D6.7 Results of the market analysis

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Executive Summary

This deliverable, *Results of the Market Analysis*, presents the market analysis conducted within the HOLDEN project to evaluate the commercialization potential of the RF sensing technologies developed across the project work packages. The assessment focuses on three application scenarios identified in Task 6.3: (i) RF holography for people and object detection, (ii) RF sensing for elderly-care monitoring, and (iii) RF sensing-enabled interaction for Smart TV ecosystems. The analysis was performed through a structured framework combining technological assessment, market validation, competitive positioning, business-model definition, and financial sustainability evaluation.

The results indicate that HOLDEN technologies address emerging market needs related to privacy-preserving sensing, non-contact monitoring, intelligent infrastructure, and device-free environmental awareness. Across the investigated application domains, HOLDEN solutions provide a differentiated value proposition compared with conventional camera-based, wearable, or otherwise intrusive sensing approaches. In particular, RF sensing enables passive and non-line-of-sight monitoring capabilities while supporting hidden deployment architectures and reduced privacy exposure.

Within people and object detection application scenario, RF holography demonstrates strong potential for privacy-aware monitoring and situational-awareness solutions in environments such as airports, museums, and other security-sensitive facilities. The analysis identifies intelligent infrastructure protection and privacy-oriented monitoring as relevant drivers for early market adoption.

In the elderly-care domain, the proposed commercialization strategy leverages existing broadband and Wi-Fi infrastructures by integrating RF sensing functionalities directly into residential gateways and connected-home ecosystems. This approach enables scalable and non-invasive monitoring solutions without requiring dedicated healthcare hardware or wearable devices.

Within Smart TV ecosystem, RF sensing enables gesture recognition, user-presence detection, and context-aware interaction capabilities aligned with the evolution of smart-home platforms and next-generation human-machine interfaces.

The business and financial assessment indicates that the proposed commercialization pathways can achieve attractive long-term scalability through licensing-oriented business models, recurring software revenues, and strategic ecosystem partnerships. The analysis also highlights the advantages of infrastructure reuse and embedded software integration, which significantly reduce capital intensity compared with traditional hardware-centric deployment

models. Industrial benchmarking activities and stakeholder interactions involving organizations such as Netgear, Nokia, Google, Gemtek, Askey, Vodafone, TIM, Charter Communications, Samsung Electronics, Qualcomm, MediaTek, Bosch, and Thales contributed to validating assumptions related to deployment economics, operational costs, interoperability requirements, maintenance models, procurement dynamics, and commercialization timelines.

The proposed market-entry strategies follow phased commercialization roadmaps centered on pilot deployments, interoperability validation, selective ecosystem partnerships, and progressive scaling activities aimed at reducing technical and operational risks. The proposed exploitation pathways provide realistic and economically sustainable routes toward commercialization while remaining aligned with the ethical and privacy-preserving principles underpinning the HOLDEN project.

Overall, the market analysis confirms that HOLDEN technologies possess strong commercial potential across multiple high-growth sectors characterized by increasing demand for privacy-preserving sensing, intelligent infrastructure monitoring, and embedded environmental intelligence.

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1. Introduction

1.1. About HOLDEN

The ubiquitous perception by sensing of objects, subjects, and gestures is a pivotal challenge for future technology: it enables personalized services such as smart living, automated logistics, or interaction through free-space gestures. However, it also challenges ethical and moral boundaries and threatens privacy. HOLDEN proposes a radically new approach to RF-based perception by concisely analyzing ethical constraints and privacy risks while re-thinking RF-based sensing. We establish necessary conditions for privacy preserving and ethically compliant sensing and develop new paradigms respecting these constraints.

For the first time ever, HOLDEN constitutes a concentrated effort to explore social aspects of RF-sensing to guide technological advance, and to derive technology for ethically and privacy compliant perception. The development of ethical and privacy constraints is central to HOLDEN. We use these findings to derive privacy- and ethically compliant concepts for RF-based perception. We will develop a system of distributed multi-antenna devices for simultaneous multitarget recognition and ubiquitous perception with unprecedented accuracy, which constitutes a radical paradigm shift from a technology-centric perspective to a privacy-centric one via a privacy-by-design approach.

HOLDEN achieves this goal along three high risk, complementary, and privacy-centric paths:

Path 1: Continuous-space measurement points: Radio-based 3D vision by holographic image processing of RF wavefronts.

Path 2: Discrete-space measurement points: Advanced 3D beamforming for human-scale recognition and tracking through dense, massive, and connected antenna arrays.

Path 3: Signal processing and learning: High-dimensional tensor processing for the distinction of complex activities and motion from massive-dimensional RF data. The resulting breakthrough approaches and algorithms will be compared against application-level benchmarks via usage scenarios in the fields of logistics, smart living, and free-space.

1.2. Partners

The consortium consists of four academic partners and a high-tech SME partner: (a) Aalto University (AALTO), Finland, (b) Technical University of Munich (TUM), Germany, (c) Consiglio Nazionale Ricerche (CNR), with third party Politecnico di Milano (POLIMI), Italy, (d) University of Twente (TWE), Netherlands, and (e) Adant (Adant), Italy. This consortium features the specialized and complementary expertise required to achieve project objectives. AALTO will be responsible for the project management (WP1), covered by an experienced and dedicated project manager. Ethical aspects (WP2) will be addressed by TWE (Prof. Ciano Aydin) who is a pioneer in the field. TUM pioneered RF holography, which makes TUM (Prof. Thomas Eibert) the ideal leader of WP3. In advanced distributed signal and information processing, CNR has through Prof. Stefano Savazzi more than 14 years of experience. CNR will lead WP4. Since more than 10 years, AALTO is active in radio sensing and machine learning based activity recognition. This expertise makes AALTO (Prof. Sigg) the ideal leader of WP5. Adant (Daniele Piazza) will contribute to the market analysis and application exploitation (WP6). Led by AALTO, dissemination with the website as one the media will be addressed by all partners. All academic partners are committed to early publication of results, e.g., via arXiv (open science).

2. Innovations and Application Scenarios

2.1. Innovations in Holden

The HOLDEN project develops three core RF sensing innovations, each investigated within a dedicated work package: WP3 (Static Holography), WP4 (Dynamic Holography) and WP5 (Gesture Recognition). These innovations provide a tiered set of capabilities, ranging from the detection and localization of static objects and individuals to real-time monitoring of human movement and activity, and finally to interactive control of systems through gestures. Together, they illustrate the versatility and transformative potential of RF sensing, supporting applications across security, assisted living, industrial monitoring, smart living, and interactive environments, while embedding privacy, ethical, and social considerations from the outset.

2.1.1. Static Holography

Static holography captures images of static objects and individuals within a fixed environment by leveraging ambient RF waves as a “light source”. Unlike conventional scanners that rely on actively emitted signals, static holography reconstructs scenes using algorithms such as back-projection or linearized inverse source solving, leveraging the stray fields generated by existing radio sources like Wi-Fi routers, without the need for machine learning. Technology can operate through walls and in complete darkness, detecting conductive objects more easily than dampening materials. While high-resolution imaging requires longer processing times, changes between scenes are often easier to identify than interpreting a single snapshot. Applications include body imaging, metallic object detection, and precise mapping and localization, offering non-intrusive sensing that minimizes exposure of sensitive information and preserves privacy by design.

2.1.2. Dynamic Holography

Dynamic holography builds upon static capabilities to monitor and analyze movements, activities, and environmental changes in real time. It integrates Wi-Fi-based localization and people counting with machine learning algorithms for activity recognition, along with 2D and 3D imaging that may require dedicated RF emitters and receivers. This system functions effectively through walls and in low-visibility conditions, enabling robust monitoring of multiple targets simultaneously. It supports applications such as security surveillance, elderly care, and industrial process monitoring, while ensuring that ethical, social, and privacy considerations guide both deployment and data handling.

2.1.3. Gesture Recognition

Gesture recognition extends the technology to interactive applications, allowing users to control devices and systems through hand or body movements. The system extracts spatial and temporal features from point clouds and interprets them with machine learning algorithms to distinguish gestures across varying lighting conditions, angles, and movement speeds. Gesture recognition is suitable for smart home appliances, VR/AR systems, interactive services, and industrial or public environments. Because point clouds may contain sensitive information, privacy and ethical principles are embedded from the design phase, ensuring user autonomy, control, and respect for social and interpersonal boundaries.

2.2. From Innovations to Application Scenarios

Since it was not possible to conduct a full market analysis and exploitation plan for all initially proposed applications, a selection of the most relevant ones was carried out based on defined criteria (see Deliverable D6.3). Selected examples include: (i) detection of people or objects in restricted areas, addressing critical surveillance and security needs; (ii) assisted-living scenarios, enabling remote monitoring of older or vulnerable individuals through the assessment of daily activities, falls, and presence, thereby supporting healthcare professionals and improving quality of life; and (iii) consumer applications, where gesture-based interaction for smart devices (e.g. TVs, home appliances, gaming) enhances usability, reduces reliance on touch interfaces, and enables energy-saving features such as presence-based activation.

The identification of optimal applications for each Holden innovation, along with the definition of design requirements, was carried out a structured Multi-Criteria Decision Analysis (MCDA). This approach enabled the evaluation of applications in terms of feasibility, innovation potential, and market impact [1] [2]. The evaluation process ensured inclusivity by involving all partners through a transparent scoring system. Clear criteria and corresponding weights were defined prior to scoring. Despite being at an early development stage, the selected application scenarios show strong potential for real-world impact. A balanced set of criteria (covering technical, market, ethical, and social aspects) allowed applications to be ranked according to feasibility and potential.

The main criteria considered were:

- Innovation: including novelty, stage of development, and market impact;
- Complexity: including autonomy, scalability, integrability, and deployability;
- Economics: including total cost of ownership, required public funding, and investment appeal;
- Privacy and Ethics, assessing potential impacts on individual and societal rights;
- Legal, evaluating compliance with applicable regulations;

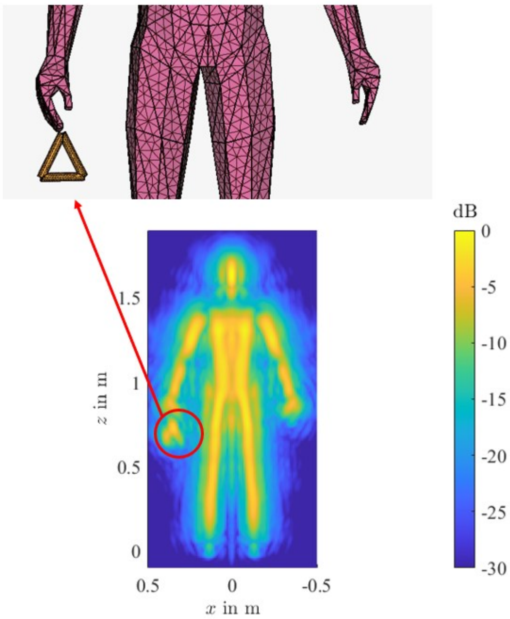
- Lab Reproducibility, assessing the ability to replicate results across partner laboratories.

As described in Deliverable D6.3, each selected application scenario is further detailed in terms of context, target users, system architecture, data flow, and key operational processes.

2.3. Application scenarios

2.3.1. People and Object Detection – Innovation 1

RF sensing technology based on static holography provides a non-invasive and reliable method for detecting the presence of people and objects. By leveraging radio waves, it enables the identification of individuals or items even when they are not directly visible, such as when they are obscured by obstacles or located behind barriers. This capability introduces a robust and complementary monitoring approach that enhances the effectiveness of traditional surveillance systems. More specifically, RF sensing can be positioned as an infrastructure-based, device-free spatial security layer, capable of detecting presence, movement, and behavioral anomalies in environments where conventional technologies reach their limits. Traditional security systems, including CCTV cameras and motion sensors, are widely deployed but exhibit inherent constraints. CCTV systems rely on clear lines of sight and are therefore vulnerable to occlusions caused by walls, furniture, or other objects, as well as poor lighting conditions or deliberate avoidance. Motion sensors, on the other hand, typically provide only binary detection, struggle to identify slow or subtle movements, and are often prone to false alarms triggered by environmental variations such as temperature fluctuations.



2.3.2. Elderly Care – Innovation 2

Providing effective care for elderly individuals presents unique challenges that require personalized, adaptive, and continuously evolving strategies [1]. Achieving holistic support necessitates integrating modern technologies and professional services to promote physical, emotional, and social well-being. Recent advancements in Information and Communication Technologies (ICT) are setting the stage for innovative and transformative progress in a way that can significantly improve the “Elderly Care” process [2], [3]. Among these, Radio Frequency (RF) sensing technology embedded in IoT and Wi-Fi-enabled devices has the potential to emerge as a game changer. This technology provides a non-invasive, continuous monitoring solution, capable of tracking vital signs such as heart rate, breathing frequency, body movement, and location, all without the need for physical contact or wearable devices.

This continuous data stream enables real-time health monitoring, including activity tracking, mobility assistance, heartbeat analysis, and cognitive behavior monitoring. Additionally, local data analysis, such as fall detection or identifying irregular heartbeats, is facilitated by edge processing within connectivity devices. This capability allows for instant alerts to secondary users or emergency services when needed.

Besides, RF sensing technology offers caregivers actionable insights, allowing for a deeper understanding of the elderly's needs and fostering a more proactive, tailored approach to care. Furthermore, these features empower family members and caregivers to respond swiftly and effectively when immediate intervention is needed.

2.3.3. *Smart TV – Innovation 3*

In the evolving landscape of home entertainment, Smart TVs have become integral to the connected home ecosystem, driven by advancements in Wi-Fi connectivity and diversified media content. Beyond delivering enhanced audio-visual experiences, they increasingly function as interactive hubs for IoT technologies, enabling information access, user interaction, and smart home control. As Smart TVs evolve into central control units of digital living, the next frontier lies in enabling more natural and seamless interaction. RF sensing technology plays a key role in this transition by allowing devices to sense and respond to users without direct physical input. By recognizing and interpreting physical movements, RF sensing enables advanced personalization while maintaining a contactless user experience. This technology opens new possibilities for gesture-based control, user presence detection, and even health and wellness monitoring.

Its integration into Smart TVs represents a significant step forward, introducing intuitive, non-intrusive interaction methods that enhance usability and redefine the user experience.

2.4. Market Analysis and Exploitation Plan Framework

The market analysis and exploitation plan follows a multi-stage framework designed to move from high-level environment scanning to granular entry strategies.

Table 1 – Market Analysis and Exploitation Plan Framework

Framework Component	**Key Activities**	**Expected Outcomes**
Strategic Environment	SWOT Analysis	Comprehensive understanding of internal/external factors.
Market Dynamics	Size, Growth, & Segmentation	Data-driven insights into viability and regional profiles.
Value Proposition	Needs, Trends, & Use Cases	Identification of market drivers and viable B2B/B2C applications.
Competitive Positioning	Competitive Advantage	Differentiation strategy and key selling points.
Commercialization	Entry Barriers & Economics	Mitigation of obstacles and financial feasibility assessments.
Strategic Execution	Marketing & Entry Strategy	A definitive roadmap for successful market entry and growth.
Business Model Synthesis	Business Model Canvas (BMC)	A holistic blueprint for value creation, delivery, and capture across the ecosystem.

This framework allows the project to map how technological innovation translates into scalable service revenue, ultimately reaching end-users through enhanced, privacy-first, and frictionless interactions. Value is typically created through seamless technology integration and captured via enhanced user experiences and downstream services. Within this evaluation, the Business Model Canvas (BMC) is utilized to visualize, design, and pivot business models as needed.

The commercialization strategy for HOLDEN's technological innovations is built upon a detailed mapping of the value chain and both B2B and B2C flows. This involves analyzing the interactions between the relevant key players of the ecosystems: Technology Suppliers, Solution Providers, Value-Added Service Providers, Intermediaries and Final Customers (End-Users).

2.5. Economic sustainability of the market analysis

The economic evaluation of the overall analysis considered a diversified revenue mix, including hardware integration, licensing models, recurring software revenues, and long-term service monetization. Importantly, the data and assumptions used for pricing structures, operational costs, and scalability assessments were not derived exclusively from theoretical market estimates. They were further validated through direct industrial interactions and commercial exchanges with stakeholders operating across the global connectivity, consumer electronics, and infrastructure-security ecosystems.

These interactions involved wireless infrastructure vendors, Wi-Fi router manufacturers, broadband operators, Smart TV ecosystem providers, semiconductor vendors, and security-system integrators, including companies such as NETGEAR, Nokia, Google, Gemtek, Askey, Charter Communications, TIM, Vodafone, Samsung Electronics, Qualcomm, MediaTek, Bosch, and Thales. Insights gathered from these stakeholders contributed to validating:

- realistic hardware integration and licensing costs;
- service pricing benchmarks and recurring revenue structures;
- operational deployment and maintenance assumptions;
- procurement and commercialization models across B2B and B2C channels;
- scalability constraints associated with integration into existing connectivity and infrastructure ecosystems.

3. Market Analysis – Object/People Detection

3.1. SWOT Analysis

The aim of this assessment is to evaluate the potential of RF sensing technology (specifically static holography-based RF imaging) for people and object detection in security-sensitive and public / semi-public spaces environments such as museums, airports, or other restricted areas of environments where security and privacy are fundamental and where light, space, and other environmental or infrastructural features reduce the effectiveness of more traditional technologies such as cameras or other types of sensors. By combining scientific literature, industry reports, and market data, the SWOT analysis identifies the key strengths, weaknesses, opportunities, and threats associated with this emerging sensing paradigm. Unlike conventional RF sensing approaches, static holography reconstructs spatial information from ambient radio signals, and this enables privacy-preserving, non-invasive, and infrastructure-light monitoring.

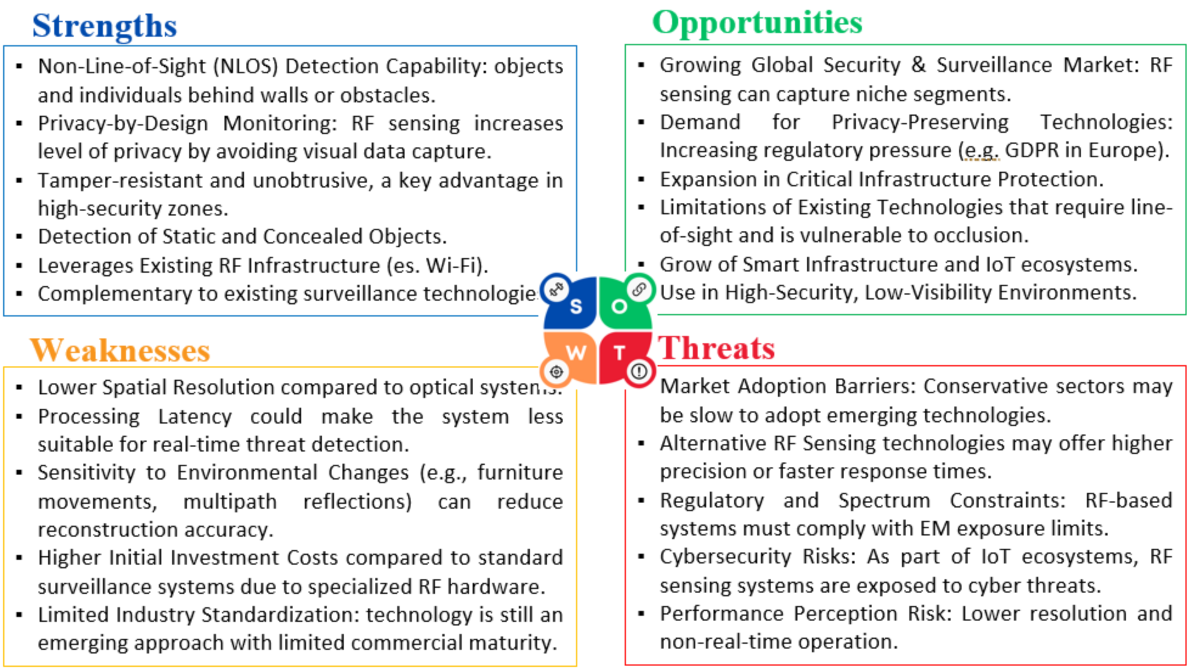


Figure 1 – SWOT Matrix for RF Static Holography in the Surveillance and Security Market

3.1.1. Strengths

RF sensing based on static holography provides several distinctive advantages compared to conventional surveillance technologies. Static RF holography primarily relies on physics-based reconstruction techniques, such as back-projection and inverse problem solving, enabling scene imaging. This deterministic approach enhances explainability and reduces dependence on training data. However, recent advancements increasingly explore hybrid approaches where machine learning is applied to improve reconstruction quality, noise robustness, and object classification, particularly in complex or dynamic environments.

- **Non-Line-of-Sight (NLOS) Detection Capability:** RF sensing enables non-line-of-sight detection, identifying objects and individuals behind walls or obstacles. Research demonstrates reliable RF-based detection and localization accuracy above 90% in controlled environments, even without visual input [4], [5].
- **Privacy-by-Design Monitoring:** Unlike cameras or biometric scanners, RF sensing does not capture identifiable visual or audio data. This aligns with GDPR principles of data minimization, making it suitable for sensitive environments such as museums, airports, or spaces where multiple people can access [6], [7].
- **Device-Free and Invisible Operation:** The system does not require tags, wearables, or active user participation, and can be fully embedded behind walls or ceilings. This makes it tamper-resistant and unobtrusive, a key advantage in high-security zones [8].
- **Detection of Static and Concealed Objects**: Static holography excels in identifying **scene changes over time**, allowing detection of removed, added, or hidden objects, even when no motion occurs. This addresses a major limitation of motion-based sensors [9].
- **Leverages Existing RF Infrastructure**: By using **ambient RF signals (e.g. Wi-Fi)** as an illumination source, the system reduces the need for dedicated transmitters, enabling partial reuse of existing infrastructure [10].
- **Complementary to Existing Systems**: RF sensing enhances, not replaces, existing surveillance technologies, improving detection coverage when combined with CCTV, access control, or alarm systems [11].

3.1.2. Weaknesses

Despite its advantages, several technical and economic limitations may hinder adoption:

- **Lower Spatial Resolution Compared to Optical Systems**: RF holography provides coarse spatial resolution, particularly for non-metallic or RF-absorbing materials, limiting detailed object identification [12].
- **Processing Latency and Non-Real-Time Operation**: High-resolution image reconstruction requires longer acquisition and computation times, making the system less suitable for real-time threat detection compared to cameras or radar [9].

- **Sensitivity to Environmental Changes**: Variations in the environment (e.g., furniture movement, multipath reflections) can reduce reconstruction accuracy by up to 20–30%, requiring calibration and stable deployment conditions [13].
- **Higher Initial Investment Costs**: A limitation of RF sensing holography is the potentially high initial deployment cost associated with specialized RF transceivers, antenna arrays, precision calibration, and computational processing requirements, particularly in high-frequency or large-area sensing applications [14].
- **Limited Industry Standardization:** RF sensing holography currently lacks broad industry standardization and commercial maturity, which can complicate system integration and large-scale deployment [15].

3.1.3. Opportunities

The market environment presents strong growth opportunities driven by security needs and regulatory trends:

- **Growing Global Security & Surveillance Market**: The global video surveillance market is projected to exceed €83 billion by 2030, driven by increasing demand for security in public infrastructure [16]. RF sensing can capture niche segments where cameras are insufficient.
- **Demand for Privacy-Preserving Technologies**: Increasing regulatory pressure (e.g., GDPR in Europe) is accelerating adoption of non-intrusive monitoring solutions, especially in public and semi-public spaces [7].
- **Expansion in Critical Infrastructure Protection:** Airports, logistics hubs, data centers, research labs, government buildings, museums require advanced detection systems. The global airport security market alone is expected to reach €30+ billion by 2030 [17].
- **Limitations of Existing Technologies**: CCTV requires line-of-sight and is vulnerable to occlusion, RFID requires tagging and manual integration, Millimeter-wave scanners are costly and intrusive. These gaps create space for RF holography as a complementary solution [18], [19].
- **Smart Infrastructure and IoT Integration**: The rise of smart buildings and IoT ecosystems enables integration of RF sensing into existing monitoring platforms, supporting scalable deployments [20].
- **Use in High-Security, Low-Visibility Environments**: RF sensing is particularly valuable in hidden areas, storage rooms, or restricted zones, where traditional surveillance is ineffective or undesirable.

3.1.4. Threats

Several external factors may challenge market adoption and scalability:

- **Strong Competition from Established Technologies**: Mature solutions such as CCTV (used in over 70% of public surveillance systems globally) and access control systems dominate the market due to lower cost and proven reliability [16].
- **Emergence of Alternative Sensing Technologies**: Competing technologies include RFID tracking systems, LiDAR and 3D imaging sensors, Millimeter-wave scanners These solutions may offer higher precision or faster response times in certain applications [18].
- **Regulatory and Spectrum Constraints**: RF-based systems must comply with spectrum regulations and electromagnetic exposure limits, which may vary across regions and limit deployment flexibility [21].
- **Cybersecurity Risks**: As part of IoT ecosystems, RF sensing systems are exposed to cyber threats. Studies indicate that over 50% of IoT devices have critical vulnerabilities, raising concerns for security-sensitive applications [22].
- **Market Adoption Barriers**: Conservative sectors such as airport security and cultural heritage institutions may be slow to adopt emerging technologies, favoring proven systems with established standards [23].
- **Performance Perception Risk**: Lower resolution and non-real-time operation may lead to perceived inferiority compared to cameras, even if RF sensing provides unique advantages.

3.2. Market Size Analysis

3.2.1. Market Potential

This section evaluates market potential to provide data-driven insights into commercial viability. From an economic perspective, the opportunity for RF sensing based on static holography must be evaluated within the broader global security and surveillance market, which is both large and regionally differentiated. The global video surveillance market is estimated at approximately €62–70 billion in 2024, with projections exceeding €100 billion by 2030, reflecting sustained investment in security infrastructure worldwide [16], [24]. When including adjacent segments such as smart security systems, sensors, integrated monitoring platforms, and AI-enabled infrastructure protection technologies, the total addressable ecosystem exceeds €120 billion globally (overall CAGR ~9–11%) [24].

Table 2 – Global Surveillance & Security Market (2024)

Market	Market Size (2024)	Market Share	Key Technologies
Total Global Surveillance & Security Market (All Technologies)	~€125–135 B	100%	Total global market including all security and surveillance systems, infrastructure, platforms, software, and services (Video surveillance, access control, perimeter protection, sensors, analytics, monitoring platforms, integrated security systems).
Video Surveillance Systems	~€62–70 B	48–53%	Video surveillance cameras, NVRs, VMS, and related infrastructure (video management systems, storage, AI video analytics).
Access Control & Perimeter Security	~€20–25 B	16–19%	Access control systems, intrusion detection, perimeter protection systems.
Smart Security Systems (Integrated Solutions)	~€18–22 B	14–17%	Integrated smart security solutions including IoT, software, cloud platforms, and analytics.
Screening & Inspection Technologies	~€10–13 B	8–10%	X-ray and millimeter-wave scanners, inspection systems (explosive and handheld detectors).
Other Sensor-Based Technologies	~€7–10 B	5–7%	Thermal cameras, radar systems, LiDAR, biometric systems, and other sensors.
RF Sensing & RF Holography (Emerging Niche)	~€0.5–1.5 B	<1%	RF sensing, RF holography, non-line-of-sight monitoring, through-wall detection, device-free sensing.

Regional distribution of this market highlights important economic dynamics. North America, led by the United States, accounts for approximately 30–35% of global security and surveillance spending, driven by high investment in critical infrastructure protection, airport security, defense modernization, and advanced technology adoption [16], [24], [25]. The region is characterized by early-adoption behavior and strong demand for solutions that combine operational performance with compliance, risk reduction, and liability mitigation. The United States Transportation Security Administration (TSA) and airport modernization programs continue to increase investment in intelligent monitoring systems, particularly for restricted and high-security areas [26]. This creates a favorable environment for RF holography-based sensing, particularly in restricted airport zones, secure storage environments, defense-related facilities, privacy-sensitive indoor monitoring. The U.S. market is expected to lead adoption of complementary sensing layers integrated with existing security ecosystems rather than standalone deployments.

The EMEA region represents approximately 25-30% of the global market, with growth strongly influenced by regulatory frameworks such as the General Data Protection Regulation (GDPR) and increasing public and private investment in transportation security, urban resilience, critical infrastructure protection, and cultural heritage preservation [27], [28], [29]. In Europe in particular, the need to balance security with privacy is accelerating demand for non-intrusive sensing technologies, positioning RF sensing as a relevant alternative to camera-based systems. In parallel, European initiatives related to smart infrastructure, critical entities resilience, and privacy-preserving technologies are creating favorable conditions for the adoption of advanced RF-based monitoring systems [31], [32]. Europe represents one of the most strategically attractive regions for RF holography due to the strong regulatory focus on privacy and data minimization under GDPR. Traditional camera-heavy surveillance systems increasingly face legal and ethical scrutiny, especially in museums, public institutions, transportation hubs, and smart buildings. By 2030, European investment trends are expected to favor privacy-preserving sensing, invisible monitoring infrastructures, non-biometric detection systems, security solutions with limited personal data collection. This makes RF holography particularly relevant because it does not require facial recognition, it can operate through walls, it enables hidden deployment, it minimizes visual surveillance concerns. Museums and cultural heritage protection are expected to become one of the highest-value niche applications in Europe.

Asia-Pacific is currently the fastest-growing region, accounting for approximately 35-40% of global market share, supported by rapid urbanization, smart city initiatives, transportation infrastructure expansion, and rising public-security investments [11], [30]. Markets such as China, India, Japan, South Korea, and Southeast Asia are driving volume growth through large-scale infrastructure modernization and airport expansion projects. However, adoption dynamics in Asia-Pacific tend to be more cost-sensitive compared to Western markets, favoring scalable and infrastructure-integrated solutions [30], [33].

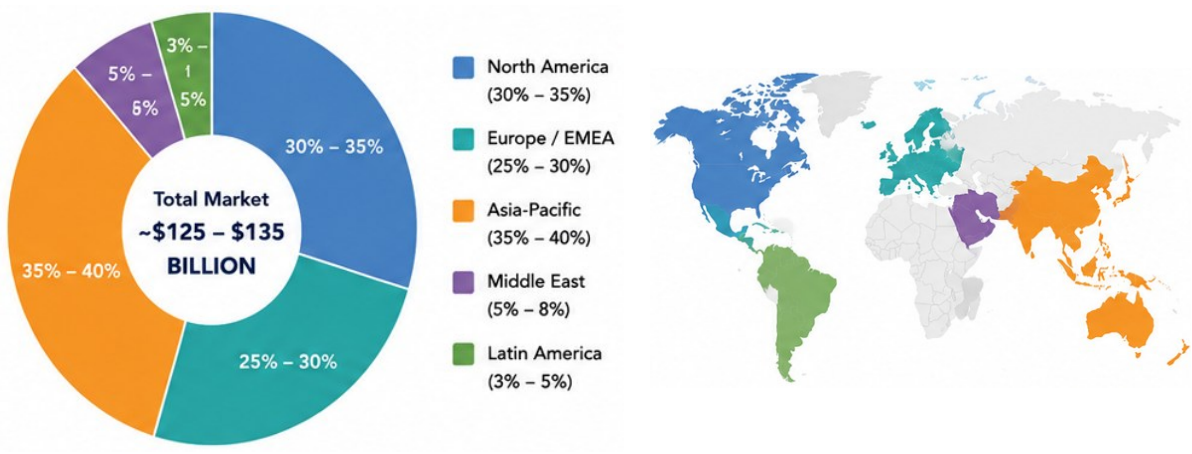


Figure 2 – Global Surveillance & Security Market by region (2024)

Table 3 – Global Surveillance & Security Market Trend by Region (2024–2030)

Region	2024 Market Share	2024 Market Value	Expected CAGR (2024–2030)	2030 Trend	Key Growth Drivers
North America	30–35%	€36–42B	7–9%	Mature but high-value market	Airport security, critical infrastructure, AI analytics, privacy compliance
Europe / EMEA	25–30%	€30–36B	8–10%	Strong regulatory-driven growth	GDPR-compliant surveillance, cultural heritage protection, smart transportation
Asia-Pacific	35–40%	€42–48B	10–14%	Fastest-growing region	Smart cities, airport expansion, urbanization, public safety investments
Middle East & Africa	5–8%	€6–9B	9–12%	Emerging strategic market	Mega infrastructure projects, border security, smart airports
Latin America	4–6%	€5–7B	7–9%	Gradual adoption	Urban security modernization, transportation hubs

When focusing specifically on application-driven potential, it becomes clear that the economic opportunity is not evenly distributed across use cases. High-security environments such as airports, critical infrastructure facilities, logistics hubs, secure warehouses, and museums represent a smaller volume but a disproportionately high share of value due to stricter operational requirements, higher security budgets, and greater willingness to invest in advanced detection technologies.

Based on aggregated analysis of infrastructure-security investment trends, transportation-security expenditure, and sector-specific operational requirements, a realistic distribution of the addressable opportunity for RF static holography sensing can be approximated as follows [25], [26], [28], [29], [31]:

- Airports and transportation security: ~40–50%
- Critical infrastructure and secure facilities: ~25–35%
- Museums and cultural heritage: ~10–15%
- Other smart security/building applications: ~10–15%

This segmentation reflects both investment intensity and unmet technological needs, particularly in environments where existing technologies such as CCTV cameras, RFID systems, motion detectors, or conventional scanners exhibit structural limitations. In many high-security environments, conventional solutions require direct line-of-sight operation, wearable tags, active cooperation, or visible installations, which can reduce effectiveness or increase operational complexity [34], [35].

Unlike RF sensing approaches focused primarily on motion or occupancy detection, static holography enables passive environmental reconstruction through computational imaging techniques using ambient radio-frequency emissions [4], [10]. This capability positions the technology closer to infrastructure-based imaging and advanced situational awareness systems rather than traditional IoT sensing alone and it introduces a differentiated value proposition by enabling:

- Non-line-of-sight detection
- Privacy-preserving sensing without cameras
- Through-wall monitoring capabilities
- Hidden or invisible deployment architectures
- Passive and non-cooperative sensing mechanisms

These capabilities are particularly relevant in restricted, security-sensitive, or privacy-regulated environments where unobtrusive monitoring is required. Unlike traditional active scanners or camera-based analytics, RF static holography can operate using ambient radio-frequency signals and reconstruct environmental changes without relying exclusively on visual information or wearable devices [1], [2], [36].

Importantly, RF sensing should not be positioned as a replacement for the entire surveillance market, but rather as a specialized and high-value complementary layer within existing security ecosystems. This technology is most economically attractive in scenarios where conventional systems face operational blind spots, privacy limitations, or deployment constraints.

Although RF static holography presents potential applicability across multiple security and infrastructure domains, the commercialization strategy intentionally focuses on high-security and privacy-sensitive infrastructure environments where the technology demonstrates clear operational differentiation and economic value like airports, transportation-security areas, museums, and cultural heritage infrastructures being identified as the most commercially attractive early-adoption segments. This prioritization is also based on the results of the functional requirements analysis and ethical appropriateness assessment, which identified these environments as particularly suitable for privacy-preserving and non-intrusive sensing technologies.

These application domains combine high-security requirements with strong operational constraints related to public accessibility, asset protection, and unobtrusive monitoring. Furthermore, airports and cultural heritage environments represent economically attractive early-adoption markets due to their relatively high security investment capacity, ongoing digital infrastructure modernization, and increasing regulatory emphasis on privacy-aware monitoring solutions [28], [29], [37], [38]. As a result, these sectors provide a strategically coherent entry point for RF static holography as a complementary sensing layer within existing security ecosystems, while avoiding some of the ethical and societal concerns associated with large-scale public or workplace surveillance applications.

This economic framing provides the foundation for defining the Total Addressable Market (TAM) and Serviceable Available Market (SAM) in the following sections, translating macro-level trends into a realistic and investable market scope.

3.2.2. Total Addressable Market (TAM)

The Total Addressable Market (TAM) represents the overall long-term global economic opportunity for RF sensing based on static holography within the broader intelligent security, infrastructure monitoring, and surveillance ecosystem. The TAM is evaluated using both top-down and bottom-up approaches to provide a realistic estimate of long-term commercial potential. From a top-down perspective, RF holography operates within the wider global smart-security and intelligent-surveillance market, including video surveillance, smart sensing, intrusion detection, access control, critical infrastructure protection, and AI-based monitoring systems. Industry analysts estimate that the combined global market for intelligent surveillance and smart-security technologies exceeded approximately €120B in 2024 and is expected to surpass €160B by 2030 [11], [16]. However, RF static holography does not target the entire surveillance ecosystem. Its commercial relevance is concentrated in specialized environments where privacy-preserving sensing, hidden infrastructure deployment, non-line-of-sight monitoring, and passive environmental detection provide operational advantages over conventional technologies. Consequently, the economically relevant market segment is substantially narrower than the overall surveillance market. The primary target sectors include airport and transportation-security infrastructures, critical infrastructure and secure operational facilities, museums and cultural heritage environments, secure logistics and restricted-storage infrastructures. Applying these segmentation constraints results in an estimated specialized addressable market of approximately €8–12B globally in 2024, with projected expansion toward €18–25B by 2030 as infrastructure-security digitization and privacy-oriented monitoring adoption increase [24], [28], [30]. From a bottom-up perspective, TAM estimation can be derived from the number of potential deployment sites and the expected infrastructure value per deployment.

<u>Airports and Transportation Security</u>

Globally, there are more than 17.000 commercial airports, including approximately 4.000 medium-to-large international airports with advanced security infrastructures [30]. However, realistic RF holography adoption is likely to focus initially on high-security operational zones rather than full-airport deployments. Assuming 2.000 strategically relevant airports globally and average deployable security-zone value between €300k–€800k, phased deployment across baggage handling, customs corridors, restricted storage, and airside operational areas the long-term airport-related TAM is estimated at approximately €2–4B globally.

Museums and Cultural Heritage

UNESCO and ICOM statistics indicate the existence of more than 95.000 museums globally, although only a limited subset represents high-security or high-value cultural institutions requiring advanced infrastructure monitoring [37], [39]. Assuming 5.000–10.000 security-sensitive museums and heritage institutions average deployment values between €75k–€250k the museum-related TAM is estimated at approximately €0.5–1.5B globally.

Critical Infrastructure & Secure Facilities

Critical infrastructure protection includes energy facilities, secure government storage, defense logistics, data-sensitive industrial environments. This segment represents one of the largest long-term opportunities due to high security spending and increasing adoption of layered monitoring systems. Estimated TAM contribution is €4–6B globally.

Overall, the TAM demonstrates that RF static holography addresses a substantial long-term market opportunity, particularly as infrastructure operators increasingly seek:

- privacy-preserving monitoring;
- invisible security architecture;
- non-cooperative sensing solutions;
- complementary sensing layers beyond traditional CCTV systems.

3.2.3. Service Addressable Market (SAM)

While the TAM reflects the broad long-term opportunity, the Serviceable Available Market (SAM) represents the realistically reachable market based on technological maturity, regulatory compatibility, operational readiness, and the initial commercialization strategy. Following the functional requirements analysis and ethical appropriateness assessment, the initial commercialization strategy focuses primarily on airport restricted-security environments and museums and cultural heritage infrastructures. These sectors were selected because they combine high-value protected assets, strong security requirements, privacy-sensitive operational conditions, operational limitations of conventional surveillance systems, and relatively high willingness to invest in advanced monitoring technologies. Importantly, these sectors also align with the current maturity level of RF static holography, which is presently more suitable for targeted infrastructure monitoring, anomaly detection, and hidden environmental sensing than for continuous large-scale real-time surveillance.

Airports and Transportation Security

The airport-security segment represents the most commercially attractive early-stage market opportunity. The SAM focuses specifically on medium and large international airports, high-security baggage-handling zones, customs and restricted-access corridors, secure logistics and operational-storage areas, primarily within Europe, North America, and selected Asia-Pacific transportation hubs. Based on ACI and IATA infrastructure statistics [30], [38], approximately 1.200–1.500 airports globally match the operational profile suitable for advanced RF sensing deployments. Assuming phased deployment values between €250k–€500k per airport, selective deployment focused on critical operational zones rather than full-airport coverage, a long-term serviceable airport-security SAM is estimated at approximately €337M–€675M.

Museums and Cultural Heritage

The museum and cultural heritage segment represents a smaller but highly differentiated market in which privacy-preserving and hidden sensing capabilities provide substantial strategic value. The SAM focuses on national museums, high-value exhibition environments, protected archives, artifact-storage infrastructures, particularly within Europe, North America, and East Asia. UNESCO and ICOM data suggest that approximately 3.000–6.000 institutions globally represent high-security or high-value cultural infrastructures [37], [39]. Assuming deployment values between €75k–€150k per institution, a long-term museum-focused SAM is estimated at approximately €337M–€675M.

Combined SAM

Combining airport-security and cultural-heritage deployments results in an estimated initial SAM of approximately €674M–€1.35B. This represents the realistic medium-term commercialization opportunity addressable through pilot deployments, infrastructure-integrator partnerships, public-sector procurement channels, and strategic security ecosystem collaborations.

3.2.4. Service Obtainable Market (SOM)

The Serviceable Obtainable Market (SOM) represents the realistically achievable market share during the first commercialization phase. Given the emerging maturity of RF static holography, the long procurement cycles typical of critical infrastructure markets, and the integration complexity associated with infrastructure-security deployments, early commercialization is expected to remain intentionally selective and partnership-driven. A realistic five-year commercialization objective may include:

- 10–20 airport deployments;
- 20–40 museum/cultural heritage deployments;
- several pilot integrations with infrastructure security partners.

Assuming the following average deployment values:

- Airport-security installations: €250k–€500k
- Museum and heritage deployments: €75k–€150k

the realistically obtainable SOM during the first five years is estimated at approximately €6M–€15M in cumulative deployment revenues, excluding recurring software and maintenance revenues. When recurring software licensing, maintenance agreements, and analytics subscriptions are included, the total five-year obtainable market value may reasonably approach €8M–€20M.

This SOM remains fully consistent with a phased deep-tech commercialization strategy based on pilot validation, lighthouse deployments, infrastructure-security partnerships, gradual deployment standardization, and progressive ecosystem integration. Rather than competing directly with mass-market surveillance platforms, RF static holography is positioned as a specialized complementary sensing layer capable of addressing operational blind spots where conventional surveillance systems exhibit structural limitations.

Table 4 – Estimated Service Obtainable Market

Deployment Type	**Expected Deployments**	**Revenue Potential**
Airport-security	10–20	€3M–€10M
Museums and cultural heritage	20–40	€1.5M–€4M
Pilot and specialized Projects	Multiple	€1M–€3M
Recurring software and maintenance	Installed base	€1M–€3M
Total SOM (5 years)	—	€8M–€20M

3.3. Market Segmentation Analysis

To better understand the commercial positioning of RF sensing based on static holography within the broader security and surveillance ecosystem, it is essential to segment the market according to operational environment, technology adoption drivers, security requirements, and infrastructure characteristics. Unlike conventional surveillance technologies that primarily rely on direct visual observation or cooperative systems, RF static holography addresses a more specialized market need focused on hidden, privacy-preserving, and non-line-of-sight sensing applications. The segmentation analysis therefore concentrates on environments where security sensitivity is high, conventional systems exhibit operational limitations, unobtrusive monitoring is required, advanced infrastructure investment already exists. Based on market trends, infrastructure investment patterns, and the functional appropriateness assessment conducted within this study, the target market can be segmented into:

- Infrastructure-security environments;
- Technology-driven security ecosystems;
- Behavioral and operational adoption factors;
- Strategic stakeholder profiles.

3.3.1. Infrastructure & Application Segmentation

The primary segmentation dimension relates to the operational environments in which RF static holography can generate measurable value. High-security and infrastructure-sensitive environments represent the most relevant early-adoption markets because they combine strong operational security requirements with increasing demand for privacy-preserving monitoring technologies. If we look at table below the segmentation highlights that RF static holography is most commercially attractive in scenarios where traditional technologies exhibit structural limitations associated with visibility, cooperative requirements, or privacy concerns.

