ISAC MARKET POTENTIAL AND TECHNOLOGY EVOLUTION

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EXECUTIVE SUMMARY

Integrated Sensing and Communication (ISAC) is an emerging technology that will enhance existing communication-only technologies with advanced sensing abilities for positioning and motion detection tasks. The same resources (hardware, spectrum, etc.) will be leveraged for both tasks, helping to raise the value that can be derived from these existing assets, and enabling the creation of lucrative new business and service models.

ISAC is being envisioned for multiple communication technologies, each of which is currently at different stages of maturity. In the cellular domain, standardization bodies are now progressing toward a common industry consensus on ISAC specifications, but there is still a significant body of work to be completed. The European Telecommunications Standards Institute (ETSI), The 3rd Generation Partnership Project (3GPP), and other organizations are discussing use cases, technical challenges, existing technologies capable of sensing, and many other issues related to introducing sensing in the network. As of 3Q 2024, multiple deployment options are being discussed: using cellular networks as an aggrega-

tor of external system sensing capabilities (e.g., Light Detection and Ranging (LiDAR), creating radar-like systems that are based on cellular technologies, but act separately from communication systems, and finally, integrated systems that can communicate and sense at the same time. Although the technological complexity of these systems is significant, turning a cellular network into ISAC-capable will likely create many new opportunities.

Within the Wi-Fi domain, the technological underpinnings of Wi-Fi sensing have been agreed upon by the broader Wi-Fi ecosystem, and there has already been significant progress on the 802.11bf Wi-Fi sensing standard, with final approval from the 802.11 Working Group (WG) and IEEE 802 Executive Committee scheduled for March 2025. Initial commercialization of the technology has also begun, with major vendors of the technology going to market through partnerships with Internet Service Providers (ISPs) and equipment vendors in the verticals of security and healthcare, which have been identified as the two most promising verticals for Wi-Fi sensing. Although these early monetization examples are promising, consumer adoption of the technology has remained limited, and additional technological advancements are required before broader acceptance can be expected. The opening up of the 6 Gigahertz (GHz) spectrum for unlicensed use is helping to enhance the capabilities of Wi-Fi sensing, but the superior precision and granularity offered by Millimeter Wave (mmWave) Wi-Fi sensing is being held back by a lack of existing mmWave 802.11 infrastructure and client devices.

This paper examines two of the key ISAC technologies—cellular and 802.11 (Wi-Fi). For each technology, we analyze the technological underpinnings, explore the most promising applications and use cases, investigate current regional market dynamics, and assess potential business and service models. The paper then concludes with some recommendations for the industry on how to successfully monetize ISAC and how to overcome some of the core challenges the technology will face in going to market.

INTEGRATED SENSING AND COMMUNICATION OVERVIEW

ISAC is a concept initially discussed in the 1960s, when scientists argued that a system that could both sense and communicate would result in better efficiency and latency, while unlocking new use cases. There was also another concept technology that introduced sensing into a communication environment, referred to as Joint Communications and Sensing (JSAC), and although there is no strict definition of JSAC and how it differs from ISAC, there is industry consensus on their differences:

- JSAC systems refer to using the same **waveform** for sensing and communications.
- ISAC systems refer to using the same **system** for sensing and communications.

In this definition, ISAC may be considered a non-exclusive subset of JSAC, with the long-term vision of ISAC systems being to operate through a single waveform. However, the industry has now wholly adopted the ISAC moniker.

At that time of their conception, underlying technologies, including processing, transceiver designs, and materials, were not advanced enough to enable ISAC. However, in the past years, many of these domains have witnessed tremendous growth and the scientific community is now restarting discussions to bring ISAC to life. For example, processing advances now allow for complex positioning algorithms even at cell sites; 5G Massive Multiple Input, Multiple Output (mMIMO) antennas allow for radar-like use cases and Artificial Intelligence (AI) systems are now advancing at a staggering rate.

It should be noted that ISAC is now being discussed and developed, and different consortia, vendors, and stakeholders are approaching the technology from their point of view. Therefore, it is important to understand what ISAC is and what the long-term vision is, especially in the context of IMT-2030 and future Wi-Fi systems.

ISAC DEFINITIONS AND VISION

ITU-R published a report on future technology trends for IMT-2030[1] that includes definitions and examples of ISAC (Section 5.2 or ITU-R report M.2516-0). It is important to note that the ITU has accepted ISAC as a key usage scenario for IMT-2030, alongside ubiquitous connectivity, immersive communications, and others. The IMT-2030 report provides the following cooperation levels for ISAC:

1) **Co-existence:** Communication and sensing systems are independent of each other, do not communicate in any form, and treat each other as interference. For example, this could be a Wi-Fi network, interfering with a sensor operating in the same spectrum.
2) **Cooperation:** The two systems operate on different hardware, but exchange information and coordinate to avoid interference. This could be the sensing system of a car, communicating to the network.
3) **Integrated Design**: The communication and sensing systems are fully integrated, sharing hardware, spectrum, processing, and more.

