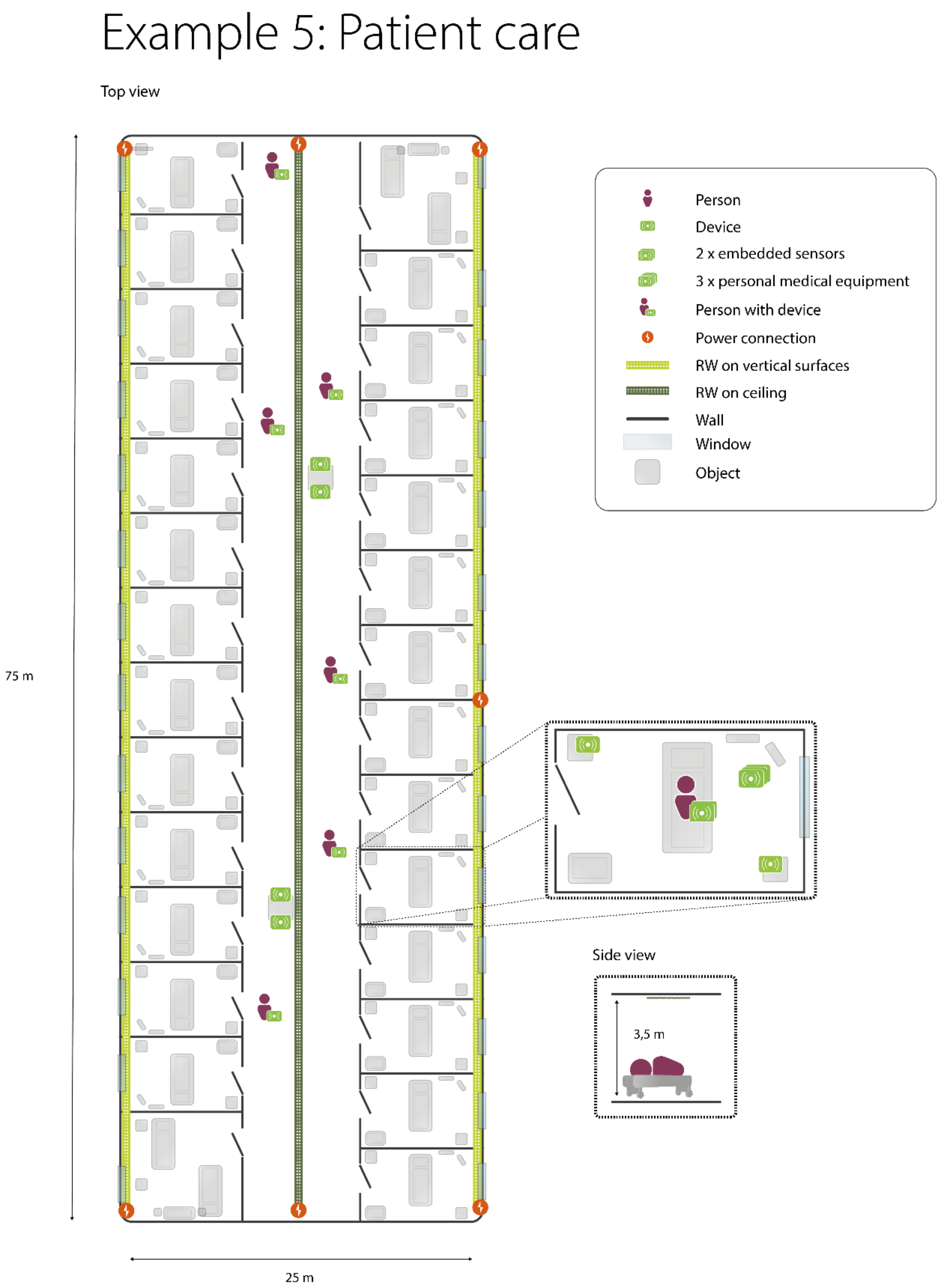


Figure 12: Patient care deployment scenario example. Hospital floor

4.3 RadioWeaves connectivity and transport

While not the main focus of the project, transport and connectivity choices are important in practical deployments. For completeness, some possibilities, not necessarily unique to the RW-based solutions, are exemplified below. These examples do not cover the full range of possible RW deployments, intended to be highly flexible and amenable to mixing different levels of back-, mid-, and front-haul concepts.