Table 5 – Application Market Segmentation

Application Segment	Global Market Relevance	Primary Security Need	RF Holography Value Proposition	Growth Drivers	Source
Airports & Transportation Security	Very High	Restricted-area monitoring, anomaly detection, baggage/security zones	Through-wall detection, hidden sensing, passive monitoring	Airport modernization, smart infrastructure, security automation	[30], [38]

Museums & Cultural Heritage	Medium-High	Asset protection, visitor safety, unobtrusive surveillance	Invisible deployment, privacy-preserving monitoring	Cultural heritage protection, smart museums, GDPR compliance	[29], [37]
Critical Infrastructure	High	Intrusion detection, perimeter security, restricted access monitoring	Non-line-of-sight sensing, infrastructure resilience	National infrastructure protection investments	[28], [40]
Secure Warehouses & Logistics	Medium	Asset tracking, unauthorized access detection	Passive sensing without tags	Supply chain security, logistics automation	[41]
Smart Buildings & Commercial Facilities	Medium	Occupancy detection, security analytics	Integrated hidden sensing	Smart-building digitization	[11]

3.3.2. Technology-Specific Segmentation

The surveillance and security market can also be segmented according to the dominant sensing and monitoring technologies currently deployed across infrastructure environments. RF static holography can enter the market as a complementary sensing layer rather than a direct replacement for existing systems. This positioning demonstrates that RF holography occupies a highly differentiated niche within the surveillance ecosystem, particularly where:

- visual monitoring is insufficient;
- hidden deployment is advantageous;
- privacy regulations restrict camera usage;
- passive sensing is operationally preferred.

Table 6 – Technology-Specific Security Market Segmentation

Technology Type	Global Market Value (2024)	CAGR (2024–2030)	Main Operational Characteristics	Structural Limitations	Source
CCTV / Video Surveillance	€62–70B	8–10%	Visual monitoring, AI analytics	Requires line-of-sight, privacy concerns	[16], [24]
RFID & Access Tracking	€18–22B	10–12%	Tagged asset/person identification	Requires cooperative tagging	[18]
Biometric & AI Analytics	€15–20B	13–15%	Identity verification,	GDPR/privacy concerns	[43]

			behavioral analytics		
Motion & Presence Sensors	€8–12B	9–11%	Basic occupancy detection	Limited contextual awareness	[11]
X-Ray & Active Scanning Systems	€12–15B	7–9%	Object screening and threat detection	High infrastructure costs, checkpoint-based operation	[44]
RF Sensing / RF Holography	Emerging Niche	15–20% (estimated)	Through-wall, passive, hidden sensing	Processing complexity, infrastructure integration	[36]

3.3.3. Behavioral & Operational Segmentation

Behavioral segmentation focuses on the operational drivers influencing adoption decisions within security-sensitive infrastructures. Unlike consumer technologies, adoption in this market is primarily determined by:

- risk reduction;
- infrastructure resilience;
- operational efficiency;
- regulatory compliance;
- public acceptance.

This analysis indicates that the strongest adoption drivers for RF static holography are not purely technological, but operational and regulatory. In particular, the ability to provide sensing capabilities without relying on direct visual surveillance creates strategic differentiation in privacy-sensitive environments.

Table 7 – Behavioral Segmentation for RF Static Holography Adoption

Behavioral Factor	Market Influence	Target Segments	Target Segments
Privacy Sensitivity	Increasing demand for non-camera monitoring solutions	Museums, public infrastructures, transportation hubs	[27], [29]
Security Criticality	Higher willingness to invest in layered sensing systems	Airports, critical infrastructure, government facilities	[28], [38]

Infrastructure Modernization	Adoption driven by smart-security upgrades	Airports, smart buildings, logistics hubs	[11], [30]
Operational Discretion	Preference for hidden/invisible monitoring systems	Museums, secure storage, restricted areas	[29], [37]
Integration Complexity	Adoption depends on compatibility with existing systems	Large infrastructure operators, system integrators	[40]
Regulatory Compliance	GDPR and privacy laws influence technology selection	European markets, public infrastructures	[27]

3.3.4. Target Market Profiling

The RF sensing ecosystem based on static holography targets multiple stakeholders operating within the security, infrastructure, and smart-monitoring sectors. The following profiles represent the most commercially relevant actors within the early go-to-market strategy.

a. Airport Infrastructure Operators

Airport operators represent one of the most attractive target segments due to their continuous investment in advanced security systems, restricted-area monitoring, and infrastructure modernization.

Key Stakeholders: International airports, Airport authorities, Airside security operators, Baggage handling operators.

Example Organizations: ACI Europe, International Air Transport Association, Major airport groups.

Strategic Need: Monitoring restricted zones, detecting unauthorized presence, enhancing situational awareness without intrusive systems.

b. Museums & Cultural Heritage Institutions

Museums and heritage institutions increasingly invest in advanced monitoring technologies to protect valuable assets while preserving visitor experience and complying with privacy regulations.

Key Stakeholders: National museums, Cultural heritage operators, Exhibition-space managers, Artifact preservation facilities.

Example Organizations: UNESCO, International Council of Museums.

Strategic Need: Monitoring restricted zones, detecting unauthorized presence, enhancing situational awareness without intrusive systems.

c. Security System Integrators

System integrators are essential commercialization partners because RF holography is likely to be deployed as part of broader security architectures rather than standalone systems.

Key Stakeholders: Smart-security integrators, Infrastructure-security solution providers, Airport security contractors.

Example Companies: Honeywell Building Technologies, Thales Group, Siemens Smart Infrastructure, Bosch Building Technologies.

Strategic Need: Complementary sensing layers, integration with CCTV and access-control systems, advanced analytics enhancement.

d. Critical Infrastructure Operators

Critical infrastructure operators represent a longer-term but highly valuable market segment.

Key Stakeholders: Energy infrastructure operators, secure logistics operators, government infrastructure agencies, defense-related facilities.

Strategic Need: Hidden intrusion detection, non-cooperative monitoring, infrastructure resilience and threat detection.

e. Smart Infrastructure & IoT Security Providers

As smart buildings and IoT-enabled infrastructures evolve, RF sensing may become integrated into broader intelligent-environment ecosystems.

Key Stakeholders: Smart-building platform providers, IoT infrastructure companies, occupancy and security analytics providers.

Strategic Need: Context-aware sensing, occupancy analytics, infrastructure intelligence without visual monitoring.

3.3.5. Strategic Segmentation Conclusion

The analysis demonstrates that RF sensing based on static holography is best positioned as a specialized infrastructure-security technology targeting high-value, privacy-sensitive, and operationally complex environments. While the broader surveillance market provides long-term expansion opportunities, the most strategically coherent early-adoption markets are airport restricted/security areas and museums / cultural heritage environments. These segments align strongly with the technological strengths of RF holography, current regulatory trends, infrastructure modernization programs, and the growing demand for privacy-preserving security architectures.

3.4. Market Needs & Trends

The security and surveillance market is undergoing a profound transformation driven by increasing infrastructure complexity, evolving threat scenarios, stricter privacy regulations, and the growing digitalization of public and critical environments. Traditional surveillance architectures based primarily on cameras, motion detectors, and physical access-control systems are increasingly being complemented by intelligent sensing technologies capable of improving situational awareness, operational resilience, and threat detection capabilities. Within this evolving landscape, RF sensing based on static holography emerges as a potential highly differentiated technology capable of addressing several unmet needs in high-security and privacy-sensitive environments. Technology's ability to operate without direct visual line-of-sight, through barriers/walls, and without requiring wearable tags or active cooperation aligns strongly with emerging market demands in airports, transportation infrastructures, museums, and restricted operational areas [4], [15], [24], [44].
The following subsections summarize the most relevant market trends and operational needs shaping the future adoption potential of RF sensing technologies.

a. Increasing Investment in Critical Infrastructure Security

Trend: Governments and infrastructure operators worldwide are significantly increasing investments in critical infrastructure protection due to rising geopolitical instability, terrorism risks, cyber-physical threats, and public safety concerns. Airports, transportation hubs, logistics infrastructures, and public facilities are undergoing major modernization programs integrating advanced sensing and intelligent surveillance systems [28], [30], [38].
Global airport infrastructure investments alone are expected to exceed hundreds of billions of dollars by 2040, driven by increasing passenger traffic and security requirements [30], [26]. Similarly, smart infrastructure and critical-security spending continue to grow across North America, Europe, and Asia-Pacific [11], [25].

Need: These environments require monitoring technologies capable of detecting unauthorized presence, identifying anomalous behavior, operating continuously under complex environmental conditions, and complementing existing surveillance systems without creating operational bottlenecks. RF static holography addresses these needs by enabling hidden monitoring, passive sensing, and non-line-of-sight detection, particularly in restricted or difficult-to-monitor areas.

b. Growing Demand for Privacy-Preserving Surveillance

Trend: Privacy concerns and regulatory pressures are reshaping the surveillance industry, particularly in Europe under frameworks such as the General Data Protection Regulation (GDPR). Public acceptance of camera-intensive surveillance systems is increasingly challenged in environments involving visitors, passengers, or employees. This trend is especially visible in museums, public infrastructures, transportation hubs, and smart public spaces, where balancing security and privacy has become a strategic requirement [29].

Need: Organizations increasingly require security technologies capable of reducing dependence on visual surveillance, minimizing biometric-data collection, and preserving anonymity while maintaining situational awareness. RF sensing based on static holography directly addresses this market need because it does not rely on facial recognition, does not capture optical imagery, and can reconstruct environmental changes without exposing sensitive visual information [4]. This privacy-by-design characteristic represents one of the strongest strategic differentiators of this technology.

c. Operational Limitations of Conventional Surveillance Systems

Trend: Existing surveillance technologies continue to face structural operational limitations in complex security environments. CCTV systems require direct line-of-sight visibility and can be affected by blind spots, poor lighting conditions, occlusions, and environmental obstacles. Similarly, other systems require tagged assets or cooperative identification mechanisms, while conventional motion detectors often struggle with contextual interpretation and false positives [34], [35].

Need: Security operators increasingly seek complementary sensing layers capable of detecting concealed objects or individuals, operating through walls or barriers, and monitoring areas invisible to cameras. RF static holography introduces a differentiated sensing capability because it can exploit ambient RF signals, reconstruct static environmental changes, and identify presence or object displacement even without visual access, [36].
This capability is particularly valuable in airport restricted zones, secure storage environments, museum backrooms, and infrastructure maintenance areas.

d. Expansion of Smart Infrastructure and Intelligent Security Ecosystems

Trend: The global expansion of smart infrastructure and connected environments is accelerating the integration of intelligent sensing technologies into existing operational ecosystems. Airports, museums, logistics facilities, and public infrastructures increasingly deploy IoT systems, AI-enabled monitoring, digital twins, and centralized security platforms [34], [35]. Security is progressively shifting from isolated hardware systems toward integrated situational-awareness ecosystems combining multiple sensing technologies.

Need: Security operators increasingly seek complementary sensing layers capable of detecting concealed objects or individuals, operating through walls or barriers, and monitoring areas invisible to cameras. RF static holography introduces a differentiated sensing capability because it can exploit ambient RF signals, reconstruct static environmental changes, and identify presence or object displacement even without visual access [5].
This capability is particularly valuable in airport restricted zones, secure storage environments, museum backrooms, and infrastructure maintenance areas.

e. Increasing Protection Needs for Cultural Heritage and High-Value Assets

Trend: Museums and cultural heritage institutions are facing increasing pressure to improve asset protection while preserving visitor experience and minimizing intrusive security measures [29], [39], [45]. At the same time, theft prevention, artifact monitoring, and restricted-area control remain critical operational priorities. The global growth of cultural tourism and digital heritage initiatives is increasing investment in advanced monitoring and smart-museum technologies.

Need: Museums require security solutions that are discreet, minimally invasive, architecturally compatible, and privacy conscious. RF static holography is particularly aligned with these needs because sensing devices can be hidden behind walls, integrated invisibly into infrastructure, and deployed without altering the visitor experience. This creates a significant competitive advantage compared to visible surveillance installations or intrusive scanning systems.

f. Rising Importance of Layered Security Architectures

Trend: Modern security strategies increasingly rely on layered security architectures combining cameras, access-control systems, biometric technologies, environmental sensors, and AI analytics [42], [43]. No single technology is considered sufficient for high-security environments, particularly in transportation and critical infrastructures.

Need: Infrastructure operators increasingly require complementary sensing technologies capable of filling operational blind spots left by conventional systems. RF static holography can provide secondary verification, hidden monitoring layers, and passive environmental sensing, strengthening overall infrastructure resilience. Importantly, the technology is best positioned not as a replacement for CCTV or other monitoring systems, but as a complementary security layer integrated into broader situational-awareness ecosystems.

g. Increasing Interest in Passive and Non-Cooperative Sensing

Trend: Traditional security systems often require active user cooperation, tagged objects, wearable devices, or checkpoint-based screening procedures. However, emerging security requirements increasingly prioritize passive and non-cooperative sensing approaches capable of monitoring environments continuously and unobtrusively [40].

Need: Airports, museums, and secure infrastructures require technologies capable of monitoring environments continuously, detecting anomalies passively, and minimizing operational disruption. RF static holography satisfies this demand because it operates using ambient RF signals, does not require direct interaction, and can detect environmental changes without visible infrastructure or cooperative devices. This capability aligns strongly with next-generation intelligent security architectures.

3.4.1. Strategic Trend Conclusion

The analyzed trends demonstrate that the market environment is becoming increasingly favorable for advanced RF sensing technologies based on static holography. The convergence of infrastructure modernization, privacy regulation, intelligent security ecosystems, and the limitations of conventional surveillance technologies, creates a strong strategic rationale for the adoption of complementary sensing approaches. Among all potential applications, airports and museums emerge as particularly attractive early-adoption environments because they combine high operational-security requirements, growing privacy sensitivity, strong infrastructure investment, and clear unmet technological needs. This positioning supports the subsequent value-chain and commercialization analysis by demonstrating that RF static holography is aligned not only with technological innovation trends, but also with broader economic, regulatory, and operational transformations within the global security market.

3.5. Value and Use-Case Analysis

This section transitions the market analysis from technological capability to practical and economic value creation. By analyzing the operational impact of RF sensing based on static holography, it is possible to identify where the technology generates measurable advantages within both institutional security ecosystems and public-space monitoring environments. Unlike conventional surveillance systems that rely on cameras, wearable tags, or direct line-of-sight sensing, RF static holography enables passive and privacy-preserving monitoring through hidden infrastructure and ambient radio-frequency signals [35].

The value proposition is particularly relevant in environments where security, privacy, and unobtrusive monitoring must coexist. In airports, museums, restricted logistics areas, and secure facilities, existing technologies often generate operational blind spots, high maintenance requirements, or privacy concerns. RF holography introduces a complementary sensing layer capable of detecting environmental changes, unauthorized presence, and object displacement without visible monitoring infrastructure.

From a market perspective, technology creates value across two interconnected dimensions:

- Infrastructure and Security Ecosystems (B2B)
- Public-Space and Asset-Protection Environments (B2C/B2B2C)

The analysis evaluates value creation through four principal dimensions:

- Operational Security Efficiency: reducing blind spots, false negatives, and dependency on visible surveillance infrastructure.
- Privacy-Preserving Monitoring: enabling compliance with increasingly strict privacy and ethical requirements.
- Infrastructure Optimization: leveraging hidden or embedded deployments with limited user interaction requirements.
- Risk Reduction and Asset Protection: improving detection of unauthorized movement, object removal, or intrusion events.

The resulting ecosystem positions RF sensing not as a replacement for conventional surveillance systems, but as a high-value complementary intelligence layer within existing security architectures.

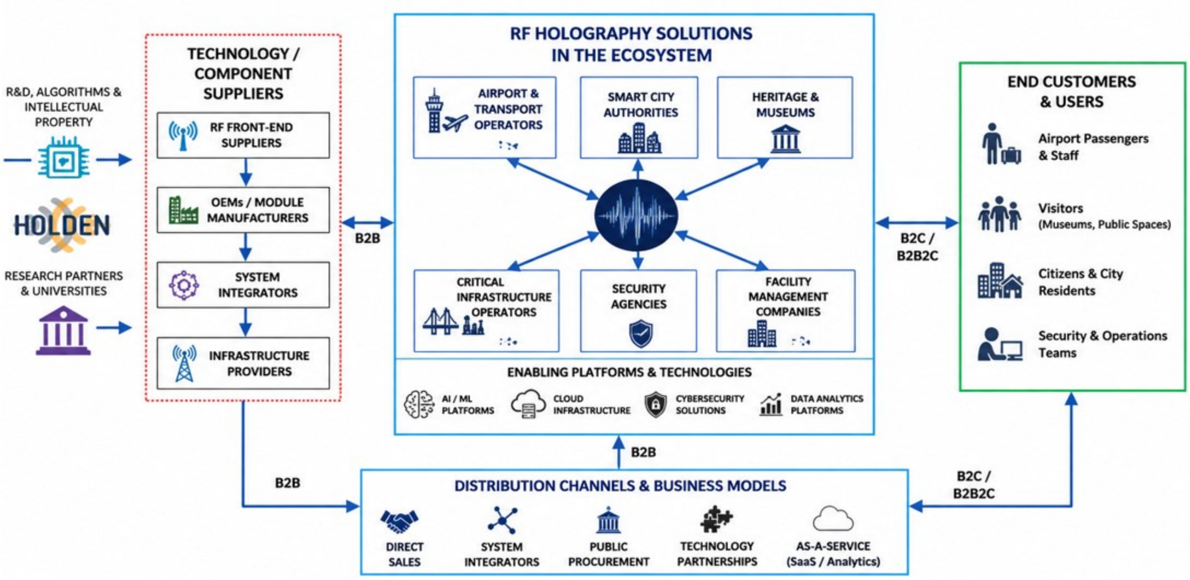


Figure 3 – RF Holography Value Chain and Business Channels

3.5.1. The B2C / Public-Environment Value Chain: Museums, Cultural Heritage, and Public Spaces

In public-facing environments such as museums, galleries, exhibitions, and cultural heritage facilities, RF sensing based on static holography creates value by enabling discreet and continuous monitoring without disrupting visitor experience or introducing invasive surveillance mechanisms. In these environments, technology functions as an invisible protective layer integrated into walls, ceilings, or existing infrastructure. Unlike RFID systems, which require tags attached to objects, or CCTV systems that depend on direct visibility and continuous visual recording, RF holography can detect environmental changes, unauthorized object movement, and abnormal presence patterns even under low visibility or partially obstructed conditions [34], [35].

Market Opportunity

The cultural heritage protection market is increasingly investing in intelligent and privacy-compliant security systems. Museums and heritage institutions face growing pressure to improve security against theft, vandalism, and unauthorized handling of valuable artifacts while maintaining an open and visitor-friendly environment [29], [45]. European museums alone receive hundreds of millions of annual visitors, while international airport retail and exhibition areas increasingly require hybrid security approaches combining analytics, monitoring, and unobtrusive detection systems [28], [37].

RF holography addresses several unmet needs within these environments:

- Hidden security monitoring
- Non-invasive sensing
- Protection of sensitive or high-value assets
- Reduced dependence on visible cameras
- Enhanced monitoring in low-light or obstructed conditions

Primary Customers

Primary adopters within this segment include Museums and cultural heritage institutions, Exhibition centers, Galleries and archives, Airport public-security operators, Public infrastructure operators, Smart-building integrators.

Key Benefits

RF holography offers several operational and strategic advantages that make it particularly well suited for sensitive or protected environments. Because the sensing infrastructure can remain concealed behind walls or architectural features, the technology preserves the visual integrity of historic or architecturally significant spaces while operating unobtrusively in the background. At the same time, it provides a more privacy-conscious alternative to traditional camera systems, as RF sensing does not continuously record identifiable visual information, making it better aligned with GDPR-oriented monitoring practices.

Another major strength of the system is its ability to detect movement and environmental changes even when direct lines of sight are blocked. This non-line-of-sight capability allows monitoring to extend into hidden or obstructed areas that conventional surveillance technologies may fail to cover. Operationally, technology also reduces friction because it does not rely on tags, wearables, or any active participation from users.

From a security perspective, RF holography can enhance asset protection by identifying unusual movement patterns or object displacement events in real time. Rather than replacing existing security infrastructure, it acts as a complementary monitoring layer that strengthens CCTV and access-control systems by covering blind spots and other difficult-to-monitor spaces.

3.5.2. The B2B Value Chain: Airports, Critical Infrastructure, and Security Operators

In high-security environments, RF sensing based on static holography operates as an advanced situational-awareness layer integrated into broader security ecosystems. Rather than replacing existing surveillance systems, the technology augments airport security infrastructures, restricted-access monitoring systems, and critical-facility protection architectures. Within this value chain, system integrators, airport authorities, infrastructure operators, and security technology providers deploy RF holography as part of multi-layered security frameworks combining CCTV analytics, Access control systems, Radar technologies, RFID systems, Intrusion detection, Edge AI analytics.

Technology is particularly valuable in areas where conventional monitoring technologies exhibit operational limitations, including hidden or blind-zone environments, storage and baggage handling areas, restricted corridors, secure logistics zones, through-wall monitoring requirements.

Market Opportunity

Airports and critical infrastructures represent the largest high-value market segment for advanced sensing technologies due to continuously increasing investments in infrastructure security and risk mitigation [25], [26], [31].

Global airport security spending is projected to grow substantially toward 2030, driven by passenger traffic growth, smart airport transformation, increasing geopolitical risks, automation of security operations, demand for privacy-compliant monitoring technologies. Static holography aligns with these trends by enabling passive sensing capabilities without introducing highly intrusive scanning architectures.

Primary Customers

Key stakeholders within this ecosystem include airport authorities, security operations centers, infrastructure operators, homeland security agencies, system integrators, smart-building and smart-city providers, transportation-security contractors.

Integrated Professional Services

Within the B2B ecosystem, value is amplified through integration with complementary security and operational services:

- Security Analytics Platforms: RF sensing data can feed centralized monitoring systems for anomaly detection and incident analysis.
- AI-Assisted Threat Detection: Combined with AI-based analytics, RF holography can support behavioral pattern analysis and threat identification.
- Emergency Response Integration: Real-time alerts can trigger rapid intervention workflows within airport or facility operations centers.
- Infrastructure Intelligence: Continuous environmental sensing enables predictive monitoring and operational optimization.
- Hybrid Security Architectures: RF holography complements cameras and access-control systems by covering non-visible or inaccessible areas.

Key Benefits

RF holography also provides important advantages in terms of resilience, scalability, and operational security. Because the sensing infrastructure can remain hidden from public view and embedded within existing architectural elements, deployments are inherently more tamper-resistant and difficult for intruders to identify or bypass. This discreet integration strengthens the overall robustness of the security environment without introducing visually intrusive equipment.

Technology is particularly valuable in reducing surveillance blind spots. Unlike conventional optical systems that depend on direct visibility and lighting conditions, RF sensing can extend monitoring coverage into areas where cameras are ineffective or obstructed. At the same time, the absence of continuous visual recording supports stronger privacy and ethical compliance by limiting the collection of identifiable personal data, thereby reducing both regulatory exposure and reputational risk.

Another significant advantage is the ability to scale deployments progressively across existing infrastructure. RF holography systems can be integrated into current security architectures in stages, allowing organizations to enhance protection without requiring complete replacement of established systems. In operational terms, automated environmental sensing also reduces reliance on constant human supervision, easing the workload placed on security personnel while enabling faster detection of anomalies.

By functioning as part of a multi-layer sensing architecture, RF holography ultimately enhances overall security resilience, improving detection reliability and strengthening situational awareness across complex environments.

3.5.3. Strategic Interpretation

The analysis indicates that the most significant commercial opportunity for RF sensing based on static holography does not lie in large-scale mass-market surveillance applications, but rather in specialized, high-value security environments where conventional monitoring technologies face clear operational and regulatory limitations. In these contexts, the combination of privacy-preserving sensing, non-visible infrastructure, and enhanced situational awareness creates a distinct strategic advantage. This is particularly relevant in environments where privacy requirements are stringent, where optical systems are constrained by blind spots or architectural barriers, and where the consequences of security failures carry substantial operational, financial, or reputational costs.

As a result, the proposed exploitation strategy prioritizes sectors in which these characteristics are most critical. Primary target markets include airports and transportation-security environments, where reliable monitoring and rapid anomaly detection are essential; museums and cultural heritage sites, where preservation requirements limit the deployment of intrusive infrastructure; and restricted infrastructure or secure operational zones that demand resilient, low-visibility security architecture.

This strategic positioning is consistent with current investment trends in advanced security technologies and aligns closely with the unique technical differentiation offered by RF holography. Rather than functioning as a standalone replacement for existing systems, the technology is best understood as a complementary sensing layer within next-generation security ecosystems, enhancing the effectiveness, resilience, and intelligence of broader monitoring infrastructures.

3.6. Competitive Landscape

The security and surveillance market is characterized by a highly fragmented technological landscape composed of multiple complementary detection and monitoring solutions. No single technology currently satisfies all operational requirements related to security, privacy, hidden deployment, real-time monitoring, and non-line-of-sight detection. As a result, modern security infrastructures increasingly rely on multi-layered architectures combining cameras, access-control systems, radar, RFID, motion sensors, AI analytics, and environmental monitoring technologies [11], [24], [33].

Within this landscape, RF sensing based on static holography represents an emerging and highly specialized sensing paradigm. Unlike traditional surveillance systems that rely primarily on optical visibility or tagged assets, RF holography reconstructs environmental changes and object presence through analysis of ambient radio-frequency reflections and propagation disturbances [4], [5], [9]. This enables through-wall sensing, hidden deployment, and privacy-preserving monitoring capabilities that are difficult to achieve using conventional technologies alone.

The competitive landscape is therefore not defined by direct substitution, but rather by overlapping and complementary functionalities across different technology categories. For targeted application domains like airports, museums, cultural heritage facilities, restricted infrastructure, and secure logistics areas, six principal competing technological groups can be identified [11], [18], [24], [25], [33]:

- CCTV & Computer Vision Systems
- RFID & Asset Tracking Systems
- Radar & Millimeter-Wave Detection Systems
- Motion & Environmental Sensors
- Access-Control & Biometric Security Systems
- RF Sensing & Wi-Fi-Based Environmental Intelligence

A structured overview is provided below.

Table 8 – Competitive Landscape Overview

Category	Technology / Devices	Typical Capabilities	Key Players / Examples
CCTV & Computer Vision	Cameras, AI video analytics, thermal imaging	Visual surveillance, facial recognition, object tracking	Axis, Bosch, Hikvision, Dahua, Sony
RFID & Asset Tracking	RFID tags, BLE tags, UWB tracking	Asset localization, inventory monitoring	Zebra Technologies, Impinj, Honeywell
Radar & mmWave Systems	Radar scanners, active RF imaging	Motion detection, concealed object detection	Vayyar, QinetiQ, Thruvision
Motion & Environmental Sensors	PIR sensors, occupancy sensors	Presence detection, intrusion alerts	Honeywell, Siemens, Johnson Controls
Access-Control & Biometrics	Badge systems, fingerprint/iris recognition	Identity verification, restricted access control	NEC, IDEMIA, Assa Abloy
RF Sensing & Static Holography	Passive RF sensing, holographic reconstruction	Through-wall detection, passive environmental mapping	Research-stage / Emerging Market

3.6.1. *CCTV & Computer Vision Systems*

CCTV and AI-enhanced video surveillance systems currently dominate the global security market. These technologies provide real-time visual monitoring, facial recognition, behavioral analytics, and object-tracking functionalities. Modern systems increasingly integrate artificial intelligence and cloud-based analytics to automate anomaly detection and threat identification [24], [33].

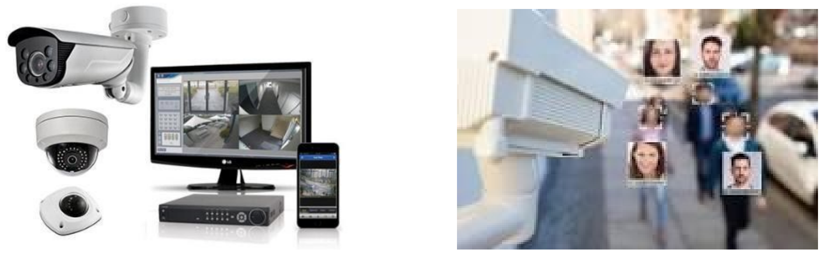


Figure 4 – CCTV & Computer Vision Systems

<u>Typical Applications</u>

This technology is widely deployed across a broad range of security-critical environments, including airport terminals, public surveillance networks, museums, smart-city infrastructures, and critical infrastructure facilities. Its versatility and long-standing market presence have made CCTV one of the most established and commercially mature components of modern security ecosystems.

<u>Key Market Players</u>

Major industry players include companies such as Axis Communications, Bosch Security, Hikvision, Dahua Technology, and Sony, all of which continue to invest heavily in AI-enhanced surveillance capabilities.

<u>Strengths</u>

One of the principal strengths of CCTV and computer vision systems lies in their ability to provide high levels of visual detail and strong forensic value. The direct visualization of events allows security personnel to rapidly interpret incidents, while AI-driven analytics can automate monitoring tasks and improve operational efficiency. The mature nature of the technology also enables broad interoperability with existing security infrastructures and access-control systems.

<u>Limitations</u>

Despite these advantages, conventional video surveillance technologies also present important operational and regulatory limitations. Their effectiveness depends heavily on direct line-of-sight conditions, meaning that performance can degrade significantly in environments affected by darkness, smoke, physical obstructions, or architectural complexity. In addition, continuous visual recording also requires significant storage capacity, network bandwidth, and ongoing data-management resources. Finally, because cameras and associated infrastructure are typically visible, they can unintentionally create predictable monitoring gaps or blind spots that sophisticated intruders may exploit.

Privacy & Ethical Considerations

Camera-based systems raise major ethical and regulatory concerns because they continuously capture personally identifiable visual information. In Europe particularly, increasing restrictions on biometric surveillance and facial recognition are reshaping deployment models [27],[28].

Strategic Position vs RF Holography

RF static holography complements CCTV systems by covering hidden or obstructed areas where optical systems fail. Unlike cameras, RF sensing can operate invisibly and without recording identifiable imagery.

3.6.2. RFID & Asset Tracking Systems

RFID-based systems are extensively used across industries for inventory tracking, logistics coordination, baggage handling, and asset-protection operations. These technologies operate through radio-frequency identification protocols in which tagged objects communicate with fixed readers positioned throughout an environment. Because of their reliability and scalability, RFID systems have become a core component of modern supply-chain and asset-management infrastructures. [35].

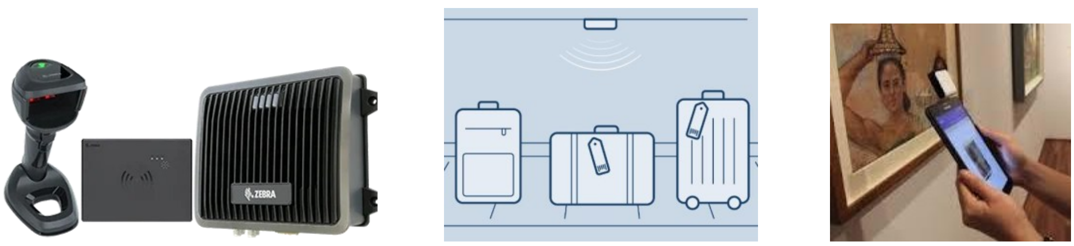


Figure 5 – RFID & Asset Tracking Systems

Typical Applications

Typical deployment areas include airport baggage-tracking systems, warehouse and logistics operations, museum asset management, inventory-control platforms, and secure supply-chain environments where the movement and status of physical assets must be monitored continuously.

Key Market Players

Major market participants in this sector include Zebra Technologies, Impinj, Honeywell, and Avery Dennison, all of which provide large-scale RFID and tracking solutions for industrial and security applications.

Strengths

One of the principal strengths of RFID systems is their high level of asset-tracking accuracy and their strong integration within existing logistics and supply-chain ecosystems. The technology supports efficient inventory automation, enables rapid identification of tagged objects, and can scale effectively across large operational infrastructures. These characteristics have made RFID an industry standard for asset visibility and operational efficiency.

Limitations

However, RFID systems also exhibit several structural limitations. Their operation depends entirely on the presence of physical tags attached to assets, meaning they cannot detect untagged objects, unauthorized items, or individuals moving within a monitored environment. In adversarial scenarios, tags may also be removed, damaged, or deliberately tampered with, reducing system reliability. Furthermore, RFID platforms generally provide only limited situational awareness, as they are designed primarily for object identification and tracking rather than broader environmental sensing or behavioral analysis.

Privacy & Ethical Considerations

From a privacy and ethical perspective, RFID technologies typically raise fewer concerns than camera-based surveillance systems because they focus on tracking tagged assets rather than continuously recording individuals. Nevertheless, risks related to unauthorized tracking, data interception, or signal exploitation remain relevant, particularly in high-security or sensitive operational environments.

Strategic Position vs RF Holography

In comparison, RF holography offers a strategically different sensing model. By eliminating dependence on physical tags and enabling passive environmental monitoring, RF holography can detect movement, object displacement, and environmental changes even when subjects are uncooperative, concealed, or intentionally attempting to avoid detection. This capability makes RF holography particularly valuable in security contexts where conventional asset-tracking approaches may be insufficient.

3.6.3. *Radar & Millimeter-Wave Detection Systems*

Radar and millimeter-wave imaging systems represent some of the closest technological counterparts to RF holography within the broader security and sensing landscape. These technologies operate by actively emitting radio-frequency signals to detect movement, identify concealed objects, or monitor environmental changes. Their ability to sense through certain materials and identify hidden threats has made them particularly important in advanced security and defense applications. [40], [42].

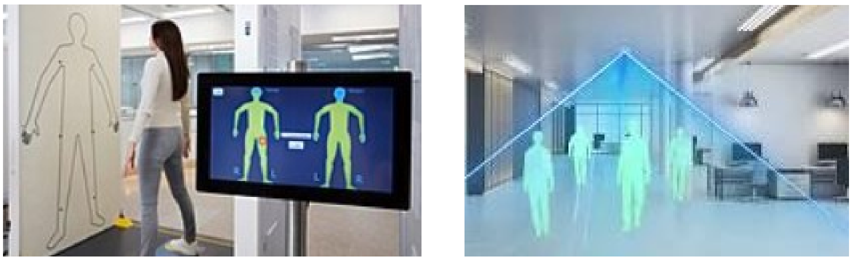


Figure 6 – Radar & Millimeter-Wave Detection Systems

<u>Typical Applications</u>

Typical deployment areas include airport body-scanning systems, perimeter-protection infrastructures, concealed-weapon detection platforms, automotive sensing technologies, and military or defense-oriented monitoring systems.

<u>Key Market Players</u>

Prominent market participants in this field include Vayyar, QinetiQ, Thruvision, and Rohde & Schwarz, all of which develop advanced RF-based sensing and detection solutions for security-critical environments.

<u>Strengths</u>

One of the primary strengths of radar and millimeter-wave systems is their ability to detect movement and objects even when direct visual observation is obstructed. These technologies provide high sensitivity to motion, strong object-detection capabilities, and effective performance in security-screening scenarios where traditional optical systems may fail. Their capacity for through-obstacle sensing makes them particularly valuable in environments requiring concealed-threat detection or enhanced situational awareness.

<u>Limitations</u>

Despite these advantages, radar-based systems often involve substantial infrastructure complexity and high deployment costs. Many solutions rely on active RF emission, which may introduce regulatory challenges or operational concerns depending on the deployment environment. In addition, installations are frequently visible and physically identifiable, potentially limiting discretion in sensitive architectural or public settings. Effective operation also typically requires sophisticated calibration and maintenance procedures, increasing implementation complexity.

Privacy & Ethical Considerations

From a privacy and ethical perspective, radar systems generally avoid the continuous capture of visual imagery, reducing some of the concerns associated with camera-based surveillance. However, body-scanning technologies may still generate ethical concerns related to perceived invasiveness, passenger acceptance, and public trust, especially in transportation-security environments.

Strategic Position vs RF Holography

Compared with these technologies, RF holography offers a distinct strategic differentiation through its emphasis on passive sensing. Rather than depending on dedicated active scanning infrastructure, RF holography leverages ambient radio-frequency environments to detect movement and environmental changes. This approach potentially reduces infrastructure visibility, lowers operational intrusiveness, and enables more discreet integration into sensitive or architecturally constrained environments.

3.6.4. *Motion & Environmental Sensors*

Environmental sensing technologies encompass a broad category of systems such as passive infrared (PIR) detectors, occupancy sensors, vibration sensors, and conventional intrusion-detection devices. These technologies are widely deployed as cost-effective security layers designed to detect basic environmental changes or unauthorized movement within monitored spaces [35]. Due to their simplicity, low power requirements, and ease of integration, they are commonly incorporated into both commercial and industrial security infrastructures.

Figure 7 – Motion & Environmental Sensors Systems

Typical Applications

Typical applications include intrusion-alarm systems, building automation platforms, smart-building environments, and the monitoring of restricted or access-controlled areas. rms

Key Market Players

Major market participants in this sector include Siemens, Honeywell, Johnson Controls, and Bosch, all of which provide integrated environmental sensing and building-security solutions.

Strengths

The primary advantages of these systems lie in their relatively low infrastructure cost, straightforward deployment processes, and compatibility with mature building-management ecosystems. Their low energy consumption and operational simplicity make them attractive for large-scale deployments where basic monitoring functionality is sufficient. As a result, environmental sensors are frequently used as foundational components within broader layered-security architectures.

Limitations

However, these technologies also exhibit important limitations in terms of intelligence and situational awareness. Conventional motion and occupancy sensors generally provide only binary or low-level event detection and lack the capability to identify specific objects, behaviors, or contextual environmental changes. False-alarm rates can also be relatively high, particularly in dynamic or crowded environments. In addition, these systems are typically unable to monitor through walls, architectural barriers, or visual obstructions, limiting their effectiveness in complex spatial environments.

Strategic Position vs RF Holography

In comparison, RF holography offers a substantially richer form of environmental sensing. By enabling passive monitoring of movement patterns, spatial changes, and concealed activity, RF holography can provide enhanced situational awareness that extends beyond the capabilities of traditional occupancy or motion-detection technologies. This broader environmental intelligence positions RF holography as a more advanced complementary sensing layer within next-generation security infrastructures.

3.6.5. Access-Control & Biometric Security Systems

Access-control and biometric security systems are designed primarily to manage identity verification and authorization processes through technologies such as badges, smart cards, biometric authentication, and digital credentialing platforms [32]. These systems play a central role in modern physical-security architectures by regulating access to restricted spaces and ensuring that only authorized individuals can enter protected environments.

Figure 8 – Access-Control & Biometric Security Systems

Typical Applications

Typical deployment areas include airport restricted zones, government facilities, critical infrastructure sites, and secure logistics or operational environments where strict identity management is essential.

Key Market Players

Leading companies in this sector include NEC, IDEMIA, Assa Abloy, and HID Global, all of which provide advanced authentication and access-management solutions for enterprise and governmental security applications.

Strengths

One of the principal strengths of access-control systems is their ability to provide strong identity authentication and enforce regulated entry policies within sensitive environments. These technologies are highly mature and benefit from extensive integration with enterprise-security infrastructures, workforce-management systems, and regulatory-compliance frameworks. Biometric authentication methods, in particular, can significantly strengthen identity assurance compared with traditional physical credentials alone.

Limitations

Despite these advantages, access-control technologies also present important operational limitations. Their effectiveness is generally confined to controlled entry points, meaning they cannot independently detect unauthorized presence, concealed movement, or suspicious activity occurring beyond established checkpoints. In addition, these systems remain vulnerable to insider threats, credential theft, misuse of authorized access, or social-engineering attacks that circumvent formal authentication processes.

Privacy & Ethical Considerations

From a privacy and ethical perspective, biometric systems are increasingly subject to regulatory and public scrutiny due to concerns surrounding the collection, storage, and use of sensitive biometric data. Questions related to surveillance practices, consent, data protection, and long-term biometric-data management have become central issues in both regulatory and societal discussions.

Strategic Position vs RF Holography

Within this context, RF holography occupies a complementary strategic position rather than a directly competing one. While access-control systems verify identity and regulate entry at designated checkpoints, RF holography can extend monitoring capabilities beyond those controlled boundaries by detecting unauthorized presence, concealed movement, or unusual environmental activity within protected spaces. This complementary functionality enhances overall situational awareness and strengthens layered-security architectures.

3.6.6. RF Sensing, Static Holography, and Competitive Advantage

RF sensing based on static holography introduces a fundamentally different sensing paradigm within the broader security and surveillance ecosystem. Unlike conventional surveillance technologies that rely on cameras, wearable devices, physical tags, or active user participation, RF holography reconstructs environmental conditions and object presence through the analysis of ambient radio-frequency reflections combined with computational reconstruction techniques. This creates a unique strategic position at the intersection of passive sensing, infrastructure intelligence, privacy-preserving monitoring, and discreet security deployment.

Privacy-by-Design and Ethical Compliance

A major component of technology's competitive differentiation lies in its privacy-by-design characteristics. In contrast to CCTV or biometric systems, RF holography does not inherently capture facial imagery, audio recordings, or directly identifiable personal data. As a result, technology significantly reduces many of the privacy and GDPR-related concerns associated with traditional surveillance approaches and aligns with the growing demand for ethically responsible and privacy-preserving monitoring solutions.

Hidden and Invisible Deployment

Another important differentiator is the possibility of hidden and invisible deployment. RF sensing infrastructure can remain concealed behind walls, ceilings, or architectural structures, allowing monitoring systems to operate unobtrusively while reducing the risk of tampering or deliberate circumvention. This capability is particularly valuable in environments such as museums, airports, cultural heritage sites, or architecturally sensitive facilities where visible security infrastructure may be undesirable or operationally limiting.

Non-Line-of-Sight Detection

RF holography also provides non-line-of-sight detection capabilities, enabling the monitoring of environmental changes and movement even when direct visibility is obstructed. This overcomes one of the principal limitations of optical surveillance technologies, which typically require clear visual access to monitored areas. By leveraging ambient RF propagation, the technology can extend situational awareness into hidden or inaccessible spaces that conventional camera systems may fail to cover effectively.

Passive and Non-Cooperative Sensing

In addition, the sensing model is inherently passive and non-cooperative. The system does not depend on badges, wearable devices, RFID tags, or any form of active participation from monitored individuals or protected assets. This characteristic makes the technology particularly relevant in scenarios involving uncooperative subjects, concealed intrusions, or environments where traditional tracking mechanisms may be impractical or vulnerable to tampering.

Complementary Infrastructure Intelligence

Rather than functioning as a replacement for existing security technologies, RF holography is strategically positioned as a complementary infrastructure-intelligence layer. Its primary value lies in enhancing existing surveillance and access-control ecosystems by adding environmental awareness capabilities that can cover blind spots, hidden areas, and operational gaps that conventional systems cannot fully address.

Strategic Differentiation Framework

From a strategic market perspective, RF static holography can be evaluated across five primary differentiation dimensions: privacy compliance, hidden deployment capability, non-line-of-sight detection, infrastructure complexity, and environmental intelligence. Across these dimensions, technology occupies a highly differentiated niche within the wider surveillance market. Its strongest competitive advantage emerges not from displacing existing systems, but from addressing structural limitations associated with visibility constraints, privacy concerns, exposed infrastructure, and dependence on cooperative sensing mechanisms.

3.7. Entry Barriers

This section consolidates the principal structural considerations shaping market entry for RF sensing based on static holography in security and surveillance environments. Unlike conventional security technologies that rely on cameras, wearable tags, or active scanning systems, RF holographic sensing introduces a novel sensing paradigm capable of passive, non-line-of-sight monitoring using ambient radio-frequency signals.

The commercialization pathway is therefore influenced not only by technological maturity, but also by infrastructure integration requirements, operational trust, procurement practices, and regulatory acceptance. To evaluate these dynamics, the analysis adopts a framework inspired by Porter's Five Forces, adapted to the specific characteristics of the security, surveillance, and critical infrastructure sectors.

The market is shaped by a complex ecosystem including Security system integrators, Airport and transportation authorities, Museum and heritage operators, Smart infrastructure vendors, CCTV and sensor manufacturers, RF hardware providers, Regulatory and public authorities.

Compared with mass-market surveillance technologies, RF static holography targets a more specialized segment characterized by high-security requirements, privacy-sensitive environments, and operational blind spots where conventional systems exhibit limitations. While this creates opportunities for differentiation, it also introduces substantial barriers related to validation, procurement cycles, and institutional trust.

3.7.1. Threat of New Entrants

<u>Technological Complexity and Infrastructure Integration (High Impact)</u>

RF static holography requires advanced signal processing, computational reconstruction algorithms, antenna engineering, and integration with existing security infrastructures. Unlike standard CCTV systems or RFID solutions, holographic RF sensing relies on reconstructing environmental changes from ambient radio-frequency fields, requiring sophisticated calibration and environmental modeling.

The complexity of integrating the technology into operational environments such as airports, museums, or restricted logistics areas creates a significant entry barrier for new competitors. In particular:

- Real-time or near-real-time environmental reconstruction remains computationally intensive;
- Through-wall sensing requires highly optimized RF architectures;
- False positive mitigation is critical in security environments;
- Deployment conditions vary substantially across buildings and infrastructure layouts

Moreover, institutional buyers in airport security and cultural heritage sectors typically require long validation periods, demonstration pilots, compliance certifications, integration with existing surveillance ecosystems. This creates high switching costs and slows the entry of inexperienced competitors [16], [28], [29], [30].