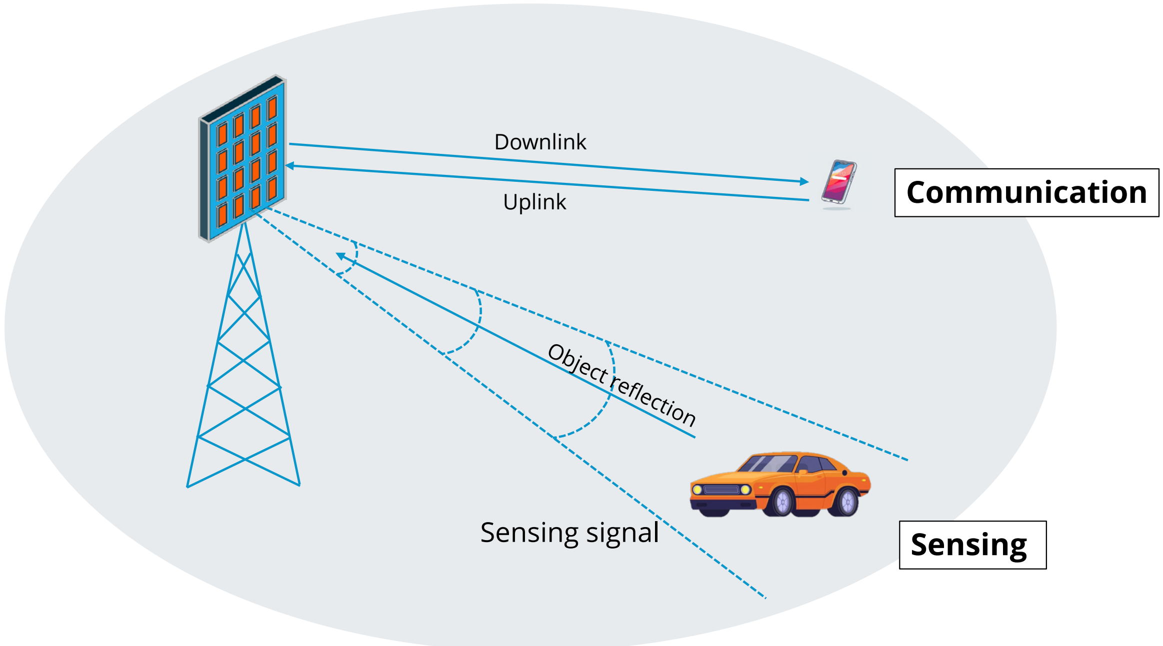
The focus of IMT-2030—and the entire industry—is option number three,[2] where ISAC systems are integrated. However, all three options above are important, as initial ISAC systems may not be completely integrated and may rely on cooperative or even independent systems. For example, 3GPP and ETSI use cases include cellular devices collecting sensing information from other systems and using them to calculate sensing information.

Broadly speaking, an ISAC system can communicate and sense its environment. Figure 1 illustrates a crude approximation of this concept.

[1] ITU-R Report M.2516-0, published 11/2022
[2] Page 14, ITU-R M2516-0 report

Figure 1: Simple Illustration of a Cellular ISAC System

Source: ABI Research



Even in 3GPP's cellular domain, the underlying reasoning and use cases considered for ISAC are not all new. In its simple form, ISAC enables positioning that has been possible in cellular networks for many years and is widely used by smartphones and other devices. However, an important distinction to make is that ISAC does not necessarily require any form of transmission from the end-user device and may operate in a radar-like fashion. This brings opportunities, but also challenges: positioning, velocity and acceleration measurements, and sensing can be extended to non-3GPP devices and any large enough object, but the transmitted signal now needs to cover twice the distance. The sensed object is completely passive and does not transmit anything in the uplink.

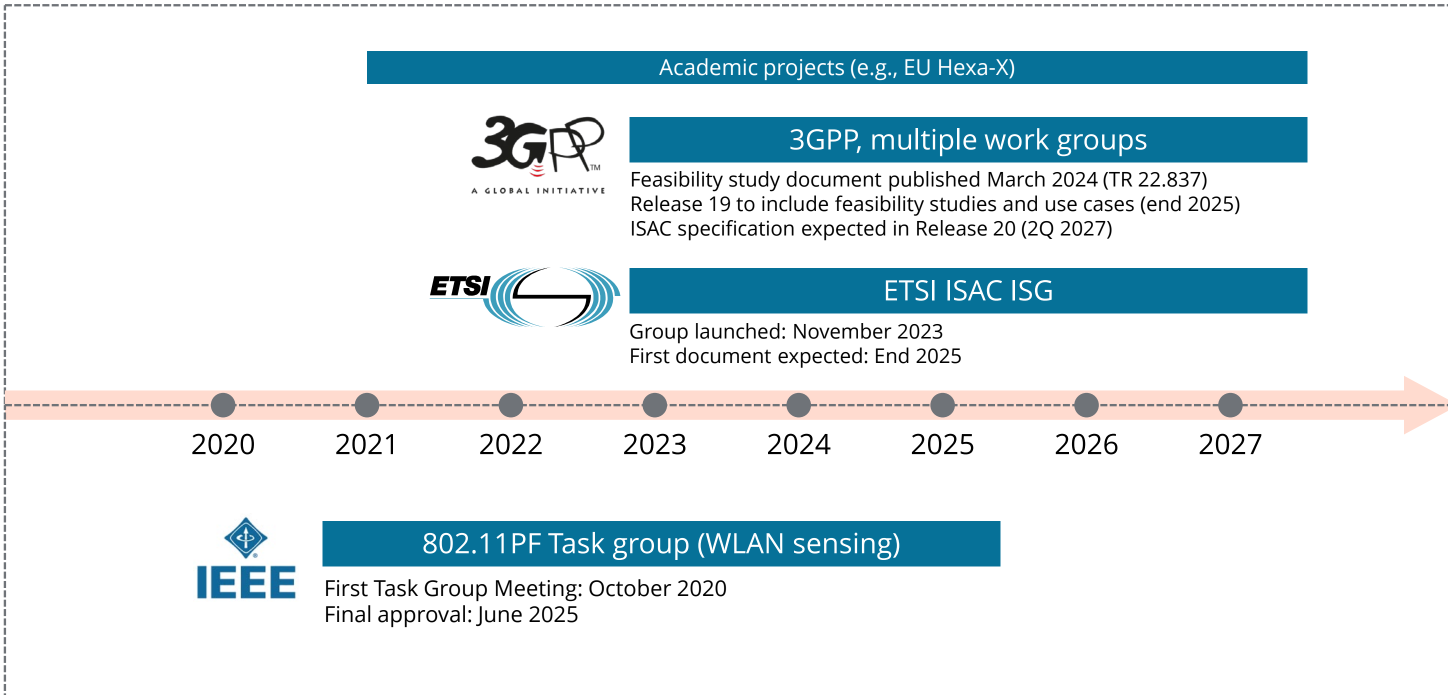
The long-term vision of cellular and Wi-Fi ISAC systems is that both communication and sensing will be available with a single set of hardware, operating simultaneously in the same spectrum. This is clearly the end goal for the new technology, which will undergo several iterations before creating a mature, commercial, and efficient system, and it may well be that ISAC is not included in either due to technical or economic challenges. ISAC is an ambitious concept and can radically change the way networks are deployed and utilized. Now, there are several ongoing processes in the industry for both cellular and Wi-Fi ISAC developments.