4.3.1 Mixed/mid-haul

Various approaches exist to connect RW fabric sections/EPUs to site backhaul location:

- Wired
- Wireless (out-of-band, dedicated or separate spectrum)
- Relay/mesh (in-band, using RW spectrum)

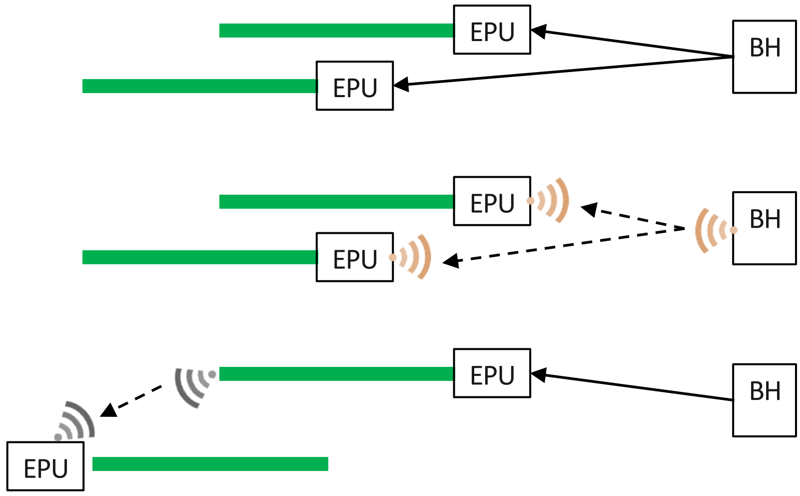


Figure 13: Mixed/mid-haul connectivity approaches

Different fabric sections in a deployment may mix different approaches, including in-band/out-of-band wireless connectivity, etc.

4.3.2 Backhaul

Similarly, various ways exist to provide transport connections to a RW site. We depict some options for providing a backhaul entry point for the site, from which further connections can be provided to EPUs/federations. We note that the backhaul provision topic is not unique to RW deployments.

- Wired backhaul
- Wireless backhaul (dedicated spectrum)
- Wireless backhaul over cellular coverage layer (IAB-like)

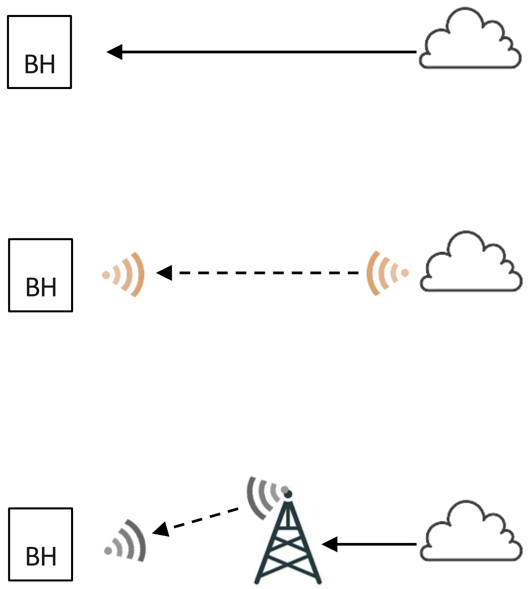


Figure 14: Backhaul connectivity approaches

4.4 Additional considerations

4.4.1 Multi-operator operation

Advanced cellular network deployments, as anticipated for RW, often require both special equipment investments and optimized placement of infrastructure components, utilizing the available space and features of the architecture and interior design of the environment. It is therefore often not practical to duplicate such a deployment on a per-operator basis. In particular, this is the case for indoor-installations that are provided by one selected operator or by a private network provider.

This situation is not unique to prospective RW deployments but pertains to many advanced installations aimed to be generally accessible by the public (as opposed to dedicated commercial applications like e.g. industrial production or goods tracking). For completeness of deployment discussions, at least two implications of such aspects should be clarified, along with typical solutions.

Network access

Preferably, the RW deployment should be accessible/available to users irrespective of their regular operator. The deployment can be integrated with a certain operator's core network, or with a private network provider, but access may be permitted to customers of any operator that has a direct or indirect sharing agreement with the operator managing the deployment. Such access may be enabled for example through proper configuration of the access barring mechanism.