<u>Mitigation Strategy</u>

- Develop pilot projects with airports and museum authorities;
- Demonstrate operational value in restricted areas;

- Focus initially on complementary deployment rather than replacement of existing systems;
- Build partnerships with established security system integrators.

3.7.2. Bargaining Power of Suppliers

Dependence on Specialized RF and Processing Components (Moderate to High Impact)

RF holographic sensing systems depend on specialized hardware components including RF transceivers, Antenna arrays, Signal acquisition modules, Edge-computing processors, FPGA/GPU acceleration platforms. The semiconductor shortages experienced globally between 2020–2023 demonstrated the vulnerability of advanced sensing technologies to supply-chain disruptions [46]. Security infrastructure vendors relying on high-frequency RF components face risks related to Supplier concentration, long lead times, rising component costs, export restrictions on advanced electronics. In addition, some critical computational capabilities may rely on specialized chipsets optimized for signal reconstruction and edge inference.

Mitigation Strategy

- Diversify RF hardware suppliers
- Develop hardware-agnostic software architectures
- Use modular infrastructure integration approaches
- Prioritize partnerships with European and trusted semiconductor ecosystems

According to Deloitte and OECD infrastructure reports, supply-chain resilience has become a strategic priority for critical security infrastructure projects after the COVID-19 and semiconductor crises [28],[41].

3.7.3. Bargaining Power of Buyers (End-User Acceptance)

Institutional Procurement Conservatism and Trust Requirements (Moderate to High Impact)

The primary buyers for RF holographic sensing are expected to be Airport operators, Security authorities, Museums and heritage institutions, Critical infrastructure managers, Public-sector operators. These organizations are traditionally conservative in adopting novel surveillance technologies due to operational risk concerns, liability exposure, procurement regulations, public scrutiny, cybersecurity requirements.

Unlike commercial consumer technologies, adoption decisions in these sectors are driven less by novelty and more by reliability, compliance, operational continuity, false alarm minimization, interoperability with existing infrastructure. Furthermore, many institutions already rely heavily on CCTV systems, access control systems, RFID tracking, motion sensors, security personnel.

As a result, RF sensing may initially face skepticism unless positioned as a complementary capability solving specific operational blind spots.

Mitigation Strategy

- Position RF sensing as an augmentation layer rather than a replacement;
- Emphasize privacy-preserving monitoring;
- Demonstrate operational advantages in non-line-of-sight environments;
- Provide measurable pilot KPIs and validation datasets.

Studies on airport and infrastructure procurement consistently show that public-sector adoption cycles for security technologies are significantly longer than consumer technology adoption cycles [16], [38].

3.7.4. Industry Rivalry (Existing Competitors)

Mature and Highly Competitive Security Ecosystem (High Impact)

The security and surveillance market is highly mature and dominated by established technologies with strong incumbent vendors. Key competing technological groups include CCTV and AI video analytics, RFID and asset tracking systems, radar and millimeter-wave sensing, thermal imaging systems, LiDAR-based monitoring, smart motion detection systems Major market players include companies like Hikvision, Axis Communications, Honeywell, Bosch Security, Siemens, Dahua, Motorola Solutions. These companies benefit from established customer relationships, large installed infrastructure bases, existing maintenance contracts, integrated software ecosystems.

RF holographic sensing therefore enters a market where competitive pressure is not based solely on functionality, but also on vendor trust, ecosystem compatibility, procurement inertia, long-term support capabilities.

However, current competing technologies still exhibit structural limitations:

- CCTV requires line-of-sight visibility;
- RFID requires tags and cooperative tracking;
- Thermal imaging struggles with object differentiation;
- Radar systems often lack spatial reconstruction detail;
- Cameras raise major GDPR and privacy concerns.

This creates a differentiated niche opportunity for RF holography.

Mitigation Strategy

- Focus on operational blind spots where existing systems underperform;
- Target privacy-sensitive and non-line-of-sight scenarios;
- Integrate with existing surveillance architectures;
- Develop hybrid deployments with system integrators.

Industry analyses from MarketsandMarkets and Allied Market Research indicate that security operators increasingly seek multi-layered sensing architectures rather than single-technology solutions [11], [24].

3.7.5. Regulatory Barriers

Privacy, Security, and Ethical Compliance (Moderate to High Impact)

The ability of RF holographic sensing systems to operate through walls and hidden infrastructures may also trigger additional ethical scrutiny regarding proportionality, transparency, and acceptable use boundaries in public environments. The regulatory landscape is particularly important in Europe (GDPR), airports and transportation security, public cultural spaces, government-regulated infrastructure. Key concerns include data minimization, monitoring transparency, ethical surveillance boundaries, cybersecurity compliance, RF exposure regulations, and public acceptance.

Unlike CCTV systems, RF holography offers a major advantage because it does not inherently capture personally identifiable visual information. This aligns strongly with European privacy-by-design principles [27]. However, because technology can operate through walls and hidden infrastructure, transparency and governance mechanisms become essential to avoid concerns related to covert surveillance.

Mitigation Strategy

- Adopt “Privacy by Design” principles;
- Process data locally whenever possible;
- Avoid storage of reconstructable personal identity information;
- Develop transparent governance and ethical frameworks;
- Ensure GDPR and cybersecurity compliance from early development stages.

The European Commission and ENISA increasingly emphasize privacy-preserving sensing technologies for smart infrastructure and public security systems [27], [47].

Table 9 – Summary of Key Market Entry Barriers

Dimension	Barrier	Impact	Examples	Mitigation Strategy
Threat of New Entrants	Technological complexity and infrastructure integration	High	RF reconstruction, environmental calibration	Pilot deployments, integrator partnerships
Supplier Power	Dependence on specialized RF and semiconductor components	Moderate–High	Semiconductor shortages, RF hardware constraints	Supplier diversification, modular architectures
Buyer Power	Institutional conservatism and procurement complexity	Moderate–High	Airports, museums, public infrastructure	Complementary positioning, operational validation

Dimension	Barrier	Impact	Examples	Mitigation Strategy
Industry Rivalry	Mature surveillance ecosystem with incumbent vendors	High	CCTV, RFID, radar, thermal imaging	Focus on operational blind spots
Regulatory Barriers	GDPR, ethical surveillance, cybersecurity requirements	Moderate–High	Public-space monitoring regulations	Privacy-by-design and local processing

4. Exploitation/Business Plan – RF Holography in the Surveillance and Security Market

The exploitation strategy transforms HOLDEN's RF holography innovation into a scalable commercialization pathway for security-sensitive environments. Unlike traditional surveillance systems that rely on cameras, wearables, or active scanning architectures, the proposed solution introduces passive RF-based environmental sensing and holographic reconstruction as a new infrastructure intelligence layer for airports, heritage sites, and critical public infrastructure. The commercialization logic is based on embedding RF holography capabilities into existing infrastructure ecosystems rather than deploying standalone monitoring hardware. This approach minimizes operational friction, lowers deployment complexity, and creates scalable integration opportunities across both public-sector and private-sector security markets.

The strategy focuses on three primary commercialization dimensions:

- Infrastructure Security Modernization
- Privacy-Preserving Situational Awareness
- Scalable Infrastructure Intelligence Services

4.1. Business Model Canvas

Business Model Canvas defines the strategic framework for commercializing RF holography technology within airports, heritage environments, and smart infrastructure ecosystems. The solution combines passive RF sensing, holographic environmental reconstruction, and AI-driven situational awareness to create a scalable infrastructure-security platform. Unlike traditional surveillance architectures requiring dense camera deployments or active scanning checkpoints, HOLDEN's solution integrates into existing wireless and infrastructure environments, enabling continuous environmental awareness with reduced operational and privacy burden. The business model combines technology licensing, infrastructure integration, recurring analytics services, and strategic public-sector partnerships.

<table>
<tr><th>KEY PARTNERS</th><th>KEY ACTIVITIES</th><th>VALUE PROPOSITION</th><th>CUSTOMER RELATIONSHIPS</th><th>CUSTOMER SEGMENTS</th></tr>
<tr>
<td rowspan="3">• Airport technology providers
• Security system integrators
• Telecommunications providers
• Smart city ecosystem partners
• Research institutions and universities
• Public-sector agencies
• Infrastructure operators
• AI and cloud technology providers
• Heritage and cultural organizations</td>
<td>• RF holography algorithm development
• AI model training and optimization
• Infrastructure integration engineering
• Pilot deployment management
• Infrastructure analytics development
• Regulatory compliance management
• Cybersecurity and privacy protection
• Business development and partnership expansion
• Continuous product refinement and testing</td>
<td rowspan="3">• Privacy-preserving infrastructure monitoring
• Passive RF holography without cameras
• Real-time environmental awareness and anomaly detection
• Non-intrusive monitoring for public and sensitive spaces
• Scalable integration into existing infrastructure ecosystems
• GDPR-friendly sensing architecture
• Situational awareness without active participation
• AI-driven infrastructure intelligence and analytics
• Smart infrastructure modernization platform</td>
<td>• Long-term infrastructure partnerships
• Pilot-based onboarding and validation
• Dedicated technical integration support
• Strategic co-development agreements
• Recurring software maintenance and upgrades
• Analytics and AI optimization
• Public-private innovation collaborations
• Account management for enterprise clients</td>
<td rowspan="3"><u>Primary</u>:
• Infrastructure technology integrators
• Airport operators and airport authorities
• Heritage sites and museums
• Critical infrastructure operators
• Public security agencies

<u>Secondary</u>:
• Telecommunications providers
• Security system integrators
• Facility management companies
• Defense and civil protection organizations
• AI and smart-building solution providers</td>
</tr>
<tr><th>KEY RESOURCES</th><th>CHANNELS</th></tr>
<tr>
<td>• Proprietary RF holography algorithms
• AI-based sensing and analytics models
• Computational imaging expertise
• Infrastructure integration frameworks
• Research datasets and pilot validation data
• Embedded RF sensing know-how
• Regulatory and cybersecurity expertise
• Strategic research partnerships
• Intellectual property portfolio</td>
<td>• Direct enterprise sales
• Infrastructure technology integrators
• Smart city and public procurement programs
• Strategic partnerships with airport/security vendors
• Industry conferences and trade fairs
• Pilot demonstration projects
• Government innovation initiatives
• Research and institutional collaborations
• Digital marketing and technical webinars</td>
</tr>
<tr><th colspan="2">COST STRUCTURE</th><th colspan="3">REVENUE STREAMS</th></tr>
<tr>
<td colspan="2">• Research and development (R&D)
• AI and software engineering
• Infrastructure integration engineering
• Pilot deployment costs
• Sales and business development
• Regulatory and legal compliance
• Cybersecurity and data protection
• Cloud and analytics infrastructure
• Technical support and maintenance</td>
<td colspan="3">• Infrastructure integration fees
• Technology licensing agreements
• Annual software subscriptions
• AI analytics and monitoring services
• Maintenance and support contracts
• Custom infrastructure deployment projects
• Consulting and integration engineering services
• Public-sector innovation funding projects</td>
</tr>
</table>

Figure 9 – Business Model Canvas RF Holography in The Surveillance & Security Market

4.1.1. Customer Segments

The commercialization strategy targets infrastructure-level stakeholders responsible for securing and managing high-value public and institutional environments. The primary customer segment consists of museums, cultural heritage institutions, and critical infrastructure operators seeking advanced, privacy-preserving monitoring technologies capable of improving security, situational awareness, and operational intelligence without relying on intrusive camera-based systems. These organizations operate in environments where traditional surveillance technologies may create privacy concerns, architectural limitations, or operational inefficiencies. Additional primary customer segments include security system integrators, public-sector infrastructure operators, airport and transportation infrastructure managers, and smart-building operators. These stakeholders increasingly require intelligent sensing solutions capable of supporting occupancy monitoring, restricted-area detection, behavioral analytics, and infrastructure protection while maintaining compliance with evolving privacy and cybersecurity regulations. Secondary customer segments include security technology vendors, research institutions, defense and surveillance integrators, insurance and risk-management organizations, and large event or exhibition venues. These actors benefit from RF holography's ability to provide non-line-of-sight environmental sensing and advanced monitoring capabilities in complex operational environments. This multi-layered segmentation enables both direct infrastructure deployments and strategic integration partnerships across the broader intelligent security and smart infrastructure ecosystem.

4.1.2. Value Proposition

The core value proposition centers on privacy-preserving environmental sensing and intelligent monitoring enabled through RF holography technology. Unlike conventional surveillance systems based on cameras or wearable devices, RF holography enables real-time environmental reconstruction, occupancy monitoring, and movement detection without capturing identifiable imagery or requiring user interaction. By leveraging computational RF imaging and advanced signal-processing algorithms, the solution provides continuous situational awareness in complex environments while preserving user privacy and maintaining compliance with GDPR and other emerging regulatory frameworks. This enables organizations to deploy intelligent monitoring capabilities in highly sensitive environments such as museums, cultural heritage facilities, critical infrastructures, and public institutions where visual surveillance may be operationally or ethically problematic. The infrastructure-based nature of the technology enables non-intrusive monitoring through walls, obstacles, and visually restricted areas, supporting advanced security and operational use cases that traditional surveillance technologies cannot easily address. The solution therefore creates a unique balance between intelligent monitoring, privacy protection, and infrastructure scalability. Additionally, RF holography systems can be integrated into existing smart-building and security infrastructures, allowing operators to enhance monitoring capabilities without fundamentally redesigning operational workflows. This positioning transforms RF holography into a foundational sensing layer for next-generation intelligent infrastructure environments.

4.1.3. Customer Relationships

The commercialization strategy prioritizes long-term institutional and infrastructure partnerships rather than transactional hardware sales. Relationships begin with pilot deployments, proof-of-concept demonstrations, and infrastructure validation projects. These pilots allow infrastructure operators to evaluate RF Holography sensing performance, operational integration, environmental adaptability, and privacy compliance. Following validation, relationships evolve into licensing agreements, long-term infrastructure integration contracts, software maintenance agreements, and recurring analytics subscriptions. For public-sector deployments, customer relationships are strengthened through collaborative innovation programs, smart infrastructure initiatives, and public-private partnerships. The relationship model emphasizes trust, operational reliability, regulatory compliance, and long-term infrastructure modernization.

4.1.4. Revenue Streams

The revenue model combines infrastructure deployment, RF sensing hardware, software analytics, and recurring service revenues to support long-term scalability and financial sustainability. Initial revenues are generated through the deployment of RF holography infrastructures, including antenna arrays, RF switching architectures, software-defined radio platforms, synchronization layers, and GPU-enabled reconstruction systems. Additional deployment revenues are generated through installation, calibration, integration engineering, cybersecurity validation, and operational configuration services. Because RF holography systems require environment-specific optimization and calibration procedures, deployment and integration services represent a significant component of early project revenues. Recurring revenues are generated through annual software licensing, AI analytics subscriptions, infrastructure monitoring services, maintenance agreements, and periodic system recalibration. These recurring services may include occupancy analytics, anomaly detection, movement reconstruction, restricted-area monitoring, operational reporting, and edge-AI environmental analysis. Additional revenue opportunities may emerge through enterprise support contracts, system upgrades, multi-site infrastructure management, and integration services with third-party security or smart-building platforms. The resulting business model combines relatively high initial infrastructure contract values with progressively expanding recurring revenues over the operational lifecycle of deployed infrastructures. This hybrid hardware-software-service architecture improves long-term revenue predictability, increases customer retention through infrastructure integration, and creates high switching costs once deployments become operationally embedded within existing security ecosystems.

4.1.5. Key Resources

The competitive advantage of the business model relies on a combination of proprietary RF holography technologies, computational imaging expertise, and deployment infrastructure. Core technological resources include advanced RF sensing algorithms, environmental reconstruction models, antenna array architectures, software-defined radio systems, and GPU-based processing platforms capable of generating high-fidelity environmental sensing outputs. Additional key resources include RF calibration methodologies, signal-processing software frameworks, AI-based activity recognition models, and proprietary environmental datasets used for system optimization and training. Mechanical integration systems, installation know-how, and deployment engineering expertise also represent critical operational assets. Non-technical resources include intellectual property portfolios, regulatory compliance frameworks, strategic industry partnerships, and validated pilot deployment data. Together, these resources create significant technological and operational barriers to entry while supporting scalable commercialization.

4.1.6. Key Activities

The primary operational activities focus on continuous refinement of RF holography algorithms, environmental reconstruction models, and deployment methodologies. Ensuring accurate sensing performance across diverse operational environments requires ongoing optimization of signal-processing pipelines, calibration procedures, and AI-based analytics models. Additional activities include RF system installation, infrastructure integration, environmental calibration, GPU optimization, hardware validation, and deployment engineering. Pilot deployment management and real-world performance testing also represent critical activities supporting commercialization and customer adoption. Business development activities focus on strategic partnerships with infrastructure operators, security integrators, public-sector organizations, and smart-building ecosystem providers. Continuous product improvement based on operational feedback ensures that the system evolves in line with emerging infrastructure security requirements and technological advancements.

4.1.7. Key Partnerships

Strategic partnerships play a central role in accelerating deployment and reducing commercialization barriers. Key partners include security system integrators, infrastructure engineering companies, RF hardware suppliers, GPU and computing providers, and smart-building technology vendors. Partnerships with museums, cultural heritage organizations, and public infrastructure operators support pilot validation and operational adoption in real-world environments. Collaboration with research institutions and universities further strengthens technological credibility and supports continuous innovation in RF sensing and computational imaging. Additional strategic relationships with cybersecurity providers, regulatory advisors, and infrastructure maintenance companies enhance interoperability, compliance readiness, and long-term operational sustainability. By embedding RF holography within existing infrastructure ecosystems, the solution benefits from accelerated adoption and improved scalability.

4.1.8. Cost Structure

The cost structure associated with the commercialization of RF holography for infrastructure security reflects the characteristics of a deep-tech infrastructure solution operating within highly regulated and integration-intensive environments. Unlike consumer-oriented digital services, deployment economics are strongly influenced by hardware integration, system interoperability, infrastructure calibration, certification requirements, and long procurement cycles typical of airport, transportation, and critical-infrastructure markets.

The overall cost structure combines four principal categories:

Infrastructure Integration & Deployment Costs

Deployment costs represent one of the largest components of the commercialization model. These costs include RF hardware integration, sensing-node installation, calibration procedures, infrastructure mapping, edge-computing deployment, interoperability validation with existing surveillance systems, and integration engineering activities performed together with system integrators and infrastructure operators. In airport and critical-infrastructure environments, deployment complexity is amplified by operational continuity requirements, restricted-area access constraints, and infrastructure-specific customization needs.

Certification, Compliance & Cybersecurity Costs

Commercial deployment within security-sensitive environments requires substantial investment in certification and compliance activities. These include electromagnetic compatibility (EMC) validation, spectrum compliance, cybersecurity testing, GDPR/privacy compliance assessments, penetration testing, infrastructure-security certification, and public-sector procurement qualification procedures. In transportation and airport-security environments, certification and validation activities may represent a substantial portion of early deployment expenditures.

Operational & Commercial Costs

Operational costs include software maintenance, cloud and edge analytics support, infrastructure monitoring, cybersecurity updates, technical support, field maintenance, and customer-service operations. Commercial expenditures include pilot-project support, public procurement participation, strategic partnerships with system integrators, business development, and long-cycle infrastructure sales activities. Because airport and public-infrastructure procurement cycles are typically long and relationship-driven, commercial acquisition costs are expected to remain relatively high during early market penetration phases. Overall, the commercialization strategy prioritizes modular deployment architectures and integration into existing infrastructure ecosystems in order to progressively reduce deployment and operational costs as commercialization scales.

4.2. Revenue Model & Financial Architecture

The financial architecture is designed around infrastructure-integrated RF holography deployments combining hardware installation, software licensing, AI analytics subscriptions, and long-term maintenance services. Unlike lightweight software-only sensing solutions, RF holography requires dedicated sensing hardware, computational imaging infrastructure, and environment-specific calibration procedures. The business model therefore combines initial infrastructure deployment revenues with recurring analytics, maintenance, and software-service contracts. Despite higher initial deployment CAPEX compared to conventional surveillance technologies, the model benefits from:

- High-value institutional deployments
- Long operational lifecycle contracts
- Recurring software and maintenance revenues
- Strong technological differentiation
- High switching costs after infrastructure integration
- Privacy-preserving sensing capabilities aligned with emerging regulatory trends

4.2.1. RF Holography System Architecture & Deployment Model

The HOLDEN RF Holography platform differs substantially from conventional software-only sensing solutions because it requires dedicated RF hardware, distributed sensing infrastructure, and computational imaging architectures. Unlike conventional surveillance systems relying primarily on optical cameras or passive motion sensors, RF holography systems require coordinated antenna arrays, RF switching architectures, software-defined radios, distributed synchronization layers, GPU-based reconstruction processing, and calibration procedures. The current system architecture includes large-scale antenna-panel arrays, RF switching and synchronization boards, software-defined radio transceivers, microcontroller-based synchronization units, GPU-enabled edge-processing workstations, RF cabling infrastructure, mechanical mounting systems, and calibration and deployment-engineering frameworks. The architecture follows a modular deployment model designed to support adaptation across different infrastructure scales and operational-security environments. Indicative Bill of Materials estimates are summarized in Table 10.

Table 10 – Estimated RF Holography Bill of Materials

Component	Function	Estimated Cost
Antenna Array Panels	RF sensing surface	€80–150 per panel
RF Switching Boards	Signal routing & synchronization	€150–400
SDR Receiver / Transceiver	RF acquisition & transmission	€300–800
GPU Processing Unit	RF reconstruction & AI processing	€1.000–3.000
MCU / Control Unit	Timing & synchronization control	€50–150
RF Cabling & Connectors	Signal transport infrastructure	€500–2.000
Mechanical Mounting Structures	Installation support	€500–3.000
Calibration & Deployment Services	System calibration & installation	€2.000–10.000

Based on deployment scale and infrastructure complexity, a complete RF holography installation is estimated to range from approximately €10k–€20k for small pilot environments, €40k–€80k for medium institutional deployments, and more than €100k for large-scale infrastructure-security deployments. Deployment costs vary depending on sensing coverage requirements, infrastructure integration constraints, calibration precision, cybersecurity compliance, and distributed processing requirements. Typical deployment configurations include small pilot installations for single-room monitoring, medium-scale institutional deployments for museums and secure operational environments, and large-scale deployments for airports, transportation-security infrastructures, and multi-zone public infrastructures. The modular architecture additionally supports progressive infrastructure scaling through additional antenna-array layers, distributed GPU-processing nodes, edge-AI processing infrastructures, and multi-zone environmental reconstruction systems.

4.2.2. Pricing Logic

The commercialization model combines one-time infrastructure deployment revenues with recurring annual software and maintenance revenues generated from deployed infrastructures. While initial deployments generate most revenues during early commercialization phases, recurring revenues progressively increase as the installed infrastructure base expands. To maintain a simple and realistic pricing structure, recurring revenues are primarily generated through annual software licensing and maintenance agreements. Recurring revenues are conservatively estimated as a percentage of the initial deployment value and are expected to generate stable long-term income with relatively limited incremental operational costs.

Table 11 – Estimated Revenue Structure

Revenue Stream	Indicative Pricing Logic
Annual software licensing	~10% of initial deployment value annually
Maintenance & support agreements	~5% of deployment value annually
Calibration & optimization support	Optional periodic service contracts

Under this structure, a €120k museum deployment may generate approximately €12k per year in software licensing revenues and approximately €6k per year in maintenance revenues. Similarly, a €450k airport deployment may generate approximately €45k per year in software licensing revenues and approximately €22k per year in maintenance revenues. This recurring-revenue structure supports increasing contribution margins over time because most engineering, calibration, and deployment costs are incurred during the initial installation phase, while recurring software and maintenance revenues require relatively limited additional operational effort. As a result, installed infrastructures progressively accumulate recurring annual revenues over their operational lifecycle.

4.2.3. Cost Structure

The operational cost structure reflects the engineering-intensive and infrastructure-integrated nature of RF holography commercialization within airport-security, transportation, museum, and public-infrastructure environments. Unlike pure software businesses, commercialization requires a combination of dedicated RF hardware infrastructure, distributed sensing architecture, deployment engineering, cybersecurity validation, and long-term technical support. The overall cost structure is divided into fixed operational costs, variable deployment costs, and commercialization and scaling costs. Indicative annual fixed operational costs are summarized in Table 12.

Table 12 – Estimated Annual Fixed Operational Costs

Fixed Cost Category	Annual Fixed Cost
RF sensing & AI software R&D	€650k
Engineering & technical personnel	€550k

Cloud / edge software infrastructure	€120k
Cybersecurity & compliance maintenance	€180k
Business development & partnerships	€220k
Administrative & operational overhead	€180k
Total Estimated Annual Fixed Cost	€1.90M

The largest fixed-cost components are expected to include RF algorithm development, distributed sensing-system integration, GPU reconstruction optimization, cybersecurity activities, and deployment-support personnel. Variable deployment costs scale proportionally with deployment complexity and infrastructure requirements. Estimated deployment economics are summarized in Table 13.

Table 13 – Estimated Variable Deployment Costs

Cost Element	Museum Deployment	Airport Deployment
RF hardware & sensing infrastructure	€25k	€70k
Edge-computing infrastructure	€10k	€35k
Installation & calibration	€20k	€80k
Integration engineering	€25k	€100k
Certification & compliance	€10k	€40k
Total Variable Deployment Cost	€90k	€325k

4.2.4. Contribution Margin

Early deployments remain engineering intensive because they require infrastructure integration, calibration activities, interoperability validation, and cybersecurity certification. Consequently, contribution margins during early commercialization phases remain relatively moderate, with medium institutional deployments generating margins of approximately 25% and airport-security deployments generating margins of approximately 28%. As deployment methodologies become increasingly standardized and the installed infrastructure base expands, recurring software licensing and maintenance revenues progressively improve overall profitability. These recurring revenues scale across already deployed infrastructures, require limited additional hardware costs, and generate lower operational overhead compared with new deployment activities. As a result, early commercialization phases remain primarily deployment-driven, whereas mature commercialization phases progressively become recurring-revenue-driven. In mature commercialization conditions, recurring revenues are expected to represent approximately 35–45% of total annual revenues, significantly improving operational leverage, financial predictability, and long-term profitability.

4.2.5. Break-Even Analysis

The break-even analysis reflects the long commercialization cycles and infrastructure-intensive economics typical of airport-security, transportation, museum, and public-infrastructure markets. Unlike conventional software-only businesses, RF holography commercialization requires substantial upfront investment associated with RF hardware industrialization, calibration optimization, distributed sensing integration, cybersecurity validation, operational certification, and infrastructure deployment engineering. Procurement and validation cycles within airport-security and public-infrastructure environments typically require approximately 12–24 months for technical validation, cybersecurity assessment, procurement approval, interoperability testing, and operational certification procedures. As a result, early commercialization phases are characterized by relatively high operational costs and limited initial revenues while pilot deployments and infrastructure demonstrations are completed. The first industrial commercialization phase is expected to require total investments of approximately €4.5M over the first three years. Indicative investment allocations are summarized in Table 14.

Table 14 – Estimated Investment Allocation

Investment Category	**Estimated Investment**
Core RF/AI product industrialization	€1.5M
Pilot deployments & demonstrations	€1.0M
Certification, EMC & cybersecurity validation	€600k
Commercial development & procurement support	€600k
Infrastructure integration ecosystem development	€800k
Total Estimated Investment	€4.5M

The commercialization model assumes a partnership-driven go-to-market strategy involving airport-security integrators, transportation-security stakeholders, smart-infrastructure operators, infrastructure-system partners, and public-security ecosystem integrators. Revenue generation is expected to progressively evolve from engineering-intensive pilot deployments toward larger infrastructure-security installations and recurring revenues associated with software licensing, infrastructure analytics, operational maintenance, and multi-site support agreements. To account for uncertainty associated with procurement cycles, infrastructure adoption dynamics, and deployment scaling, three commercialization-growth scenarios were evaluated.

Conservative Commercialization Scenario

The conservative scenario assumes relatively slow procurement cycles, limited deployment acceleration, and gradual ecosystem adoption primarily driven by pilot projects and small-to-medium infrastructure deployments.

Table 15 – Conservative Commercialization Scenario

Year	New Deployment Revenue	Recurring Revenue	Total Revenue	Total Cost	Profit/Loss
Year 1	€0.6M	€0.0M	€0.6M	€1.7M	-€1.1M
Year 2	€1.1M	€0.4M	€1.5M	€1.9M	-€0.4M
Year 3	€2.0M	€1.0M	€3.0M	€2.9M	€0.1M
Year 4	€3.0M	€1.8M	€4.8M	€3.8M	€1.0M
Year 5	€4.0M	€2.5M	€6.5M	€4.5M	€2.0M

Under this scenario, operational break-even is expected near the end of Year 3 or early Year 4, primarily supported by selective airport-security deployments, medium institutional projects, and gradual growth of recurring maintenance and software revenues.

Moderate Commercialization Scenario

The moderate commercialization scenario assumes progressive infrastructure adoption, successful lighthouse deployments, stronger integrator partnerships, and increasing recurring software and maintenance revenues after initial pilot validation.

Table 16 – Moderate Commercialization Scenario

Year	New Deployment Revenue	Recurring Revenue	Total Revenue	Total Cost	Profit/Loss
Year 1	€0.8M	€0.0M	€0.8M	€1.8M	-€1.0M
Year 2	€1.6M	€0.4M	€2.0M	€2.2M	-€0.2M
Year 3	€3.0M	€1.2M	€4.2M	€3.5M	€0.7M
Year 4	€4.5M	€2.5M	€7.0M	€4.8M	€2.2M
Year 5	€6.0M	€4.0M	€10.0M	€6.2M	€3.8M

Under this scenario, operational break-even is expected during Year 3 through a combination of airport-security deployments, medium institutional deployments, accumulated recurring software licensing revenues, and maintenance agreements associated with deployed infrastructures. By Year 5, recurring revenues are expected to represent approximately 40% of total annual revenues, thereby improving operational leverage, financial predictability, long-term profitability, and revenue stability independently from new deployment volumes. This revised financial structure is more closely aligned with the pricing logic, contribution-margin evolution, recurring-maintenance assumptions, and long-term infrastructure-service strategy described throughout the commercialization model.

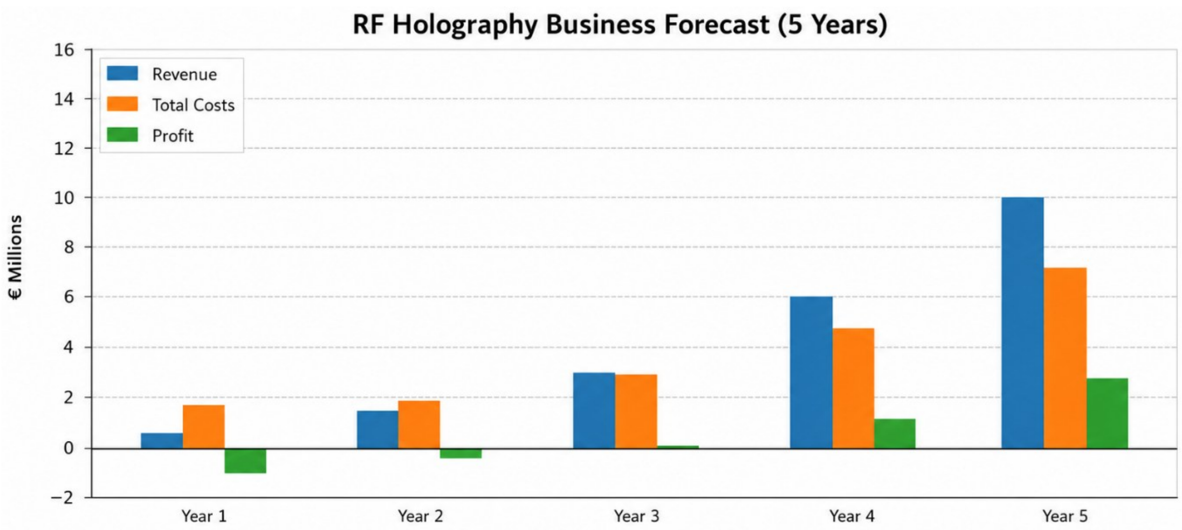


Figure 10 – Five years revenue/cost/profit forecast for moderate growth scenario

Partnership-Driven Scaling Scenario

The partnership-driven scaling scenario assumes successful lighthouse deployments, strong ecosystem credibility, accelerated procurement support through infrastructure-security integrators, and rapid expansion of recurring software and analytics revenues.

Table 17 – Partnership-Driven Scaling Commercialization Scenario

Year	New Deployment Revenue	Recurring Revenue	Total Revenue	Total Cost	Profit/Loss
Year 1	€1.0M	€0.0M	€1.0M	€1.9M	-€0.9M
Year 2	€2.1M	€0.7M	€2.8M	€2.6M	€0.2M
Year 3	€3.8M	€1.7M	€5.5M	€4.0M	€1.5M
Year 4	€5.8M	€3.2M	€9.0M	€5.5M	€3.5M
Year 5	€8.0M	€5.0M	€13.0M	€7.0M	€6.0M

Under this scenario, operational break-even is expected between Years 2 and 3 as recurring revenues progressively increase and deployment methodologies become increasingly standardized. Long-term profitability improves substantially because recurring software and analytics revenues scale faster than deployment costs and infrastructure-security partnerships reduce customer-acquisition complexity.

4.3. Market Entry Roadmap

The market-entry strategy follows a phased infrastructure-commercialization approach designed to progressively validate the technology, reduce deployment risk, and establish strategic positioning within intelligent-security ecosystems. Because airport-security and public-infrastructure markets are characterized by long procurement cycles, high compliance requirements, and integration complexity, commercialization initially focuses on pilot validation, lighthouse deployments, ecosystem integration, and strategic partnerships with infrastructure-security integrators. The roadmap prioritizes operational reliability, cybersecurity and regulatory compliance, interoperability with existing surveillance infrastructures, and indirect commercialization through trusted ecosystem partners. Rather than pursuing rapid mass-market deployment, the strategy emphasizes controlled scaling, deployment credibility, and progressive integration into existing infrastructure-security architectures.

4.3.1. Phase 1 – Pilot Validation & Infrastructure Demonstration (0–12 Months)

The first commercialization phase focuses on technical consolidation, operational validation, infrastructure demonstration, and pilot deployment preparation. Activities include RF sensing validation in operational environments, pilot-scale RF holography deployments, cybersecurity and GDPR compliance validation, calibration optimization, distributed synchronization testing, and interoperability assessment with existing infrastructure-security systems. This phase additionally focuses on validating deployment methodologies and operational reliability under real-world environmental conditions. The primary objective is to reduce perceived deployment risk among infrastructure operators while establishing initial strategic relationships with airport operators, transportation-security stakeholders, museums, and public-infrastructure organizations.

4.3.2. Phase 2 – Early Commercial Deployment (12–24 Months)

The second commercialization phase focuses on selective commercial deployments, infrastructure-integrator partnerships, and the establishment of initial recurring-service revenues. Commercialization during this phase remains intentionally selective and partnership-driven to minimize operational complexity while improving deployment maturity and ecosystem credibility. Key target environments include transportation-security operators, museums and heritage infrastructures, smart-building environments, and controlled airport-security pilot deployments. Activities include selective infrastructure deployments, optimization of calibration frameworks, maintenance and support agreements, deployment automation improvements, and integration into broader situational-awareness platforms.

4.3.3. Phase 3 – Infrastructure Scaling (24–48 Months)

The third commercialization phase focuses on selective infrastructure scaling through lighthouse deployments and strategic partnerships with major infrastructure-security providers and smart-infrastructure operators. At this stage, core deployment methodologies and interoperability-validation procedures are expected to have been validated during earlier phases, enabling commercialization efforts to progressively shift toward deployment scalability and recurring infrastructure-service revenues. Commercial growth during this phase is expected to be driven increasingly through indirect go-to-market channels involving established infrastructure-security companies capable of supporting deployment, certification, operational maintenance, and multi-region scaling activities.

4.3.4. Phase 4 – Ecosystem Consolidation (48–60 Months)

The final commercialization phase focuses on consolidating the RF holography platform as a recognized infrastructure-intelligence technology within broader smart-security ecosystems. Commercialization is expected to rely increasingly on recurring software licensing, analytics-service revenues, long-term maintenance agreements, ecosystem partnerships, and infrastructure-management integrations. As commercialization matures, the platform may additionally support applications involving occupancy analysis, infrastructure-utilization monitoring, anomaly detection, and distributed environmental intelligence across transportation, smart-building, and public-security environments.

4.3.5. Intellectual Property Strategy

The intellectual-property strategy combines patent protection, proprietary software frameworks, RF holography architectures, calibration methodologies, algorithmic know-how, and infrastructure integration expertise to establish long-term competitive differentiation within RF sensing and infrastructure-security markets. Protection activities focus on RF holographic reconstruction algorithms, distributed sensing architectures, privacy-preserving RF sensing methodologies, AI-assisted environmental analytics, synchronization methodologies, and edge-processing optimization techniques. In addition to formal patent protection, competitive differentiation is expected to derive from deployment know-how, interoperability frameworks, operational reliability methodologies, and infrastructure integration expertise developed through real-world deployments.

4.3.6. Capital Strategy and Funding Requirements

The commercialization strategy follows a staged capital-allocation approach aligned with the progressive maturation of the technology and the long procurement cycles associated with airport-security and public-infrastructure markets. The initial commercialization phase is expected to require approximately €4.5M over the first three years, primarily allocated toward RF holography product industrialization, pilot deployments, cybersecurity certification, calibration optimization, infrastructure integration, ecosystem partnership development, and commercial expansion activities. Potential funding sources include European innovation programs, strategic industrial partnerships, infrastructure-security innovation funds, venture capital specialized in deep-tech and intelligent infrastructure, and co-development agreements with infrastructure-security integrators. The staged funding strategy reduces financial exposure during early commercialization phases while preserving long-term scalability and strategic flexibility

4.4. Marketing and Communication

The marketing strategy positions RF Holography innovation as a next-generation infrastructure intelligence platform, rather than a traditional surveillance provider. Communication focuses on privacy-preserving monitoring, passive infrastructure sensing, operational resilience, and smart infrastructure modernization.

4.4.1. Positioning Strategy

Core positioning pillars are privacy-preserving infrastructure intelligence, passive environmental awareness, infrastructure-wide situational analytics, AI-driven operational optimization, and smart infrastructure modernization. The positioning differentiates this innovation from camera-centric surveillance systems, biometric analytics platforms, and active scanning infrastructures.

4.4.2. Market Penetration Activities

Strategic demonstrations in pilot showcases in airports and heritage environments, industry conferences. Participation in Smart City Expo, Passenger Terminal Expo, other relevant technological trades and critical infrastructure events. Public-Sector Engagement participating in innovation calls, smart infrastructure initiatives, and EU digital infrastructure programs. White papers, technical demonstrations, webinars, and infrastructure-security publications. Strategic Co-Marketing communication with infrastructure integrators, airport technology providers, and smart infrastructure partners.

4.5. Strategic Commercial Conclusion

The exploitation strategy demonstrates a scalable commercialization pathway for RF holography within the infrastructure security and smart infrastructure markets. The business model combines strong technological differentiation, recurring software revenues, infrastructure-driven scalability, and privacy-preserving monitoring capabilities. By avoiding dependence on camera-heavy surveillance architectures, wearable ecosystems, or checkpoint-centric infrastructure, RF Holography creates a differentiated position within the emerging market for intelligent infrastructure sensing. The phased deployment roadmap reduces technical and commercial risk while enabling progressive expansion across airports, heritage environments, and broader critical infrastructure ecosystems. Overall, the strategy establishes a defensible and scalable foundation for transforming RF holography into a long-term infrastructure intelligence platform. Although RF holography deployments involve higher initial installation complexity and infrastructure CAPEX than traditional software-centric sensing solutions, the technology addresses market segments where privacy, non-line-of-sight sensing, and advanced environmental reconstruction capabilities provide unique strategic value.

This positions the innovation not as a replacement for conventional surveillance systems, but as a complementary high-value infrastructure intelligence layer for environments where traditional optical sensing technologies face operational or ethical limitations.

5. Market Analysis – Elderly Care

5.1. SWOT Analysis

The aim of the assessment is to determine the potential of RF-sensing technology for enhancing elderly care. This analysis will highlight the unique advantages of RF sensing, such as its non-invasive monitoring capabilities, and identify possible challenges, including technological limitations or adoption barriers. Additionally, we will explore external factors that could influence the successful implementation of this technology in elderly care [48], [49], [50]. The findings will provide clear guidance on how to effectively integrate RF sensing technology to improve the quality of care and responsiveness for elderly individuals.

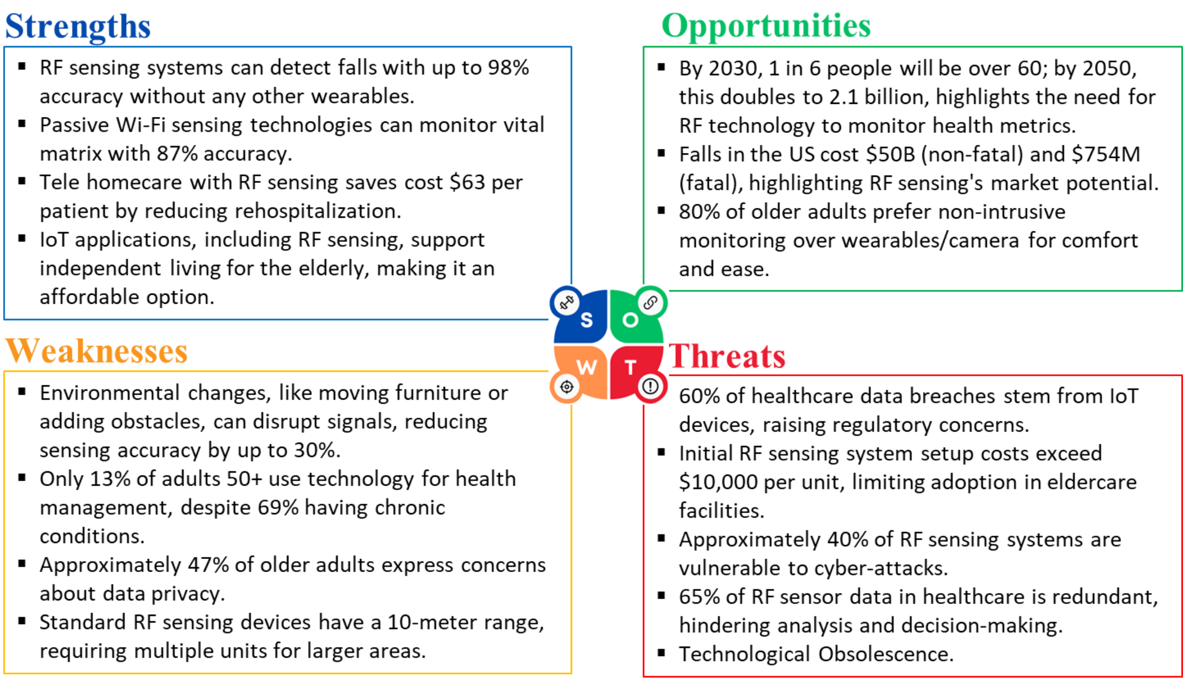


Figure 11 – SWOT Matrix for the Elderly Care Market

5.1.1. Strengths

RF sensing technology offers several key strengths that position it as a highly promising solution within healthcare, particularly for elderly care and monitoring systems:

- **Market Potential:** RF sensing technology offers high novelty with strong market potential. It can accurately detect falls (98%) and monitor vital signs (87%) without wearables, making it an attractive solution for healthcare [51], [52].

- **Autonomy and Integrability:** The technology operates 100% autonomously, requiring no wearables, and integrates seamlessly into existing IoT systems, supporting scalable healthcare applications [53], [54].
- **Cost Efficiency:** RF sensing reduces healthcare costs, such as €63 per patient through telehomecare and €50 billion in annual fall-related costs in the U.S., demonstrating its financial viability [55].
- **Ethical Design:** The non-intrusive nature of RF sensing technology aligns with the growing demand for privacy-conscious solutions, especially for the elderly who prefer non-wearable monitoring [56].
- **Healthcare Expansion**: With an aging population (projected to double by 2050 and in the United States, the number is projected to increase from 58 million in 2022 to 82 million by 2050, a 47% increase), RF sensing can support elderly independent living, positioning it as a key technology for future healthcare needs [57].