ISAC STANDARDS AND DEVELOPMENT HISTORY

As discussed earlier, ISAC is not a new concept, in either the cellular or Wi-Fi domains. Recent technical advances are, however, now making its commercial application a possibility, and there is significant interest from the market. Figure 2 illustrates a brief timeline of ISAC developments and how the standards are expected to develop in the future.

Figure 2: Standardization Timeline for ISAC in Cellular and Wi-Fi

Source: ABI Research



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In the cellular domain, several ongoing academic projects are assessing the technical viability of ISAC and how it will likely be deployed in the future.[3] Moreover, 3GPP has initiated discussions and preliminary work on ISAC and has published TR 22.837 that outlines key use cases and applications for the new concept. More discussions will commence in September 2024 as part of the formal Release 19 process and will be published with this release. The full specification and development work for ISAC in 3GPP will, however, likely take place in Release 20 or even in Release 21, which will be published in 2025 and 2027, respectively.

ETSI launched the ISAC Industry Specifications Group (ISG) in November 2023 to consolidate and streamline Research and Development (R&D) activities from the market and create a foundation on which future standards will be built, including 3GPP. It is arguably the biggest specification and standards group developing ISAC in 2024. The group aims to publish its first official release at the end of 2025 and consists of four different WGs:

1) Use cases
2) Channel modeling and validation
3) System-level and Radio Access Network (RAN) architecture
4) Sustainability, security, and other issues

The first deliverable is expected in November 2024, outlining key ISAC use cases, followed by more specifications.

[3] *Academic project examples include: EU Hexa-X, UCL ISAC PoC, BMBF KOMSENS-6G, U.K. DSIT TUDOR*

WI-FI

Initial theoretical proposals for achieving ISAC with Wi-Fi emerged in the early 2010s, with a range of novel methods being introduced. The year 2013 saw the introduction of WiSee, designed to measure human motion through minute Doppler shifts and multi-path distortions in Wi-Fi signals, and Wi-Vi, which uses Multiple Input, Multiple Output (MIMO) interference nulling and Inverse Synthetic Aperture Radar (ISAR) to track human movement. This was followed by PeriFi in 2017, which suggested measuring each multipath reflection component independently to detect moving and static occupants. Although promising, each of these initiatives remained purely conceptual because they were isolated approaches that lacked support from the broader industrial ecosystem.

IEEE Standardization for ISAC Wi-Fi Sensing began in September 2020, when the IEEE 802.11 WG approved the Project Authorization Request (PAR) for a new Task Group (TG) to work on the IEEE 802.11bf (Wi-Fi sensing) standard, called TGbf. The 802.11bf standard aims to introduce amendments to the IEEE 802.11 Physical Access Layer (PHY) and Medium Access Control (MAC) layer to enable the collection of Channel State Information (CSI) measurements for Wi-Fi sensing purposes. Modifications were made to the Directional Multi Gigabit (DMG) and Enhanced DMG (EDMG) PHYs to improve WLAN's sensing capabilities. The amendment will enable WLAN Access Points (APs) and Stations (STAs) to request, schedule, perform, and exchange WLAN sensing measurements, and create a MAC service interface designed for layers above the MAC to be able to request and retrieve WLAN sensing measurements. Importantly, the standard will be backward-compatible with legacy 802.11 devices.

Since launching in 2020, the technical foundations of 802.11bf have been defined by the TGbf, with the WG passing four successful ballots on the proposed 802.11 amendments introduced with 802.11bf. At the most recent TGbf meeting in May 2024, the initial IEEE Standards Association (SA) ballot of D4.0 commenced, and after closing in June 2024, it passed with 90%.