Legacy service access

When a user is connected to the RW deployment, provision of home operator services is preferably maintained. In a basic configuration, the user only obtains services via the managing operator's backhaul stream, whereby e.g. conventional voice calls and SMS/MMS traffic from the home operator cannot be terminated. Delivery of such functions may be enabled by e.g. registering the RW operator as a roaming network, operating in dual-SIM mode whereby a connection to both operators is maintained, or by reverting to over-the top services for voice and messaging.

Chapter 5 Latency in wireless applications

The discussed use cases pose challenging technical requirements in terms of combinations of huge data throughputs, large numbers of devices, low latency, high reliability, accurate positioning and, on top of that, good user experience for all device classes where energy transfer may have to be provided. This chapter focuses on the different latency requirements for the use cases. Within 5G, the use cases and their corresponding latencies can be classified as Ultra-Reliable Low-Latency Communications (URLLC) or even enhanced URLLC (eURLLC), massive Machine Type Communications (mMTC) and Enhanced Mobile Broadband (eMBB). For novel 6G services to be supported by RadioWeaves other classifications are proposed based on functionality and challenges as discussed in Section 0. As a result, the latency requirement is not defined per classification family and needs to be considered for each individual use case.

A general overview of latency requirements for emerging applications in the entertainment, Industry 4.0, automotive, IoT and healthcare sectors is shown in Table 29. Depending on use case, latency is defined as end-to-end (E2E) or round-trip time (RTT), where the E2E latency describes the communication latency between the application layers of two devices and the RTT latency is equal to the E2E delay with an additional response from the device. Here a difference occurs with 5G, where URLLC latency is defined as the latency between MAC layers.

Field	Sub-field	Latency (ms)	Type	Reference
XR	VR entertainment	< 20	RTT and E2E	[RY1, TA1]
	Professional AR/MR usage	< 10		[3GPP1, MAS1]
Gaming	Pro gaming (not XR)	< 50	E2E	[TA1, AT1]
Ind. 4.0	Cooperative robots	< 1	RTT	[5GACIA1]
	Process remote control and monitoring	< 50	E2E	
	Human machine interface (HMI)	< 200		[TA1]
V2X and UVs	Remote and cooperative driving, position sharing	< 10	E2E except cooperative driving (RTT)	[3GPP1, MAS1,AK1]
	Platooning	< 50		[3GPP1, AK1]
	Collective information sharing	< 100		[AK1]
UAVs	Traffic management, racing drone control	< 10	RTT	[CK1]
	Aerial command and control, UAV logistics	< 50	E2E	[CK1, 3GPP2]
IoT	Safety-critical event monitoring	< 10	E2E	[3GPP1]
	General monitoring	< 1000		
Healthcare	Exoskeletons and Prosthetic hands	< 20	RTT	[TA1]
	Telediagnosis and monitoring	< 200	E2E	

Table 29: General latency constraints for different fields and use cases

Interactive and immersive applications such as extended reality (XR) and gaming require high throughputs in combination with low latencies. Since there is human involvement within these applications, certain latency conditions based on human reactions and human mobility must be ensured. To meet a display error of less than 5 mrad, a latency of 10 ms or 20 ms is determined for fast and slow movements, respectively [REB1, PL1]. Furthermore physiological parameters reinforce these values as the human mind needs 13 ms to extract conceptual meaning from a picture, without advance knowledge [MCP1]. Latency values below 13 ms will therefore not contribute to a better user experience. This reasoning is also useful in gaming where the frame rate, e.g. 60 fps corresponding with 16.7 ms per frame, or the physiological parameters are decisive [TA1]. A negative impact on gaming performance is noticeable for latencies above 75 ms. A latency value of 50 ms can be seen as sufficient, meeting the physiological parameters and the technological possibilities for gaming not XR related [TA1, AT1].

Industry 4.0 is a more extensive domain with many diverse applications, leading to latency requirements ranging from 1 ms for cooperative robots whereby very fast-working robots must be able to respond quickly to each other, to 200 ms for human machine interfaces (HMIs) [5GACIA1, TA1]. An assignment for this value is the human response time, which is approximately 200 ms [DRL1]. Process remote control and monitoring satisfies with 50 ms latency [5GACIA1].