5.1.2. Weaknesses

While RF sensing technology offers numerous advantages, several weaknesses could hinder its widespread adoption and deployment in healthcare settings:

- **Precision and Reliability:** Environmental changes (e.g., furniture movement) can reduce signal accuracy by up to 30%, affecting system performance [58].
- **Limited Data Control:** RF sensing systems often rely on third-party cloud services, which can compromise data security and user control over sensitive health information [59].
- **High Setup Costs:** Initial setup costs exceeding €10.000 per unit limit adoption, especially in eldercare facilities with tight budgets [60].
- **Technical Limitation:** Standard RF sensing devices have a 10-meter range, requiring multiple units for larger areas [61].

5.1.3. Opportunities

RF sensing technology is poised to capitalize on several opportunities within the healthcare market, driven by both demographic trends and advancements in technology:

- **Aging Population:** by 2030, one in six people will be over 60, increasing the demand for healthcare solutions like RF sensing to monitor health metrics and reduce risks [62], [63], [64].
- **Fall Detection and Cost Savings:** RF sensing technology can significantly reduce the financial impact of falls, which cost the U.S. €50 billion annually, highlighting its market potential [65].

- **Non-Intrusive Monitoring:** 80% of older adults prefer non-intrusive monitoring methods, making RF sensing an ideal solution for eldercare [66].
- **IoT Integration:** RF sensing's compatibility with IoT systems enables faster commercialization and scalability across healthcare applications, from private homes to healthcare institutions.
- **Tele-homecare Expansion:** RF sensing can reduce rehospitalization costs (€63 per patient) and support independent living, presenting significant cost-saving opportunities for healthcare systems.

5.1.4. Threats

Despite the promising opportunities, RF sensing technology faces several threats that may impede its adoption and development in the healthcare sector:

- **Data Security Risks:** With IoT devices being a major source of healthcare data breaches (60%), RF sensing systems face significant data security and privacy challenges [67].
- **Regulatory Concerns:** Strict healthcare regulations, such as HIPAA and GDPR, present compliance challenges for RF sensing systems, especially in terms of data handling [68].
- **Low Adoption Readiness:** Despite the high prevalence of chronic conditions in older adults (69%), only 13% use technology for health management, signaling a gap in technology adoption.
- **Vulnerability to Cyber-Attacks:** 40% of RF sensing systems are vulnerable to cyber-attacks, which could undermine trust and limit adoption in healthcare [69].
- **Environmental Challenges:** Signal disruption due to environmental changes and the need for multiple units to cover large areas (limited range of 10 meters) may hinder system effectiveness [58], [61].

5.2. Market Size Analysis

This section evaluates market potential to provide data-driven insights into commercial viability. The Global Healthcare market, valued at €12 trillion in 2022, is an immense and diverse industry, and within the global healthcare industry, the *Long-term Care and Assisted Living* segment represents a significant portion, projected to reach €1.25 trillion by 2024 [70]. However, exploring more 'niche and accessible' markets could be a more prolific approach for leveraging RF-sensing technology. Upon narrowing down the market, we observe several key segments within the broader healthcare ecosystem.

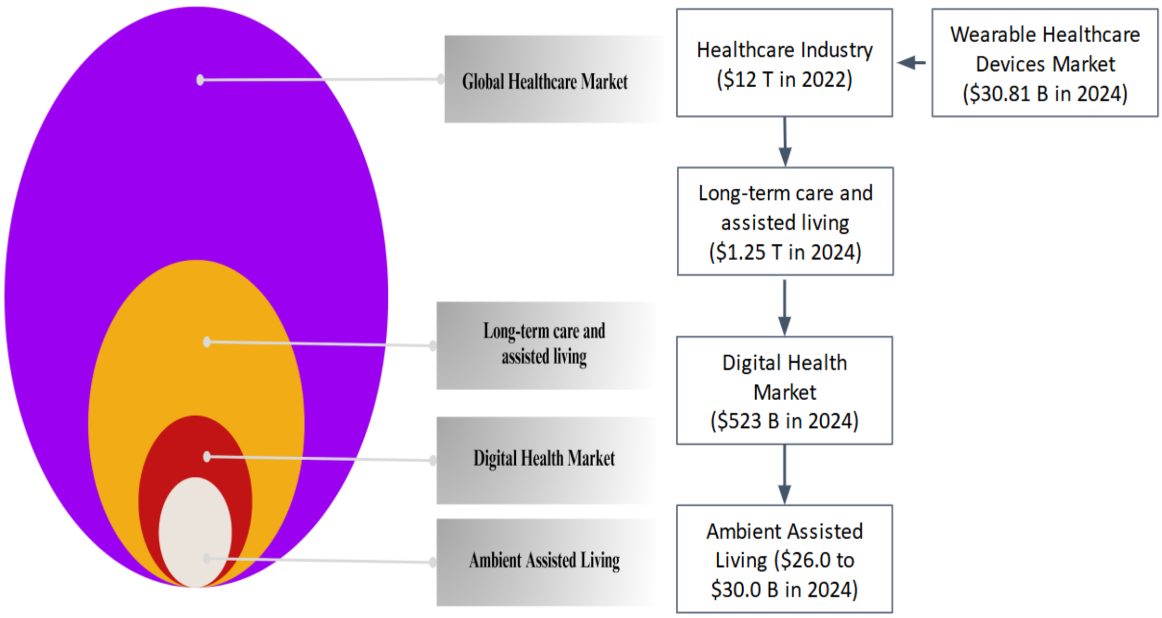


Figure 12: Elderly Care Market Size

The Digital Health market, valued at €523 billion [71], is a broad space, and within the digital health technologies market, the Ambient Assisted Living (AAL) technology sector is worth €26 to €30 billion [72], from while the Wearable Healthcare Devices market, which is slightly distinctive but inclusive to the scope of the "healthcare ecosystem," stands at €30.81 billion in the financial year 2024 [73].

However, our primary go-to-market strategy will focus on integrating RF-sensing technology into Wi-Fi routers, enhancing their functionality, and offering advanced solutions. Consequently, it is more relevant and strategic to assess the current Wi-Fi router market landscape.

The global Wi-Fi router market, encompassing both Home and Industrial devices, is projected to reach approximately €16.25 billion in 2024 [74]. The home router segment is valued at €5.05 billion in 2023 (Noor-A-Rahim et al., 2022), and the industrial Wi-Fi router market is forecasted to be worth €11.20 billion by 2024 [75], reflecting the growing need for robust and secure connectivity solutions.

5.2.1. Demographic Foundations of Demand Expansion

According to Eurostat population projections (EUROPOP2023), the share of individuals aged 65+ in the EU is projected to increase from approximately 21% today to nearly 30% by 2050. More significantly, the population aged 80+ is expected to grow at the fastest rate across Member States. The European Commission's 2023 Ageing Report further confirms that the old-age dependency ratio will rise substantially, long-term care expenditure as a share of GDP is projected to increase in most Member States, and public budgets will face sustained structural pressure due to ageing populations. This demographic transition implies rising care intensity per resident and increasing operational complexity within long-term care facilities. Unlike discretionary corporate technology markets, demand in elderly care is structurally anchored in demographic inevitability and public health necessity.

This structural pressure is not limited to Europe. The World Health Organization projects that by 2050, approximately 3.5 billion people aged 60 years or older will require some form of care, reflecting both population ageing and the increasing prevalence of non-communicable diseases. The global dimension of aging reinforces the long-term expansion of care-related services and associated technological support systems.

5.2.2. Total Addressable Market (TAM)

To estimate the Total Addressable Market (TAM), we need to focus on the annual demand for routers across multiple regions, based on household broadband penetration and router replacement cycles. Here's how we break it down reporting Total Population, Total number of households, and Elderly Population Data in the target market (USA, EU, and Asia):

Table 18: Total and Elderly Population Statistics in Key Global Regions

Region	Total Population	Elderly Population (65+)
USA	340.1 M	58 M
EU	447 M	90.4 M
Asia	4.7 B	414 M

- USA: 131.43 million households (Statista)
- EU: 200 million households (EUC)
- Asia: 1.04 billion households (Total population 4.7 B / an average household size of 4.5) (OECD; PRB)

Broadband penetration rate: USA 97.1%, EU 93.8% (average[1]), Asia 73.4% (average[2]), (Statista):

[1] EU – The European Union (EU) is a supranational political and economic union of 27 member states that are located primarily in Europe.

[2] Asia – As of World Population Review Demographics, the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), there are 58 nations in Asia | https://worldpopulationreview.com/country-rankings/apac-countries

- USA: 131.43M × 97.1% =127.62 million households with broadband
- EU: 200M × 93.8% = 187.6 million households with broadband
- Asia: 1.040M × 73.4% = 763.36 million households with broadband

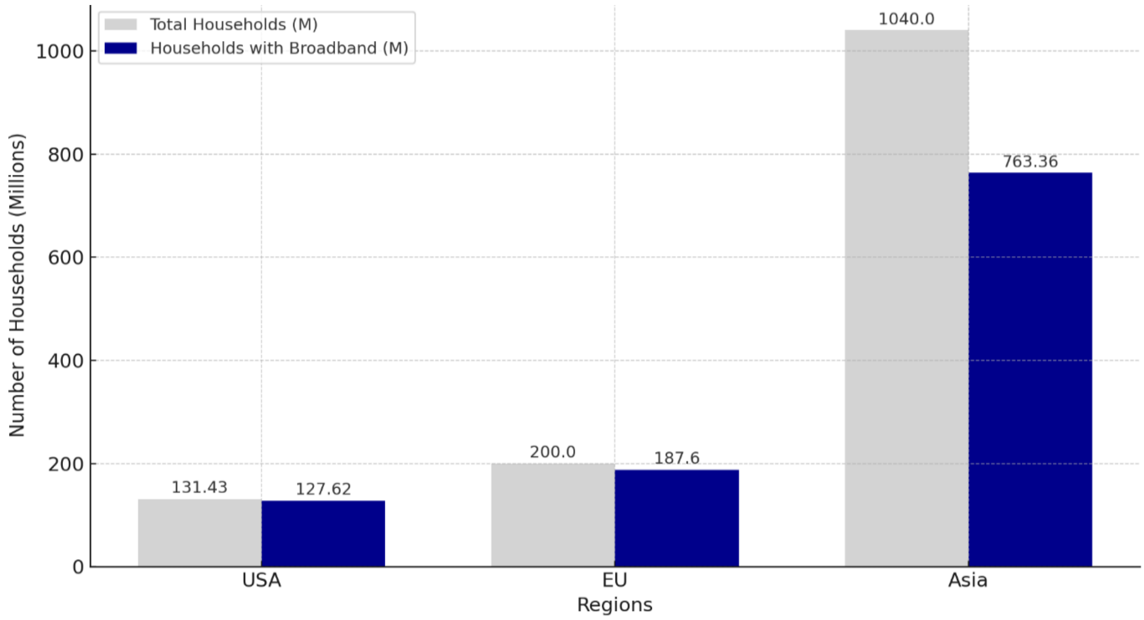


Figure 13: Total Households and Households with Broadband by Region

Router replacement cycle: A study in 2022 shows that 52% of consumers acquired their routers from their ISP, and nearly 36% of consumers own the router. There are several reasons why Wi-Fi routers are frequently replaced (Parks Associates, 2023). For ISPs, the replacement of routers can sometimes be an additional cost, especially if they need to offer new, upgraded devices to their customers. However, for vendors, this situation presents a significant new opportunity to sell advanced products.

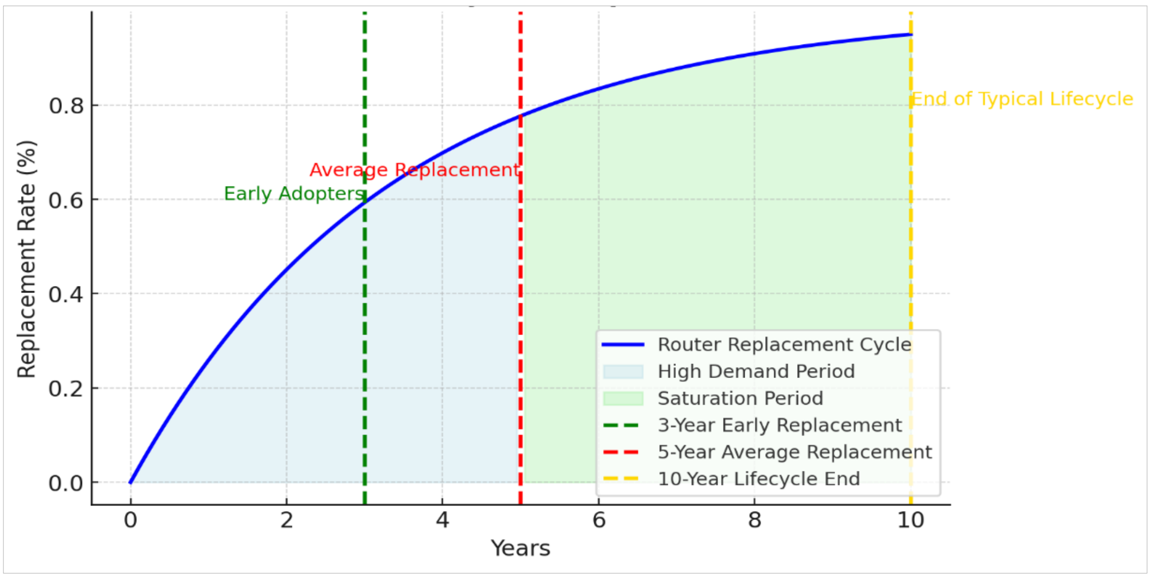


Figure 14: Wi-Fi Router Lifecycle and Average Replacement Rate

Typically, Wi-Fi routers have a lifecycle of 3 to 10 years, with the average replacement occurring every 5 years, so we divide the number of households with broadband by 5 to calculate the annual demand for routers in each region (CNET; Superloop; All West Communication).

Annual Demand for Routers:

- *USA: 127.62M / 5 = 25.52 million routers per year*
- *EU: 187.6M / 5 = 37.52 million routers per year*
- *Asia: 763.36M / 5 = 152.67 million routers per year*

5.2.3. Serviceable Available Market (SAM)

In this section, we aim to evaluate the potential market size in a more precise manner, which includes two different approaches to better understand the exact serviceable market size. Each of the approaches has been explained in a detailed and comprehensive way to visualize the overall market.

First Analytical Approach

Estimating the presence of elderly individuals in households starts with calculating the average number of elderly residents per household per region. This value forms the basis for identifying how many households contain at **least one elderly person**—a key to measure the potential market for RF-sensing embedded routers.

To calculate the **Elderly per Household ratio**, the formula used is:

$$Elderly\ per\ Household = \frac{Elderly\ Population\ (65+)}{Total\ Number\ of\ Households}$$

USA

- Elderly Population: 58 million
- Total Households: 131.43 million

$$\frac{58.000.000}{131.430.000} = 0.44\ elderly\ per\ household$$

European Union

- Elderly Population: 90.4 million
- Total Households: 200 million

$$\frac{90.400.000}{200.000.000} = 0.452\ elderly\ per\ household$$

Asia

- Elderly Population: 414 million
- Total Households: 1.04 billion

$$\frac{414.000.000}{1.040.000.000} = 0.398\ elderly\ per\ household$$

Households with Elderly Population by Region (using the Elderly per household ratio):

- $USA: 131.43M \times 0.44 = 57.83M\ households\ with\ elderly$
- $EU: 200M \times 0.452 = 90.4M\ households\ with\ elderly$
- $Asia: 1.040M \times 0.398 = 413.92M\ households\ with\ elderly$

Broadband-connected Households with Elderly (penetration rate):

- $USA: 57.83M \times 97.1\% = 56.15M\ elderly\ households\ with\ broadband$
- $EU: 90.4M \times 93.8\% = 84.77M\ elderly\ households\ with\ broadband$
- $Asia: 413.92M \times 73.4\% = 303.79M\ elderly\ households\ with\ broadband$

Potential Demand of RF-Sensing Embedded Routers by Households with Elderly Population:

Using a 5-year replacement cycle:

- $USA: 56.15M\ /\ 5 = 11.23\ million\ routers/year$
- $EU: 84.77M\ /\ 5 = 16.95\ million\ routers/year$
- $Asia: 303.79M\ /\ 5 = 60.76\ million\ routers/year$

Second Analytical Approach

It is important to recognize that premium-featured routers, while offering advanced functionalities, may not be reasonable or necessary for every household or organization. Many users, require only basic networking capabilities, such as stable connectivity, moderate speed. Since it is hard to estimate the exact percentage of potential customers' willingness to pay for a premium router, we try to understand the potential customer by using similar or comparable product benchmarks. For example, in the USA, 17% of people aged over 50 use a smartwatch [76]. The total number of people aged over 50 in the USA is 124 million [77].

Therefore, the number of smartwatch users in this segment is calculated as follows:

$$124\,million \times 17\% = 21.08\,million\,people$$

To express this in terms of the total population (340.1 million), we calculate:

$$(21.08\,million \div 340.1\,million) \times 100 = 6.20\%\,of\ the\ total\ population$$

This suggests that around 6.20% of the population has adopted a smart device like a smartwatch, which can serve as a proxy for potential smart router adoption. Now, if we apply this 6.20% to the **annual router demand of 25.52 million households** in the USA (based on router replacement cycle).

Potential customers in the USA are interested in premium Wi-Fi routers:

$$USA: 25.52M \times 6.20\% = 1.58\,million\ households\ per\ year$$

In parallel, we apply the same approach in the EU using available smartwatch adoption data. Nearly 16% of the population aged over 55 use smartwatches [78]. It is estimated that 33.6% of the EU population is aged over 55. Given the total EU population is 447 million, we first calculate the number of people aged 55 and above:

$$447\,million \times 33.6\% = 150.19\,million\,people$$

Next, we calculate how many among them use smartwatches:

$$150.19\,million \times 16\% = 24.03\,million\,people$$

To find what percentage this represents of the total EU population, we calculate:

$$(24.03\,million \div 447\,million) \times 100 = 5.37\%\,of\ the\ total\ population$$

Using this as a proxy for potential premium router adopters and applying it to the EU's annual router demand of 37.52 million households (based on earlier replacement cycle estimates).

Potential customers in the EU are interested in premium Wi-Fi routers:

$$EU: 37.52M\ x\ 5.37\% = 2.01\,million\ households\ per\ year$$

Moreover, to balance the previous population-wide benchmark, we conducted a complementary analytical approach focusing specifically on the U.S. senior population (aged 65+).

Table 19: Estimated Premium Wi-Fi Router Demand Among 65+ in the USA (2023)

Living Arrangement (65+ Age Group)	Population	% of 65+	Household Size Assumption	Target Households	Potential Premium Demand (6.20%)
Alone	14.895.931	25.8%	1 per household	14.895.931	923.548
Spouse/Partner	34.013.170	58.9%	2 per household	17.006.585	1.054.408
Other Relatives	6.735.392	11.7%	1 per household	6.735.392	417.594
Others (Non-Relatives)	785.507	1.4%	Ave. 15 per resident	52.367	3.247
Alone in Quarters (Care Homes)	1.300.000	2.3%	—	47.531[1]	—
Total	**57.728.000**	**100.0%**	—	**38.737.806**	**2.398.797**

Data Source: U.S. Census Bureau (2023)

Note 1: 47.531 is the total number of elderly care homes in the USA.
Note 2: To estimate "Potential Premium Demand," we applied a 6.20% adoption rate based on smart device usage (e.g., smartwatches).

Similarly, we applied the same analytical framework to the European Union's senior population (aged 65+). The estimation considers diverse living arrangements across the EU, allowing us to assess the potential demand for premium Wi-Fi routers within this demographic.

Table 20 – Living Arrangements and Estimated Premium Wi-Fi Router Demand Among 65+ in EU

Living Arrangement	Population	% of 65+ Population	Household Size / Facility Size	Estimated Households / Facilities	Premium Demand (5.37%)
Living Alone	28.024.000	31.0%	1 person per household	28.024.000	1.504.889
With Spouse/Partner Only	43.844.000	48.5%	2 persons per household	21.922.000	1.177.187
With Other Relatives/Non-Relatives	18.532.000	20.5%	1 person per household (avg)	18.532.000	995.168
In Elderly Care Homes	2.577.000	2.85%	32.8 residents per facility	104.400[1]	—
TOTAL	90.400.000	100%	—	68.582.400	3.678.244

Data Source: Eurostat, 2018 – Ageing Europe report

Note 1: 104.400 is the estimated number of elderly care homes in the EU.
Note 2: To estimate "Potential Premium Demand," we applied a 5.37% adoption rate based on smart device usage (e.g., smartwatches).

To provide a broader comparative perspective, we compiled a summary table that synthesizes key metrics across the USA, EU, and Asia. The table allows for cross-regional comparisons and strategic planning. Notably, data for Asia remains limited due to inconsistencies in census reporting and data harmonization.

Table 21: Estimated Premium Wi-Fi Router Demand Among 65+ in Key Global Regions

Region	Total HHs (M)	Elderly per HH	HHs with Elderly (M)	HHs with Broadband (M)	Elderly HHs with Broadband (M)	Annual Demand (M)	Elderly Annual Demand (M)	Premium Demand (1) (M)	Premium Demand (2) (M)
USA	131.43	0.44	57.83	127.62	56.15	25.52	11.23	1.58	2.39
EU	200.00	0.452	90.40	187.60	84.77	37.52	16.95	2.01	3.68
Asia	1.040.00	0.398	413.92	763.36	303.79	152.67	60.76	-	-

*Note: HH – Household; EU – European Union (27), Asia (the whole continent)
**Asia: Lack of harmonized census systems complicates regional data consistency, resulting in limited coherence across datasets.

Additionally, considering the Eurostat 2024 Healthcare Resources database and the Statista Research Department, the EU hosts approximately 104.400 long-term collective elderly care facilities alongside over 24.000 hospitals and specialized rehabilitation centers. When compared globally using data from the American Hospital Association (AHA), the National Center for Health Statistics (NCHS), and the OECD's 2024 Health at a Glance report for the Asia-Pacific region, it becomes evident that the target market is vast. As shown in Table 22, the global environment consists of hundreds of thousands of potential deployment points across three primary economic regions.

Table 22: Regional Distribution of Elderly Care Homes and Hospitals

Considering USA	**Considering Europe**	**Considering Asia Pacific[3]**
• Elderly care homes: 47.531 • Hospitals: 6.093	• Elderly care homes: 104.400 • Hospital: 24.217	• Elderly care homes: 68.951 • Hospital: 119.062

[3] Asia Pacific – As of World Population Review Demographics, there are 37 nations in Asia Pacific | However, given the access to public data, our estimation considers only China, Japan, Malaysia, Singapore, Indonesia, India, and Thailand.

Assuming an average of 10% of these facilities are willing to adopt Wi-Fi solutions or routers in year 1.

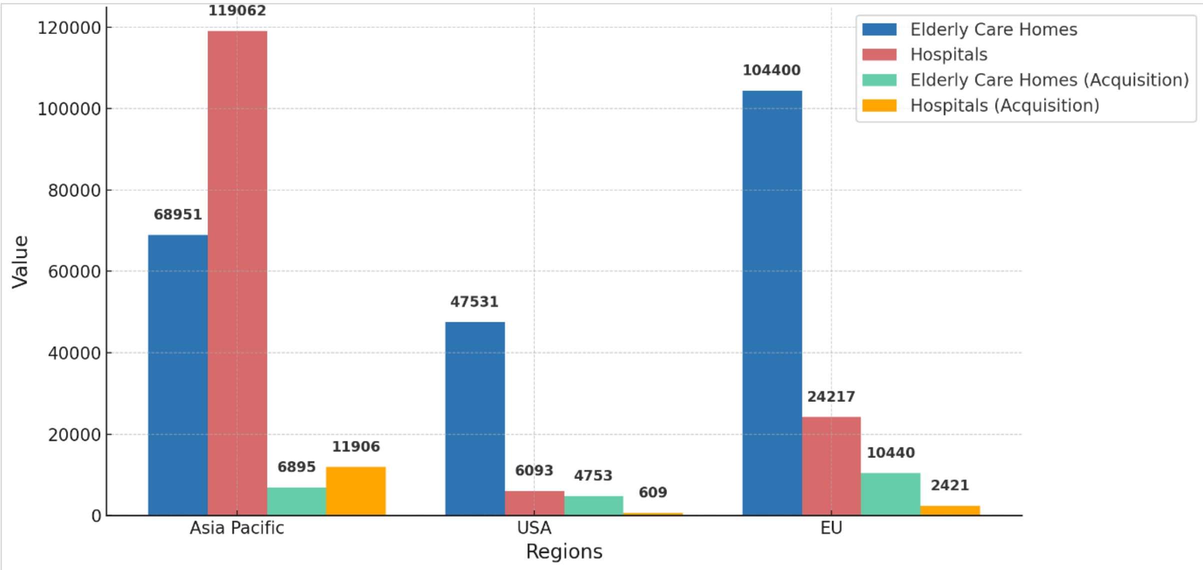


Figure 15: Institutional Potential Adoption of RF-sensing Embedded Router by Region

In the USA, potential acquisition in 1 year:

- $Elderly\ care\ homes: 47.531 \times 10\% = 4.753\ facilities$
- $Hospitals: 6.093 \times 10\% = 609\ facilities$

Total facilities in the USA may adopt Wi-Fi solutions:

$$4.753\ (elderly\ care\ homes) + 609\ (hospitals) = 5.362\ facilities$$

In Europe, potential acquisition in 1 year:

- $Elderly\ care\ homes: 104.400 \times 10\% = 10.440\ facilities$
- $Hospitals: 24{,}217 \times 10\% = 2.421\ facilities$

Total facilities in Europe may adopt Wi-Fi solutions:

$$10.440\ (elderly\ care\ homes) + 2.421\ (hospitals) = 12.861\ facilities$$

In Asia Pacific, potential acquisition in 1 year

- $Elderly\ care\ homes: 68.951 \times 10\% = 6.895\ facilities$
- $Hospitals: 119.062 \times 10\% = 11.906\ facilities$

Total facilities in Asia Pacific may adopt Wi-Fi solutions:

$$6.895\ (elderly\ care\ homes) + 11.906\ (hospitals) = 18.801\ facilities$$

5.2.4. Structural Growth Drivers

Market growth is not solely demographic. It is reinforced by multiple structural drivers:

Long-Term Care Expenditure Growth

OECD Health at a Glance (2023) reports rising LTC expenditure across Member States, driven by ageing populations, increased dependency duration and workforce cost pressure. Technology positioned as cost-avoidance support aligns directly with this macro-trend.

Workforce Shortage Pressure

OECD analyses indicate persistent shortages in long-term care workers across Europe. As resident-to-staff ratios increase, facilities require better attention allocation, early anomaly detection, operational situational awareness.

Digital Health Transformation

According to the (WHO, 2024b), assistive living technologies include any products or systems that maintain or improve an individual's functioning and independence to promote their well-being. These can range from low-tech aids to advanced digital systems and they are characterized by their ability to capture and provide user and environmental information in order to allow situation-sensitive support of the individual. They often leverage smart-home sensors, Internet of Things (IoT) devices, telehealth platforms, wearable monitors, and even robotic or AI-based assistants to help individuals age in place safely and with dignity. Such technologies enable older persons and those with disabilities to perform tasks they might otherwise find difficult, thereby rendering impairments less disabling by adapting the environment to their needs (OECD, 2022). For example, home sensor networks can detect falls or health anomalies, medication reminder apps support cognitive limitations, and socially assistive robots might provide companionship or caregiver functions.

The overarching objective is to allow individuals to live healthy, independent, and productive lives for as long as possible, whether in private homes, long-term care facilities, or workplaces. The global need for assistive technologies is substantial and growing: more than 1 billion people currently require one or more assistive products, a figure projected to exceed 2 billion by 2050 as populations age. Yet only approximately one in ten individuals in need currently has access to such technologies (UNICEF & WHO, 2023).

Recognizing this gap, international policy framework, including the WHO's Global Cooperation on Assistive Technology (GATE) initiative (WHO, 2018; WHO, 2025c) and the United Nations Convention on the Rights of Persons with Disabilities (United Nations Department of Economic and Social Affairs, 2006), call for urgent action to expand equitable access to assistive products as a core component of universal health coverage.

5.2.5. Strategic Implications

As previously introduced, the elderly care market is structurally expanding, supported by strong long-term demographic fundamentals that anchor its growth beyond cyclical dynamics. It has clearly measurable economic exposure, both in terms of public and private expenditure, and is institutionally concentrated, with public systems and large organized operators forming the backbone of the sector. At the same time, it is undergoing a process of digital transformation, with increasing integration of technologies for monitoring, management, and service delivery.

5.3. Market Segmentation Analysis

This section refines the TAM/SAM opportunity into **actionable segments**, enabling disciplined market entry and prioritization.

5.3.1. Market Dimension & Growth

Although precise regional market dynamics and demand estimates for Ambient Assisted Living (AAL) technology solutions are not available, many people worldwide experience communication impairments due to developmental disorders, injuries, and age-related issues [79].

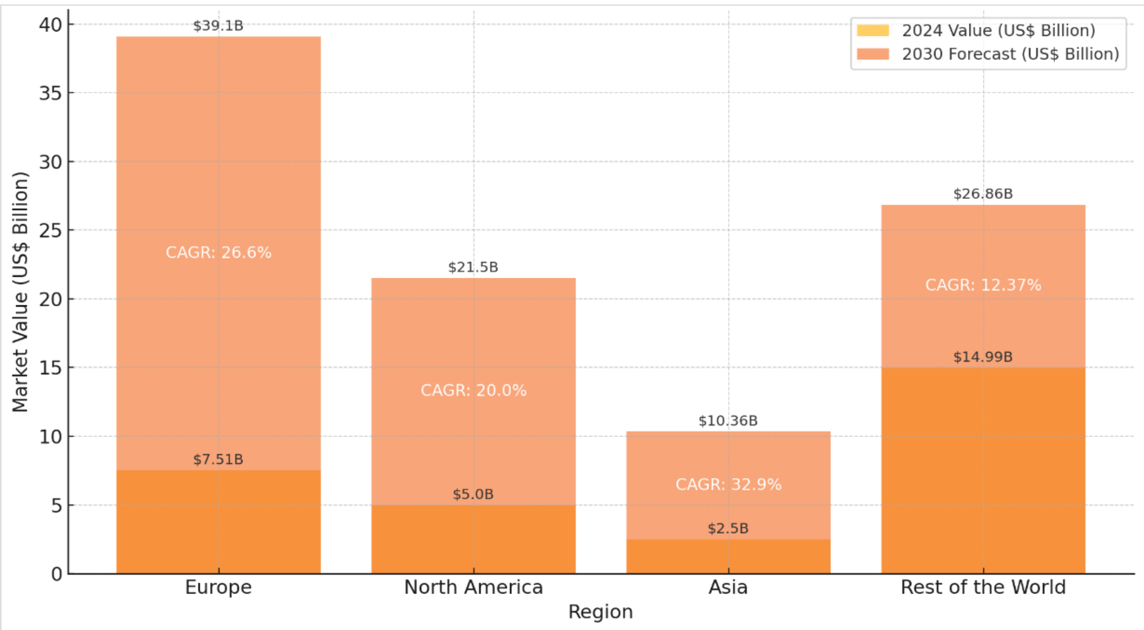


Figure 16: Ambient Assisted Living Technology Market Value (2024 vs 2030)

However, collected data from numerous sources shows that Europe represents the largest market segment in 2024, with a current market value of approximately €7.5 billion and projected to reach over €39 billion by 2030 with a CAGR of 26.6% [80]. North America follows with a current market value of €5.00 billion, forecasted to grow to €21.50 billion by 2030, at a 20.0% CAGR. Conversely, Asia, with a market value of €2.5 billion, stands to expand rapidly, reaching €10.36 billion by 2030, driven by an aggressive 32.9% CAGR. [81], [82]. The Rest of the World market, initially valued at €14.99 million, is expected to experience significant growth, reaching over €26.86 billion by 2030.

According to the World Health Organization's 2024 report, over 2.5 billion people worldwide were in need of one or more assistive products in 2020 [64]. With an ageing global population and a rise in noncommunicable diseases, it is projected that by 2050, approximately 3.5 billion people aged 60 years or older will require some form of assistive technology [83]. This growing demand features the substantial role that AAL technologies will play in meeting the needs of an increasingly ageing and health-challenged global population.

On the other hand, Wi-Fi router market data reveals that North America characterizes the largest market segment in 2024, with a current market value of approximately €5.50 billion, and is projected to reach €8.68 billion by 2030, driven by a 7.9% CAGR. Europe follows, with a market value of €4.18 billion in 2024, forecasted to grow to €6.71 billion by 2030 at an 8.2% CAGR.

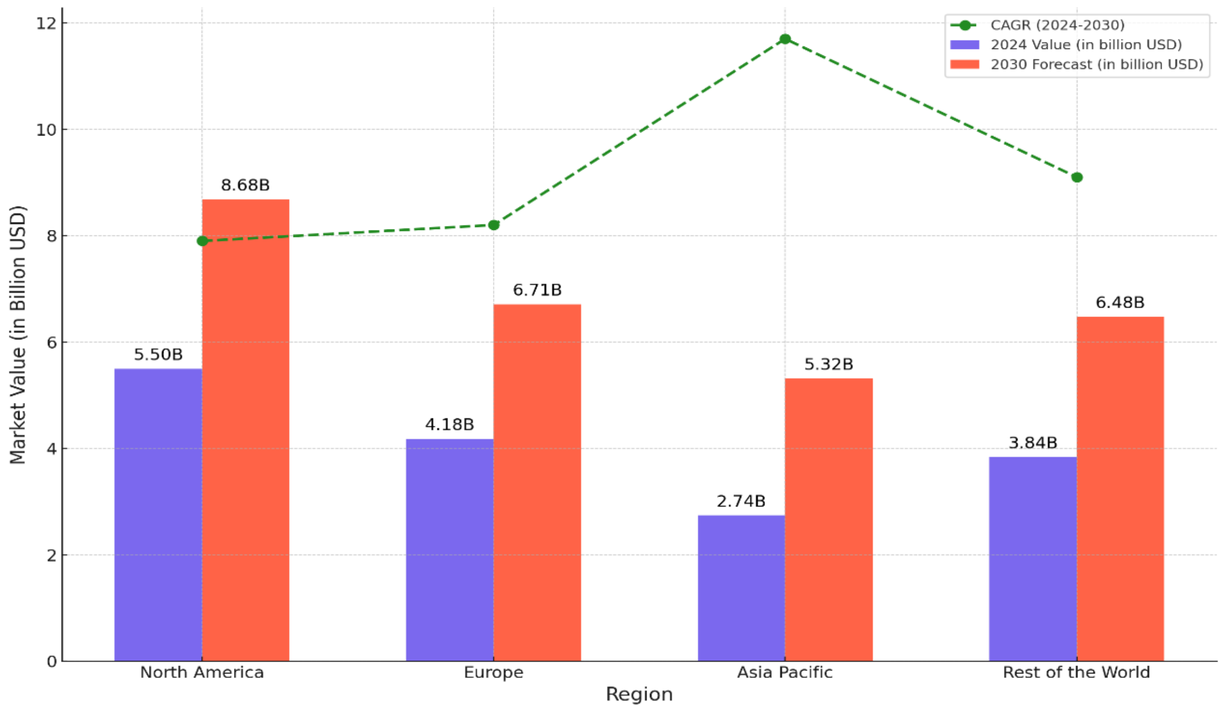


Figure 17: Wi-Fi Router Market by Region: 2024 – 2030 (Forecast)

Meanwhile, the Asia Pacific region, valued at €2.74 billion in 2024, is expected to experience rapid growth, reaching €5.32 billion by 2030, fueled by an 11.7% CAGR. Lastly, the Rest of the World segment, initially valued at €3.84 billion, is also poised for significant growth, projected to expand to €6.48 billion by 2030, with a 9.1% CAGR [84].

5.3.2. Target Market Segmentation

To better understand the target market within the healthcare sector, particularly within the Ambient Assisted Living (AAL) technology space, it's essential to break down the market by various key dimensions such as age groups, technology-specific segmentation, and the specific healthcare needs they cater to. Primarily, the market can be segmented into:

Age Group Segmentation

A key driver of the demand for AAL technologies is the global aging population. According to WHO projections, the number of people aged 60 years and older will significantly increase in the coming decades, creating an expanding market for AAL solutions.

Table 23: Demographic Segmentation for AAL Technologies Adoption

Age Group	Global Need for Assistive Products (2020)	Projected Need by 2050	Technologies Targeted	Source
60+ years	2.5 B people	3.5 B people	Mobility aids, health monitoring devices, smart homes	*Eurostat, 2024 & WHO, 2024*
80+ years	140 M	425 M	Intensive care, enhanced mobility, and cognitive impairment support	*WHO, 2024*
Chronic Disease Patients	1.4 B people	2.5 B people	AAL solutions for disease management (e.g., Dementia, Parkinson's)	*WHO, 2024*

Technology-Specific Segmentation

The AAL technology market can be segmented based on the specific technologies employed in the solutions or ecosystem at present. These include:

Table 24: Tech-specific Segmentation for AAL Technologies Adoption

Technology Type	Market Value (2024)	CAGR (2024-2030)	Projected Value by 2030	Key Players/Technologies	Source
Smart Home Devices	€9 billion	28.40%	€40 billion	Smart sensors, IoT-enabled devices, AI-powered automation	*Statista, 2024*
Wearable Healthcare Devices	€30.81 billion	15.20%	€60 billion	Apple Watch, Fitbit, smartwatches, fall detection systems	[85]
Health Monitoring Systems	€15 billion	18.30%	€35 billion	Telemedicine devices, real-time health tracking	[85]
Cognitive Assistance Devices	€3 billion	20%	€7 billion	AI-powered cognitive aids, smart memory devices	[86]

Behavioral Segmentation

Behavioral segmentation focuses on the reasons for technology adoption, user behavior, and engagement with AAL technologies. This is particularly important because consumer preferences, such as cost sensitivity, ease of use, and reliability, directly impact product adoption.

Table 25: Behavioral Segmentation for AAL Technology Adoption

Behavioral Factor	Influence Market	Target Market Segment	Source
Cost Sensitivity	Consumers in developing regions are more price-sensitive; in developed markets, consumers are more willing to pay for premium, innovative products.	Lower-income elderly in emerging markets, middle and upper-income elderly in developed countries	[87]
Ease of Use	Technology needs to be user-friendly, especially for elderly people and those with cognitive impairments.	Elderly individuals, caregivers, chronic disease patients/ patient's relatives	[87]
Reliability & Trust	The healthcare nature of AAL devices requires high trust in technology, particularly in terms of ethical, safety, accuracy, and emergency response features.	Elderly consumers, health/elderly care institutions, caregivers	[87]

Besides these, the socioeconomic status of individuals also impacts their access to and adoption of AAL technologies. High-income countries with developed healthcare systems (e.g., North America and Europe) are seeing more widespread adoption of advanced AAL solutions.

5.3.3. Target Market Profiling

The RF-sensing technology for elderly care and health monitoring is opted to target multiple key stakeholders and market segments within the healthcare ecosystem. Below is a detailed analysis of the primary **market profiles for the technology**, segmented based on their *roles*, *functions*, and their *specific needs in the context* of elderly care.

a. IoT Health Monitoring Device Manufacturers

These are the companies that design and produce Internet of Things (IoT)-based devices used for health monitoring in elderly care. RF sensing technology can be integrated well with existing IoT systems for continuous, non-invasive health monitoring, which can add value to the manufacturers' product offerings.

Key Players: Companies producing smart home health devices, connected wearables (not limited to traditional wearables like fitness trackers), and non-invasive monitoring solutions.

Example: Companies like Philips, Honeywell, Tunstall Healthcare, and Siemens, which are already active in health monitoring, could be key players to target.

b. Healthcare Providers & Elderly Care Facilities

This group includes hospitals, long-term care facilities, assisted living centers, and other senior care providers who can use RF sensing technology to improve their services. The focus will be on institutions that provide continuous care or remote monitoring of elderly individuals.

Key Players: Healthcare facilities, home care agencies, retirement communities, and hospice care organizations.

Example: Large healthcare providers like the Mayo Clinic or long-term care facility chains like Brookdale Senior Living could be key adopters.

c. Wearable Device Companies

Although RF sensing technology is not wearable, it complements wearable healthcare devices by offering real-time data without the need for physical contact. These companies could integrate RF sensing as an additional layer to enhance their products.

Key Players: Companies producing wearables like Fitbit, Garmin, Apple, and other health-focused device manufacturers.

Example: Companies already in the wearable space, such as Fitbit or Apple Watch, could be interested in integrating RF sensing into their technology offerings to enhance elderly care solutions.

d. Assistive Technology Providers

Assistive technology (AT) companies focus on creating products designed to improve the daily life of individuals with disabilities or age-related impairments. These companies would benefit from incorporating RF sensing technology for monitoring the health and safety of elderly users in both home and institutional care settings.

Key Players: Manufacturers of mobility aids, telemedicine devices, and cognitive assistance tools.

Example: Companies such as Medline, Invacare, and Assistive Technology Manufacturers could be key targets.

e. Telehealth Service Providers

Telehealth companies offer remote healthcare services, such as virtual consultations and monitoring. These service providers are increasingly looking for innovative ways to provide ongoing care for elderly patients remotely.

Key Players: Teladoc Health, MDTech, and other telemedicine or telehealth companies.

Example: Companies in the telemedicine space, such as Teladoc or Amwell, could benefit from integrating RF sensing technology into their remote monitoring offerings.

f. Insurance Providers

Insurance companies are key players in promoting and adopting new healthcare technologies as they have a vested interest in reducing costs related to elderly care and promoting healthier lifestyles.

Key Players: Health insurance companies, long-term care insurance providers, and pension funds offering health-related products.

Example: Companies like Blue Cross Blue Shield or Humana, which are actively involved in health risk management for the elderly, could be key adopters.

g. Government & Public Health Agencies

Government agencies focused on elderly welfare and public health organizations have a crucial role in the widespread adoption of health technologies. These entities may act as enablers or regulators of technologies like RF sensing.

Key Players: Ministries of Health, public health organizations, and government-funded elderly care programs.

Example: National Health Service (NHS) in the UK or U.S. Department of Health and Human Services could be relevant entities to target for public sector adoption.

h. Caregiver & Family Support Platforms

Technology platforms that support caregivers and families who assist elderly individuals can benefit from incorporating RF sensing technology to enhance care delivery.

Key Players: Homecare agencies, caregiver support platforms, and apps designed to connect caregivers and families.

Example: Caregiver platforms like Care.com or Honor could be interested in adopting RF sensing technology for their networks.

5.4. Market Needs & Trends

The dynamics of the elderly care market are evolving rapidly due to multiple current and emerging trends that are shaping the industry. Understanding these market trends and needs is crucial for identifying opportunities where RF sensing technology can play a pivotal role in transforming elderly care solutions. The dynamics of the elderly care market are evolving rapidly due to multiple current and emerging trends that are shaping the industry. Understanding these market trends and needs is crucial for identifying opportunities where RF sensing technology can play a pivotal role in transforming elderly care solutions.

a. Aging Population and Increased Demand for Elderly Care Solutions

Trend: The global aging population is rapidly increasing. By 2050, the number of people aged 60 and older is expected to more than double (2*x*). This demographic shift is driving demand for elderly care solutions [88].

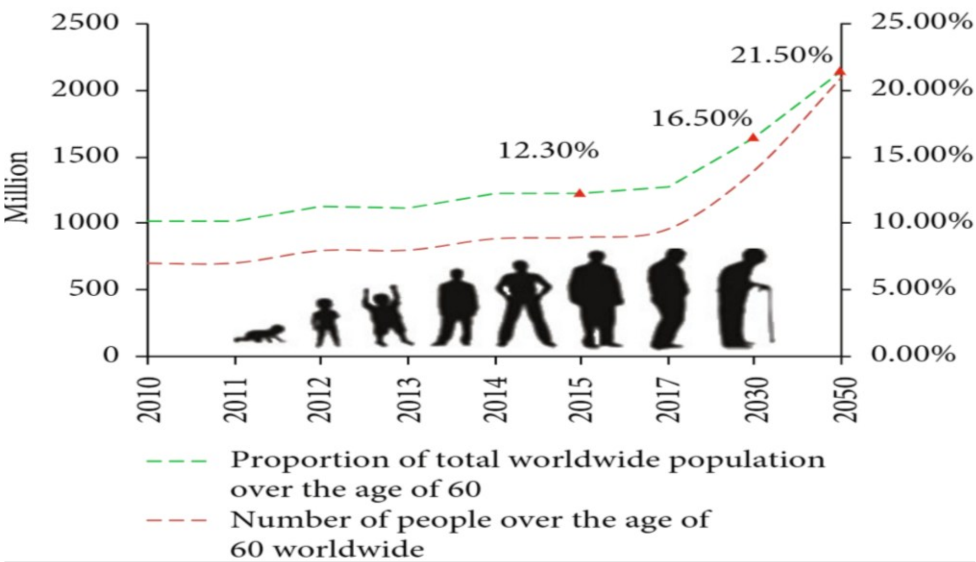


Figure 18: Epidemiological trends of aging worldwide

Need: There is an extensive scope for technologies like RF sensing are required to offer continuous monitoring and support, enabling elderly individuals to live independently while ensuring their safety and well-being.

b. Preference for Non-Invasive and Wearable-Free Monitoring

Trend: Elderly individuals are increasingly seeking non-invasive and wearables-free monitoring technologies due to discomfort or resistance to traditional medical devices.