Going forward, after a first SA Ballot Recirculation (D5.0) in September 2024, a second SA Ballot Recirculation (D6.0) is planned for January 2025, and a third SA Ballot Recirculation for March 2025. Assuming each of these SA ballots exceeds the 75% approval rate, then March will see 802.11bf receive final 802.11 WG approval and final IEEE 802 Executive Committee (EC) approval, and 802.11bf will become a finalized standard. Later, in June 2025, 802.11bf is expected to pass the Standards Review Committee (RevCom) and receive SA Standards Board (SASB) approval. Advancements in other 802.11 standards will also incidentally improve Wi-Fi sensing performance. For example, the proposed multi-AP coordination feature of the upcoming 802.11bn (Wi-Fi 8) standard, for which certified devices are anticipated to arrive in 2028, will make it possible to track individuals with greater precision.

TECHNICAL CONSIDERATIONS FOR ISAC

WI-FI SENSING

TECHNOLOGIES

There are numerous technologies underpinning Wi-Fi sensing. The sensing measurements themselves are derived from the 802.11 RF waves. The method for taking these readings has evolved over time. Early approaches relied on the Received Signal Strength Indicator (RSSI) approach—that is, fluctuations in the received signal strength at receivers were monitored to recognize motion. Although simple to implement and cost-effective, RSSI methods of Wi-Fi sensing offer low levels of accuracy and are vulnerable to interference. These drawbacks resulted in the exploration of the CSI approach. This leverages MIMO and Orthogonal Frequency-Division Multiplexing (OFDM) to capture amplitude attenuation and phase information of multi-path Wi-Fi channels, and uses a time series of these measurements (known as CSI data) to record how wireless signals travel through surrounding objects in the time, frequency, and spatial domains.

Initially, CSI measurements from commercial Wi-Fi chipsets were not accessible, so developers had to either rely on RSSI measurements or, as Wi-Fi sensing developer Cognitive did, engineer a custom chipset (in Cognitive's case, the R10) that provided CSI data. Yet, once the potential of Wi-Fi sensing with CSI measurements was proven, the major Wi-Fi chipset vendors gradually began to make available CSI measurements from their chipsets. Today, all the major Wi-Fi chipset vendors provide CSI data, and the industry has coalesced around the CSI approach. To improve accuracy, the recorded CSI signals are processed before use with noise reduction, signal transforming (time-frequency analysis of a time series CSI measurement), and signal extraction (extracting the target signal from pre-processed CSI measurement).

The interpretation of the received Wi-Fi sensing data (i.e., the algorithms used to prescribe actions or movements to the CSI measurements) is not covered by 802.11bf, and therefore, a range of divergent, proprietary approaches are on the market. There are two main approaches—model algorithms founded on theories or statistical models, and Machine Learning (ML) algorithms that are trained to discern objects or movements. The first approach benefits from being relatively low cost and eschews extensive data collection and model training, but at the same time, demands extensive model parameter tuning and signal processing, and is not scalable for use in new environments or tasks. The advantages of the second (ML algorithmic) approach is that the training helps to continuously improve the model, and it has a greater ability to be adaptable for application toward other tasks. At the same time, ML and Deep Learning (DL) algorithms cost more, necessitate large amounts of data for training, and face a high potential of overfitting (the model cannot predict unseen data).

The processing of the data can occur either at the edge (i.e., on the AP) or in the cloud (i.e., a centralized server). 802.11bf's low-latency requirements (100 ms is the benchmark) mean that edge processing has been implemented to varying degrees by all currently available Wi-Fi sensing applications. Edge processing also allows effective sensing to occur in the absence of an Internet connection, and offers superior privacy and security. That said, cloud processing enables implementing recognition tasks with aggregated real-world data, thereby supporting further development and refining of sensing algorithms.

There are three possible sensing configurations for Wi-Fi sensing. The first is monostatic, in which the transmitter and receiver are co-located in the same equipment, and the measurement is derived from a reflected Radio Frequency (RF) signal. Although this approach does not offer the range and precision of others, it does benefit from only requiring one device, which reduces network complexity and does not require an Internet connection for operation. The second possible configuration is a bistatic one, which relies on spatial separation of the transmitter and receiver (typically between two devices), with measurement gained via the attenuation of RF waves as they pass through materials between the two. Coverage can exceed monostatic approaches, but sensing resolution is inferior to the third approach, the multistatic configuration, where more than two spatially diverse transmitters and the signals with a shared area of coverage are used for measurement. While a multistatic configuration provides the greatest coverage, it tends to be the most expensive approach, requiring a greater number of devices. 802.11bf has been designed to be compatible with all three sensing configurations.

Some are critical of the technical underpinnings chosen by the TGbf for 802.11bf. For example, in late 2022, a team from Carnegie Mellon University released a paper arguing that 802.11bf Wi-Fi sensing has major limitations due to its reliance on CSI and on the accurate measurement of Time of Fight (TOF) and Angle of Arrival (AoA) of the signal between the transmitter and receiver. This approach, they claim, means that Wi-Fi sensing is only capable of locating the center of objects, is vulnerable to potential interference from other devices using similar frequency ranges, and is restricted to a location accuracy of 0.5 meters due to the random phase shift allowed by 802.11n/ac Wi-Fi. The team proposed an alternative method that maps the phase and amplitude of Wi-Fi signals to 24 regions on a Two-Dimensional (2D) image model of a Three-Dimensional (3D) human figure, enabling the estimation of dense human pose correspondence.