Assisted and autonomous vehicles, with the advent of Vehicle-to-everything (V2X), Unmanned Vehicles (UVs) and Unmanned Aerial Vehicles (UAVs), are increasingly important and interesting in economic, technological and environmental terms. Defined latency requirements for these diverse applications range from 10 to 100 ms as shown in Table 29**.** The 3 GPP defines a latency requirement of 10 ms for autonomous driving logistics solutions with 5G and a UE mobility of less than 30 km/h. The targeted horizontal positioning accuracy is less than 30 cm [3GPP1]. RadioWeaves targets similar values, with the exception of more accurate positioning, denser environments and different and more autonomous vehicles.

IoT applications are furthermore, experiencing a strong growth in industrial, commercial and residential environments. These applications are typically not severely latency limiting (< 1000 ms) with the exception of safety-critical applications (< 10 ms) [3GPP1]. However, these latency requirement values can be challenging as the IoT devices within RadioWeaves can also be energy neutral devices that can be found in large quantities in a limited space.

Healthcare is a final domain discussed where latency-critical applications can be found for prosthetics and exoskeletons (< 20 ms) [TA1]. Non latency-critical applications, with a given latency requirement value of less than 200 ms, such as telediagnosis and monitoring, can also pose a challenge in terms of latency, just like with IoT devices, because of the type and number of devices.

Based on these general latency specifications, the latency requirements of the described use cases within the REINDEER project are determined and summarized in Table 30. A wide scene can be retrieved with latencies ranging from 1 ms to 1 s. These latencies are defined as E2E latencies which makes comparison between applications more clear.

Use case ID	Use case name	E2E latency (ms)
1	Augmented reality for sport events	< 20
2	Real-time digital twins in manufacturing	1 - 50
3	Patient monitoring with in-body and wearable sensors	< 200
4	Human and robot co-working	< 1
5	Tracking of goods and real-time inventory	< 1000
6	Electronic labelling	< 1000
7	Augmented reality for professional applications	< 10
8	Wander detection and patient finding	< 1000
9	Contact tracing and people tracking in large venues	< 1000
10	Position tracing of robots and UVs	< 10
11	Location-based information transfer	< 1000
12	Virtual reality home gaming	10 - 100
13	Smart home automation	< 100

Table 30: Latency constraint for the defined use cases

To get an idea of the deployment complexity of the use cases, these are brought together in Figure 15, in which the maximum traffic volume density in Mbps/m² is compared with E2E latency constraints per UE in ms. By using the traffic volume density instead of the necessary data rate per UE, the complexity of the amount of devices per m² is also included. The use cases have their own deployment challenges to meet all properties and an approach to ordering by complexity can be found in this figure. Implying a deterministic E2E latency across the protocol stack and provide cost-efficient services will be needed for a successful deployment. The latency services will also depend on the type of UE since e.g. backscattered devices (Class 1) behave differently than battery-powered communicative devices (Class 4).