Need: RF sensing technology, which provides non-contact, non-wearable monitoring, meets this demand by tracking health metrics like movement, heart rate, and fall detection without physical devices.

c. Rising Healthcare Costs and Focus on Preventive Care

Trend: Healthcare costs for the elderly are increasing, particularly due to fall-related injuries and chronic conditions. This is placing pressure on healthcare systems to find cost-effective solutions (Healthcare expenditure statistics, Eurostat, 2023).

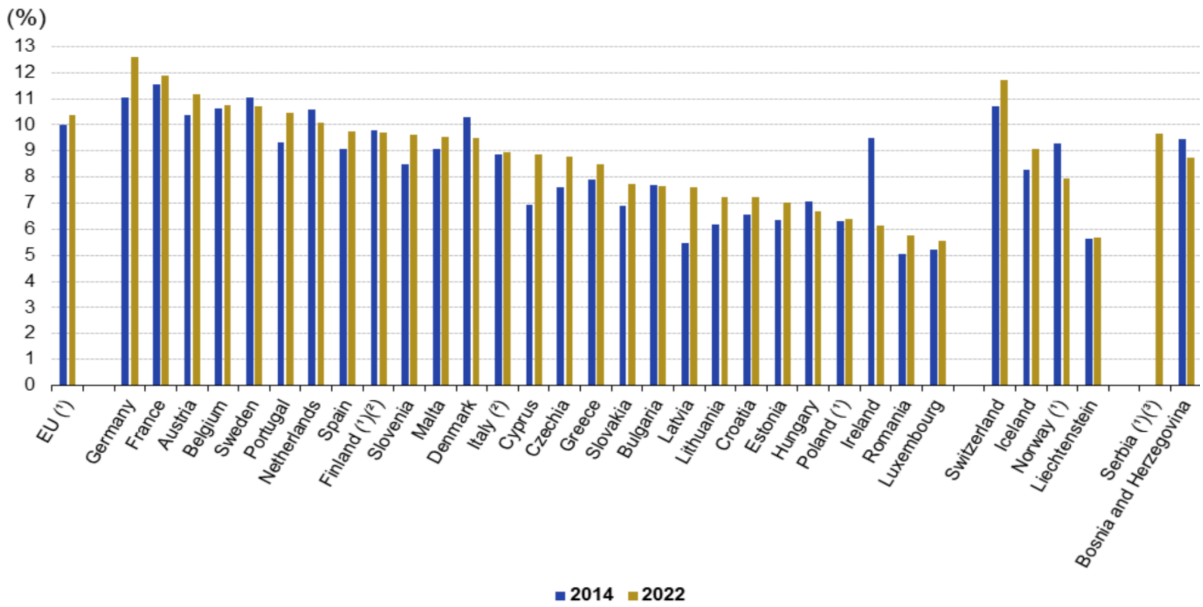


Figure 19: Healthcare Expenditure relative to GDP (2014 and 2022)

Need: RF sensing technology can prevent costly hospital readmissions by detecting early warning signs (e.g., falls, irregular heartbeats) and alerting caregivers in real-time, reducing healthcare expenses.

d. Demand for Affordable Healthcare Solutions

Trend: Globally, with many elderly individuals and healthcare facilities facing budget constraints, and similarly, the demand for nursing staff is projected to outstrip supply, with estimates suggesting a shortfall of over 500.000 registered nurses by 2030, there is an increasing demand for affordable healthcare solutions that do not compromise on quality (Visual Representation Based on Google Trends Data).

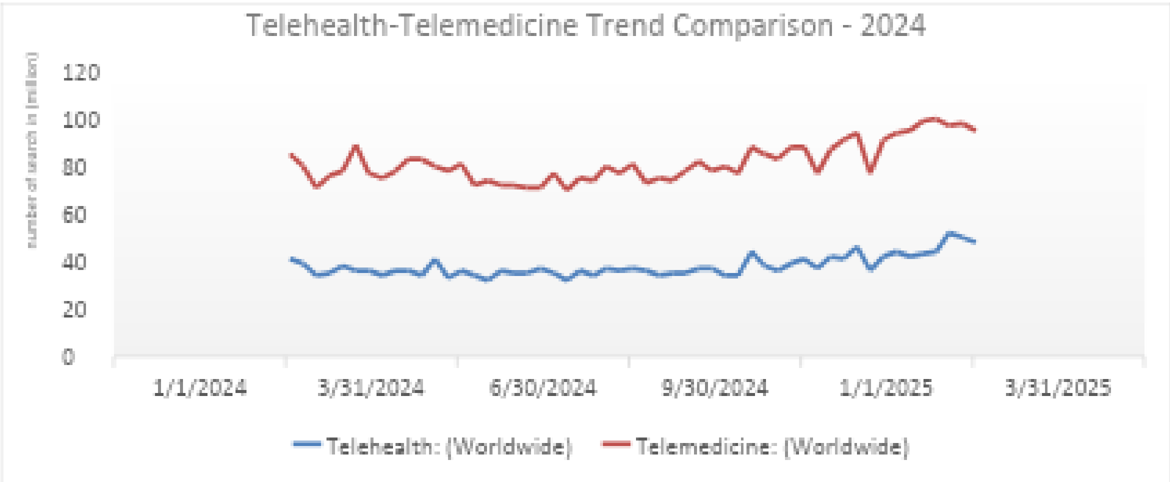


Figure 20: Trend Comparison between Telehealth and Telemedicine in 2024

Need: RF sensing technology is a cost-effective solution compared to traditional wearable devices or expensive monitoring systems, making it accessible for both individuals and healthcare providers looking to reduce operational costs.

e. Increased Adoption of Telehealth and Remote Monitoring

Trend: The COVID-19 pandemic accelerated the adoption of telehealth, and this trend is expected to continue. Remote monitoring is becoming an essential part of elderly care.

Need: RF sensing technology can seamlessly integrate into telehealth systems, providing continuous remote health monitoring that allows caregivers and healthcare providers to respond promptly to emergencies.

f. Rise in Chronic Conditions and Need for Ongoing Health Monitoring

Trend: The prevalence of chronic conditions (in the USA, *nearly 95% of older adults are managing at least one chronic disease, with 80% dealing with two or more*) [89] such as Parkinson's disease, dementia, hypertension, heart disease, and asthma is rising among older individuals (*The Alzheimer Cohorts Consortium and Global Data Pharma Intelligence Centre*). Currently, more than 55 million people have dementia worldwide, and every year, there are nearly 10 million new cases. Therefore, necessitating continuous health monitoring [90].

Need: RF sensing technology can track a wide range of vital signs, activities, movements, and cognitive behaviors, offering continuous monitoring to manage chronic conditions effectively and prevent complications.

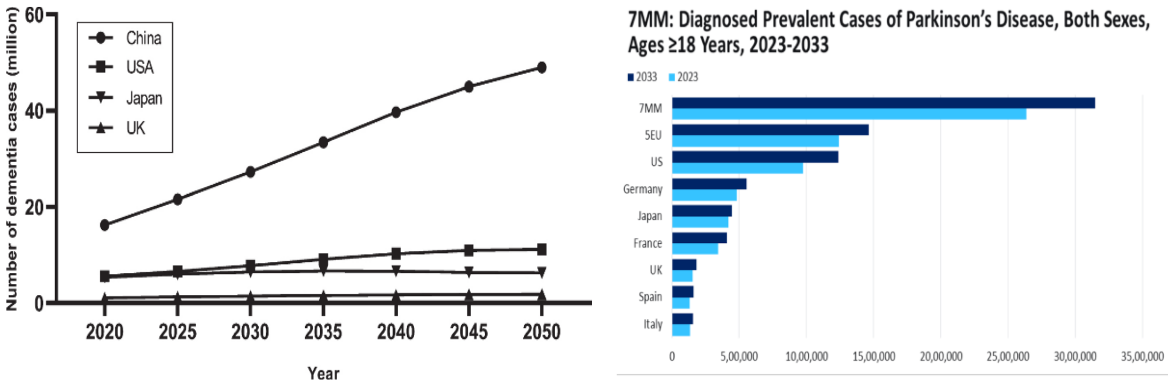


Figure 21: Global Dementia and Parkinson's Disease Situation

g. Emphasis on Fall Detection and Prevention

Trend: Falls remain one of the leading causes of injury among the elderly, with the incidence of fall-related injuries increasing at a national level, and fall-related injuries are a major driver of healthcare costs. In figure 22 we report Google Trends based on "fall detection" as the search term.

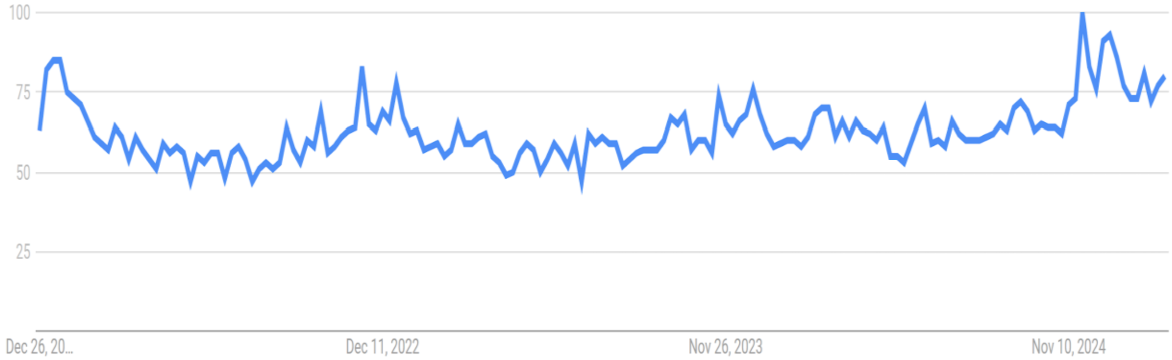


Figure 22: Global Fall Detection Device Search on Google Trends (Million)

Need: RF sensing technology offers highly accurate fall detection (with up to 98% accuracy) without requiring wearables. This capability is crucial for preventing falls and enabling quick emergency responses.

h. Integration with Smart Home Technologies

Trend: The rise of smart homes, particularly in developed nations, is enabling more elderly individuals to "age in place" with smart technologies ensuring safety, connectivity, and convenience. In figure 23 we report growth trend in Smart Home Technology Adoption in the USA (Statista, 2023).

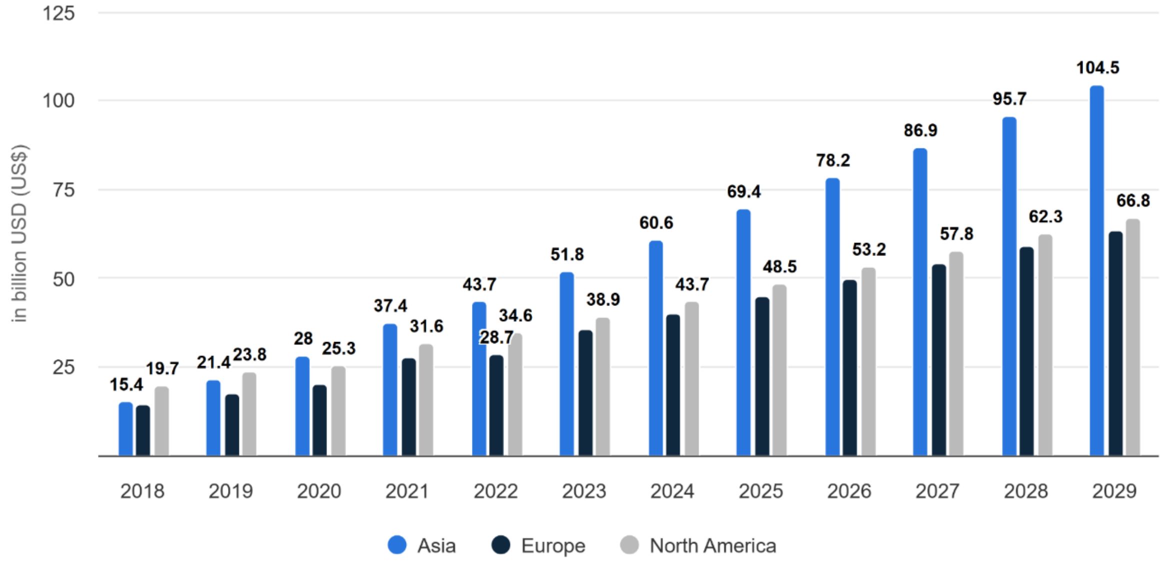


Figure 23 – Growth Trend in Smart Home Technology Adoption in the USA

Need: RF sensing technology can integrate with IoT systems in smart homes, offering real-time health monitoring while enhancing the functionality of other devices like CCTV cameras, lighting, alarms, and security systems.

5.5. Value and Use-Case Analysis

This section transitions our market analysis from theoretical technology to practical application. By defining the specific product benefits and real-world outcomes of RF sensing, we identify the high-value intersections within both the Business-to-Business (B2B) and Business-to-Consumer (B2C) value chains.

The integration of Holden's RF innovation into standard Wi-Fi routers represents a paradigm shift: the evolution of a household utility into a life-monitoring health hub. This dual-pathway approach allows us to address the unique needs of institutional healthcare providers while simultaneously empowering individual families.

The following analysis quantifies these impacts through three primary metrics:

Operational & Economic Efficiency: reducing the high costs associated with traditional monitoring and emergency interventions.

Quality of Life: Enhancing elderly independence through non-invasive, "invisible" technology.

Caregiver Sustainability: Systematically reducing the physical and emotional burden on both professional and family caregivers. By mapping these outcomes, we demonstrate how Holden's innovation creates a cohesive ecosystem (see Figure 24) where hardware vendors, service providers, and end-users all derive measurable value.

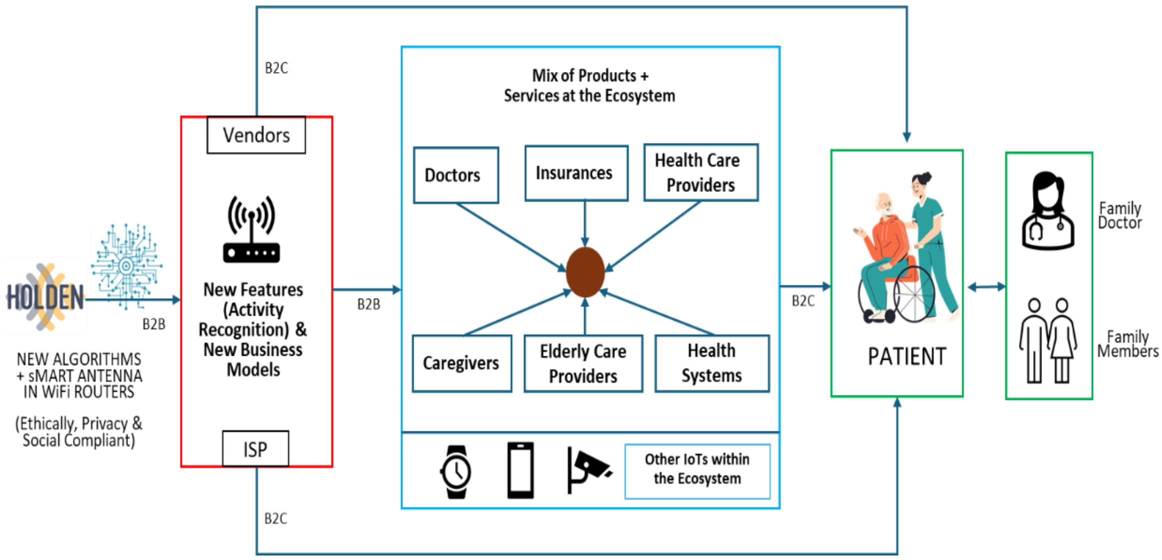


Figure 24 – Holden Innovation's impact in the Assisted Living Ecosystem

5.5.1. The B2C Value Chain: Retail Vendors & ISPs

In this model, the hardware vendor (e.g., Netgear, TP-Link) or the Internet Service Provider (ISP) acts as the bridge to the home. They purchase the integrated technology from the Wi-Fi Manufacturers (ODMs) and sell the Wi-Fi Router and/or the Internet Connectivity service directly to the consumer.

Market Opportunity

The home care and smart home markets are growing rapidly, driven by the aging population and the increasing adoption of non-invasive health solutions. By providing this technology directly to consumers, the product addresses a significant demand for affordable and convenient elderly care solutions.

Primary Customers

Patients, elderly individuals living alone, and their family members can directly purchase or ask the ISP provider the Wi-Fi router with integrated RF sensing technology, enabling a home-based health monitoring solution. Consumers can use the Wi-Fi router as an all-in-one device for both Wi-Fi connectivity and elderly care, without requiring wearables or additional health monitoring devices.

Key Benefits:

- **Low Friction/High Adoption:** Unlike wearables that seniors often forget to charge or wear, this system is "invisible." It resides in the router, requiring zero lifestyle changes.
- **Cost-Efficiency for Families:** By purchasing a retail router with integrated RF sensing, families avoid expensive, proprietary medical hardware and high monthly monitoring fees.
- **Privacy-First Safety:** Unlike cameras, RF sensing maintains the dignity of the elderly user while still providing "movement detection" and "activity recognition" alerts to family members via a mobile app.
- **ISP Revenue Expansion:** ISPs can offer "Elderly Care & Safety" tiers, moving beyond simple bandwidth to become a "connected care" provider, significantly reducing customer churn.
- **Customer Loyalty**: By providing value-added features, Vendors and ISPs can improve brand loyalty and increase long-term customer retention.

5.5.2. The B2B Value Chain: Elderly Organizations & Healthcare Solution Providers

This model shifts the focus from individual home use to the "Mixed Products + Services" ecosystem. In this landscape, the Wi-Fi router is no longer just a connectivity tool; it is integrated into a broader professional care framework. Wi-Fi Vendors and ISPs provide "health-ready" hardware to Solution Providers and Healthcare Organizations, who then layer on sophisticated services to create an "All-in-One" care offers.

Market Opportunity

The transition to RF-sensing technology can create new revenue streams across the B2B landscape:

- **Wi-Fi Manufacturers (ODMs):** Can secure high-volume, long-term enterprise contracts. This allows them to pivot from a "race to the bottom" on hardware pricing to providing specialized, high-margin equipment for the healthcare sector.

- **Vendors & ISPs:** Can transition into **"Managed Care Connectivity"** providers. By bundling high-speed internet with an enterprise-level safety dashboard, they become strategic partners to nursing homes and assisted living facilities.
- **Solution Providers:** These firms can build the software "intelligence" layer that offers tele-health services, creating a dominant position in the Remote Patient Monitoring (RPM) market, by providing actionable alerts and clinical insights.

Primary Customers

The primary customers are entities that manage high-density elderly populations, including **Assisted Living Facilities, Nursing Homes, Hospitals, and Rehabilitation Centers.** For these organizations, the router serves as the non-invasive backbone of their monitoring infrastructure. Unlike the B2C model's focus on individual peace of mind, the B2B focus is on **population management**. It allows staff to safely monitor hundreds of residents simultaneously, identifying risks (like gait changes or other activity patterns) without the privacy intrusions of cameras or the compliance hurdles of wearables.

Integrated Professional Services

In the B2B chain, value is realized through the "bundling" of the hardware with other value-added services:

- **Insurance & Risk Management:** Health and life insurers can offer lower premiums or "wellness incentives" to facilities that use RF sensing, since this technology can help to reduce the operative costs.
- **Telehealth & Clinical Integration:** The system can create a direct data pipeline to clinics and doctors. By providing objective gait and activity data, it enables more accurate remote diagnoses and personalized care plans.
- **Automated Emergency Response:** Integration with 24/7 medical dispatch centers ensures that "silent" emergencies (like a cessation of vitals or overnight health accidents) trigger immediate protocols without the resident needing to press a button.
- **Caregiver Analytics & Staff Optimization:** Facilities receive aggregated "health trend" reports. These insights allow management to optimize staffing levels and prioritize care for residents, showing signs of health decline before a crisis occurs.

Key Benefits

- **Scalable, Maintenance-Free Monitoring:** Facilities can oversee hundreds of residents simultaneously through Wi-Fi infrastructure. This eliminates the "logistical" costs of managing wearable device inventories, frequent battery charging, and the constant risk of residents forgetting to wear their sensors.

- **Transition to Preventative Care:** Healthcare providers can receive high-fidelity data on sleep patterns and activity levels, allowing for "preventative" rather than "reactive" care (as example, early detection of declining mobility can prevent a fall before it happens).
- **Quantifiable Risk Mitigation:** RF-sensing provides an objective "audit trail" of resident safety. Insurance providers can leverage this data to offer lower premiums or wellness incentives, as the technology directly reduces the frequency of undetected falls and costly hospital readmissions.
- **Alleviation of Caregiver Burnout:** By automating routine "well-being checks" and filtering out false alarms, the system allows overextended staff to prioritize their physical presence for high-need patients. This optimization of human capital improves both staff retention and the overall quality of resident care.

5.6. Competitive Landscape

In the rapidly evolving healthcare and elderly care market, various technologies offer solutions aimed at improving patient monitoring, particularly for elderly individuals who require constant care. The competitive landscape is increasingly shaped by advancements in Internet of Things (IoT), wearable devices, and smart home systems, each offering distinct capabilities to address health and safety challenges. This section provides a structured overview of existing technologies and key players available within the elderly care and assisted living market.

The technology market for elderly care is not dominated by a single category but is instead stratified across distinct technological paradigms. Beside the RF sensing “Holden Solution” five main competing technological groups can be identified:

- Wearable Monitoring Technologies
- Environment Monitoring Technologies
- Passive Technologies Monitoring Health
- Interactive Technologies
- Wi-Fi Sensing

A summary of the technologies is reported in Table 26.

Table 26: Competing Technologies in the Elderly Care Ecosystem

Category	**Technology/Device**	**Key Players Examples**
Wearable	Watches, Rings, GPS Tracker	Fitbit, Garmin, Apple, Galaxy
Environment Monitoring Technologies	Motion Sensors, Cameras	Philips, Honeywell, Sony, Arlo, Siemens
Passive Technologies monitoring health	Smart Furniture, Fall Detectors	Baxter International, E.C.H.O. Care, Essence
Interactive Technologies	Voice-Operated Virtual Assistants	Apple Siri, Google Assistant, Amazon Alexa, Cortana
Wi-Fi Sensing	WiFi routers, RF sensors	Cognitive systems, Origin Wireless, Vayyar

5.6.1. Wearable Monitoring Technologies

Wearable Monitoring Technologies, while common in elderly care (e.g., Smartwatches, Rings, GPS trackers), demand constant user compliance and regular charging, which may be unsuitable for elderly users with cognitive or physical limitations. Common solutions include fall-detection pendants, smart bracelets, panic buttons, basic physiological monitoring.

Figure 25: Wearable Monitoring Technologies

Despite being widely accepted, wearables are often intrusive, relatively high in lifecycle costs, and may lead to user fatigue or abandonment over time.

<u>Key Market Players</u>: examples include Fitbit (Google), Garmin, Apple, Samsung.

<u>Privacy & Ethics</u>: these devices create a continuous stream of biometric data. While widely accepted, they pose ethical risks regarding who owns the long-term health history stored in corporate databases.

AI & Cloud Impact: monitoring is highly dependent on cloud synchronization for data processing. This raises "data residency" concerns when sensitive health metrics are transmitted from the home to external servers.

Impact on Private Life: intrusiveness is physical rather than visual; users must "wear" the surveillance, which can lead to fatigue and a constant reminder of their frailty.

5.6.2. Environment Monitoring Technologies

Environment Monitoring Technologies, such as motion sensors and cameras, are more passive but come with significant privacy concerns, particularly when visual monitoring is involve. While they provide a degree of automation, they still lack the seamless, ambient intelligence needed for holistic, real-time health assessments.

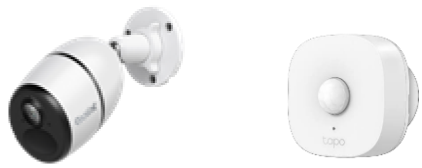


Figure 26: Environment Monitoring Technologies

These systems rely on image recording and analysis based typically on computer vision algorithms and analytics. Some vendors also offer real-time fall alerts, behavioral pattern tracking, and room monitoring dashboards. Their adoption often depends on cultural acceptance and explicit consent mechanisms.

Key Market Players: examples include Philips, Honeywell, Sony, Arlo, Siemens.

Privacy & Ethics: This category carries the highest privacy risk, as video recording is considered highly sensitive personal data. Ethical resistance is common due to the "Big Brother" feel of home cameras.

AI & Cloud Impact: Relies on heavy Computer Vision AI and cloud-based analytics. The potential for AI regulation exposure is high, particularly if the system attempts to infer emotions or distress from visual cues.

Impact on Private Life: Highly intrusive; it changes the nature of a private home into a monitored "facility," often requiring explicit, complex consent mechanisms from the elderly.

5.6.3. Passive Monitoring Health Technologies

Passive Technologies Monitoring Health, such as smart furniture (e.g., pressure-sensing chairs) or fall detectors, serve a more reactive function. While less invasive, their functional range is often limited to specific events or environments, reducing their overall versatility. These technologies often require complementary systems to deliver a full monitoring solution.

Figure 27: Passive Monitoring Health Technologies

<u>Key Market Players</u>: examples include Baxter International, E.C.H.O. Care, Essence.

<u>Privacy & Ethics</u>: Often viewed as "benign" because they lack cameras, yet they still track intimate domestic habits (e.g., how long someone sits in a chair).

<u>AI & Cloud Impact</u>: Typically use simpler AI for reactive event detection (e.g., a fall). Data is often processed locally but may rely on the cloud for emergency alerts.

<u>Impact on Private Life</u>: Low physical intrusion, but limited versatility means they often require "patchwork" installations across the home to be effective.

5.6.4. Interactive Technologies

Interactive Technologies, such as voice-operated virtual assistants, support remote interaction and engagement but are not primarily designed for continuous health monitoring. Their functionality is limited unless combined with other systems. They typically require user initiation, making them less effective for continuous or emergency-based care scenarios.

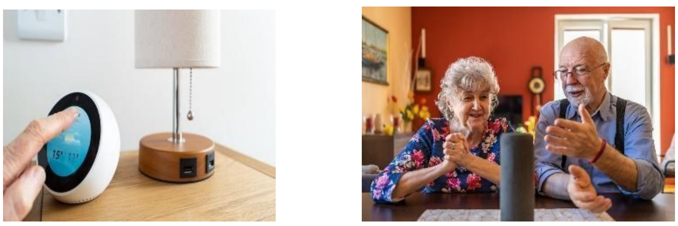


Figure 28: Interactive Technologies

<u>Key Market Players</u>: examples include Apple (Siri), Google (Assistant), Amazon (Alexa), and Microsoft (Cortana).

Privacy & Ethics: Significant ethical concerns exist regarding "passive listening" and the potential for unintentional recording of private home conversations.

AI & Cloud Impact: These systems are highly cloud-dependent, utilizing Natural Language Processing (NLP) on manufacturer servers to interpret commands. This creates high privacy sensitivity regarding the storage of "voice-prints" and personal dialogue.

Impact on Private Life: These systems require the user to be conscious and capable of initiating interaction, making them largely ineffective during medical emergencies where the patient is incapacitated.

5.6.5. *Wi-Fi Sensing Technologies*

Wi-Fi sensing offers an infrastructure-based, non-intrusive solution by analyzing RF signal disturbances to detect occupancy, movement, and basic activity levels. They often require complementary devices to achieve full functionality, such as Wi-Fi routers and mesh devices, Wi-Fi smart plugs and lamps, Radar systems are used, using Wi-Fi signal analysis, RF reflection patterns analysis, AI engines.

Figure 29: Wi-Fi Sensing Technologies

Key Market Players: examples include Vayyar, Origin Wireless and Cognitive Systems.

Privacy & Ethics: While they avoid visual recording, current market systems often struggle with inadequate privacy compliance, potentially allowing for unauthorized "presence mapping" of a resident's movements within their home.

AI & Cloud Impact: High-performance AI engines are required to distinguish human movement from environmental noise. Most current commercial solutions are cloud-based to handle these complex calculations, requiring robust encryption to protect sensitive RF signatures.

Impact on Private Life: These systems provide "ambient intelligence" without physical or visual intrusion. However, limitations in precise movement detection in standard models can lead to false alarms that disrupt the sanctity of home life.

5.6.6. Holden Innovation and Competitive Advantage

HOLDEN Innovation can represent a paradigm shift in the AAL (Ambient Assisted Living) market, specifically engineered to overcome the friction points of traditional monitoring. By moving beyond the limitations of cameras and wearables, HOLDEN provides a high-fidelity "health-ready" infrastructure.

The solution's competitive edge is defined by the following core pillars:

- **Privacy-by-Design & Ethical Compliance**: unlike vision-based systems or voice assistants, HOLDEN does not capture identifiable personal imagery or audio. It operates on RF signal data, ensuring that the resident's dignity remains intact while maintaining the highest levels of GDPR and ethical compliance.

- **Edge AI & Data Protection:** to address cloud-sensitivity, HOLDEN's advanced algorithms are designed for localized processing. By minimizing the volume of sensitive raw data transmitted to the cloud, the system reduces the risk of data breaches and ensures that "Private Life" signatures remain secure within the home or facility.

- **Zero-Friction Interaction:** HOLDEN Innovation eliminates "User Burden." There are no batteries to charge, no pendants to wear, and no voice commands to remember. It is an "invisible" system that provides continuous, contactless monitoring of vitals, movement, and health monitoring.

Strategic Differentiation Framework

To contextualize HOLDEN Innovation role within the broader ecosystem, we assess its performance against competing categories based on five critical strategic factors:

- **Lifecycle Cost of Ownership**: Unlike wearables (high replacement/battery costs) or cameras (high bandwidth/storage costs), HOLDEN leverages existing Wi-Fi infrastructure, significantly lowering the Total Cost of Ownership (TCO).

- **Sensing Functionality**: Offers higher awareness level, detecting movements and monitoring health status conditions that basic motion sensors cannot capture.

- **Ethical / Privacy Compliance**: Provides the precision of a camera with the total privacy of a standard Wi-Fi router.

- **Ease of Use**: Requires zero lifestyle changes from the elderly user and minimal training for caregivers.

- **Integrability**: Designed as an embeddable solution for ODMs and ISPs, making it highly scalable across both institutional (B2B) and residential (B2C) settings.

This comparison helps us understand the unique advantages of HOLDEN Innovation, its market potential, and its limitations when compared to other technologies. Overall, when assessed across the five strategic criteria, HOLDEN Innovation demonstrates superior alignment with the emerging needs of both consumers and care providers. It is non-intrusive, respects privacy, is cost-effective over time, and scalable across institutional and home settings. Moreover, HOLDEN Innovation is highly integrable within existing alternatives, not requiring user interaction and providing seamless user experiences across diverse care environments. It creates a unique market niche: a solution that is as non-intrusive as a smart plug but as clinically insightful as a dedicated general health monitor. This balance makes HOLDEN Innovation a primary candidate for disrupting the current fragmented landscape.

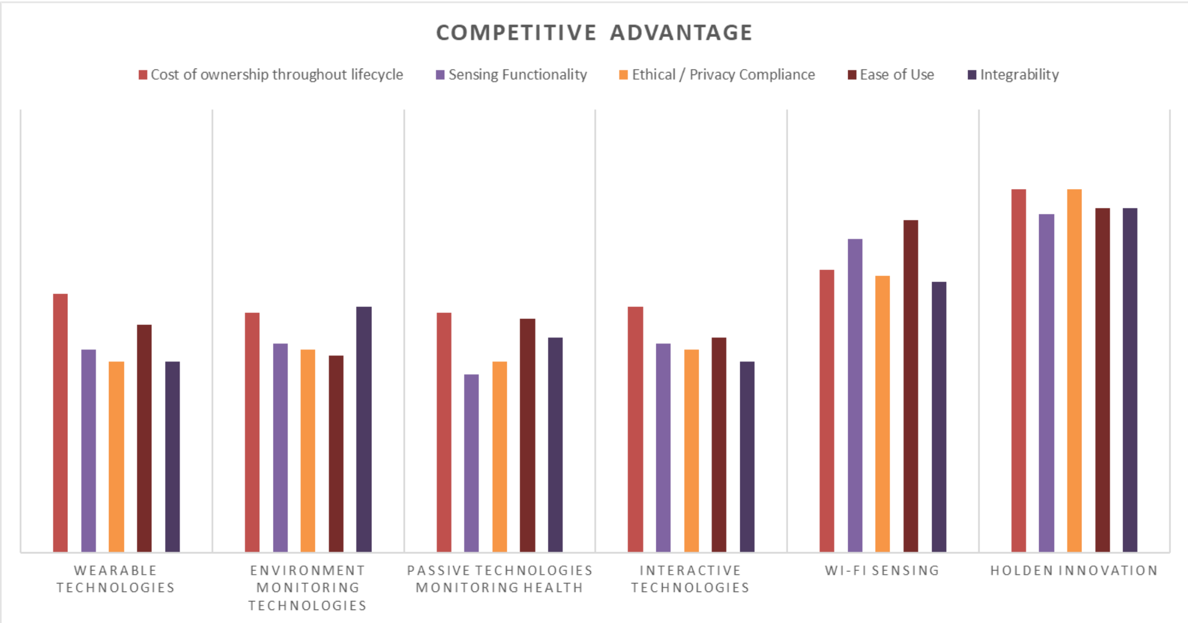


Figure 30: Comparison of HOLDEN Innovation with Existing Alternatives

5.7. Entry Barriers

This section consolidates the principal structural considerations shaping market entry. In analyzing the barriers to market entry for embedding RF sensing technology inside Wi-Fi routers, we can apply Porter's Five Forces to understand the competitive dynamics and external factors that will influence our success. The market is not only shaped by Wi-Fi router producers but also by wearable device manufacturers and tech producers from various sectors.

5.7.1. Threat of New Entrants

<u>Technological Complexity and Additional Costs: (High Impact)</u>

The integration of RF sensing into Wi-Fi routers involves extra functional or technological complexity, significant R&D, and additional costs for manufacturers. This poses a high barrier as ISPs, Vendors and router manufacturers may be hesitant to incur these costs without a clear, compelling return on investment (ROI). Integrating new technology into existing products requires convincing customers and partners of long-term value while maintaining competitive pricing.

<u>Mitigation Strategy</u>

Launching pilot programs to demonstrate the effectiveness of RF sensing technology in Wi-Fi routers and to highlight its long-term value. This can provide proof of concept and make the business case more compelling.

5.7.2. Bargaining Power of Suppliers

<u>Supplier Dependence: (Moderate to High Impact)</u>

RF sensing requires specialized components and sensors, making technology providers highly dependent on a limited number of suppliers. If these suppliers control pricing or availability, it could disrupt production and increase costs, which could limit the scalability of the technology. Example: in 2021, fluctuations in the supply of semiconductors have already led to delays and price hikes in various tech industries, including consumer electronics. Major companies like Cisco and TP-Link faced delays and higher manufacturing costs due to the limited availability of critical components (Bloomberg News, 2021).

<u>Mitigation Strategy</u>

To reduce dependency on a small number of suppliers, it is essential to identify and secure relationships with multiple suppliers for both hardware components (e.g., sensors) and software solutions. If feasible, the company could consider developing proprietary algorithms or components in-house, reducing reliance on third-party suppliers.

5.7.3. Bargaining Power of Buyers (End Users Acceptance)

<u>Consumer Preferences: (Moderate to High Impact)</u>

Wearable devices such as smartwatches, SOS button, Smart trackers, alongside various motion sensors are deeply rooted in the consumer market. Their established presence creates a moderate barrier, as consumers may prefer wearable health tech over integrated solutions. Moreover, care facilities and caregivers who are accustomed to using wearables may resist the shift to integrated solutions due to the need for new training, potential learning curves. Example: care facilities have invested and integrated wearables into their systems to monitor patient health, creating a degree of inertia in switching to non-wearable solutions.

Mitigation Strategy

Hybrid Solutions and Seamless Integration: to reduce resistance, it is necessary to offer hybrid solutions that combine the best of both worlds—alongside existing wearables, integrated RF sensing technology in Wi-Fi routers, adding value through enhanced functionality.

5.7.4. Industry Rivalry (Existing Competitors)

Industry Preference: (Moderate Impact)

Existing ISP provider or router manufacturers might see the integration of RF sensing as a potential value-added feature but may resist if they already have partnerships with other tech providers or if the integration is deemed cost-ineffective. Market players might perceive the adoption of this new technology as unnecessary, especially if their existing products are already meeting consumer demands. Example: a 2023 study by Ookla highlighted that as of February 2023, Wi-Fi 6 adoption remained relatively low, with Wi-Fi 4 and Wi-Fi 5 still being dominant. This slow uptake was partly due to ISPs' reluctance to upgrade infrastructure and consumers' satisfaction with existing Wi-Fi 5 networks (Ookla, 2023).

Mitigation Strategy

Market Promotion & Awareness: promotional activities towards consumers and industry players about the long-term benefits of new technologies, such as improved security and user experience, can drive adoption. During many events, Netgear, and TP-Link showcased advancements in Wi-Fi6E / Wi-Fi7 technology, aiming to accelerate its adoption and highlight its advantages over previous standards.

5.7.5. Regulatory Barriers

Regulatory frameworks: (Moderate to High Impact)

Integrating new technologies like RF sensing into Wi-Fi routers can pose significant obstacles. The technology's real-time monitoring of user activities within private spaces raises concerns over the collection and processing of sensitive data, especially in regions with strict laws such as the EU's GDPR and the US's CCPA. Moreover, technology’s application in elderly care systems may face additional hurdles if it is prone to errors, false indications, or negative impacts on care quality, leading to potential legal and ethical issues. Example: the European Union's General Data Protection Regulation imposes stringent regulations on how data from devices, including those that monitor movement or behavior, can be collected, processed, and stored. If router collects sensitive data that is not adequately protected, it could lead to legal issues or delays in market entry. A similar issue was seen with Google Home devices, which faced scrutiny in the EU for violating GDPR with their handling of personal data (The Verge, 2020).

Mitigation Strategy

Design privacy by default: to meet both GDPR and CCPA standards, RF sensing technology must adopt a "Privacy by Design" approach, where privacy measures are integrated into the system architecture from the outset.

Table 27: Summary Table of Key Barriers and Mitigation Strategies

Dimension	**Barrier**	**Details**	**Impact**	**Examples**	**Mitigation Strategy**
Threat of New Entrants	Technological Complexity and Additional Costs	The integration of RF sensing into Wi-Fi routers requires significant R&D, technological complexity, and additional costs for manufacturers.	High	Google (Smart Home Products)	Launch pilot programs to demonstrate long-term value and effectiveness, providing proof of concept.
Bargaining Power of Suppliers	Supplier Dependence	RF sensing requires specialized components and sensors, creating dependency on limited suppliers, which increases cost risks.	Moderate to High	Cisco, TP-Link (tech companies facing component shortages)	Secure relationships with multiple suppliers and explore in-house development of proprietary components or algorithms.
Bargaining Power of Buyers	Consumer Preferences for Wearables	Consumers have an established preference for wearable devices, which may hinder acceptance of integrated RF sensing technology in routers.	Moderate to High	Care Facilities tie up with leading wearable brands	Offer hybrid solutions combining wearables with integrated RF sensing technology in Wi-Fi routers to enhance functionality.

Industry Rivalry	Industry Preference	Existing router manufacturers may resist integrating RF sensing due to existing partnerships or cost concerns.	Moderate	Netgear, TP-Link (Slow Wi-Fi 6 adoption, industry reluctance)	Promote long-term benefits of RF sensing technology, highlighting advantages over existing technologies to drive adoption.
Regulatory Barriers	Regulatory Frameworks	Strict regulations on data privacy and protection (e.g., GDPR, CCPA) pose challenges for integrating RF sensing in routers due to sensitive data collection.	Moderate to High	Google Home Devices (facing GDPR scrutiny)	Implement "Privacy by Design" to comply with GDPR and CCPA, ensuring privacy measures are integrated into the system architecture.

6. Exploitation/Business Plan – Elderly Care

The exploitation strategy translates the RF sensing innovation integrated into Wi-Fi routers into a scalable commercialization pathway. The plan combines clear competitive positioning, infrastructure-based deployment, and modular revenue streams to support adoption across both institutional elderly care environments and home-based monitoring scenarios. By leveraging existing connectivity infrastructure, the approach minimizes deployment barriers while enabling rapid scaling and sustainable long-term growth.

6.1. Business Model Canvas

This Business Model Canvas defines the strategic framework for commercializing the solution within the elderly care application scenario. By integrating the RF-sensing technology into Wi-Fi routers, the model enhances operational efficiency for caregivers while ensuring long-term financial sustainability. The following sections describe how technical innovation, diversified revenue streams, and strategic partnerships converge to create a scalable, defensible, and high-impact presence in the evolving digital healthcare ecosystem.

<table>
<tr><th>KEY PARTNERS</th><th>KEY ACTIVITIES</th><th>VALUE PROPOSITIONS</th><th>CUSTOMER RELATIONSHIPS</th><th>CUSTOMER SEGMENTS</th></tr>
<tr>
<td rowspan="3">• Hardware integration partners (OEM/ODMs)
• Distribution partners (ISPs)
• Validation partners (care facilities and Research institutions)
• Technology ecosystem partners (smart home platforms, healthcare system integrators and solution providers)</td>
<td>• Algorithm development and optimization
• Router firmware integration
• Pilot deployment and validation
• Partner onboarding and technical support
• Data analysis and model training
• Business development and partnership management</td>
<td rowspan="3">• Privacy-preserving monitoring without cameras or wearables
• Continuous passive monitoring via existing Wi-Fi infrastructure
• Activity recognition
• Support for independent living of elderly people
• Reduced caregiver workload and improved safety</td>
<td>• Strategic partnerships with OEMs and ISPs
• Pilot-based onboarding and validation phase
• Technical integration support and co-development
• Continuous software updates and performance improvements</td>
<td rowspan="3">Primary:
• Wi-Fi router manufacturers
• Internet Service Providers (service bundling)

Secondary:
• Elderly care facilities and assisted living providers
• Home-care service organizations
• Smart-home ecosystem integrators
• Families with elderly relatives (indirect end users)</td>
</tr>
<tr><th>KEY RESOURCES</th><th>CHANNELS</th></tr>
<tr>
<td>• Technical expertise in RF and embedded systems
• RF sensing algorithms
• Integration framework
• Analytics Infrastructure
• Pilot deployment datasets</td>
<td>• OEM integration into commercial Wi-Fi routers
• ISP service bundling within broadband subscriptions
• Partnerships with smart-home solution providers
• Direct collaboration with elderly care facilities
• Pilot deployments and demonstration projects
• Industry events and healthcare technology networks</td>
</tr>
</table>

<table>
<tr><th>COST STRUCTURE</th><th>REVENUE STREAMS</th></tr>
<tr>
<td>• R&D and algorithm development
• Software engineering and integration
• Cloud infrastructure and analytics
• Technical support and maintenance
• Sales and partnership development
• Administrative and operational costs</td>
<td>• Integration fees from router manufacturers
• Per-unit royalty on sensing-enabled routers
• Subscription fees via ISP monitoring services
• Licensing fees for institutional deployments
• Premium analytics modules (advanced monitoring)
• Revenue-sharing agreements with partners</td>
</tr>
</table>

Figure 31 – Business Model Canvas RF Holography in The Elderly Care Market

6.1.1. Customer Segments

The commercialization strategy targets infrastructure-level stakeholders capable of enabling large-scale deployment of RF sensing technology through existing connectivity ecosystems. The primary customer segment consists of Wi-Fi router manufacturers seeking to differentiate their hardware. These players operate in a highly competitive market where incremental innovation in connectivity performance alone is no longer sufficient to sustain competitive advantage. Integrating RF sensing technology transforms routers into multifunctional smart-home hubs, creating additional value for end users while opening new service-based revenue opportunities. Another segment includes Internet Service Providers (ISPs), which can bundle monitoring capabilities as value-added services within connectivity subscriptions. ISPs benefit from increased customer retention, higher average revenue per user, and differentiation in mature broadband markets. By leveraging their installed base of routers, ISPs can deploy monitoring services with minimal additional infrastructure investment.