SPECTRUM

802.11bf has been developed for use in the unlicensed spectrum bands available to 802.11, namely the sub-7 GHz frequencies of 2.4 GHz, 5 GHz, and 6 GHz, alongside the mmWave unlicensed bands of 45 GHz and 60 GHz. The different propagation properties of each spectrum band means that sensing performance will differ considerably depending on which bands are utilized. Spectrum access to these bands also varies considerably between regions. For example, in the United States, the full 1200 Megahertz (MHz) of the 6 GHz spectrum has been made unlicensed, whereas in Europe, only the lower 500 MHz has been made available, and in some nations, none of the spectrum has been opened for unlicensed use. The knock-on effect of this regulatory divergence is that sensing performance will vary significantly between regions.

Within the sub-7 GHz range, the lower frequencies provide greater penetration and range abilities, but lack the location precision of the higher frequencies, and are also vulnerable to more interference. Highlighting the vast differences in range abilities is the fact that the 2.4 GHz spectrum can deliver a range between 8 and 12 meters, the 5 GHz spectrum between 6 and 10 meters, and the 6 GHz spectrum between 4 and 8 meters. Additionally, because more spectrum is available at the higher frequencies (1200 MHz within 6 GHz, compared to 70 MHz for 2.4 GHz and approximately 500 MHz for 5 GHz), wider channels can be utilized for sensing, which enables higher granularity sensing. In practice, whereas 20 MHz channels are standard in 2.4 GHz, and 5 GHz typically uses 40 MHz channels, the 6 GHz band can support up to seven 160 MHz channels, and up to three 320 MHz channels. These contrasting attributes make each spectrum band best suited for different applications. For example, the 2.4 GHz band may be best positioned for whole home motion detection, whereas the 6 GHz band has high potential for high granularity sensing tasks, such as human identification through traits.

Compared to the sub-7 GHz frequencies, mmWave frequencies offer far superior positioning accuracy, but have severely limited range and penetration abilities due to their Line of Sight (LOS) requirements. Unlicensed access to mmWave frequencies also varies considerably between regions. In the 60 GHz region, nations like the United States and the United Kingdom have favorable access with a widespread option from 57 GHz to 71 GHz, while Japan and South Korea only have 57 GHz to 64 GHz. Mainland China, on the other hand, does not have access to 60 GHz unlicensed, but has the 45 GHz spectrum. The propagation limitations of unlicensed mmWave has hindered the adoption of mmWave Wi-Fi in the residential market, leading to a lack of existing mmWave infrastructure and client devices. This is one of the main reasons that 802.11bf has focused its efforts on the sub-7 GHz frequencies over the mmWave frequencies.

6G

The industry is now forging ahead as a unified front, having accepted that ISAC will be an important part of 6G and IMT-2030. On the other hand, there is no consensus yet on how ISAC will be implemented and on which frequencies. There are several options for its implementation, which depend on many parameters, including regional spectrum availability, maturity of 5G network deployments, operator willingness to deploy a new system, and much more. The next sections present the technologies being discussed today for ISAC and how ABI Research expects these to develop further.

TECHNOLOGIES

Several cellular technologies are necessary to enable ISAC, many of which are already available in the market today in some form. These will likely need to be adapted for ISAC, but their foundation is there today. Some of these are presented below.

As presented in Section 2.2.1., **channel modeling** is now part of an ETSI ISG WG. This is an important study area for ISAC, because the sensing channel differs from the communication channel in that there is no uplink from the sensed device. The sensing part of the channel needs to have complex channel models, which are not studied in detail as part of cellular standards. In the sensing scenario, the base station will need to detect a reflection from the sensed object, which is a considerably different channel scenario compared to bi-directional communication.

The focus of these WGs will not likely be new, as radar applications utilize these channel models, but will likely have to be adapted for ISAC.

mMIMO active antenna units are another key enabler for ISAC. These units include multiple antennas to allow for beamforming and can increase the capacity of a cellular sector significantly by reusing spectrum in multiple, spatially separated beams. It is this capability that can allow for radar-like applications, where the antenna can direct sensing energy toward an object and track it effectively. Naturally, there is significant work to be done to enable existing mMIMO units to sense their environment in a standardized and efficient manner, but the foundation is already there.

ML and AI will also be a foundation for ISAC, and advanced algorithms will need to be developed to accurately measure and predict the location of an object in the vicinity of a cellular base station. Despite the ongoing work for ISAC channel modeling, the radio channel is a complex, rapidly changing and scattered environment, which will likely utilize AI algorithms for interference management, signal processing, and optimal resource allocation. For example, the network may need to proactively assign resources between communication and sensing capabilities, something that is well-suited to AI/ML algorithms.

Lastly, there are many new areas that need to be studied and explored, including **new waveforms**. Current cellular systems rely on waveforms designed for communication, including OFDM and Quadrature Amplitude Modulation (QAM), all of which have been designed to make communication more efficient, reduce interference, and increase system capacity as much as possible. However, these waveforms are not ideal for sensing, and new waveforms may emerge in the future to cater for both communications and sensing.

In the short and medium term, it is unlikely that early ISAC systems will include new waveforms that communicate and sense simultaneously, as they are a fundamental part of cellular systems and changing them would translate into a complete overhaul of existing cellular infrastructure. It is more possible that minor additions will be made in existing waveforms to add sensing capabilities to existing systems. For example, there is discussion about adding a chirp-like signal in existing waveforms to sense the environment or going as far as to create new waveforms that combine both sensing and communication payloads. One such proposal is the Trapezoidal Frequency Modulation Continuous Wave (TFMCW) modulation, in which the sensing and communication signals are multiplexed in the time domain.[4] Also, there is a proposal to add sensing capabilities to existing waveforms via a blank subframe, where the communication and sensing signals are orthogonal, thus not interfering.