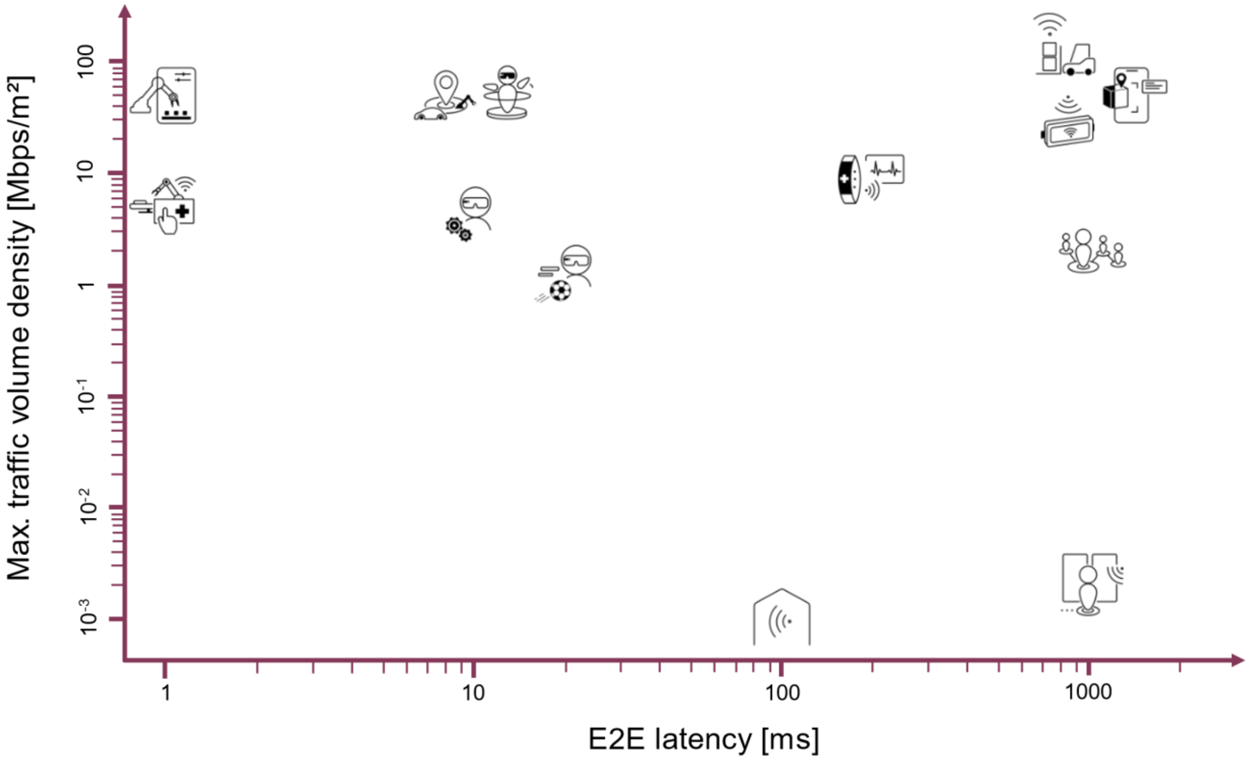


Figure 15: Comparison of maximum latency and traffic volume density constraints for the use cases

Chapter 6 Initial channel model

From a communication perspective, it is essential to model the extreme diversity that the RW offers. In the development of the RW infrastructure and architectural and algorithmic approaches to support diverse services, we introduce the concept of federations in the REINDEER project. A federation represent an ad-hoc sub-set of resources in the RW cooperating to support a certain service/class of devices (Deliverable D2.1 will clarify the concept further). The many antennas in the RW enable ultra-reliable communication, but for a particular user only a subset of them is active. Hence, to investigate the concept of federations it is necessary to model the relative powers of the different channels in a proper way. Similarly, in the case of communication with passive devices using back scattering it is of high importance to capture the variations in link gains to the different antenna elements of the RW in order to determine a suitable federation. For any kind of communication, it is also crucial to have a spatially consistent model at the user side as the use cases include tracking in time and over space. At the RW it is crucial that the model is consistent over space to enable realistic assessment of the MIMO and multiuser MIMO performance.

From a positioning perspective, it is not just the direction of the line-of-sight, but also the position of scatterers that is of interest. As the RW often will operate in the near-field, i.e. at a distance being smaller than the Rayleigh distance, both the direction and the distance to scatterers are of interest. The direction only will not suffice, as it differs depending which part of the RW that is considered. Ideally, it should be possible to do mapping between the radio environment and the physical environment and extract contextual information from the extracted radio based information.

From a learning perspective, it is also essential that the channel model can provide long time consistency and spatial consistency. Dynamic events and blocking have to be represented in a realistic manner both in the time domain and over space.

In all environments, there is some kind of blocking, from humans as well as from objects and machinery. Some blockers are static and belong to the environment, whereas both human and robot like blocking is dynamic in nature. Both static and dynamic blocking are essential to model from a reliability point of view and form a positioning point of view.

The important environments listed in previous chapters are limited to a maximum space of 140x70x15 m, mostly indoor, with the smallest rooms in patient care and residential environments limited to 3x4x3 m. In some cases, like logistics and retail, there are also longer corridors that may have a width of down to 2 m.

The requirements above call for some kind of geometry-based model. It will be hard to model all dependencies and correlations mentioned above with a purely stochastic approach. If a purely stochastic approach anyway is needed for initial evaluations, a simple Ricean model is advised, where for each antenna pair a distance-dependent K-factor, distance-dependent link gain and a stochastic on/off function for the availability of the LOS component is used.

For more realistic simulations we suggest to use either a full ray tracing approach or a geometry based stochastic channel model (GSCM). Ray tracing can provide realistic samples of channel snapshots given that the details of the environment - including furniture, machinery and other objects that can act as blockers - are modelled properly.