Secondary customer segments include elderly care facilities, home-care providers, and smart-home ecosystem integrators. These stakeholders benefit from non-intrusive monitoring solutions that improve safety and operational efficiency. In parallel, a direct-to-consumer segment exists, targeting elderly individuals and families seeking affordable and privacy-based health/behavior monitoring solutions.

This multi-layered segmentation enables both top-down infrastructure-driven deployment and bottom-up consumer adoption.

6.1.2. Value Proposition

The core value proposition centers on privacy-preserving, infrastructure-based monitoring for elderly care, embedded directly into Wi-Fi routers. Unlike wearable devices or camera-based systems, the solution enables continuous monitoring without requiring behavioral changes from elderly users. By leveraging RF sensing technology, the system detects movement and activity patterns through ambient signal analysis, ensuring a completely contactless and non-intrusive experience. This approach addresses several key limitations of existing technologies. Wearables require consistent user compliance and frequent charging, while camera-based solutions raise significant privacy concerns and regulatory barriers. In contrast, RF sensing embedded within existing network infrastructure operates passively in the background, reducing friction and increasing adoption potential. The solution therefore supports independent living for elderly individuals while providing caregivers and family members with actionable safety insights. Additionally, the infrastructure-based nature of the technology allows for scalable deployment across both residential and institutional environments. The solution becomes a foundational monitoring layer that complements existing care workflows rather than replacing them. This positioning emphasizes augmentation of human caregiving through situational awareness, improving safety outcomes while maintaining dignity and privacy.

6.1.3. Customer Relationships

The business model emphasizes long-term strategic relationships rather than transactional hardware sales. For router manufacturers and ISPs, engagement begins with pilot-based onboarding designed to validate technical performance and demonstrate value in real-world environments. This collaborative phase allows partners to assess integration complexity, evaluate monitoring accuracy, and quantify potential revenue opportunities.

Following successful validation, relationships transition into licensing agreements combined with ongoing technical support and software updates. This approach fosters sustained collaboration and creates recurring value for partners. Continuous improvements to sensing accuracy, analytics capabilities, and regulatory compliance are delivered through software updates, ensuring that deployed systems remain competitive over time.

For consumer-facing deployments, customer relationships can evolve toward subscription-based service models. End users benefit from continuous monitoring, alerting features, and periodic feature enhancements. This recurring engagement strengthens customer retention and creates predictable revenue streams. Overall, the relationship model prioritizes trust, long-term value creation, and collaborative innovation.

6.1.4. Revenue Streams

The revenue model is designed to balance immediate monetization with long-term recurring income. The primary revenue stream derives from technology licensing agreements with router manufacturers, allowing them to integrate RF sensing capabilities into their products. These agreements may include upfront integration fees combined with per-unit royalties, ensuring scalability as device shipments increase.

A second revenue stream emerges from software analytics subscriptions, particularly in ISP-led deployments. Monitoring services can be offered to households as monthly add-ons, generating recurring revenue while providing continuous value through real-time insights and alerts. This SaaS-like component enhances financial predictability and supports long-term growth.

Additional revenue opportunities include revenue-sharing agreements with ISPs, onboarding and integration fees for enterprise deployments, and premium analytics modules for advanced monitoring features. These modules may include predictive risk analysis, behavioral anomaly detection, and caregiver dashboards. The combination of licensing, subscriptions, and partnerships creates a diversified and resilient revenue architecture.

6.1.5. Key Resources

The competitive advantage of the business model relies on a combination of technological and organizational resources. At the core are proprietary RF sensing algorithms capable of extracting meaningful behavioral and physiological indicators from ambient Wi-Fi signals. These algorithms are complemented by embedded antenna designs optimized for integration within commercial routers. Additional key resources include AI-based activity recognition models, software integration frameworks, and data processing infrastructure. Regulatory compliance documentation and privacy-by-design architecture represent critical non-technical assets, particularly in healthcare-related deployments. Market validation data obtained from pilot deployments further strengthens credibility and supports commercial expansion.

6.1.6. Key Activities

The primary operational activities focus on continuous refinement of sensing algorithms and integration capabilities. Ensuring high detection accuracy across diverse environments requires ongoing model training and performance optimization. Firmware integration with router platforms also represents a critical activity, enabling seamless deployment across different hardware configurations.

Additional activities include partner onboarding, pilot deployment management, and regulatory compliance monitoring. Marketing and business development efforts support the expansion of OEM/ODM and ISP partnerships. Continuous product improvement based on field feedback ensures that the solution evolves in line with user needs and technological advancements.

6.1.7. Key Partnerships

Strategic partnerships play a central role in accelerating adoption and reducing market entry barriers. Router manufacturers provide the primary hardware integration pathway, while ISPs enable large-scale service deployment. Collaboration with smart-home ecosystem providers enhances interoperability with existing devices and platforms.

Healthcare technology companies and research institutions contribute to validation and clinical credibility. These partnerships support performance evaluation, regulatory acceptance, and market trust. By aligning with infrastructure owners and ecosystem stakeholders, the solution becomes embedded within existing digital environments, facilitating scalable adoption.

6.1.8. Cost Structure

The cost structure reflects a technology-driven model characterized by high initial development investment and relatively low marginal deployment costs. Fixed costs include research and development, algorithm optimization, integration engineering, and business development activities. These investments are necessary to maintain technological differentiation and support partner onboarding.

Variable costs are primarily associated with software maintenance and upgrade, and technical support for deployed systems. Because the solution leverages existing Wi-Fi infrastructure, hardware-related expenses remain minimal.

6.2. Revenue Model & Financial Architecture

This section defines the economic logic underpinning the commercialization of RF sensing technology integrated into Wi-Fi routers. Financial architecture is designed to leverage infrastructure-driven scalability while maintaining an asset-light operational model. By focusing on technology licensing, per-unit royalties, and optional revenue-sharing agreements, the model enables sustainable growth without requiring direct management of end-user monitoring services. The revenue model follows a hybrid structure combining upfront integration revenues with recurring royalty-based income. This approach ensures early cash flow during initial partnerships while generating long-term recurring revenues as sensing-enabled routers scale in volume. Additional upside may be achieved through limited participation in downstream subscription services offered by integration partners. This structure improves predictability and supports high contribution margins.

6.2.1. Pricing Logic

The commercialization strategy for the elderly-care RF sensing platform follows a pure software-licensing business model targeting broadband operators, internet service providers (ISPs), Wi-Fi router manufacturers, and smart-home connectivity ecosystems. Unlike traditional healthcare-device business models requiring dedicated sensing hardware deployments, the HOLDEN approach leverages existing Wi-Fi and broadband infrastructures already deployed within residential and assisted-living environments. The solution is commercialized as an embedded RF sensing and environmental-intelligence software layer integrated directly into ISP broadband gateways, Wi-Fi router platforms, smart-home connectivity ecosystems, and edge-computing residential infrastructures. Target commercialization partners include Wi-Fi router manufacturers, broadband gateway OEMs and ODMs, fixed-network operators, and smart-home platform providers. Indicative industrial targets include Netgear, Askey, Gemtek, Nokia, Vodafone, TIM, and Charter Communications. The commercialization model combines per-device licensing revenues with recurring annual maintenance agreements. Indicative licensing assumptions are summarized in Table 28.

Table 28 – Estimated Licensing Revenue Assumptions

Licensing Type	Estimated Value
Standard embedded sensing license	€0.50-€1.50 per router
Premium wellness-oriented sensing license	€1.50-€3.00 per router
Annual maintenance agreements	5-10% of annual licensing revenues
Maintenance cap	~€150k per SKU/platform

The licensing architecture is designed to support large-scale broadband deployments, low marginal deployment costs, scalable ISP integration, and infrastructure reuse across existing router ecosystems. Annual maintenance agreements cover firmware maintenance, compatibility validation, security updates, interoperability maintenance, platform support, and incremental firmware upgrades. The overall commercialization strategy intentionally avoids dedicated hardware manufacturing, direct healthcare-device commercialization, and operational analytics-service provision, thereby enabling strong scalability through existing telecom and broadband distribution channels.

6.2.2. Cost Structure

The operational cost structure reflects the software-centric and infrastructure-integrated nature of the elderly-care RF sensing commercialization strategy. Because the business model follows a pure licensing approach without dedicated hardware manufacturing, operational expenditures remain substantially lower than traditional infrastructure-security or healthcare-device deployment models. Most operational expenditures are concentrated during initial firmware integration, interoperability validation, chipset adaptation, and ISP onboarding phases. After successful onboarding of a router SKU/platform, incremental deployment costs are expected to remain relatively low. Indicative annual fixed operational costs are summarized in Table 29.

Table 29: Estimated Annual Fixed Operational Costs

Fixed Cost Category	Annual Fixed Cost
RF sensing & AI software R&D	€400k
Firmware integration engineering	€300k
ISP/OEM interoperability validation	€220k
Privacy, cybersecurity & compliance	€120k
Business development & operations	€250k
Total Estimated Annual Fixed Cost	€1.29M

The largest operational cost drivers are expected to include RF sensing algorithm development, interoperability validation across router platforms, chipset adaptation, firmware optimization, ISP integration support, and cybersecurity compliance. Commercial deployments require adaptation and testing across Broadcom-based platforms, Qualcomm-based platforms, MediaTek architectures, Realtek broadband platforms, and OEM-specific firmware environments. Because the commercialization model does not require dedicated hardware deployment, field-installation operations, or operational analytics services, marginal deployment costs remain relatively low once firmware integration and interoperability validation are completed. Commercial scaling is therefore expected to progressively reduce operational overhead through reusable firmware integration frameworks, standardized chipset support layers, deployment-validation automation, and strategic OEM and ISP partnerships

6.2.3. Contribution Margin

Contribution margins are expected to evolve differently from traditional infrastructure-deployment business models because the HOLDEN commercialization strategy follows a pure software-licensing approach integrated into existing ISP and router ecosystems. Most of the engineering, interoperability validation, and firmware adaptation activities occur during the initial OEM integration phase, chipset adaptation, ISP provisioning validation, and platform-specific optimization activities. Once integration into a given router platform is completed, subsequent deployment scaling across the same OEM or ISP ecosystem requires only limited incremental operational effort.

Indicative commercialization economics are summarized in Table 30.

Table 30: Contribution Margin Assumptions

Commercial Activity	Average Revenue	Initial Integration Cost	Contribution Margin
Router-platform onboarding	€150k equivalent engineering effort	€90k	~40%
ISP pilot deployment	€250k equivalent deployment value	€150k	~40%
Post-integration recurring licensing	Recurring firmware-license revenues	Low incremental cost	75–90%

These integration costs primarily represent one-time engineering expenditures associated with firmware adaptation, interoperability testing, chipset optimization, and deployment validation activities. After successful onboarding and interoperability validation for a given router SKU/platform, subsequent deployment scaling benefits from reusable firmware integration frameworks, completed interoperability validation, and maintenance obligations that remain proportional to deployed-license volumes while support exposure remains capped per SKU/platform. Annual maintenance and support agreements cover firmware updates, platform compatibility maintenance, security patching, incremental feature upgrades, and customer technical support. Contribution margins are therefore expected to improve substantially after onboarding phases because most engineering costs are incurred once during initial integration activities while subsequent deployments generate limited incremental operational costs.

6.2.4. Break-Even Analysis

The break-even analysis reflects the commercialization dynamics associated with telecom, ISP, and broadband-infrastructure ecosystems. Unlike hardware-intensive healthcare-device business models, the HOLDEN commercialization strategy leverages existing ISP infrastructures, deployed Wi-Fi gateways, broadband router ecosystems, and firmware-level sensing integration, thereby significantly reducing capital intensity while improving long-term scalability. Commercialization timelines are nevertheless influenced by OEM integration cycles, ISP validation procedures, interoperability testing, firmware-certification processes, and procurement approvals. Typical telecom and ISP integration cycles are expected to require approximately 12–24 months for validation, integration, and operational deployment approval. The first commercialization phase is expected to require total investments of approximately €3.0M over the first three years. Indicative investment allocation is summarized in Table 31.

Table 31 – Estimated Investment Allocation

Investment Category	Estimated Investment
RF sensing & AI product industrialization	€1.0M
Firmware integration & interoperability validation	€700k
Commercial development & ISP partnerships	€500k
Privacy, cybersecurity & compliance	€500k
Platform optimization & deployment validation	€300k
Total Estimated Investment	€3.0M

Part of these commercialization activities may be partially supported through ISP pilot partnerships, OEM co-development initiatives, European innovation programs, and collaborative telecom deployment activities. The break-even model assumes a licensing-driven commercialization strategy involving broadband operators, router manufacturers, connectivity OEMs and ODMs, and smart-home infrastructure providers. Under realistic telecom and ISP commercialization assumptions, operational break-even is expected within approximately 3–5 years through a combination of 4–6 active OEM and ISP partnerships, recurring firmware-license revenues, scalable ISP deployment volumes, and annual maintenance agreements. At operational break-even, recurring firmware-license revenues are expected to represent the substantial majority of total revenues, while maintenance agreements provide stable recurring support revenues with limited operational exposure through capped support obligations.

6.2.5. Five-Year Revenue Scenarios

Three commercialization scenarios were evaluated to estimate the potential financial evolution of the RF sensing licensing platform across ISP, broadband, and smart-home ecosystems. All scenarios assume that recurring maintenance revenues scale proportionally with deployed-license volumes, annual maintenance obligations remain capped per router SKU/platform, and the majority of engineering effort occurs during onboarding and interoperability-validation phases. Across all scenarios, recurring firmware-license revenues and maintenance agreements are expected to progressively dominate the revenue mix, improving operational leverage, financial predictability, and long-term profitability.

<u>Conservative Commercialization Scenario</u>

The conservative scenario assumes relatively slow ISP procurement cycles, limited pilot-to-commercial conversion, and gradual OEM adoption driven primarily by small-scale residential deployments.

Table 32 – Conservative Commercialization Scenario

Year	Total Revenue	Total Cost	Profit/Loss
Year 1	€0.2M	€1.2M	-€1.0M
Year 2	€0.6M	€1.4M	-€0.8M
Year 3	€1.5M	€1.8M	-€0.3M
Year 4	€3.0M	€2.4M	€0.6M
Year 5	€5.0M	€3.2M	€1.8M

Under this scenario, operational break-even is expected during Year 4 as recurring firmware-license revenues progressively accumulate across deployed ISP infrastructures and maintenance agreements begin generating stable recurring cash flow. Slower onboarding dynamics and limited deployment scale delay profitability compared with more aggressive commercialization assumptions.

<u>Moderate Commercialization Scenario</u>

The moderate commercialization scenario assumes successful ISP pilot deployments, progressive OEM integrations, recurring licensing growth, and broader expansion across broadband ecosystems.

Table 33 – Moderate Commercialization Scenario

Year	Total Revenue	Total Cost	Profit/Loss
Year 1	€0.35M	€1.3M	-€0.95M
Year 2	€1.0M	€1.6M	-€0.6M
Year 3	€2.5M	€2.2M	€0.3M
Year 4	€5.0M	€3.2M	€1.8M
Year 5	€8.0M	€4.5M	€3.5M

Under this scenario, operational break-even is expected during Year 3 through a combination of recurring firmware-license revenues, expanding ISP deployment volumes, OEM integrations, and maintenance agreements associated with deployed broadband platforms. By Year 5, recurring licensing and maintenance revenues are expected to represent the majority of total annual revenues, thereby improving operational leverage, financial predictability, and long-term profitability.

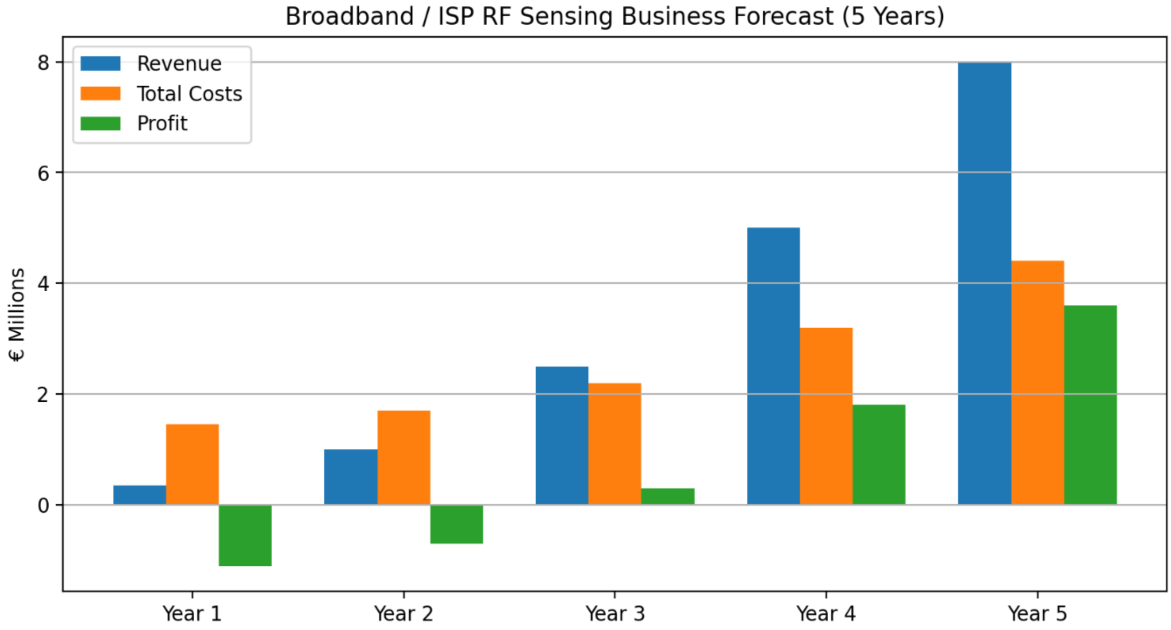


Figure 32 – Five years revenue/cost/profit forecast for moderate growth scenario

<u>Partnership-driven Scaling Commercialization Scenario</u>

The partnership-driven scaling scenario assumes accelerated OEM onboarding, strong ecosystem credibility, successful lighthouse deployments with major broadband operators, and rapid expansion of recurring software-license revenues across multiple ISP platforms.

Table 34 – Partnership-driven Scaling Commercialization Scenario

Year	Total Revenue	Total Cost	Profit/Loss
Year 1	€0.5M	€1.4M	-€0.9M
Year 2	€1.8M	€1.9M	-€0.1M
Year 3	€4.0M	€2.8M	€1.2M
Year 4	€7.5M	€4.0M	€3.5M
Year 5	€12.0M	€5.5M	€6.5M

Under this scenario, operational break-even is expected between Years 2 and 3 as recurring firmware-license revenues scale rapidly across multiple OEM and ISP ecosystems while operational costs remain partially capped after initial integration phases. Profitability improves substantially in later commercialization stages because recurring licensing revenues scale with deployed broadband infrastructures while incremental operational costs remain comparatively limited.

6.2.6. Financial Sustainability

The long-term financial sustainability of the commercialization model derives from recurring per-device firmware licensing, scalable ISP deployment volumes, reusable firmware integration frameworks, maintenance revenues proportional to deployed-license volumes, capped annual support obligations per SKU/platform, and low marginal operational costs after onboarding. Unlike hardware-centric healthcare-monitoring solutions, the HOLDEN business model avoids dedicated sensing hardware manufacturing, large deployment CAPEX, complex field-installation operations, and infrastructure replacement costs. Because interoperability engineering is primarily concentrated during onboarding phases, subsequent deployments require limited incremental effort and maintenance exposure remains operationally bounded. As a result, the business model benefits from strong operational leverage, scalable recurring-license economics, and predictable long-term support costs. The commercialization strategy also benefits from increasing smart-home adoption, broadband infrastructure modernization, aging-population trends, and growing demand for privacy-preserving sensing technologies. Because the solution operates through existing connectivity infrastructures, long-term scalability can be achieved without requiring substantial physical deployment expansion, thereby supporting sustainable growth while maintaining relatively low operational complexity.

6.3. Market Entry Roadmap

The market entry roadmap translates the business model and financial architecture into a phased commercialization strategy designed to minimize technological, operational, and commercial risks while enabling scalable deployment. The approach prioritizes validation through pilot deployments, followed by structured partnerships with router manufacturers, broadband operators, and smart-home ecosystem stakeholders. This staged methodology ensures that technological performance, interoperability, user acceptance, and economic value are demonstrated before large-scale market penetration.

The roadmap emphasizes infrastructure-driven adoption through router manufacturers, ODMs, and Internet Service Providers, allowing scalable deployment while maintaining relatively low capital intensity. By leveraging existing broadband and connectivity ecosystems, the strategy reduces deployment complexity, accelerates access to both institutional and consumer markets, and progressively increases recurring firmware-license revenues associated with deployed infrastructures.

Commercialization timelines are aligned with realistic telecom and ISP validation cycles, which typically require extended interoperability testing, firmware certification, cybersecurity validation, and operational integration activities before large-scale deployment approval.

6.3.1. Phase 1 – Pilot Validation and Technical Consolidation (0–12 months)

The first commercialization phase focuses on validating the RF sensing technology within real-world broadband and elderly-care environments while consolidating production-ready technical maturity. Initial pilot deployments are conducted in collaboration with selected router manufacturers, ODMs, and early ISP partners. These pilots target controlled environments such as elderly-care facilities, assisted-living residences, and selected residential households to evaluate sensing accuracy, operational reliability, interoperability, and user acceptance. The objectives of this phase include demonstrating movement-detection performance, validating activity-recognition accuracy, assessing integration with existing router hardware and broadband infrastructures, and evaluating operational stability under real deployment conditions. Quantitative performance metrics, including detection precision, false-alarm rates, latency stability, and sensing reliability, are collected alongside qualitative feedback from caregivers, institutional operators, and end users. During this phase, technical consolidation activities include firmware optimization, interoperability validation across multiple router platforms, cybersecurity assessment, privacy-compliance validation, and edge-processing optimization. By the end of Phase 1, the solution is expected to reach pilot-ready commercial maturity supported by validated operational-performance data. The outcomes of this phase support technical consolidation, reduce adoption barriers, strengthen ecosystem credibility, and prepare the solution for formal commercial partnership agreements.

Target outcomes:

- 1–2 router manufacturer or ODM pilot integrations
- 1–3 elderly-care pilot environments
- 200–500 monitored households
- Production-ready interoperability framework
- Commercial validation dataset supporting ISP onboarding

6.3.2. Phase 2 – Partnership Expansion and Early Commercial Deployment (12–24 months)

Following successful pilot validation, the second commercialization phase focuses on expanding partnerships with router manufacturers, ODMs, and Internet Service Providers. This phase marks the transition from pilot validation to early commercial deployment, generating initial recurring firmware-license revenues and maintenance agreements. The objective is to integrate RF sensing functionality into commercial broadband-router product lines through formal OEM and ODM agreements while enabling initial subscription-based monitoring services across selected ISP ecosystems. These partnerships support the release of sensing-enabled router platforms integrated within existing broadband-service portfolios targeting households with elderly residents and assisted-living applications. Activities during this phase include firmware industrialization, interoperability standardization, deployment-validation expansion, operational-support optimization, recurring-license framework definition, and commercial onboarding activities with additional broadband ecosystem partners. Marketing and ecosystem-development activities during this stage emphasize awareness building, operational education, and stakeholder engagement. Demonstrations, webinars, industry events, healthcare partnerships, and smart-home ecosystem collaborations support outreach toward healthcare providers, ISPs, and elderly-care stakeholders. By the end of this phase, the commercialization model is expected to transition from pilot-oriented deployments toward repeatable ecosystem integration and scalable recurring-license economics.

6.3.3. Phase 3 – Market Scaling (24–48 months)

The third commercialization phase focuses on scaling through broader ISP adoption, recurring-license expansion, standardized interoperability frameworks, and progressive integration into larger broadband and smart-home ecosystems. At this stage, interoperability engineering, onboarding procedures, and deployment-validation activities are expected to be substantially standardized, enabling stronger operational leverage, lower marginal deployment costs, and scalable recurring firmware-license revenues. Commercial growth is expected to be driven primarily through recurring-license expansion across deployed router infrastructures rather than engineering-intensive onboarding activities. Activities include expansion across additional ISP ecosystems, broader OEM and ODM partnerships, deployment automation, analytics-service enhancement, and maintenance-service optimization. The installed infrastructure base progressively generates recurring revenues associated with firmware licensing, maintenance agreements, analytics services, and platform-support activities. Because the commercialization model leverages existing broadband infrastructures and embedded deployment architectures, scaling can be achieved without substantial physical deployment complexity or hardware manufacturing expansion. This significantly improves financial predictability and long-term profitability while maintaining relatively limited incremental operational costs.

6.3.4. Phase 4 – Large-Scale Deployment and Ecosystem Integration (48–60 months)

The fourth commercialization phase focuses on large-scale ecosystem integration, international expansion, and long-term recurring-revenue optimization across mature broadband and smart-home infrastructures. At this stage, the commercialization strategy aims to establish RF sensing functionality as a standardized value-added feature within broadband-router ecosystems and connected-home platforms. Commercial growth is expected to derive primarily from recurring-license revenues, installed-base monetization, firmware-maintenance agreements, analytics-service expansion, and ecosystem-wide interoperability frameworks. Activities include multi-region ISP expansion, integration into broader smart-home and ambient-assisted-living ecosystems, long-term strategic partnerships with telecom operators and connectivity vendors, and optimization of scalable deployment-support frameworks. Because operational complexity remains partially capped after onboarding and interoperability standardization, mature commercialization conditions are expected to generate strong operational leverage and predictable long-term profitability. Recurring-license and maintenance revenues are expected to progressively dominate the revenue mix while incremental deployment costs remain comparatively limited.

6.3.5. Risk Mitigation Strategy

The commercialization strategy incorporates a phased risk-mitigation framework designed to address technological, operational, regulatory, ecosystem, and market-adoption risks associated with RF sensing deployment within broadband infrastructures. Technical risks are mitigated through progressive pilot validation, interoperability testing across multiple router platforms, firmware-standardization activities, and staged ecosystem integration. Operational risks are reduced through partnership-driven deployment models that leverage existing ISP infrastructures and avoid large-scale dedicated hardware deployment requirements. Regulatory and privacy-related risks are mitigated through privacy-by-design architectures, edge-processing approaches, cybersecurity validation procedures, and compliance with GDPR and emerging AI-governance frameworks. Commercial risks associated with ISP procurement cycles and OEM onboarding are mitigated through phased commercialization, diversified ecosystem partnerships, and progressive geographic expansion. The phased roadmap further reduces commercialization uncertainty by ensuring that large-scale deployment activities occur only after operational validation, ecosystem compatibility assessment, and commercial-readiness confirmation.

6.3.6. Strategic Growth Outlook

The long-term strategic outlook for RF sensing within elderly-care ecosystems remains highly favorable due to demographic aging, increasing caregiver shortages, smart-home expansion, broadband infrastructure modernization, and growing demand for privacy-preserving monitoring solutions. Unlike conventional healthcare-monitoring technologies requiring dedicated hardware or wearable devices, the HOLDEN commercialization strategy benefits from scalable integration into existing connectivity infrastructures. This enables long-term expansion with relatively limited incremental deployment complexity and reduced operational exposure. As interoperability frameworks become standardized and recurring-license revenues progressively dominate the business model, the commercialization strategy is expected to benefit from increasing operational leverage, predictable recurring revenues, and scalable ecosystem expansion across both institutional and residential care environments.

6.3.7. Intellectual Property Strategy

Intellectual property protection is a critical pillar of the exploitation strategy, ensuring technological differentiation and supporting long-term commercial value. The RF sensing solution combines signal processing algorithms, embedded firmware integration, and AI-based activity recognition models, creating multiple layers of protectable innovation. Rather than relying on a single protection mechanism, the strategy adopts a balanced approach combining patents, trade secrets, and software-based control mechanisms. Selective patenting focuses on architectural innovations that are difficult to replicate, particularly those combining RF signal sensing with behavioral inference for elderly monitoring. Potential patentable elements include signal processing techniques for activity detection, fall recognition algorithms, and methods for integrating sensing functionality into Wi-Fi routers without additional hardware complexity. Initial filings should prioritize European jurisdictions, with potential extension to North America and Asia depending on commercialization expansion. Given the software-centric nature of the system, trade secret protection represents an equally important component. High-value assets such as model training datasets, optimization parameters, feature extraction pipelines, and integration tuning methods are best protected through restricted access and confidentiality agreements. This approach avoids premature disclosure while maintaining flexibility in future development. Typically, a SaaS architecture further strengthens intellectual property protection. Core analytics algorithms remain server-side, preventing transfer of proprietary code to hardware partners. As deployments scale, anonymized performance data becomes a strategic competitive asset, improving model accuracy and creating a data-driven barrier to entry for competitors. This layered IP strategy strengthens defensibility, increases investor confidence, and supports long-term scalability within the elderly care technology market.

6.3.8. Capital Strategy and Funding Requirements

The commercialization pathway is designed to maintain moderate capital requirements while enabling scalable growth. Because the solution leverages existing Wi-Fi infrastructure, hardware manufacturing investments are minimal, reducing upfront capital intensity. The primary funding needs relate to technology refinement, algorithm optimization, deployment support and validation, integration engineering and partner onboarding, marketing, and business development, regulatory and legal support.

Total estimated scale-up funding: €3.0M

This funding supports the transition from prototype to commercial deployment and covers operational costs until break-even. Based on the financial model, break-even is achievable within approximately 11 ISP partnerships or equivalent deployment scale, which is expected during Phase 3–4 of market entry. The capital strategy prioritizes staged investment aligned with validated milestones. Initial funding supports pilot validation, followed by additional investment to accelerate partnership expansion. This approach reduces financial risk and ensures efficient capital utilization. Potential funding sources include European innovation and digital health funding programs, public grants supporting aging population technologies, strategic corporate partnerships with router manufacturers, venture capital investment focused on deep-tech IoT solutions. The combination of moderate capital requirements and recurring revenue potential enhances investor attractiveness and supports sustainable growth.

6.3.9. Risk Mitigation and Financial Resilience

Long-term financial resilience derives primarily from recurring firmware-license revenues, maintenance agreements, scalable deployment volumes, reusable interoperability frameworks, and relatively low marginal operational costs after onboarding phases are completed. Because engineering and interoperability activities are concentrated primarily during initial integration phases, subsequent deployment scaling generates progressively stronger operational leverage and more predictable long-term support costs. The business model therefore becomes increasingly resilient as installed deployment volumes expand across ISP and OEM ecosystems. Financial resilience is further strengthened through diversified partnership structures involving router manufacturers, ODMs, broadband operators, healthcare ecosystem stakeholders, and smart-home technology providers. This diversified ecosystem reduces dependency on single deployment channels while supporting long-term recurring-revenue stability.

6.3.10. Strategic Financial and Commercial Conclusion

The exploitation strategy demonstrates a scalable and financially sustainable pathway for commercializing RF sensing technology integrated into broadband and Wi-Fi infrastructures. The business model combines onboarding and integration revenues with recurring firmware-license revenues and maintenance agreements, enabling progressively improving contribution margins, scalable operational leverage, and predictable long-term growth. By leveraging partnerships with router manufacturers, ODMs, and broadband operators, the solution can scale rapidly without requiring substantial direct investment in hardware manufacturing, dedicated deployment infrastructures, or large-scale field-installation operations. The financial analysis indicates strong long-term profitability potential, with mature recurring-license contribution margins potentially exceeding 70–80% after onboarding and interoperability engineering activities are completed. Depending on commercialization speed and ecosystem adoption dynamics, operational break-even is expected between Years 3 and 4 under realistic deployment assumptions, while accelerated partnership expansion may enable earlier profitability. Strategically, the solution addresses a critical societal need driven by demographic aging, caregiver shortages, and increasing demand for privacy-preserving monitoring technologies. By enabling non-invasive monitoring without cameras or wearable devices, the technology aligns with emerging regulatory frameworks, ethical requirements, and user expectations surrounding privacy and data minimization. Overall, the proposed exploitation strategy establishes a coherent, defensible, and scalable commercialization pathway. The combination of strong technical differentiation, recurring-license economics, limited marginal deployment costs, phased ecosystem integration, and scalable infrastructure reuse creates a robust foundation for transforming RF sensing technology into a sustainable long-term business opportunity within the elderly-care ecosystem.

6.4. Marketing and Communication

Marketing for RF sensing technology focuses on introducing the product as a value-added feature for Wi-Fi routers, specifically designed to enable non-invasive monitoring of movement and activity recognition. Without the need for additional devices, wearables, or cameras, this feature will significantly enhance elderly care by providing real-time health insights and improving safety. We aim to build awareness among ISPs and router manufacturers about the technology's unique capabilities and its potential to support elderly care without requiring invasive or complex setups.

Our plan to introduce RF sensing technology into Wi-Fi routers involves a tailored communication approach, focusing on educating and inspiring ISPs and manufacturers. Through multi-channel outreach, including webinars, a mix of digital media, and strategic alliances we will empower ISPs and manufacturers on the value proposition of our innovative technology, aiming to foster partnerships and drive adoption.

6.4.1. Positioning and Market Penetration

Our primary objective is to position RF sensing technology as an essential, innovative feature for Wi-Fi routers, enhancing their functionality while adding value. This includes features such as movement monitoring and activity recognition for elderly care, an emerging demand in the market.

Key Goals

- **Educate the Market on Benefits**: We will focus on educating ISPs and manufacturers about the competitive advantages of integrating RF sensing technology into their products. This includes demonstrating how it can provide differentiation.
- **Establish Key Partnerships**: Establishing strategic partnerships with router manufacturers, ISPs, and other tech companies will be crucial for market penetration.
- **Build Awareness through Effective Campaigns**: By leveraging targeted digital and social media campaigns, webinars, and public relations, we aim to generate awareness and create demand for RF sensing technology.

6.4.2. Public Relations

Press Releases

Press releases will be strategically timed to announce key milestones, such as technology advancements, partnerships, and product launches. These will be distributed to leading industry outlets to ensure visibility among ISPs and manufacturers.

Co-Marketing

Forming co-marketing partnerships with complementary technology providers, such as router manufacturers or health-tech companies, will help leverage each partner's audience and increase the credibility of the RF sensing technology. Joint campaigns and product bundles can demonstrate how the integrated solution provides additional value in markets like elderly care.

Social Media Campaigns

Social media platforms like LinkedIn and X are essential for targeting professionals in the ISP and router manufacturing industries. Through a mix of organic posts, sponsored content, and interactive discussions (e.g., polls, Q&A sessions), we can engage potential customers, share success stories, and position the technology as a key differentiator.

Webinars & Online Demos

Offering live webinars and online demos provides a direct, interactive channel to showcase the technology's capabilities and answer specific customer inquiries. This approach allows us to address real-time concerns, showcase product functionality, and establish credibility by presenting the product’s impact on network performance or elderly care.

Event Participation

Participating in industry conferences and trade shows (e.g., CES, Broadband World Forum) is crucial for networking, raising product awareness, and directly engaging with key players in the industry. These events offer opportunities for face-to-face interaction with ISPs and router manufacturers, which is essential for building relationships and exploring co-marketing or partnership opportunities.

Digital Ads plus Visual Content

Digital advertising will help reach a targeted audience of ISPs and router manufacturers. Visual content, such as infographics and explainer videos, can illustrate the technology's benefits, such as unique features like activity monitoring for elderly care. This approach leverages platforms with high engagement from industry professionals and decision-makers, particularly in the B2B space.

7. Market Analysis – Smart TV

7.1. SWOT Analysis

The convergence of RF sensing technology with Smart TVs represents a unique opportunity to redefine user interaction within the connected home ecosystem. With the rise of IoT integration and personalized content delivery, Smart TVs are no longer just passive entertainment devices. Incorporating RF sensing could further elevate user engagement through gesture control, presence detection, and non-intrusive health monitoring, creating a seamless, intuitive experience that adapts to user behavior and preferences.

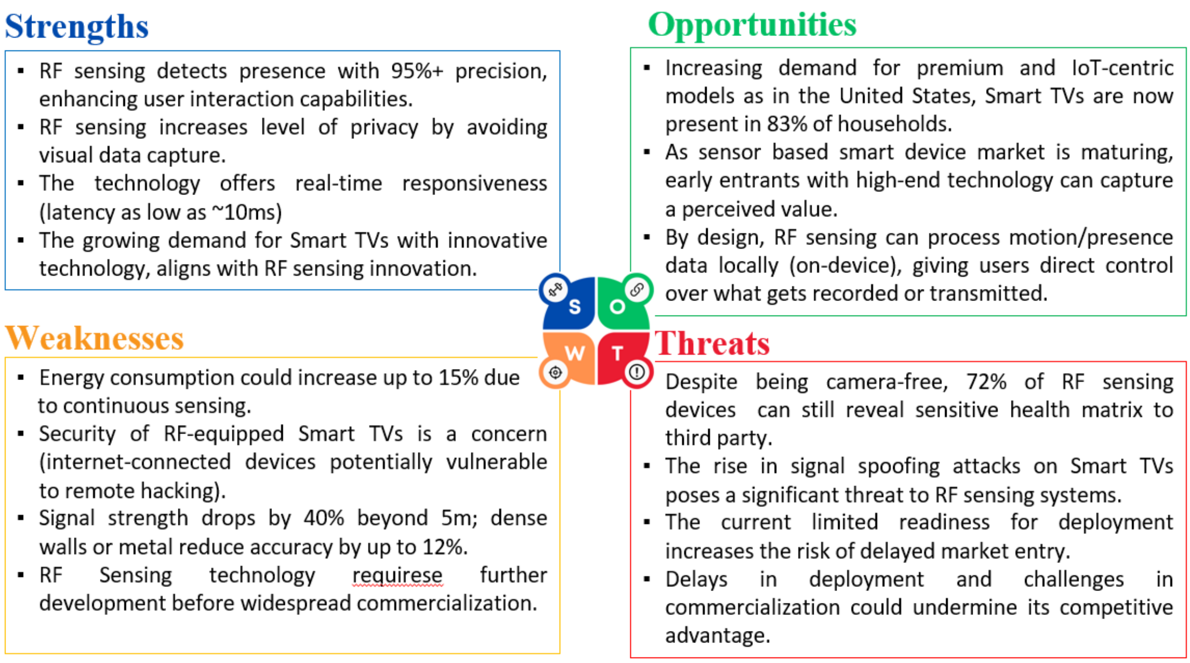


Figure 33 – SWOT Matrix for the Smart TV Market

7.1.1. Strengths

The integration of RF sensing technology within Smart TVs offers several key advantages that enhance both functionality and user experience:

- **Reliability and Responsiveness**: RF sensing technology excels in accuracy, detecting user presence with over 95% precision and detecting motion up to 30 feet (approximately 9 meters), enhancing user interaction capabilities [91].
- **Privacy Preservation**: Unlike camera-based systems, RF sensing ensures 100% privacy by avoiding visual data capture positioning it as a secure and privacy-friendly solution [92].

- **Low Latency and Scalability**: The technology offers real-time responsiveness (latency as low as 10 milliseconds) and is scalable to different Smart TV systems, making it versatile [93].
- **Market Demand**: The growing demand for Smart TVs [94], along with RF sensing scalability, positions it as a promising innovation.

7.1.2. Weaknesses

Despite its promising capabilities, RF sensing technology faces several challenges that could hinder its widespread adoption:

- **Energy Consumption**: Continuous RF sensing increases power consumption by 15%, potentially reducing overall energy efficiency [95].
- **Security Vulnerabilities**: The security of RF-equipped Smart TVs is a concern, with 90% of such devices vulnerable to remote hacking via rogue TV signals [96].
- **Limited Range and Environmental Sensitivity**: RF sensing's accuracy diminishes by 40% beyond 5 meters, and performance can decline by up to 12% in environments with dense walls or high metal content [97].
- **Commercial Readiness**: The technology is not fully prepared for widespread commercialization and requires further development before it can be seamlessly integrated into consumer Smart TVs [98].

7.1.3. Opportunities

Several market trends present significant opportunities for the adoption and growth of RF sensing technology in Smart TVs:

- **Growing Smart TV Market**: The growing Smart TV market, with 76.5% of UK households owning Smart TVs in 2024 and in the United States, Smart TVs are now present in 83% of households, provides significant opportunities for RF sensing technology to expand its reach [99], [100].
- **Investment Potential**: As the technology matures, it presents a strong opportunity for high returns on investment (ROI), attracting investors eager to capitalize on a rapidly expanding market.
- **Regulatory Compliance**: RF sensing technology's alignment with emerging data privacy and security regulations positions it as a potential leader in the industry, giving it a competitive edge in a privacy-conscious market [101].
- **User Data Control**: There is a growing opportunity to enhance user control over personal data, empowering consumers with greater control and transparency in how

their data is used, which aligns with current market trends towards data self-governance.

7.1.4. *Threats*

Despite the promising potential of RF sensing technology, several threats could hinder its successful market entry and adoption:

- **Privacy Concerns**: Despite privacy benefits, RF sensing is still vulnerable to privacy violations. Concerns about third-party data sharing, with 72% of IoT devices transmitting user data, could hinder consumer trust and adoption [102].
- **Competition and Market Readiness**: RF sensing faces stiff competition from more market-ready or easily integrable technologies. Delays in deployment and challenges in commercialization could undermine its competitive advantage [103].
- **Cybersecurity Risks**: The rise in signal spoofing attacks on Smart TVs (increasing by 22% last year) poses a significant threat to RF sensing systems. Addressing cybersecurity vulnerabilities is essential to maintain user confidence [104].
- **Deployment Delays**: The current limited readiness for deployment increases the risk of delayed market entry, which could slow the technology's adoption and impact its growth trajectory in a fast-evolving market [105].

7.2. Market Size Analysis

The Consumer Electronics Industry is valued at €949.7 billion in 2024, with the Global Television Market representing a significant share at €96.8 billion (Statista, 2024). Forecasts indicate a sustained rise in global television unit sales within the consumer electronics sector, set to grow by 9.9 million units (+3.91%) between 2024 and 2029. If the trend continues, 2029 will witness a new record, reaching 262.88 million units sold worldwide, up from 252.96 million in 2024 (Electro IQ, 2024).

Smart TV, however, its growth is driven by rising demand for connected entertainment, streaming services, and smart home integration. The Asia-Pacific (APAC) region dominates with a 35.9% market share, fueled by China, India, and Southeast Asia's expanding middle class and digital infrastructure (Counterpoint, 2024). Meanwhile, North America and Europe remain strong markets, with 83% of U.S. households and 76.5% of UK households owning Smart TVs (Ofcom, 2024; Frankel, 2025), indicating near-saturation in developed economies but continued growth in premium and feature-rich models.

Table 35: Consumer Electronics and Smart TV Market Size

Category	2024 Value	2029 Projection	Notes
Consumer Electronics	€949.7 billion	€1.14 trillion *(est. CAGR ~3.7%)*	Based on industry CAGR average (Statista global forecast trend)
Global TV Market	€96.8 billion	€110.5 billion *(est. +2.7% CAGR)*	Unit sales projected at 262.88M (+3.91%), revenue scaled similarly
Smart TV Ownership (US)	83% of households	90%	Near saturation; growth mostly in upgrades to premium models
Smart TV Ownership (UK)	76.5% of households	85%	Continued growth but approaching saturation (Statista)
APAC Market Share	35.9%	39%	Growth driven by expanding middle class & infrastructure (Counterpoint)

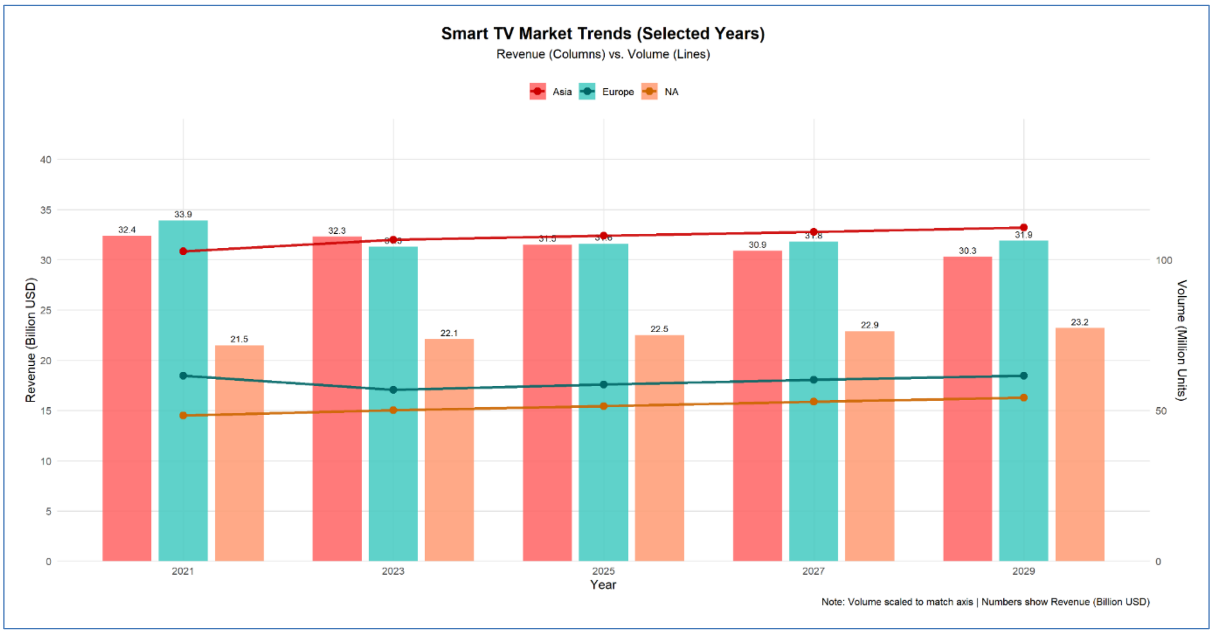


Figure 34: Smart TV Market Trends

Sensing technology is emerging as a key differentiator in Smart TVs, enabling gesture control, presence detection, and personalized user experiences. Sony's acquisition of SoftKinetic (now Sony Depth Sensing Solutions) highlights the industry's shift toward non-contact interaction, as the company integrates time-of-flight (ToF) sensors and AI-driven gesture recognition into its products (GameDeveloper, 2015). Sony's Xperia Touch demonstrated early applications of projection-based gesture control, while its semiconductor division has advanced 3D sensing and RF-based motion tracking (Sony Semiconductor, 2024). These innovations align with the broader trend of AI-enhanced Smart TVs, where machine learning and sensor fusion optimize user interactions (Sony Research, 2024).