Arguably, there is considerable work to be done before ISAC is fully standardized. A more important fundamental question is in which spectrum ISAC will operate, and there are now several options.

[4] Huawei: Integrated Sensing and Communication – From Concept to Practice

SPECTRUM

Cellular spectrum is a precious commodity, often worth billions of dollars due to a competitive environment, frequency position, and many more parameters. For 5G, the 3.5 GHz band, often referred to as the C-band, has proven to be an ideal compromise between coverage and capacity. The availability of mMIMO has improved system capacity by a factor of ~10X compared to 4G, while reusing existing 4G cell site locations without needing major densification. However, 5G has now become mainstream and with the introduction of new services, including Fixed Wireless Access (FWA), many 5G networks will see congestion. In fact, Verizon Wireless expects congestion in areas where FWA is popular in the next 6 to 12 months, with additional measures needed to either densify its network, acquire new spectrum, or balance usage.

It is unlikely that sensing will be deployed in spectrum that is currently utilized for existing consumer-oriented communications. This argument, coupled with the fact that sensing requires high frequency (to allow units with many antennas that allow radar-like sensing) and high bandwidth (to allow for sufficient sensing resolution), means that ISAC will likely be deployed in new spectrum, perhaps in the FR2 (26.5 – 71 GHz) or FR3 (7.125 – 24.25 GHz) spectrum bands. The industry has not yet decided on which frequencies ISAC will be deployed, and both options introduce pros and cons, as illustrated in Table 1.

Table 1: Pros and Cons of ISAC in Different Spectral Bands

Source: ABI Research

	ISAC in FR1	ISAC in FR2/FR3
Pros	Minimize cost, reuse existing cell sites Modify existing mMIMO for ISAC Enhance existing waveforms (e.g., with blank-subframe)	Potential high-resolution sensing through higher frequencies and more bandwidth Opportunity to utilize new waveforms selectively
Cons	Potential disruption to existing services Spectrum may already be exhausted	May require significant investment-> needs clear business model Completely new technology development cycle

Although it is not likely that ISAC will be deployed in FR1, especially in the 3.5 GHz band, its deployment in FR2 or FR3 will require a solid business case to justify a significant deployment. However, due to the nature of sensing use cases, it may be that this capability will initially be localized, rather deployed nationwide, making its deployment a much more sensible and gradual process compared to public consumer-oriented 5G networks. Thus, it is important to understand what types of use cases are being discussed currently for ISAC and to identify which ones could be the most prevalent.

ISAC APPLICATIONS AND USE CASES

The previous sections focused largely on technical and standardization issues, laying the foundation on which ISAC will be developed. A more important aspect of ISAC is its applications and use cases, which will drive commercialization and can accelerate its development. If the telecoms and Wi-Fi markets discover valuable and even critical use cases, and uncover a truly unexplored technical domain, then development and commercialization of ISAC will accelerate. Similar examples include Carrier Aggregation in 4G and mMIMO in 5G, both of which resulted in a leap ahead in terms of customer experience, and both were developed and deployed rapidly. ISAC can achieve the same for both the consumer and enterprise markets, and can theoretically unlock capabilities that no other technology can currently enable. The following sections describe ISAC use cases currently being discussed and developed in the Wi-Fi and cellular markets.

WI-FI

The 802.11bf WG, Wi-Fi sensing vendors, and the broader Wi-Fi industry have developed and proposed a broad range of different applications for Wi-Fi sensing. With the currently available technology, there are three main applications deployed in the market today—elderly healthcare monitoring, home security, and smart home automation. There is also broad consensus within the industry that these three are also the most commercially viable applications and are anticipated to bring in the highest revenue for the technology going forward. Table 2 details the advantages, disadvantages, and Go-to-Market (GTM) strategies of these three use cases.

Table 2: Current Wi-Fi Sensing Abilities

Source: ABI Research

Application	Description	Advantages	Disadvantages	Go-to-Market
Elderly Healthcare Monitoring	Family, carers, or emergency responders can get instant alerts with features such as fall detection and vital sign monitoring. Abnormal adjustments to typical daily routines over time can be tracked, such as changes in sleeping patterns, idle times, number of trips to the bathroom, etc.	Unobtrusive. Non-stigmatizing. Low cost. Does not require wearables that users can forget to wear or lose. No need for user input in case of emergencies.	Consumers may have low confidence in using existing infrastructure for this critical application. Advanced features such as fall detection are challenging to guarantee high accuracy for.	Work with Internet Service Providers (ISPs) to incorporate with existing service packages. Partner with healthcare providers. Develop dedicated devices with additional features (i.e., two-way radios).
Home Security	Presence detection to alert consumers about unexpected movements. Track traits such as height and gait to discern whether the person who has entered the network area is a verified or unverified person.	Low-cost and easy implementation expands the serviceable market of the technology. High device security with WPA3. Consumer privacy protected, as only movement patterns are tracked and all data are processed at the edge.	Users may feel uneasy using non-dedicated equipment for security. Potential for criminals to use Wi-Fi signals against victim through passive Wi-Fi sniffing, where criminals use wireless reflections to locate target's locations and movements.	Work with Mobile Service Providers (MSPs) so they can offer both digital and physical security. Partner with security Original Equipment Manufacturers (OEMs) to augment their existing security technology or replace it altogether. Enhance value proposition with monostatic configurations, which allow greater precision and operation in the absence of Internet or a device pair.
Smart Home Automation	Presence detection can be used to activate/deactivate smart home devices. Long-term platform insights could be used to further optimize smart home usage.	Non-invasive. Can aid with energy conservation. Can discern movement if the human is obscured behind walls or objects. Can detect presence, even if the target remains inactive (i.e., standing or sitting still).	Requires smart home devices to support Wi-Fi. Bistatic Wi-Fi sensing configurations that require pairs are not suited for standalone smart home devices.	At retail, with Wi-Fi sensing pre-installed on smart home device. Through subscription model, where device and sensing functionality is leased to consumer for a monthly fee.