There are to date no extensive measurement-based investigations of the RW-channels in the literature. Cell-free massive MIMO has similarities to the concepts of distributed MIMO, cooperative MIMO, coordinated multipoint and network MIMO and hence there are some relevant results with respect to correlations of large scale fading, delay spreads, and clusters for different base station locations in this domain, see, e.g., [GD1][TC1] and the references therein. [APG1] reports measurement from a co-located massive MIMO, distributed massive MIMO in form of a radio stripe and distributed RW scenario in a smaller room, with emphasis on the spatial distribution of the field strengths with the various setups. [JF1] analyse the impact of closely spaced users in an indoor and outdoor massive MIMO setup and concludes that it is possible to spatially separate a group of closely located users even in the case of LOS and co-located massive MIMO. One explanation for this is the limited area over which a particular multipath component can be seen [JF2], i.e. the limited lifetime of multipath components. The concept of gain functions for individual multipath components (MPCs) is an important extension of the COST 2100 channel model for massive MIMO reflecting this phenomenon. This, together with the concept of a base station-side visibility region (BS-visibility region) to model the appearance and disappearance of clusters when using a physically-large array and the support for polarimetric channels makes the COST 2100 channel model with its massive MIMO extension a suitable initial framework for RW. We aim to further adapt this framework and make it suitable for RW channel modelling. The original COST 2100 channel model is described in [LL1]. There is an open source MATLAB implementation of this and its massive MIMO extension, available at [Git21]. The simulation starts by defining a simulation area, the considered carrier frequency, the locations of the RW antennas and the types of antennas used for the RW as well as for the UE. In a second step, clusters and their corresponding visibility regions (RW antenna visibility region, UE visibility region) are randomly positioned in the simulation area. Finally, after defining the route of the UE or several UEs, the channel between each and every antenna is represented as a sum of multipath components from each of the active clusters. The complex gain of each multipath component is determined by the exact propagation distance between antennas, and hence a spatially consistent and frequency consistent channel model is achieved. Once a channel realization (a "drop") is performed, it can be saved and the particular realization can be used for environment learning, multipath aided positioning, communication, for any UE position in the simulation area.

The concept of clusters, RW antenna visibility region, the UE visibility region, and the MPC gain function are shown in Figure 16. Consider in this case the x-axis in (a) as the possible locations of the antennas building up the Radio Weave, with a specific RW antenna located at the point BS. This antenna is within the RW antenna visibility region of the cluster also connected to the UE visibility region "B". So when the UE is within the area "B" it will see the RW antenna element at point BS through the cluster of multipath components connected to those visibility regions. (b) When the UE is inside the UE visibility region "D" it will also see the antennas in the red circle of the Radio Weave, through the cluster of MPCs connected to those visibility regions. (c) illustrates the gain functions. Each MPC is connected to a gain function in the UE visibility region. For a specific position of the UE inside the UE visibility region, the gains of the different MPCs are given by the distances from the UE to the center points of the gain functions inside the visibility region. This ensures a smooth death and birth process of individual MPCs and thereby a limited but spatially consistent lifetime of individual MPCs.