Samsung has filed patents for radar-based gesture control in Smart TVs, aiming to replace traditional remotes with hand-motion recognition (US Patent Office, 2023). Their 2024 Neo QLED TVs already feature built-in IoT sensors for smart home integration (Samsung Newsroom, 2024). TCL has showcased AI-powered gesture control prototypes at CES 2024, using RF and camera fusion for more accurate motion tracking. TCL has filed patents for RF-based "attention tracking" to pause content when viewers look away, leveraging technology from its research arm, TCL CSOT (USPTO Patent #US20240137214A1) (TCL, 2024). The integration of RF sensing will potentially unlock a €5–7 billion niche market within Smart TVs by 2030, particularly in high-end models and IoT-connected ecosystems [106].

7.2.1. Market Dimension & Growth

The global Smart TV market in 2024 shows significant regional variation, reflecting diverse consumer adoption and technological trends. Europe and Asia Pacific dominate the market with sizes of €31.6 billion and €31.5 billion, respectively, but exhibit vastly different growth trajectories.

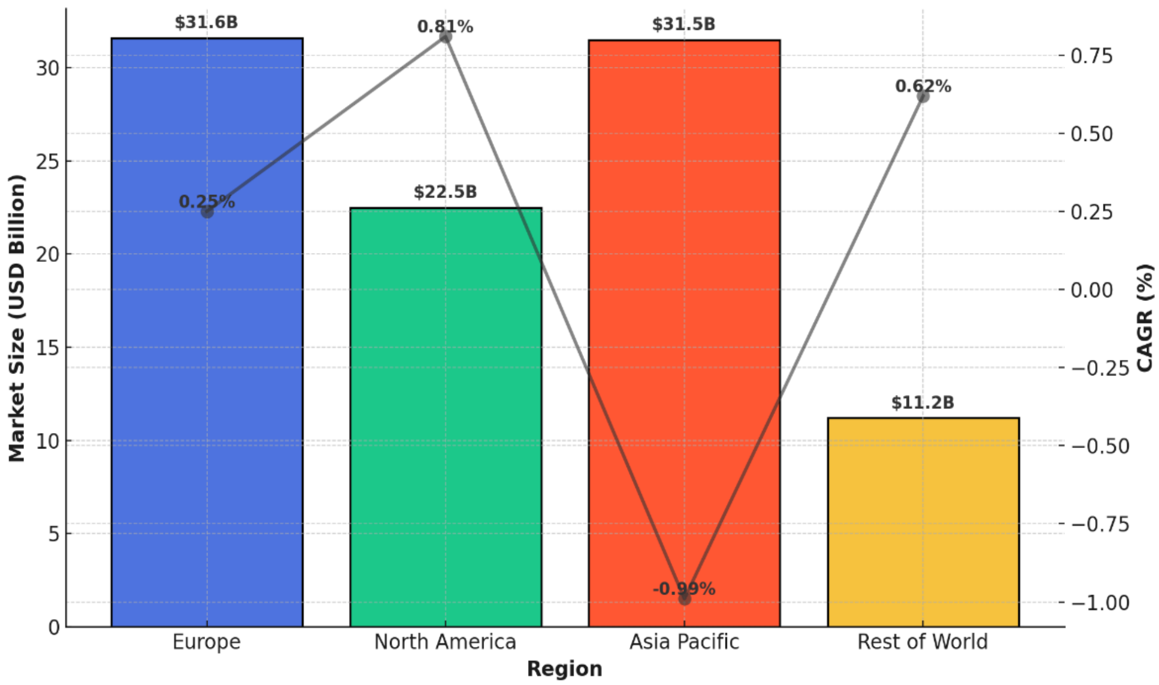


Figure 35: Smart TV Market Size and Regional variations

Europe experiences minimal growth with a CAGR of 0.25%, indicating stable demand, while Asia Pacific faces a negative CAGR of -0.99%, suggesting a potential slowdown in market expansion or even stagnation, possibly due to market saturation or external economic factors. North America, with a market size of €22.5 billion, shows moderate growth at 0.81% CAGR, which is indicative of steady demand, albeit slower than Europe. The Rest of the World (including emerging markets) has the smallest market share at €11.2 billion, but it demonstrates a 0.62% CAGR, reflecting gradual expansion in regions like Latin America, and Africa driven by increasing access to technology and rising middle-class incomes.

7.3. Market Segmentation Analysis

7.3.1. Target Market Segmentation

Given the market potential of Smart TVs empowered by RF sensing technology, it is essential to dissect the target market using multidimensional segmentation. This includes demographic patterns, technology-specific adoption behaviors, and psychological or behavioral drivers shaping usage. Smart TVs are no longer just passive viewing devices; they are becoming dynamic nodes in the broader IoT ecosystem, shaping, sensing, and responding to user behaviors. RF sensing adds a transformative, contactless interaction layer to this shift, appealing to specific consumer needs ranging from convenience to wellness and privacy.

a. <u>Age Group Segmentation</u>

Age remains a fundamental factor in the adoption and use of Smart TV innovations. RF-sensing Smart TVs, through non-contact gesture control and adaptive interface design, address the needs of distinct age groups across generations, from hyper-connected Gen Z to aging populations seeking ease and safety.

Table 36: Demographic Segmentation for RF Smart TV Adoption

Age Group	Market Characteristic (2024)	Key Needs / Interaction Triggers	Relevant RF Sensing Features	Source
18–34 (Gen Z/Millennials)	90% Smart TV ownership in developed markets	Hands-free control, multi-tasking, immersive streaming/gaming	Gesture-based UI, quick-switch functions, attention tracking	Ofcom, 2024; Pew, 2023
35–54 (Working Professionals & Parents)	High dual-device usage rate; smart home integrators	Smart home sync, family safety, child-proof interaction	Presence detection, profile-based content personalization	Frankel, 2025

55–74 (Young Seniors)	Moderate Smart TV adoption, increasing smart tech curiosity	Ease of use, larger interfaces, privacy, health monitoring	Simplified gesture control, passive wellness sensing	WHO, 2024
75+ (Elderly & Care-supported)	Low adoption, but rising through assisted setups	Accessibility, fall detection, emergency alert integration	Passive sensing (no remote use), auto wake/sleep functions	Khan et al., 2024

b. <u>Technology-Specific Segmentation</u>

The integration of RF sensing technology within Smart TVs is not uniformly applicable across all product categories. Rather, its adoption correlates strongly with product tier and the associated expectations of user experience, interactivity, and technological sophistication. Smart TVs can be broadly categorized into entry-level, mid-range, and premium tiers, each catering to distinct consumer needs, budget constraints, and behavioral patterns. Understanding these nuances is essential for positioning RF sensing capabilities where they can deliver the most value and achieve meaningful adoption.

Table 37: Tech-specific Segmentation for RF Smart TV Adoption

Product Tier	Price Band / Market Share	Consumer Needs / Features Expected	RF Sensing Alignment	Source
Entry-Level Smart TVs	<€400 / ~38% of global market	OTT access, basic connectivity	Low—price-sensitive segment; may adopt later	Statista, 2024
Mid-Range Smart TVs	€400–€900 / ~42% of market	Voice assistants, smart home integration	Moderate to high—gesture control & presence sensing	Counterpoint ,2024
Premium Smart TVs	€900+ / ~20% of market	Multi-user customization, seamless automation, and design	High—RF sensing as a value-added differentiator	Sony Research, 2024

c. <u>Behavioral Segmentation</u>

Consumer behavior toward Smart TVs has evolved significantly in recent years, shaped by technological advancements and shifting lifestyle patterns. No longer perceived as passive viewing devices, Smart TVs are now evaluated by consumers through a multidimensional lens—one that prioritizes effortless user experience, data privacy assurance, context-aware functionality, and seamless integration within smart living ecosystems.

Table 38: Behavioral Segmentation for RF Smart TV Adoption

Behavioral Trait	Market Influence	Primary Target Segments	RF Sensing Value Contribution	Source
Convenience-Seekers	Prefer contactless, intuitive control	Tech-savvy professionals, multi-device users	Hands-free navigation, gesture shortcuts	Samsung, 2024
Privacy-Conscious Users	Avoid camera-based surveillance or intrusive AI	Families, solo dwellers, elderly individuals	Non-visual data collection ensures privacy	Anwar et al., 2025
Health & Wellness Monitors	Interested in passive wellbeing checks via everyday devices	Seniors, caregivers, chronic disease households	Movement tracking, anomaly detection	Sony Research, 2024
Tech Enthusiasts / Innovators	Early adopters of novel tech, seek personalization	Urban high-income users, smart home ecosystem owners	Multi-user gesture control, ambient automation	TCL, 2024

d. Regional & Socioeconomic Segmentation

Geographic and socioeconomic factors play a pivotal role in shaping both the adoption patterns and commercial viability of emerging technologies such as RF-sensing Smart TVs. Regional segmentation, when viewed through the lens of infrastructure maturity, income distribution, and technological openness, reveals a complex but strategically valuable landscape.

Table 39: Regional & Socioeconomic Segmentation for RF Smart TV Adoption

Region	Smart TV Market Size (2024)	Adoption Conditions	RF Sensing Readiness	Key Growth Catalysts	Source
North America	€22.5B	High disposable income, strong IoT ecosystems	High—early adoption via premium brands	Privacy regulations, smart home density	Ofcom, 2024
Europe (Western)	€31.6B	Privacy-sensitive, aging population	High—privacy-compliant tech favored	GDPR alignment, wellness focus	Frankel, 2025

Asia-Pacific (Urban)	€31.5B	Tech-forward, large middle-class base	Moderate to High—urban uptake likely	Manufacturing innovation, youth tech affinity	Counterpoint, 2024
Emerging Markets (RoW)	€11.2B	Price-sensitive, infrastructure developing	Low to Moderate—entry-level pilot needed	Mobile-first transition, growing middle class	Statista, 2024

7.3.2. Target Market Profiling

RF-sensing technology aims to enhance the Smart TV functionality & capabilities, revealing a multifaceted ecosystem composed of various stakeholder groups, each contributing distinct functional roles and exhibiting unique needs, behaviors, and adoption triggers. Unlike traditional market models focused purely on audiovisual consumption, RF-enabled Smart TVs are positioned at the intersection of home entertainment and smart living.

a. <u>TV OEMs / Global & Regional Brands</u>

These are the core producers of hardware and integrated firmware, often categorized as Original Equipment Manufacturers (OEMs) and Original Design Manufacturers (ODMs). Their strategic positioning in the consumer electronics value chain makes them the primary channel for introducing RF sensing technology into Smart TV and their adoption of RF sensing would be driven by:

- Product differentiation: standing out in a saturated hardware market.
- Premium upsell: justifying higher price points through advanced features.
- Privacy Compliance: offering a "vision-free" sensing alternative to intrusive cameras.

Key Players:

- **OEMs** like Samsung, LG, Sony, TCL, Hisense, Vizio, Panasonic, GestureTek: they have direct control over software ecosystems, proprietary chipsets, high-level feature sets, and define user experience.
- **ODMs** like Compal Electronics, Foxconn, and TPV Technology: they provide technology focusing on mass-scale engineering, blueprint design, and manufacturing.

Example:

The industry is shifting toward "interaction-first" hardware. For instance, Samsung's radar-based gesture patents (USPTO, 2023) signal a clear trend toward RF-powered models designed to replace traditional remotes and improve accessibility through motion tracking, using mmWave radar. TCL's move into RF sensing is anchored in their SQD-Mini LED technology and NXTHOME ecosystem. At CES 2026, they unveiled how they use high-precision sensors to drive "Intelligent Living" (https://www.tcl.com/eg/en/news/tcl-displays-the-future-of-visual-technologies-and-intelligent-living-with-groundbreaking-products-and-solutions-at-ces-2026) to highlight the shift from mere display specs to AI-powered hardware that manages home energy and interaction. Their "NXTHOME" platform uses background sensing to manage device states based on user presence, effectively replacing cameras with privacy-compliant RF modules. Hisense has branded their RF-sensing capability under the "FollowMe" and "Full-Scenario Smart Living" initiatives. Their focus is on a TV that "follows" the user's needs through spatial awareness (https://hisenseme.com/about-hisense/newsroom-details/hisense-brings-fullscenario-smart-living-to-life-at-ces-2026)

b. Backward Linkage (Silicon Architects & Component Suppliers)

Beyond OEMs and ODMs, a critical layer of the Smart TV ecosystem lies in the backward linkage: upstream semiconductor and component suppliers that provide the foundational silicon, RF sensing hardware, and connectivity modules. These players enable scalable adoption across multiple downstream TV manufacturers by offering highly integrated, modular components that can be incorporated into broader chipset or system-on-module designs, reducing the need for fully bespoke sensing architectures at the product level. This layer forms the physical and electronic foundation of sensing-enabled smart devices.

Key Players: Rather than delivering finished intelligence, these firms provide the enabling infrastructure that allows OEMs and software partners to build higher-level perception and interaction systems on top of standardized, reusable hardware building blocks.

- **Chipset & SoC Providers:** Firms like Qualcomm, MediaTek design the primary system-on-chips that handle compute, multimedia processing, and AI workloads, and coordinate system-level integration of sensing data from peripheral modules.
- **Radar & RF ICs Providers**: Firms like Infineon Technologies, Texas Instruments develop mmWave radar chips and RF sensing solutions that enable presence detection, motion tracking, and gesture recognition at the hardware signal level.
- **RF Front-End & Connectivity Modules:** Firms like Qorvo, Murata Manufacturing supply RF front-end components such as antenna arrays, filters, and signal conditioning modules that ensure reliable transmission and reception of high-frequency radar and connectivity signals.

Example:

Qualcomm, as a premier chipset maker, is leveraging its Snapdragon / Dragonwing platforms to push Wi-Fi Sensing (802.11bf). In this model, the TV's Wi-Fi chip doubles as an RF sensor. By analyzing disruptions in Wi-Fi signals, the Qualcomm chipset focuses on “sensing” patterns without needing a dedicated radar module, essentially turning a connectivity component into a functional sensor. At CES 2026, Qualcomm and BOE announced a next-gen Android TV platform powered by the Dragonwing QCS8550 processor, specifically designed to bring premium AI-enhanced sensing and interaction to the global TV market (https://www.qualcomm.com/networking-infrastructure/products/n-series/n8-platform). While Qualcomm focuses on the general processor, Infineon leads to dedicated Radar-on-Chip solutions. Their XENSIV™ 60GHz radar sensors are the specialized components that OEMs buy to achieve "Micro-Gesture" recognition (like finger-snapping or pinch-to-zoom in the air). Murata & Qorvo provide the RF Front-End. As TVs move to higher frequencies (like 60GHz mmWave), these suppliers provide the miniaturized antenna modules that ODMs like Foxconn physically solder into the TV's chassis.

c. Software & AI Ecosystem (The Intelligence Layer)

While upstream semiconductor and RF suppliers provide the physical sensing infrastructure, the software and AI ecosystem represents the intelligence layer that transforms raw RF signals into meaningful, human-interpretable outputs. This layer is responsible for converting radar reflections and sensor data into structured behavioral understanding such as presence detection, motion tracking, gesture recognition, and activity inference. Its primary function is not raw signal capture, but rather signal interpretation and decision-making, enabling devices to respond contextually to user behavior in real time.

Key Players:

Unlike a standardized software stack provided by a single dominant vendor, this ecosystem is fragmented and highly application-specific, typically combining chipset vendor SDKs, OEM in-house algorithms, and selective external research contributions. Below we report some examples of key ecosystem contributors “by function”.

- **Chipset software platforms (SoC layer integration)**: Firms like Qualcomm, MediaTek provide compute environments and AI acceleration frameworks that enable real-time processing of sensor inputs within the device system architecture.
- **Radar and signal processing software stacks**: Firms like Infineon Technologies, Texas Instruments supply reference algorithms, firmware, and signal-processing toolchains that convert raw RF reflections into structured detection data (e.g., motion vectors, proximity, and gesture primitives).
- **OEM AI and application-layer intelligence**: Firms like Samsung, LG, Sony, TCL develop proprietary models and user-interface logic that translate processed sensing data into product features such as gesture control, ambient awareness, and adaptive UI behaviors.

Example:

This layer acts as the interpretation and decision engine of the Smart TV sensing ecosystem. Rather than functioning as a single unified software platform, it is a distributed intelligence stack built across hardware drivers, chipset SDKs, and OEM-specific AI models. Its value lies in turning low-level RF signal outputs into actionable and user-facing experiences, enabling seamless interaction without requiring explicit user input devices such as remotes or cameras. Although RF-based gesture sensing is not yet widely deployed in smart TVs, several adjacent implementations demonstrate how the intelligence layer operates in practice. Google Project Soli provides a clear proof of concept, using 60 GHz radar and AI models to translate micro-movements into precise gestures, as seen in the Google Pixel 4. At the hardware and signal-processing level, companies such as Infineon Technologies and Texas Instruments already offer commercially available mmWave radar platforms combined with software development kits that enable presence detection, motion tracking, and basic gesture recognition. These solutions are actively used in smart home and consumer electronics applications and can be adapted for TV environments. On the OEM side, manufacturers like Samsung Electronics, Sony Group Corporation, and LG Electronics illustrate how the final layer of intelligence is controlled at the product level, integrating sensing inputs, whether RF-based or alternative modalities, into user-facing features and interaction models.

d. Value-Added Service Providers (B2B Feature Market)

This group represents potentially B2B partners who leverage RF-sensing data to deliver specialized applications, transforming Smart TV from a passive display into an active, context-aware service platform. Rather than interacting directly with hardware, these providers build services on top of interpreted sensing outputs such as presence, motion, and activity patterns.

Potential Key Players:

- Gaming & VR/AR: NVIDIA (GeForce Now) and Microsoft (Xbox). These players could use RF sensing for "controller-free" navigation and proximity-based gameplay.
- Fitness & Wellness: Gym & Fitness apps could offer "Activity Recognition" (e.g., posture monitoring, rep counting) as a privacy-safe alternative to camera-based tracking.
- EdTech: Interactive learning platforms could adapt content based on a child’s proximity and engagement level.
- Smart Home Automation: RF sensing from vendors like Infineon Technologies is already used in lighting and HVAC systems to detect presence and movement, a capability that could be extended to TV-centered ecosystems.

Example:

These providers could drive consumer stickiness and service differentiation, as users may select a TV ecosystem based on its ability to integrate with health monitoring, fitness platforms, or other ambient intelligence services.

e. OS Platforms & Connectivity Enablers

Moving toward the end-user space, another layer potentially involved in the value chain is represented by platforms that mediate access between sensing capabilities and end-user services provided thanks to the internet connectivity. These actors can control how data flows, which applications can access it, and how features are exposed within the user interface.

Key Players:

- Operating System Platforms like Tizen, webOS, Roku OS: they can act as the true gatekeepers and service orchestrators, controlling APIs, data access, and integration of third-party applications. They determine how RF sensing capabilities are exposed to developers and ultimately shape the user experience.
- Broadband operators bundling smart home and media services: they play a complementary role as distribution enablers, potentially bundling value-added services (e.g., home monitoring or assisted living subscriptions), but with limited control over sensing functionality itself.

Example:

- OS-Level Ecosystems: platforms such as Tizen and webOS already integrate AI-driven features like presence detection, content recommendation, and voice control, acting as centralized hubs for smart home and media services.
- Platform Aggregators: Roku OS demonstrates how TV operating systems aggregate streaming, advertising, and third-party services, a model that could extend to sensing-driven applications.
- ISP Bundling Models: Telecom operators (e.g., Comcast, Deutsche Telekom) already bundle home security, monitoring, and entertainment services, creating a pathway for integrating RF-based sensing features into subscription offerings.

7.4. Market Needs & Trends

The Smart TV market is evolving faster than ever due to technological revolutions and immersive R&D. Understanding these market trends and needs is crucial for identifying opportunities where RF sensing technology can play a pivotal role in transforming user interaction, entertainment, retail, and operational efficiency.

a. Demand for Frictionless and Adaptive User Experiences

Trend: Consumers across all segments (market.us, 2025) now expect technology to anticipate their needs and respond instantly, eliminating unnecessary latency or steps for common tasks like navigation, playback, and control [107].

Need: RF sensing embedded smart TVs will address this most effectively and accurately by allowing for presence-based automatic wake/sleep, gesture shortcuts for volume and playback, and personalized profile switching as a user approaches the TV, creating a truly seamless and "invisible" interface.

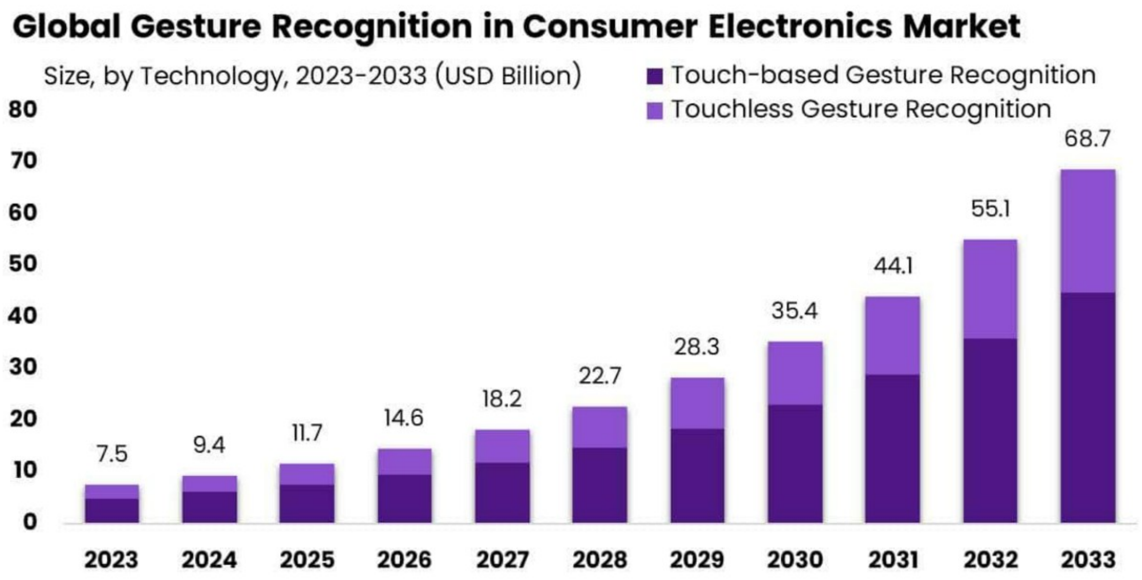


Figure 36: Global Gesture Recognition in Consumer Electronic Market

b. <u>Preference for Intuitive and Immersive Gaming Control</u>

Trend: Video gamers are increasingly seeking more immersive and responsive control systems that go beyond traditional gamepads, aiming for an experience that mirrors physical movement and intention.

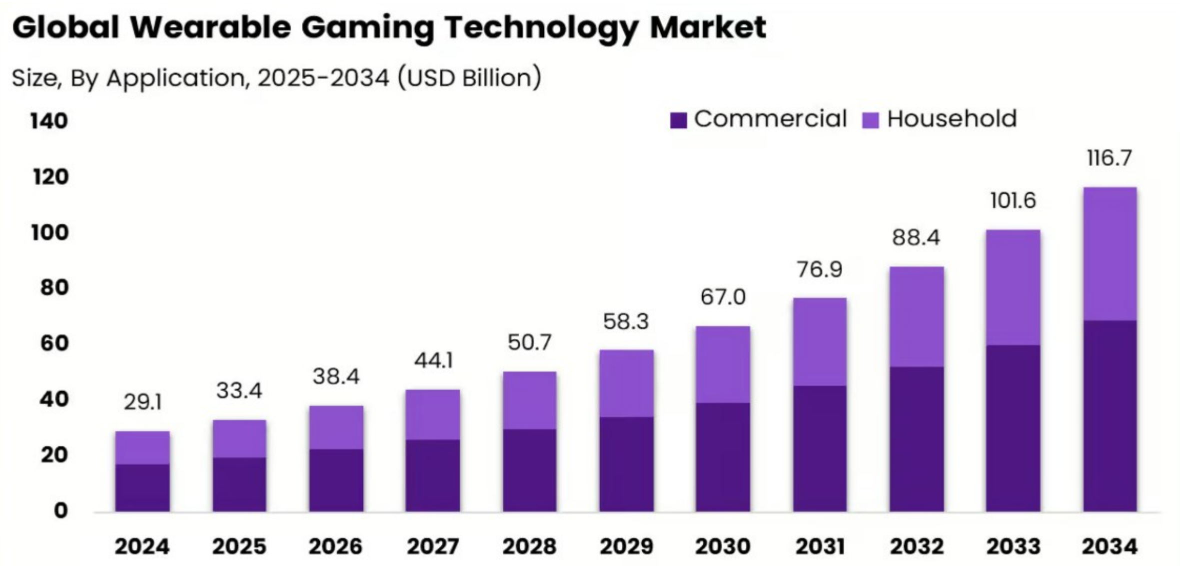


Figure 37: Global Gesture Recognition in Consumer Electronic Market

Need: RF sensing technology meets this demand by enabling low-latency, whole-body gesture control for casual and fitness gaming, creating a more engaging and physically active experience without the need for cameras or wearable controllers.

c. Expansion of Interactive Learning and Digital Classrooms

Trend: Educational institutions are adopting interactive displays and digital tools more than ever to foster collaborative and engaging learning environments, moving beyond static presentations (market.us, 2025.

Need: RF sensing technology enables students or instructors to interact with educational content on a large screen through touchless gestures, facilitating a more dynamic classroom experience that promotes group participation without the need for physical contact, cameras, or specialized wearables.

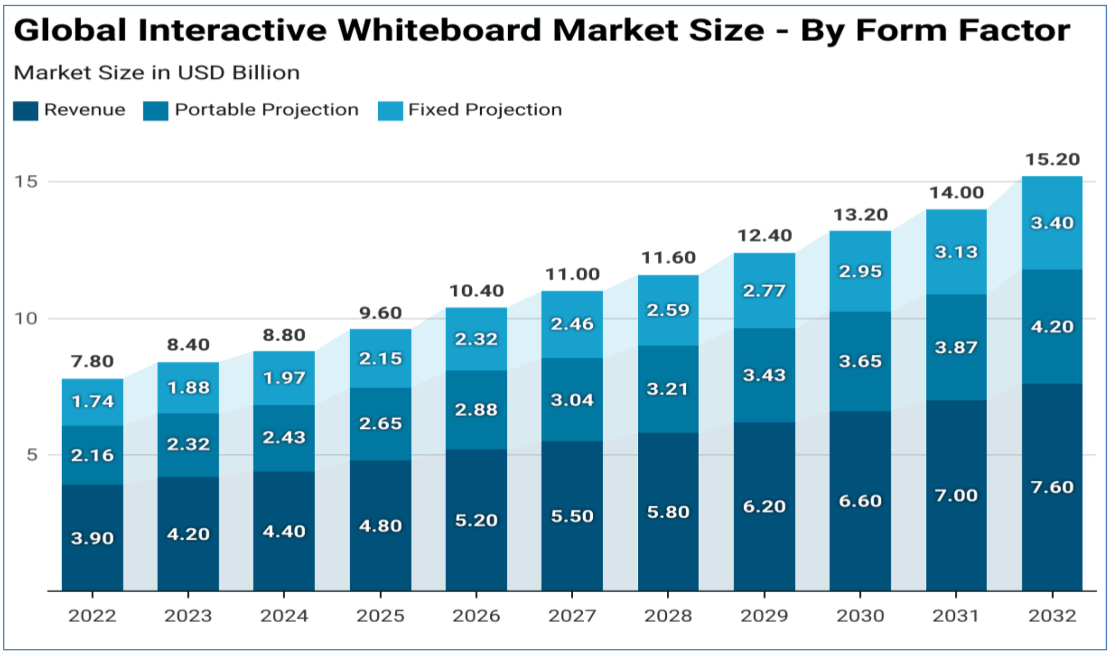


Figure 38: Global Interactive Whiteboard Market

d. Integration with Augmented and Virtual Reality Ecosystems

Trend: The convergence of AR/VR with traditional media is creating new paradigms for entertainment and social interaction, requiring spatial awareness and user tracking (IDC Corporate, 2023).

Need: RF sensing can serve as a bridge, allowing a Smart TV to track a user's position and movements relative to the screen, enabling AR overlays on broadcast content or serving as a calibration point for VR experiences within a living room space.

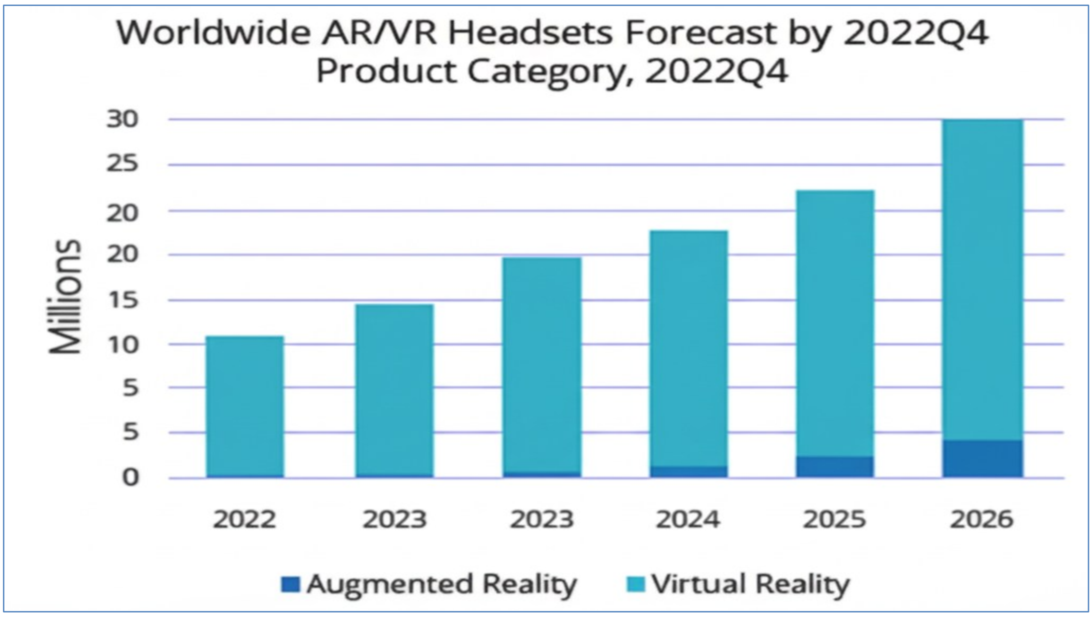


Figure 39: Global Augmented and Virtual Reality Market

e. Requirement for Autonomous Public Display Interaction

Trend: Businesses like McDonald's, shopping malls, and restaurants are deploying self-ordering kiosks and interactive informational displays that require robustness and hygiene.

Need: Unlike camera-based solutions that raise privacy concerns and struggle with lighting, RF sensing offers a reliable and private method for touchless interaction with public Smart TV displays, enabling gesture-based menus and navigation that work consistently in various environmental conditions.

7.5. Value and Use-Case Analysis

This section transitions the analysis from enabling technologies to concrete market applications within the Smart TV ecosystem. By identifying how RF sensing capabilities translate into user-facing features and service-layer opportunities, we highlight the most valuable intersections across both Business-to-Business (B2B) and Business-to-Consumer (B2C) value chains. The integration of RF sensing into Smart TVs represents a structural shift: the evolution of the television from a passive entertainment device into an interactive, context-aware hub within the connected home. This transformation is enabled by a multi-layered architecture in which upstream semiconductor providers, OEMs/ODMs, software intelligence layers, and operating system platforms collectively convert RF signals into meaningful user interactions.

This dual-pathway model creates value across two dimensions:

- **B2B value creation**, driven by the integration of sensing technologies across the hardware and software stack.
- **B2C value capture**, enabled through enhanced user experiences and service-based applications delivered to end users.

The impact of this innovation can be assessed across three primary dimensions:

Operational & Economic Efficiency: enabling sensing capabilities without requiring additional hardware such as cameras or wearables.

Quality of Experience: improving usability, accessibility, and personalization through touchless and context-aware interaction.

Ecosystem Expansion: unlocking new service-layer integrations across entertainment, gaming, fitness, and smart home domains

By mapping these outcomes, we demonstrate how RF sensing enables a multi-layered ecosystem (see Figure 40), where semiconductor providers, OEMs, platform operators, and service providers jointly contribute to value creation and capture.

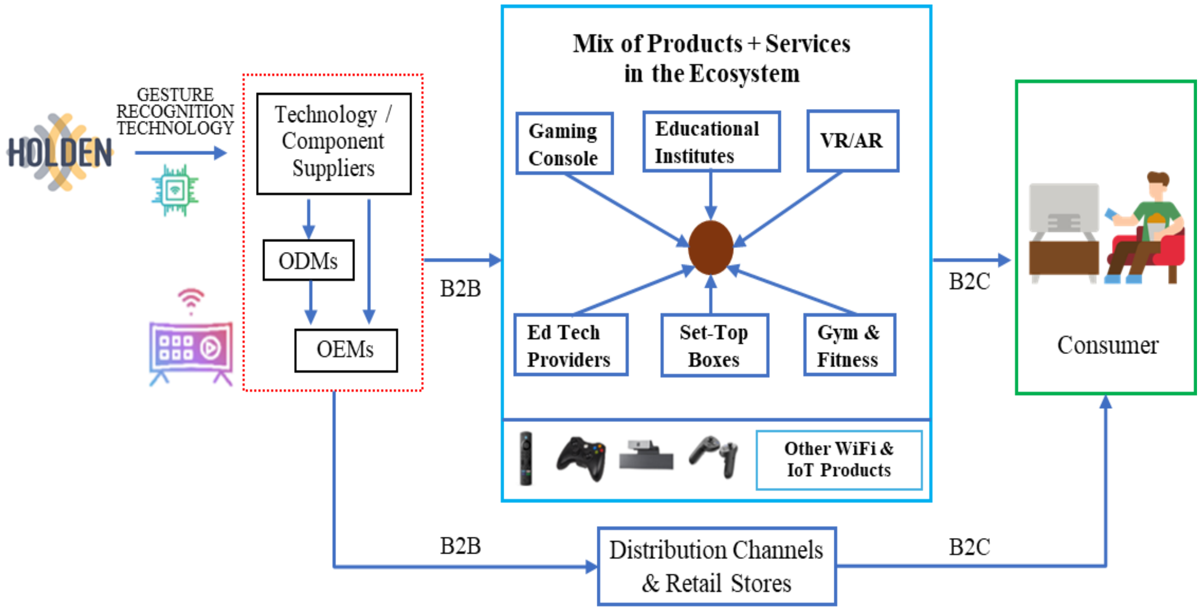


Figure 40: Innovation Impact in the Smart TV Ecosystem

7.5.1. The B2C Value Chain: OEMs & Platform Providers

In the B2C model, Smart TV OEMs and operating system platforms act as the primary interface with the end user. OEMs integrate RF sensing modules into the device, while software and platform layers orchestrate how sensing data is translated into user-facing features. Operating systems such as Tizen, webOS, and Android TV play a central role by acting as gatekeepers of the user experience, managing APIs, applications, and integration with third-party services.

Market Opportunity

The global Smart TV market continues to grow steadily, driven by demand for connected home devices and premium user experiences. RF sensing introduces a new differentiation layer, particularly in mid-to-high-end segments, where consumers increasingly value seamless interaction, personalization, and privacy-preserving technologies.

Primary Customers

End users include:

- Households adopting smart home ecosystems.
- Tech-oriented consumers seeking advanced interaction models.
- Elderly and accessibility-focused users benefiting from hands-free control.

In this model, the Smart TV evolves into a multi-functional device, combining entertainment, ambient sensing, and smart home interaction without requiring additional peripherals.

Key Benefits:

- **Low Friction/Seamless Interaction:** Enables gesture-based control and presence awareness without remotes, wearables, or cameras.
- **Privacy-First Experience:** RF sensing allows motion and activity detection without visual data collection.
- **Enhanced Personalization:** Content and interface elements can dynamically adapt based on user presence and behavior.
- **Accessibility & Inclusivity:** Supports hands-free interaction for elderly users and individuals with mobility limitations.
- **Platform Stickiness & Ecosystem Lock-In**: Integration with OS platforms increases user retention and long-term engagement.

7.5.2. The B2B Value Chain: ODMs, Technology Providers & Service Ecosystem

In the B2B model, value is created through the integration of RF sensing across the upstream and midstream layers of the ecosystem. ODMs, semiconductor providers, and platform operators collaborate to embed sensing capabilities into scalable hardware and software architectures, which are then leveraged by service providers to deliver value-added applications.

Market Opportunity

RF sensing enables new revenue streams across multiple actors in the value chain:

- **ODMs:** (e.g., Foxconn, Compal Electronics): can deliver RF-enabled reference designs on a scale, moving beyond low-margin manufacturing.
- **Semiconductor & RF Suppliers** (e.g. Infineon Technologies, Qualcomm): benefit from increased demand for radar chips, RF modules, and sensing toolkits.
- **Software & Platform Layers:** Enable integration of sensing data into applications through AI models and OS-level frameworks.
- **Service Providers**: build new business models on top of sensing-driven insights landscape.

Primary Customers

The B2B ecosystem serves:

- Healthcare and assisted living providers.
- Fitness and wellness platforms.
- Smart home and IoT service providers.

In contrast to the B2C model, which focuses on individual interaction, the B2B model emphasizes scalable deployment and service integration across multiple users or environments.

Integrated Professional Services

In the B2B chain, value can be realized through "bundling" RF-enabled hardware with service-layer applications:

- **Healthcare & Assisted Living:** RF sensing can enable presence detection, gesture recognition, sleep monitoring, and activity tracking without intrusive cameras.
- **Smart Home Automation:** Presence detection enables automated control of lighting, HVAC, and security systems.
- **Fitness & Wellness:** Enables activity recognition and posture monitoring as privacy-preserving alternatives to camera-based systems.

- **Data-Driven Platforms:** Aggregated behavioral data enables predictive analytics and personalized services.

Key Benefits

- **Scalable, Non-Intrusive Monitoring:** enables deployment without the operational burden of wearables or cameras.
- **New Revenue Streams:** supports subscription-based and service-driven business models.
- **Transition to Preventative Models:** enables early detection of behavioral changes and proactive intervention.
- **Ecosystem Synergies:** strengthens collaboration across hardware, software, and service providers.

7.6. Competitive Landscape

In the rapidly evolving Smart TV market, the competitive landscape is being reshaped by parallel advances in gesture recognition, voice assistance, sensor technologies, and smart home integration. Multiple technologies already offer varying degrees of interactivity and automation, but they often face challenges related to precision, usability, privacy, and long-term adoption. The introduction of RF sensing into Smart TVs creates a new category of non-intrusive, ambient intelligence that has the potential to overcome many of these limitations. In table 40 the Smart TV interaction ecosystem is illustrated by categorizing competing alternatives across four major and existing technological domains:

- Remote Controllers and Smart Remotes
- Voice Assistants and AI-driven Control Systems
- Camera-based Gesture Control Technologies
- Wearables & Companion Devices

and the comparatively emerging domain **RF Sensing-enabled Interaction**. Each domain is represented by key players, flagship solutions, and examples of real-world deployment.

Table 40: Competing Technologies in the Smart TV Ecosystem

Category	**Technology / Device**	**Key Players Examples**
Remote Controllers and Smart Remotes	Traditional IR/Bluetooth remotes, smart remotes with touchpads, voice	Samsung Smart Remote, LG Magic Remote, Sony One-Flick, Roku Remote, Vizio Voice Remote

	buttons, motion sensing, and laser pointers	
Voice Assistants and AI-driven Control Systems	Integrated voice assistants for Smart TVs and connected ecosystems	Amazon Alexa, Google Assistant, Apple Siri, Samsung Bixby, LG ThinQ AI
Camera-based Gesture Control Technologies	Depth-sensing cameras, computer vision for body/hand gestures	Microsoft Kinect (legacy), Intel RealSense, LG Gesture TVs, Sony PlayStation Camera
Wearables & Companion Devices	VR controllers, Smart Glasses	Apple, Google, Oculus/Meta VR Controllers
RF Sensing-enabled Interaction (Emerging Domain)	Radar-based gesture sensing, presence/motion detection via RF signals	Samsung (radar patents), Sony Semiconductor, Infineon (60GHz radar), Origin Wireless, Google Soli, Radar Sensor for Smart TVs by Texas Instruments.

7.6.1. Remote Controllers and Smart Remotes

Remote Controllers remain the dominant interaction technology in the Smart TV ecosystem, ranging from traditional infrared devices to advanced Bluetooth-enabled smart remotes with touchpads, motion sensing, and integrated voice buttons. These devices provide a familiar and reliable interaction model but rely entirely on explicit user input, limiting their ability to support seamless or adaptive interaction.

Figure 41: Remote Controller-Based Interaction Systems

Despite their widespread adoption, remote controllers introduce friction in the user experience, requiring constant physical engagement and often leading to usability issues such as device misplacement or complexity for elderly users.

Key Market Players: Examples include Samsung Smart Remote, LG Magic Remote, Sony One-Flick, and Roku Remote.

Privacy & Ethics: Remote-based interaction is inherently privacy-safe, as no personal data is passively collected. However, this also limits the system's ability to provide context-aware services.

AI & Cloud Impact: Minimal AI dependency; interaction is primarily hardware-driven, with limited cloud integration beyond content recommendations.

Impact on Private Life: Non-intrusive, but also non-adaptive. The user must continuously initiate interaction, preventing the development of ambient intelligence.

7.6.2. Voice Assistants and AI-Driven Control Systems

Voice-based interaction systems enable hands-free control of Smart TVs through natural language commands, integrating devices into broader smart home ecosystems. Platforms such as Amazon Alexa, Google Assistant, Apple Siri, and Samsung Bixby have become central to modern Smart TV interfaces.

Figure 42: Voice-Based Interaction Ecosystems

While voice assistants improve accessibility and convenience, they remain reactive systems, requiring explicit user activation and clear command structures.

Key Market Players: examples Amazon, Google, Apple, Samsung, LG (ThinQ AI).

Privacy & Ethics: Significant concerns arise from "always-listening" microphones and potential unintended recording of private conversations.

AI & Cloud Impact: Highly dependent on cloud-based Natural Language Processing (NLP), raising issues related to data storage, latency, and regulatory compliance.

Impact on Private Life: Moderately intrusive; while physically non-invasive, constant voice monitoring may alter user behavior and reduce perceived privacy within the home.

7.6.3. *Camera-Based Gesture Control Technologies*

Camera-based systems leverage computer vision and depth sensing to enable gesture recognition and body tracking. Technologies such as Microsoft Kinect, Intel RealSense, and integrated TV solutions from LG Electronics and Sony Group Corporation have demonstrated the potential for rich, immersive interaction.

Figure 43: Camera-Based Gesture Interaction Systems

These systems offer advanced interactivity but face significant adoption barriers related to cost, environmental dependency, and privacy concerns.