A range of other potential applications for Wi-Fi sensing have also been proposed by contributors to the 802.11bf standard and the broader Wi-Fi sensing ecosystem. Many of these can be achieved using the sub-7 GHz spectrum bands, which are commonplace throughout consumer and enterprise networks today, but certain applications require high levels of sensing precision and granularity, necessitating the use of mmWave frequencies (45 GHz and 60 GHz, see Section 3.1.2.). Table 3 details 14 Wi-Fi sensing applications, noting which frequency band they need for operation and assessing their likelihood of monetization. Among those listed, the application with one of the highest potentials for monetization in the near-term is Child Protection Detection (CPD), for which trials are already underway on a fleet of school busses in Japan.

It should be noted that although there are numerous future Wi-Fi sensing applications on the horizon, those already in the early stages of commercialization (healthcare, security, and smart home automation) are viewed as having the highest monetization potential. It is also noticeable that, among the list in Table 3, there are multiple applications that are technically possible with existing 802.11bf technology, but have been assigned a relatively low likelihood of monetization. This is because they will be hard to monetize, as there is little value in adding communications alongside sensing for these applications, and there are already existing alternative technologies that fulfill the need.

Table 3: IEEE and Vendor 802.11bf ISAC Use Cases and ABI Research's Subjective Assessment

Sources: IEEE, ABI Research

Use Case	Vertical	Description	Commercial Application	Spectrum	Monetization Likelihood
Emotional Reaction to Content	Consumer	Measure fluctuations in heartbeat to infer emotional response of viewers to content	Identify consumer response and engagement level with video streaming or video game content.	mmWave	Low
Gesture Recognition	Consumer	Finger movements for control of smart home appliances.	Gesture recognition technology that does not require LOS or light.	mmWave	Medium
Audio Tracking	Consumer	Track people to target audio at them.	Additional revenue stream or differentiator for smart speakers.	Sub-7	Medium
Breathing Monitoring	Consumer	Use CSI measurements to track chest displacement.	Enhance healthcare services with vital sign monitoring.	mmWave	Medium
Animal Health	Consumer	Track animal behavior	Detect atypical animal behavior or abnormal heartbeat fluctuations.	mmWave	Medium
Child Presence Detection (CPD)	Consumer	Alert vehicle owners that a child has been left in the vehicle.	Vehicle manufacturers can implement to improve safety.	Sub-7	High
Hidden Object Detection	Enterprise	Reveal concealed objects on people.	Low-cost, easy to implement method for building managers to enhance security.	Sub-7	Low
Sneeze Sensing	Enterprise	Detection of sneeze droplet volume.	Localization of potentially infectious individuals within facility.	mmWave	Low
People Identification	Enterprise	Determine a person's identity by recognizing features such as height or gait.	Send customized notifications or distinguish whether an individual is known or unknown.	mmWave	Low
3D Vision	Enterprise	Build a 3D matrix of an environment using multiple STAs in a room.	Map environment for site survey.	mmWave	Medium

Use Case	Vertical	Description	Commercial Application	Spectrum	Monetization Likelihood
Smart Manufacturing	Enterprise	Wi-Fi sensing for localization, navigation, and authorization in industrial environments.	Used for robotics localization and navigation, employee health oversight and authorization, and predictive facility maintenance.	mmWave	Medium
Smart Meeting Rooms	Enterprise	Automate meeting room based on presence.	Automatically turn on/off devices like lights or Air Conditioning (AC).	Sub-7	Medium
Driver Drowsiness Detection	Enterprise	Identify signs of drowsiness, such as low heart rate.	Reduce likelihood of road accidents by building this security capability into vehicle.	mmWave	Medium
People Counting	Enterprise	Non-invasive people counting in a room/floor/building.	Building climate control, tracking of customer/guest numbers.	Sub-7	High

CELLULAR

Several standards groups are now assessing cellular ISAC use cases and applications, including 3GPP and ETSI. The former has already published a document outlining use cases and their feasibility, and the latter is expected to publish its own document in 4Q 2024. Several use cases are being developed currently, and all of them are creating new value, meaning new types of use cases for both consumer and enterprise value. On the other hand, many previous cellular technologies have focused on making the network more efficient, translating to cost-savings, which cannot justify a mainstream deployment or any ambitious use cases. ISAC, on the other hand, is being positioned as an enabler of new functionality, predominantly in the enterprise domain. Table 4 illustrates a selection of use cases identified in 3GPP and ABI Research's assessment on the availability of cellular capabilities in the domain these use cases will be deployed in, their monetization likelihood, and whether this functionality is available in the market through other technologies.