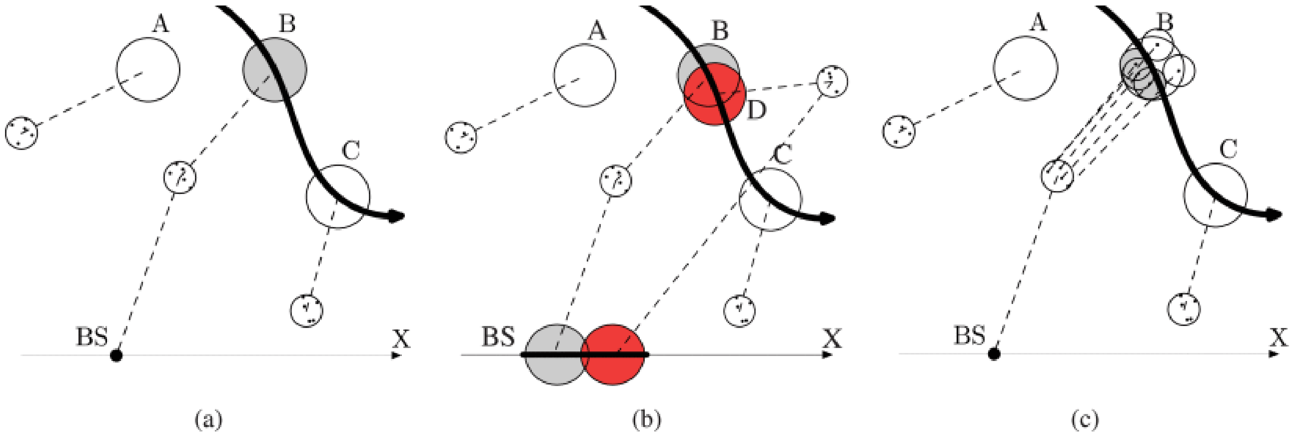


Figure 16: The concept of visibility regions and clusters in the COST 2100 channel model with its massive MIMO extension, from [JF2]. The x-axis constitute here the possible locations of the antennas building up the Radio Weave with a specific antenna element located at the point BS. The UE travels through the UE visibility regions, different clusters are active depending on the specific UE location.

Occasional blocking can also be considered by simply introducing blockers in the simulation environment. Any multipath component travelling through a blocker is deemed dead and hence does not contribute to the overall impulse response.

Another recent interesting development of the COST 2100 channel model concept is the extension to vehicular intersections [CG1]. There the clusters are constrained to be located along walls of buildings in the geometry. This approach makes it possible to use a stochastic approach but still enforcing realism and similarities to typical geometries of vehicular intersections. Such an approach is also preferred for RadioWeaves and is to be evaluated, since it can be interesting for specific geometries of the environments in the use cases considered.

The implementation in [Git21] results in a transfer function matrix for each UE location, i.e. a large MIMO channel matrix from each UE antenna to each RW antenna. Conceptually we aim to use a similar approach for RadioWeaves, maybe also with a specification of which RW antennas that should be considered active for the particular user.

Chapter 7 Summary and Conclusion

This deliverable reports on the work performed in task T1.1, focusing on the analysis of interactive use case scenarios and detailed technical requirements, and also provides an update on the progress in task T1.2 by providing an initial channel model.

A rich diversity of future interactive use cases in different application domains have been considered, based on contributions from all partners and the viewpoints brought by them from different perspectives. Through the analysis it became clear that structuring and classification is needed. In this deliverable this structuring is presented for uses cases, that have been clustered in three main categories according to applications, and devices, for which we identified five classes. Furthermore, the technical requirements have been derived and, importantly, also quantified. These demonstrate that not only are the expectations inflated according to the three axes of the "5G triangle" [ITU1] — higher mobile throughput, ultra-reliable and low-latency communication, and support for low-energy devices, — moreover many pose extra challenges, such as the need for position information and wireless power transfer. It is clear that several of the technical requirements are raising the bar for wireless network infrastructure, far beyond what is possible in emerging 5G deployments. For example, end-to-end latency down to 1 ms will need to be supported, indoor location accuracy of 0,1 m is expected, and the reliability requirements less than 10^{-5} for process automation.

Furthermore, in task T1.1 a number of systems services, ranging from edge processing and federated learning to environment mapping and device tracking, have been identified that could be offered on, and by, the RW infrastructure.

This analysis of future use cases is key for driving the further innovative development of RW technology in the REINDEER project. Moreover, we noticed that technical requirements are largely missing today in literature for envisioned 6G applications, and this deliverable may therefore be of interest to a broad community.

We have also outlined a channel model framework for RW based on the COST 2100 channel model and its massive MIMO extension. We believe this framework is flexible enough and fulfils the requirements to give a spatially consistent and frequency consistent channel model that can be used for learning, positioning as well as communication.

Chapter 8 List of Abbreviations

Abbreviation	Translation
AR	Augmented reality
BH	Backhaul
BLE	Bluetooth Low Energy
E2E	End-to-end
eMBB	Enhanced Mobile Broadband
EPU	Edge Processing Unit
HMIs	Human Machine Interfaces
IoT	Internet of Things
ISM	Industrial, Scientific and Medical Band
KPI	Key performance indicator
LCD	Liquid Crystal Display
MIMO	Multiple-input and multiple-output
MMS	Multimedia Messaging Service
mMTC	Massive Machine Type Communications
MPC	Multi Path Component
NLOS	Non-line-of-sight
RF	Radio Frequency
RFID	Radio-frequency identification
RTT	Round-trip time
RW	RadioWeaves
SMS	Short Message Service
SP	Service Point
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UL/DL	Upload/Download ratio
URLLC	Ultra-Reliable Low-Latency Communications
UV	Unmanned Vehicle
VR	Virtual reality
WPT	Wireless power transfer
XR	Extended Reality

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