Key Market Players: examples include Microsoft, Intel, Sony, LG.

Privacy & Ethics: High privacy risk due to continuous video capture and image processing. Users often perceive these systems as intrusive or “surveillance-like”.

AI & Cloud Impact: Requires intensive computer vision algorithms, often supported by cloud or edge AI processing.

Impact on Private Life: Highly intrusive; transforms the home environment into a visually monitored space, often requiring explicit consent and limiting widespread adoption.

7.6.4. *Wearables & Companion Devices*

Wearables and companion devices, including VR controllers and smart glasses, extend interaction beyond the TV itself by enabling immersive and spatial computing experiences. Devices from Apple, Meta, and Google illustrate this category.

Figure 43: Wearable-Based Interaction Ecosystems

While these technologies enable highly engaging experiences, they rely on continuous user compliance, limiting their suitability for mainstream, everyday TV interaction.

Key Market Players: examples include Apple, Meta (Oculus), Google.

Privacy & Ethics: Moderate concerns related to biometric and behavioral data collection.

AI & Cloud Impact: Strong reliance on onboard and cloud-based AI for tracking, rendering, and interaction.

Impact on Private Life: Physically intrusive; requires users to wear or hold devices, which can lead to fatigue and reduced long-term adoption.

7.6.5. RF Sensing-Enabled Interaction (Emerging Domain)

RF sensing introduces a fundamentally different interaction paradigm by leveraging radio frequency signals to detect presence, motion, and gestures without requiring cameras, wearables, or explicit user input. This technology enables ambient intelligence, allowing Smart TVs to interpret user behavior passively and respond in real time.

Figure 44: RF Sensing-Based Interaction Systems

Unlike competing technologies, RF sensing operates as an invisible interaction layer, removing friction while maintaining high levels of privacy.

Key Market Players: Semiconductor firms like Infineon Technologies, Sony Semiconductor Solutions, Texas Instruments.

Privacy & Ethics: Strong privacy advantage, as no visual or audio data is captured. However, emerging concerns relate to “presence inference” and behavioral tracking through RF patterns.

AI & Cloud Impact: Requires advanced signal processing and machine learning models to interpret RF reflections. Increasingly shifting toward edge AI processing to reduce latency and privacy risks.

Impact on Private Life: Minimally intrusive; enables continuous, passive monitoring without requiring user awareness or interaction, supporting a seamless and adaptive experience.

7.6.6. Holden Innovation and Competitive Advantage

HOLDEN Innovation represents a paradigm shift within the Smart TV interaction landscape by addressing the fundamental limitations of existing technologies. Unlike remote controls, voice assistants, cameras, or wearables, HOLDEN leverages RF sensing to create a fully passive, privacy-preserving, and frictionless interaction layer.

Its competitive advantage is defined by the following pillars:

- **Privacy-by-Design & Ethical Compliance**: Operates without capturing visual or audio data, ensuring high levels of ethical compliance and user trust.
- **Edge AI & Data Protection:** Minimizes reliance on cloud infrastructure by processing RF signals locally, enhancing data security and reducing latency.
- **Zero-Friction Interaction:** Eliminates the need for remotes, voice commands, or wearable devices, enabling truly ambient interaction.
- **Seamless Integrability:** Designed for integration into OEM and ODM ecosystems, enabling scalable deployment across Smart TV platforms.

Strategic Differentiation Framework

To position HOLDEN within the competitive landscape, we evaluate its performance across key dimensions:

- **Lifecycle Cost of Ownership**: Lower than camera-based systems and wearables due to reduced hardware and maintenance requirements.
- **Sensing Capability**: Enables continuous presence and motion detection beyond the capabilities of traditional interaction methods.
- **Privacy & Ethics**: Combines high sensing accuracy with minimal privacy intrusion
- **Ease of Use**: Requires no behavioral adaptation from users.
- **Scalability & Integrability**: Easily embedded into existing Smart TV architectures and ecosystems.

This comparison helps us understand the unique advantages of HOLDEN Innovation and its market potential, when compared to other technologies. Compared to existing interaction paradigms, HOLDEN Innovation achieves a unique balance between usability, privacy, and intelligence. It enables Smart TVs to evolve into ambient, context-aware systems, bridging the gap between entertainment, smart home control, and emerging service-based applications, ultimately positioning Smart TVs as centralized, future-ready interaction hubs that surpass existing paradigms in both usability and consumer trust.

7.7. Entry Barriers

This section consolidates the principal structural considerations shaping market entry. In analyzing the barriers to market entry for embedding RF sensing technology inside Smart TVs, we can apply Porter's Five Forces to understand the competitive dynamics and external factors influencing adoption.

Unlike routers, the Smart TV market intersects not only with consumer electronics but also with content ecosystems, smart home platforms, and entertainment providers.

7.7.1. Threat of New Entrants

Technological Complexity and Additional Costs: (High Impact)

The integration of RF sensing into Smart TVs introduces hardware complexity, requiring additional antenna arrays, chipsets, and firmware optimization, alongside higher testing and compliance costs. OEMs and ODMs, already facing razor-thin profit margins in the TV segment, may hesitate to adopt unless clear consumer demand and premium pricing potential are evident.

As example, in 2021, Google discontinued its Soli radar-based gesture control in Pixel phones after facing integration cost challenges and limited user uptake, signaling the risk of premature adoption without consumer readiness (The Verge, 2021).

Mitigation Strategy

Launch pilot RF-TV models in premium segments (€1.000+) to build consumer awareness and justify higher prices. Gradually scale down to mid-range models once economies of scale reduce sensor and integration costs.

7.7.2. Bargaining Power of Suppliers

Supplier Dependence: (Moderate to High Impact)

RF sensing requires advanced radar chipsets, RF front-end modules, and specialized antennas. The supply chain is highly concentrated among a handful of semiconductor leaders (e.g., Infineon, Qualcomm, NXP). Supply disruptions or pricing power can significantly affect Smart TV manufacturers' margins. As example, the 2021 semiconductor shortage delayed shipments for major Smart TV brands like Samsung and LG, causing production bottlenecks and forcing ODMs to prioritize high-margin models (Bloomberg, 2021).

Mitigation Strategy

To reduce dependency on a small number of suppliers, it is essential to identify and secure relationships with multiple suppliers across multiple regions (Asia, US, EU) for both hardware components (e.g., sensors) and software solutions. Parallelly another strategy could be to invest in modular RF add-on designs so that TV models can switch suppliers without full redesign. Finally, to reduce reliance on external sensing software vendors, is suggested to explore in-house software algorithms (gesture recognition, presence detection).

7.7.3. Bargaining Power of Buyers (End Users & OEM Acceptance)

Consumer Preferences & ROI Concerns: (Moderate to High Impact)

The Smart TV market is price-sensitive, with most consumers prioritizing screen size, resolution (4K/8K), and streaming compatibility over additional sensing features. Moreover, end-users may prefer camera- or voice-based control (already familiar from Alexa/Google Home) instead of adopting a novel, less understood RF-based interface. As example, when 3D TVs launched in the 2010s, they failed due to consumer indifference despite heavy R&D and marketing investments. This demonstrates the challenge of introducing novel features without clear everyday value (CNET, 2017).

Mitigation Strategy

To reduce resistance, a couple of mitigation strategies could be:

- Hybrid integration: bundle RF sensing with value-added features (gesture gaming, entertainment functionalities, hands-free navigation).
- Focus on privacy-first messaging, positioning RF sensing as a safer alternative to cameras, appealing to privacy-conscious households.

7.7.4. Industry Rivalry (Existing Competitors)

Industry Preference: (Moderate Impact)

The Smart TV industry is highly competitive, dominated by a few global OEMs (Samsung, LG, TCL, Sony). Rival technologies (voice assistants, AI remotes, AR/VR headsets) already offer interaction alternatives. Industry players may resist adopting RF sensing if they perceive it as redundant or cost-inefficient compared to existing solutions. Example: a 2023 IDC report noted that despite heavy investment in AI-powered voice control, adoption has been mixed, with 40% of Smart TV users still relying on traditional remotes, indicating consumer inertia and industry reluctance to pivot too quickly (IDC, 2023).

Mitigation Strategy

To reduce industry rivalry from existing competitors' mitigation strategies could be:

- Demonstrate unique, irreplaceable use cases (e.g., presence-based auto-pause, fitness/gaming without cameras).
- Co-market with smart home partners and health tech, reinforcing multi-functional value beyond entertainment.

7.7.5. Regulatory Barriers

Data Privacy and Compliance: (Moderate to High Impact)

RF sensing tracks human presence, gestures, and in advanced cases, vital signs. This raises privacy concerns like those faced by camera-based TVs and smart speakers. Strict frameworks like GDPR (EU) and CCPA (US) regulate how such behavioral data is processed, stored, and shared. Non-compliance risks reputational damage, fines, and delayed adoption. Example: in 2019, Samsung Smart TVs faced global backlash when it was revealed that voice commands were transmitted to third-party servers without clear user consent, sparking privacy concerns and regulatory scrutiny (BBC News, 2019). Smart TVs with passive RF tracking could face similar backlash if not designed with Privacy by Design.

Mitigation Strategy

To reduce non-compliance risks and reputational damage several strategies could be:

- Adopt Privacy-by-Design principles (local on-device processing, no cloud storage without consent).
- Provide transparent opt-in settings, allowing users to control sensing features.
- Engage with regulatory bodies early to shape RF compliance frameworks (similar to EU's approval of 60GHz radar bands for consumer use in 2023).

Table 41: Summary Table of Key Barriers and Metrics

Dimension	Barrier	Impact	Examples	Mitigation Strategy
Threat of New Entrants	Technological complexity and additional integration costs	High	Integration of RF antenna arrays, radar chipsets, firmware optimization, testing and compliance requirements; Google Soli discontinuation due to limited adoption and integration cost challenges	Launch pilot RF-TV models in premium segments to validate demand and justify pricing; gradually scale to mid-range models as economies of scale reduce costs
Supplier Power	Dependence on specialized RF	Moderate –High	Reliance on suppliers such as Infineon Technologies, Qualcomm, and NXP Semiconductors;	Diversify suppliers across regions; adopt modular RF hardware

	semiconductor suppliers		semiconductor shortages affecting Smart TV production	architectures; develop in-house sensing and gesture-recognition software capabilities
Buyer Power	Consumer price sensitivity and uncertain perceived value	Moderate –High	Consumers prioritize display quality and streaming capabilities over sensing features; historical failure of 3D TV adoption due to limited everyday value	Bundle RF sensing with value-added services such as gesture gaming and hands-free navigation; position RF sensing as a privacy-preserving alternative to cameras
Industry Rivalry	Strong competition from incumbent interaction technologies	Moderate	Existing alternatives including voice assistants, AI remotes, AR/VR ecosystems, and conventional remote controls; resistance from dominant Smart TV OEMs such as Samsung Electronics and LG Electronics	Focus on differentiated use cases such as presence-aware automation, fitness tracking, and camera-free interaction; establish partnerships with smart home and health-tech ecosystems
Regulatory Barriers	Data privacy, behavioral tracking, and compliance requirements	Moderate –High	GDPR and CCPA concerns regarding gesture, presence, and vital-sign monitoring; backlash related to Smart TV voice-data collection practices	Implement privacy-by-design principles, local on-device processing, transparent opt-in controls, and early engagement with regulatory authorities

8. Exploitation/Business Plan – Smart TV

The commercialization of RF sensing in Smart TVs is built on a B2B2C architecture, where value is created through technology integration and captured through enhanced user experience and downstream services and the model leverages existing Smart TV ecosystems, allowing rapid scalability.

8.1. Business Model Canvas

The Business Model Canvas is a strategic management framework used to visualize, design, and pivot business models. It provides a single-page architectural blueprint that aligns high-level strategy with operational activities, making critical trade-offs and value drivers visible at a glance. For the RF-sensing Smart TV ecosystem, this framework allows us to map how hardware innovation (OEMs/ODMs) translates into scalable service revenue and ultimately delivered to end-users through enhanced, privacy-first, and frictionless interaction experiences. Revenue is driven by a mix of hardware integration, licensing, and long-term service monetization, while scalability is enabled through strategic partnerships and modular technology design.

<table>
<tr><th>KEY PARTNERS</th><th>KEY ACTIVITIES</th><th>VALUE PROPOSITIONS</th><th>CUSTOMER RELATIONSHIPS</th><th>CUSTOMER SEGMENTS</th></tr>
<tr>
<td rowspan="3">• Smart TV OEMs (integration and distribution)
• ODMs (manufacturing and scaling)
• Semiconductor suppliers (RF chips, SoCs)
•OS /platform providers (software ecosystem)
• Content providers (gaming, streaming, edtech)
• Smart home and health-tech partners</td>
<td>• Research & development (RF sensing + AI models)
• Product engineering and system integration
• Testing, validation, and certification
• Partnership development and sales
• Marketing, pilots, and demonstrations</td>
<td rowspan="3">• Privacy-first interaction (no cameras, no audio capture)
• Hands-free, zero-friction control (gesture + presence detection)
• Product differentiation for OEMs in a saturated market
• Improved accessibility and inclusivity
• Enablement of new services (wellness, gaming, smart home)</td>
<td>• Long-term strategic partnerships (OEMs/ODMs)
• Co-development and technical integration support
• Dedicated account management
• Continuous software updates and support
• Joint marketing and product launches</td>
<td rowspan="3">Primary:
• Smart TV OEMs (premium and mid-range brands)
• ODM manufacturers (large-scale production partners)
• OS / platform providers (TV ecosystems)

End-Users:
• Smart Home & IoT-integrated households
• Privacy-Conscious & Tech Adopters
• Elderly / accessibility-focused users
• Gamers & Immersive Entertainment Enthusiasts</td>
</tr>
<tr><th>KEY RESOURCES</th><th>CHANNELS</th></tr>
<tr>
<td>• RF sensing hardware (antennas, radar modules)
• AI/ML algorithms for signal processing
• Engineering and R&D expertise
• Intellectual property (patents, designs)
• Strategic industry partnerships</td>
<td>• Direct B2B sales to OEMs and ODMs
• Strategic partnerships with Smart TV brands
• Integration through OS platforms (e.g., app ecosystems)
• Industry events and trade shows, digital channels
• Co-marketing via partners and distributors</td>
</tr>
<tr><th colspan="2">COST STRUCTURE</th><th colspan="3">REVENUE STREAMS</th></tr>
<tr>
<td colspan="2">• R&D and innovation costs (high initial investment)
• Hardware components (RF chips, antennas)
• Integration and manufacturing costs
• Marketing and business development expenses
• Operational costs (support, updates, maintenance)</td>
<td colspan="3">• Direct sales (RF hardware + software integration)
• Licensing fees (per device / royalties)
• Revenue-sharing agreements with OEMs
• Future subscription services (wellness, fitness, smart home features)</td>
</tr>
</table>

Figure 45 – Business Model Canvas for the Smart TV Market

8.1.1. *Customer Segments*

The primary customer base consists of Smart TV manufacturers (OEMs) such as Samsung Electronics, LG Electronics, Sony Group Corporation, TCL Technology, and Hisense. These players dominate a market where differentiation is increasingly driven by software and interaction capabilities rather than display specifications alone. Complementing them are ODMs such as Foxconn and TPV Technology, which play a critical role in scaling production, and operating system platforms like Tizen, webOS, and Android TV that act as gatekeepers of the user experience. On the demand side, the end users include Smart home households, Tech-savvy consumers, Elderly and accessibility-focused users, Gamers and wellness/entertainment-oriented users. These segments reflect a shift toward multi-functional, context-aware devices, where interaction quality becomes as important as content consumption.

8.1.2. *Value Proposition*

RF sensing introduces a new interaction paradigm based on ambient intelligence. Unlike camera or voice-based systems, it operates without capturing visual or audio data, delivering a privacy-first experience aligned with increasing regulatory and consumer sensitivity. At the same time, it enables a zero-friction user experience, where gestures and presence replace remotes and explicit commands. This reduces interaction latency and improves usability, particularly for elderly or mobility-constrained users. From a commercial perspective, the value proposition for OEMs is equally strong. In a market approaching saturation, RF sensing could provide a clear differentiation lever, enabling:

- Premium pricing
- Product innovation beyond display features
- Expansion into new service ecosystems (gaming, wellness, IoT).

8.1.3. *Customer Relationships*

Customer relationships are primarily long-term, partnership-driven engagements with OEMs and platform providers. Given the integration complexity and strategic nature of the technology, relationships are characterized by:

- Co-development agreements
- Technical collaboration and support
- Joint go-to-market initiatives

At the end-user level, relationships are mediated through OEM platforms but strengthened via:

- Continuous software updates
- Service-based features (subscriptions)
- Personalized user experiences

8.1.4. Revenue Streams

The revenue model for RF sensing in Smart TVs is designed to balance immediate cash flow with long-term scalability. In the short term, revenues are primarily generated through direct sales of RF sensing hardware modules combined with embedded software, supplied to OEMs and ODMs as part of their Smart TV production. Complementing this, a licensing model enables recurring income through per-unit royalties, allowing the technology to scale efficiently across large production volumes without proportional increases in cost. Strategic partnerships may further introduce revenue-sharing agreements, particularly for premium Smart TV models where RF sensing acts as a differentiating feature. Over the longer term, the business model evolves toward service-based monetization, unlocking subscription revenues linked to value-added applications such as wellness monitoring, fitness tracking, and smart home automation, thereby extending revenue generation beyond the initial hardware sale.

8.1.5. Key Resources

The core resources underpinning this business model are both technological and organizational. At the center lies the RF sensing technology itself, which includes specialized hardware components (such as antennas and radar chips) and advanced software algorithms capable of interpreting RF signals into meaningful user interactions. This is complemented by strong capabilities in artificial intelligence and machine learning, essential for signal processing, gesture recognition, and presence detection. Human capital represents another critical asset, particularly highly skilled engineering and R&D teams responsible for continuous innovation and system optimization. In addition, intellectual property, comprising patents, proprietary algorithms, and system designs play a strategic role in maintaining competitive advantage and market positioning. Finally, established relationships with industry stakeholders further enhance the company’s ability to scale and integrate within existing Smart TV ecosystems.

8.1.6. Key Activities

The successful deployment of RF sensing technology relies on a set of tightly interconnected activities spanning innovation, integration, and commercialization. Research and development represent the foundation, focusing on advancing RF sensing accuracy, improving AI-driven signal interpretation, and optimizing system performance in real-world environments. Parallel to this, product development and engineering activities ensure that the technology can be seamlessly integrated into Smart TV architectures, requiring extensive testing, validation, and certification processes. Another critical activity involves collaboration with OEMs and ODMs, including customization and co-development efforts to align the technology with different product tiers and user requirements. On the commercial side, business development and partnership management are essential to secure integration agreements and expand market reach. Finally, marketing activities, such as pilot programs, demonstrations, and industry engagement play a key role in educating the market and driving adoption.

8.1.7. Key Partnerships

The business model is inherently ecosystem-driven, relying on a network of strategic partnerships across the Smart TV value chain. At the forefront are OEMs and ODMs, which act as the primary integration and distribution channels, embedding RF sensing technology into final consumer products. Upstream, partnerships with semiconductor and RF component suppliers are critical to ensure access to high-performance chips, antennas, and connectivity modules necessary for reliable sensing capabilities. Collaboration with operating system and platform providers further enables seamless integration at the software level, determining how sensing features are exposed to applications and end-users. In addition, partnerships with content providers, such as gaming, streaming, and educational platforms, help unlock new use cases and enhance the value proposition of RF-enabled interaction. Finally, alliances with smart home and health-tech companies create opportunities to expand into adjacent service domains, reinforcing the role of Smart TVs as central hubs within connected living environments.

8.1.8. Cost Structure

The cost structure of RF sensing integration in Smart TVs is characterized by a high initial investment phase followed by gradual cost optimization as the technology scales. In the early stages, research and development represent the most significant cost component, driven by the need to design RF sensing architectures, develop AI-based signal processing algorithms, and ensure reliable performance across diverse home environments. These upfront investments are critical to achieving the accuracy, latency, and robustness required for commercial viability. Hardware-related costs form another major component, including RF antennas, radar chips, and supporting electronic modules. These costs are initially elevated due to low production volumes and specialized components but are expected to decline over time through economies of scale, supplier diversification, and increased standardization of RF modules within Smart TV architectures. Manufacturing and integration costs also play a key role, particularly for ODMs adapting existing production lines to incorporate RF sensing capabilities. This includes system integration, calibration, and compliance testing to meet regulatory and quality standards. In parallel, marketing and business development expenditures are necessary to drive adoption, encompassing pilot programs, industry events, demonstrations, and partnership development efforts aimed at OEMs and ecosystem players. Finally, ongoing operational costs include software maintenance, system updates, technical support, and continuous performance optimization. As the business evolves toward a service-oriented model, additional costs may emerge related to data processing, platform management, and service delivery. Overall, while the cost base is initially R&D-intensive, it progressively shifts toward a more balanced and scalable structure, supported by modular design, software reuse, and increasing market penetration.

8.2. Revenue Model & Financial Architecture

This section outlines the economic logic underlying the commercialization of RF sensing technology embedded in Smart TVs. Unlike infrastructure-driven models such as routers, the Smart TV market is characterized by high-volume consumer electronics, strong OEM control, and rapid product cycles. As a result, the financial architecture is designed to combine hardware-linked scalability with recurring, software-driven value creation, while maintaining a modular and integration-focused business model. The revenue model follows a hybrid B2B structure, combining upfront integration revenues with per-unit royalties tied to Smart TV shipments. This ensures immediate monetization during product integration phases, while enabling long-term recurring income as RF-enabled Smart TVs scale across global markets. Additional upside is expected through premium model differentiation and service-layer monetization, particularly in high-end segments where RF sensing acts as a key feature. Overall, the model is designed to achieve high contribution margins, leveraging low marginal costs and strong alignment with OEM production volumes.

8.2.1. Pricing Logic

The commercialization strategy for the Smart TV RF sensing platform follows a pure embedded-software licensing model targeting Smart TV manufacturers, consumer-electronics OEMs, Smart TV operating-system providers, and semiconductor ecosystem partners. Unlike conventional computer-vision analytics platforms requiring dedicated cameras or cloud-based AI infrastructures, the HOLDEN approach focuses on embedded RF sensing and environmental-intelligence capabilities integrated directly into Smart TV ecosystems. The solution is designed as a lightweight embedded middleware layer enabling presence-aware interaction, occupancy sensing, contextual environmental intelligence, gesture and movement detection, ambient interaction capabilities, and privacy-preserving smart-environment awareness. The platform is intended to operate directly on Smart TV operating systems, edge AI processing layers, TV firmware environments, and embedded SoC architectures. Indicative industrial targets include Samsung Electronics, LG Electronics, Sony Group, TCL Technology, Hisense, MediaTek, Google TV ecosystems, and Roku platforms. The commercialization model is based on two primary revenue streams including per-device licensing and annual maintenance agreements. Indicative licensing assumptions are summarized in Table 42.

Table 42 – Estimated Licensing Revenue Assumptions

Licensing Type	Estimated Value
Standard environmental sensing license	€0.20–€1.00 per device
Premium ambient-intelligence feature set	€1.00–€3.00 per device
Annual maintenance agreements	5–10% of annual licensing revenues
Maintenance cap	USD 100k–150k per SKU/platform

The commercialization strategy intentionally avoids dedicated sensing hardware manufacturing, cloud-based analytics-service operation, and direct consumer-service commercialization. Instead, the business model focuses on embedded environmental-intelligence licensing integrated into existing Smart TV ecosystems, enabling scalability through established consumer-electronics distribution channels.

8.2.2. Cost Structure

The operational cost structure reflects the embedded-software and consumer-electronics nature of the Smart TV RF sensing commercialization strategy. Because the business model follows a pure licensing approach without dedicated hardware deployment, operational expenditures are concentrated primarily during initial Smart TV platform integration, chipset optimization, firmware adaptation, operating-system compatibility validation, and OEM onboarding phases. After successful onboarding of a Smart TV SKU/platform, incremental deployment costs are expected to remain relatively low. Indicative annual fixed operational costs are summarized in Table 43.

The largest operational cost drivers are expected to include embedded RF sensing optimization, edge inference optimization, memory and compute-footprint optimization, Smart TV firmware integration, chipset adaptation and validation, and OEM ecosystem compatibility. One of the most significant commercialization challenges is interoperability validation across heterogeneous Smart TV ecosystems and semiconductor platforms.

Table 43 – Estimated Annual Fixed Operational Costs

Fixed Cost Category	Annual Fixed Cost
RF sensing & AI software R&D	€450k
Embedded TV middleware engineering	€350k
SoC/chipset optimization	€250k
TV OS compatibility validation	€150k
OEM support & business development	€250k
Privacy & compliance	€100k
Total Estimated Annual Fixed Operational Cost	€1.55M

8.2.3. Contribution Margin

Most of the engineering effort is expected to occur during initial Smart TV platform onboarding, SoC optimization, TV operating-system integration, firmware adaptation, and OEM compatibility validation. Once integration into a given Smart TV platform is completed, subsequent deployment scaling across the same OEM ecosystem is expected to require relatively limited incremental operational effort. Contribution-margin assumptions are summarized in Table 44.

Table 44: Contribution Margin Assumptions

Commercial Activity	Average Revenue	Initial Integration Cost	Contribution Margin
Smart TV platform onboarding	€180k	€110k	~40%
OEM pilot deployment	€300k	€180k	~40%
Post-validation deployment scaling	Recurring license revenues	Low incremental cost	75–90%

Contribution margins are expected to improve after onboarding phases because most engineering costs are incurred once during initial integration activities, while subsequent deployments generate limited incremental operational costs and maintenance obligations remain bounded through capped support structures.

8.2.4. Break-Even Analysis

The break-even analysis reflects commercialization dynamics associated with consumer-electronics and Smart TV ecosystems. Commercialization timelines are influenced by Smart TV product-generation cycles, OEM integration timelines, firmware-certification procedures, SoC optimization activities, and ecosystem compatibility validation. Typical Smart TV integration cycles are expected to require approximately 12–24 months for integration, validation, and deployment synchronization.

Table 45 – Estimated Investment Allocation

Investment Category	**Estimated Investment**
RF sensing & AI product industrialization	€1.2M
Embedded middleware & SoC optimization	€900k
TV OS compatibility & interoperability validation	€500k
OEM partnerships & commercial development	€500k
Privacy, compliance & deployment validation	€400k
Total Estimated Investment	€3.5M–€4.0M

The commercialization model assumes that most of the integration and optimization costs occur during onboarding phases, while subsequent deployment scaling generates relatively low incremental operational costs. Revenue generation is expected to progressively evolve from engineering-intensive pilot integrations toward scalable recurring middleware-license revenues, maintenance agreements, and ecosystem-wide deployment expansion across multiple Smart TV generations.

The commercialization strategy follows a partnership-driven go-to-market model involving Smart TV OEMs, semiconductor vendors, Smart TV operating-system ecosystems, middleware integrators, and consumer-electronics ecosystem stakeholders. Because interoperability engineering activities are primarily concentrated during onboarding phases, mature commercialization stages are expected to benefit from stronger operational leverage, scalable recurring-license economics, and predictable long-term support costs.

Depending on OEM onboarding dynamics, middleware adoption speed, and ecosystem expansion, operational break-even is expected between Years 3 and 5 under realistic commercialization assumptions, while accelerated ecosystem adoption may enable earlier profitability.

8.2.5. Five-Year Revenue Scenarios

Three commercialization scenarios were evaluated to estimate the potential financial evolution of the RF sensing Smart TV licensing platform across consumer-electronics ecosystems. All scenarios assume that recurring maintenance revenues scale proportionally with deployed-license volumes, annual support obligations remain partially capped per SKU/platform, and most interoperability engineering activities occur during onboarding phases. Across all commercialization scenarios, recurring middleware-license revenues and maintenance agreements are expected to progressively dominate the revenue mix, improving operational leverage, financial predictability, and long-term profitability while reducing dependence on new integration activities.

Conservative Commercialization Scenario

The conservative commercialization scenario assumes relatively slow OEM adoption, limited pilot-to-commercial conversion, and gradual integration into selected Smart TV product lines.

Table 46 – Conservative Commercialization Scenario

Year	Total Revenue	Total Cost	Profit/Loss
Year 1	€0.25M	€1.5M	-€1.25M
Year 2	€0.8M	€1.8M	-€1.0M
Year 3	€1.8M	€2.1M	-€0.3M
Year 4	€3.8M	€2.8M	€1.0M
Year 5	€6.0M	€3.8M	€2.2M

Under this scenario, operational break-even is expected during Year 5 as recurring middleware-license revenues progressively expand across deployed Smart TV platforms while interoperability engineering costs gradually stabilize. Slower OEM onboarding dynamics and limited ecosystem expansion delay profitability compared with more aggressive commercialization assumptions.

Moderate Commercialization Scenario

The moderate commercialization scenario assumes successful OEM pilot deployments, progressive Smart TV ecosystem integration, recurring-license expansion, and broader middleware adoption across multiple consumer-electronics platforms.

Table 47 – Moderate Commercialization Scenario

Year	Total Revenue	Total Cost	Profit/Loss
Year 1	€0.4M	€1.6M	-€1.2M
Year 2	€1.4M	€2.0M	-€0.6M
Year 3	€3.0M	€2.7M	€0.3M
Year 4	€6.0M	€3.8M	€2.2M
Year 5	€10.0M	€5.0M	€5.0M

Under this scenario, operational break-even is expected between Years 3 and 4 through a combination of recurring middleware-license revenues, broader OEM integration, scalable deployment across multiple Smart TV generations, and maintenance agreements associated with deployed consumer-electronics platforms. By Year 5, recurring middleware-license and maintenance revenues are expected to represent a substantial portion of total annual revenues, significantly improving operational leverage, financial predictability, and long-term profitability.

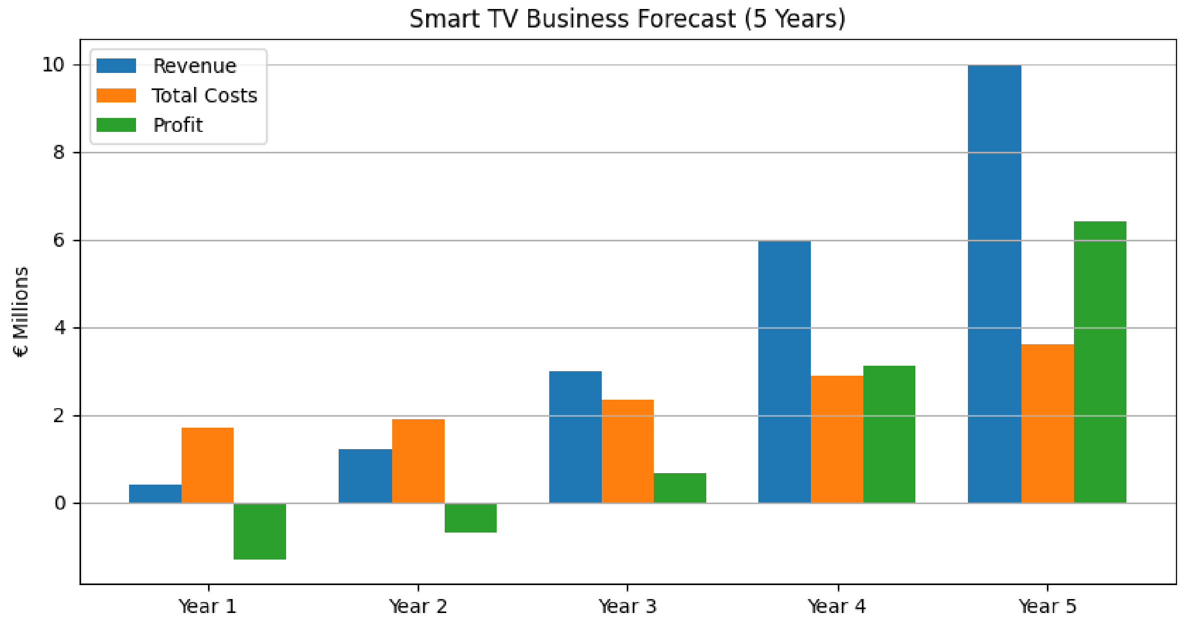


Figure 46 – Five years revenue/cost/profit forecast for moderate growth scenario

<u>Accelerated Commercialization Scenario</u>

The accelerated commercialization scenario assumes strong OEM adoption, successful lighthouse integrations with major Smart TV ecosystem providers, rapid middleware standardization, and broad recurring-license expansion across multiple global Smart TV platforms.

Table 47 – Accelerated Commercialization Scenario

Year	Total Revenue	Total Cost	Profit/Loss
Year 1	€0.6M	€1.7M	-€1.1M
Year 2	€2.2M	€2.3M	-€0.1M
Year 3	€5.0M	€3.2M	€1.8M
Year 4	€9.0M	€4.5M	€4.5M
Year 5	€15.0M	€6.0M	€9.0M

Under this scenario, operational break-even is expected between Years 2 and 3 as recurring middleware-license revenues rapidly scale across multiple OEM ecosystems while operational costs remain partially capped after onboarding and interoperability-standardization activities are completed. Long-term profitability improves substantially because recurring-license revenues scale proportionally with deployed Smart TV infrastructures while incremental operational costs remain comparatively limited.

8.2.6. Financial Sustainability

The long-term financial sustainability of the commercialization model derives from recurring per-device firmware licensing, scalable Smart TV deployment volumes, reusable middleware integration frameworks, maintenance revenues proportional to deployed-license volumes, capped annual support obligations per SKU/platform, and low marginal operational costs after onboarding. Because interoperability engineering is primarily concentrated during onboarding phases, the business model benefits from strong operational leverage, scalable recurring-license economics, and predictable long-term support costs.

8.3. Market Entry Roadmap

The market-entry strategy follows a phased consumer-electronics ecosystem commercialization approach designed to progressively validate the technology, reduce integration risk, and establish strategic positioning within Smart TV and smart-home infrastructures. The roadmap prioritizes firmware compatibility, SoC interoperability, edge inference optimization, Smart TV operating-system integration, and scalable embedded licensing deployment models.

8.3.1. Phase 1 – OEM Validation & Technical Demonstration (0–12 months)

The first commercialization phase focuses on validating RF sensing technologies within real Smart TV environments and demonstrating interoperability across representative consumer-electronics ecosystems. Activities include middleware integration into selected Smart TV platforms, chipset and firmware compatibility validation, RF sensing calibration, edge AI optimization, and privacy-compliance assessment across ecosystems such as Tizen, webOS, Android TV, and Google TV. The primary objective of this phase is to achieve pilot-ready technical maturity, reusable integration frameworks, and initial engagement with Smart TV OEMs and semiconductor partners.

8.3.2. Phase 2 – OEM Pilot Deployments (12–24 months)

The second commercialization phase focuses on pilot deployments with selected OEM partners and the establishment of initial recurring-license revenues. The technology is integrated into limited Smart TV product lines to validate deployment scalability, interoperability, UX consistency, and operational-support requirements. Activities include firmware optimization, multi-generation Smart TV validation, recurring-license framework definition, and certification activities. This phase remains partnership-driven in order to reduce operational risk and accelerate ecosystem maturity.

8.3.3. Phase 3 – Commercial Ecosystem Scaling (24–48 months)

The third commercialization phase focuses on scaling through broader OEM adoption, middleware licensing expansion, semiconductor ecosystem integration, and standardized embedded deployments across multiple Smart TV generations. At this stage, interoperability engineering and deployment-validation activities are expected to be largely completed, enabling stronger operational leverage, lower marginal deployment costs, and scalable recurring-license revenues. Commercial growth is expected to be driven primarily through OEM partnerships, Smart TV operating-system ecosystems, and reusable middleware integration frameworks.

8.3.4. Phase 4 – Platform Consolidation & International Expansion (48–72 months)

The final commercialization phase focuses on consolidating RF sensing as an embedded environmental-intelligence layer within Smart TV and smart-home ecosystems while supporting international expansion and ecosystem diversification. Commercialization activities rely primarily on recurring firmware-license revenues, annual maintenance agreements, and long-term OEM partnerships. As adoption scales, the technology may support broader ambient-computing applications including contextual interaction, smart-home orchestration, accessibility services, wellness-oriented functionalities, and connected-living environments. The long-term objective is to position RF sensing as a scalable platform capability embedded across next-generation Smart TV ecosystems.

8.3.5. Risk Mitigation Strategy

Key identified risks include OEM dependency risk, Smart TV product-generation obsolescence, chipset fragmentation, TV operating-system fragmentation, aggressive pricing pressure, feature commoditization, and privacy and regulatory constraints. Mitigation strategies include diversification across OEM and chipset partners, reusable middleware integration frameworks, standardized compatibility-validation methodologies, and progressive pilot validation.

8.3.6. Strategic Growth Outlook

The roadmap outlines a structured transition from technology validation to large-scale commercialization, aligning product maturity with market readiness, OEM integration timelines, and ecosystem expansion opportunities. Long-term growth is expected to be driven by increasing Smart TV penetration globally, growing demand for privacy-preserving interaction technologies, and expansion of smart-home ecosystems. RF sensing technologies can progressively evolve from premium feature differentiation toward becoming a foundational interaction layer embedded within Smart TV ecosystems. Future expansion opportunities include contextual TV interaction, occupancy intelligence, multimodal environmental sensing, smart-home orchestration, wellness-oriented applications, accessibility services, and ambient-computing infrastructures.

8.3.7. Intellectual Property Strategy

Intellectual property represents a central pillar of the commercialization strategy for RF sensing technologies within Smart TV ecosystems, ensuring long-term differentiation and defensibility within a highly competitive consumer-electronics market. The IP strategy follows a multi-layered protection approach combining selective patenting, proprietary implementation know-how, confidential software optimization methodologies, and restricted-access engineering frameworks. Selective patenting activities focus on RF-based gesture recognition, occupancy sensing, multi-user interaction, and privacy-preserving environmental-intelligence methodologies. Proprietary RF signal-processing pipelines, machine-learning optimization methodologies, calibration procedures, embedded middleware architectures, and interoperability optimization techniques are expected to be protected through trade secrets, internal access restrictions, controlled deployment procedures, and non-disclosure agreements with partners.

8.3.8. Capital Strategy and Funding Requirements

The commercialization pathway for RF sensing technology within Smart TV ecosystems is designed to balance moderate upfront investment requirements with high long-term scalability by leveraging the existing manufacturing and deployment infrastructures of major Smart TV OEMs. The primary funding requirements are concentrated during technology maturation, interoperability engineering, OEM integration, ecosystem validation, and early-stage commercialization activities. Indicative scale-up funding requirements are summarized in Table 48.

Table 48 – Estimated Scale-Up Funding Requirements

Funding Category	Estimated Investment
Technology refinement and AI/ML optimization	€1.0M – €1.3M
Hardware integration and RF module industrialization	€700k – €900k
OEM pilot deployments and validation programs	€500k – €700k
Integration engineering and firmware compatibility	€400k – €600k
Sales, marketing, and business development	€400k – €500k
Legal, IP protection, and certification	€300k – €400k
Total Estimated Scale-Up Funding	€3.3M – €4.4M

8.3.9. Strategic Financial and Commercial Conclusion

The commercialization strategy for RF sensing technologies within Smart TV ecosystems demonstrates a strong balance between scalability, profitability, operational efficiency, and controlled risk exposure. Given that the global Smart TV market exceeds approximately 200 million units annually, even relatively modest penetration levels in the range of 1–5% could translate into substantial recurring licensing revenues. Financially, the commercialization model benefits from a high-margin embedded-software licensing structure where marginal deployment costs remain relatively low due to reusable firmware architectures, standardized interoperability methodologies, and scalable middleware integration frameworks. Contribution margins are expected to progressively exceed 80% following initial onboarding and interoperability-validation phases, while operational break-even is expected to become achievable through approximately two to three major OEM partnerships. The phased market-entry roadmap further reduces commercialization risk by ensuring that scaling activities remain driven by validated technical performance, interoperability maturity, and strategic ecosystem partnerships.

8.4. Marketing and Communication

The marketing and entry strategy for RF sensing technology focuses on introducing the product as a value-added feature for Smart TVs, designed to enable non-invasive monitoring of movement and activity/gesture recognition. Without requiring additional devices, wearables, or cameras, this feature will enhance user experience and privacy for smart home applications. By leveraging digital advertising, social media campaigns, webinars, and event participation, we aim to build awareness among Smart TV OEMs, ODMs, and tech integrators about the technology's unique capabilities and its potential to differentiate their products in a competitive market.

8.4.1. Positioning and Market Penetration

Our primary objective is to position RF sensing as a foundational technology for Smart TVs, evolving the device into an ambient interaction hub. By integrating movement monitoring and gesture recognition, we enhance media engagement and provide high-value, privacy-compliant functionalities.

Key Goals

Educate the Market on Benefits: Demonstrate how integrating RF sensing technology differentiates Smart TVs, providing competitive advantages and added value to consumers.

Establish Key Partnerships: Forge strategic partnerships with Smart TV manufacturers, tech integrators, and complementary tech companies to accelerate market penetration.

Build Awareness through Effective Campaigns: Leverage targeted digital advertising, social media, webinars, events, and public relations to generate awareness, demand, and adoption of RF sensing technology.

8.4.2. Public Relations

Press Releases

Strategically timed press releases will announce key milestones (such as technology advancements, partnerships, and product launches) distributed to leading tech media outlets to ensure visibility among Smart TV manufacturers and industry influencers.

Co-Marketing

Co-marketing partnerships with complementary tech providers—such as Smart TV brands, home automation companies, or health-tech innovators—will leverage each partner's audience and increase credibility. Joint campaigns and bundled offerings can demonstrate the added value of the integrated solution in smart homes.

Social Media Campaigns

Platforms like LinkedIn and X are essential for targeting professionals in Smart TV development and integration. Through organic posts, sponsored content, and interactive discussions (e.g., polls, Q&A sessions), we can engage potential customers, share success stories, and position technology as a differentiator.

Webinars & Online Demos

Offering live webinars and online demos provides provide an interactive channel to showcase the technology's capabilities, answer questions, and demonstrate its value in enhancing Smart TV functionality and smart home applications.

Event Participation

Participating in tech conferences and trade shows is crucial for networking, raising product awareness, and engaging directly with Smart TV manufacturers and tech integrators. These events allow face-to-face interactions that build trust, partnerships, and potential co-marketing opportunities.

Digital Ads plus Visual Content

Digital advertising will target Smart TV manufacturers, tech integrators, and industry decision-makers. Visual content such as explainer videos, infographics, and demonstration clips will showcase the technology's benefits—like gesture recognition, movement tracking, and health monitoring—making complex capabilities easy to understand.

9. Conclusions

This deliverable demonstrates that the RF sensing technologies developed within the HOLDEN project possess significant long-term commercialization potential across infrastructure-security, elderly-care, and consumer-electronics markets. The market analysis confirms that the convergence of privacy regulation, infrastructure digitalization, intelligent sensing ecosystems, and growing demand for non-invasive monitoring creates favorable conditions for the adoption of privacy-preserving RF sensing technologies.

The study highlights that HOLDEN technologies are particularly well positioned in application domains where conventional sensing approaches present operational limitations associated with line-of-sight dependency, intrusive monitoring practices, wearable-device requirements, or privacy concerns. Across the investigated scenarios, RF sensing provides differentiated capabilities through passive sensing, hidden deployment, non-contact monitoring, and environmental intelligence generation.

The commercialization and financial assessment further demonstrate that licensing-oriented business models combined with strategic ecosystem partnerships can provide attractive long-term scalability and sustainable operational leverage. By leveraging infrastructure reuse, embedded software integration, recurring licensing structures, and maintenance-oriented revenues, the proposed business architectures significantly reduce the capital intensity typically associated with traditional hardware-centric deployments.

The analysis also indicates that successful commercialization will depend on interoperability validation, ecosystem integration, regulatory compliance, and strategic collaboration with OEMs, broadband operators, semiconductor vendors, and infrastructure-security stakeholders. Consequently, the proposed market-entry strategies prioritize phased deployment, pilot validation, and partnership-driven scaling approaches aimed at progressively reducing technical and operational risks. Importantly, the exploitation pathways developed within this deliverable remain fully aligned with the ethical and privacy-preserving principles underpinning the HOLDEN project. Unlike many existing sensing technologies, HOLDEN solutions are designed to minimize intrusive monitoring practices while enabling advanced environmental perception and intelligent sensing capabilities.

Overall, the market analysis and exploitation assessment confirm the technological relevance, economic sustainability, and strategic commercial potential of the HOLDEN innovations. The proposed commercialization frameworks provide realistic pathways toward industrial adoption while preserving scalability, operational efficiency, regulatory alignment, and long-term market flexibility.

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