Table 4: 3GPP ISAC Use Cases and ABI Research's Subjective Assessment

Sources: 3GPP TR 22.837, ABI Research

Use Case	Vertical	Market	Domain	5G Availability	Monetization Likelihood	Already Available?
Intruder detection	Smart home	Consumer	LAN	Low	Low	Yes
Pedestrian/animal intrusion detection	Transportation	Enterprise	WAN	High	Medium	No
Rainfall monitoring	Agriculture	Enterprise	WAN	High	Medium	Yes
Transparent sensing	Agnostic	Enterprise	WAN	High	Unknown	No
Flooding sensing	Smart city	Enterprise	WAN	High	Medium	Yes
Intruder detection on home surroundings	Smart home	Consumer	LAN	Medium	Medium	Yes
Railway intrusion detection	Transportation	Enterprise	WAN	High	Medium	Yes
Assisted automotive maneuvering and navigation	Automotive	Enterprise	WAN	High	Low	No
Automated Guided Vehicle (AGV) detection and tracking	Industrial	Enterprise	LAN	Low	Medium	Yes
Unmanned Aerial Vehicle (UAV) flight trajectory testing	Transportation	Enterprise	WAN	High	High	Yes

Use Case	Vertical	Market	Domain	5G Availability	Monetization Likelihood	Already Available?
Crossroads sensing with/without obstacles	Transportation	Enterprise	WAN	High	Low	No
Network assisted sensing to avoid UAV collision	Transportation	Enterprise	WAN	High	Low	Yes
Sensing for UAV intrusion detection	Transportation	Enterprise	WAN	High	Low	No
Tourist spot traffic management	Smart city	Enterprise	WAN	High	Low	Yes
Contactless sleep monitoring	Healthcare	Enterprise	LAN	Low	Low	No
Protection of sensing information	Agnostic	Enterprise	Agnostic	Agnostic	Low	No
Health monitoring at home	Healthcare	Consumer	LAN	Low	Medium	No
Service continuity of unobtrusive health monitoring	Healthcare	Enterprise	LAN	Low	Low	No
Sensor groups	Agnostic	Enterprise	Agnostic	Agnostic	Low	No
Parking space determination	Automotive	Enterprise	WAN	High	Low	Yes
Seamless Extended Reality (XR) streaming	Media	Enterprise	WAN	Medium	Low	No
UAV/vehicle/pedestrian detection near smart grid	Transportation	Enterprise	WAN	High	Low	No
Autonomous Mobile Robot (AMR) collision avoidance in smart factories	Industrial	Enterprise	LAN	Low	Low	Yes
Roaming for sensing of sports monitoring	Healthcare	Enterprise	LAN	Low	Low	No
Immersive experience based on sensing	Media	Consumer	LAN	Low	Low	No
Accurate sensing for automotive maneuvering	Automotive	Enterprise	WAN	High	Low	No
Public safety search and rescue or apprehend	Public sector	Enterprise	WAN	High	High	No
Vehicles sensing for Advanced Driver-Assistance Systems (ADAS)	Automotive	Enterprise	WAN	High	Low	Yes
Coarse gesture recognition for application navigation	Agnostic	Consumer	LAN	Low	Medium	No
Sensing for automotive maneuvering with no RAN	Automotive	Consumer	WAN	High	Low	Yes
Blind spot detection	Automotive	Consumer	WAN	High	Low	Yes
Integrated sensing and positioning in factory hall	Industrial	Enterprise	LAN	Low	Low	Yes

We need to recognize that these use cases are preliminary and will likely be augmented as the formal standards development process continues, so these use cases should be treated as the first step toward mature use cases. Many of these would compete against established technologies and concepts already in the mainstream market, for example:

3GPP Use Case 1: Intruder Detection

This case study assumes that there are multiple 6G Customer Premises Equipment (CPE) or small cells available in a home, which are used to detect intruders or environmental changes when the homeowners are away. In this case, ISAC would compete against home security products and services, and it is assumed that multiple 6G devices are available in the home, but regardless of these challenges, the monetization opportunity is tangible, and the telco operator would be able to enter completely new markets.

On the other hand, there are a few use cases that are unique, and their capability is neither available in the market today, or easily available through other commercial technologies. These include the following:

3GPP Use Case 17: Health Monitoring at Home

This use case includes comprehensive health monitoring at home, including fall detection, lack of movement, breathing rate, and even heart rate monitoring, which would be possible once multiple small cells are deployed within the home. This use case allows health monitoring without the person wearing a device, offering an unobtrusive way to track multiple critical characteristics. Although this use case requires multiple small cells to cover an entire home, no other technology can offer similar capabilities, except for Wi-Fi. However, the mobile operator could create a carrier-grade health monitoring service, having existing customer relationships and a presence in the home environment.

3GPP Use Case 27: Public Safety Search and Rescue or Apprehend

This use case would operate on the public cellular network and would utilize ISAC capabilities to locate humans in natural disasters or when a crime has been committed. Arguably, this would be a complex use case to implement as there are multiple challenges, but the use case presents unique and critical functionality that no other technology can provide. The functionality could also be coupled with adjacent technologies, including AI, Augmented Reality (AR) and Virtual Reality (VR), and Heads-up Displays (HUDs) to provide first responders with visual indications of the environment. This is another example of a use case that cannot be replicated with another technology and would place the mobile operator in a completely new market position, where they become a trusted partner for public safety agencies and create new high-value business models and lucrative revenue streams.

There are many other use cases and applications studied in 3GPP, including gesture recognition, network-assisted sensing to avoid UAV collision, tourist spot foot traffic management, and many more. ISAC introduces unique functionality in cellular networks and expands existing functionality (e.g., cellular positioning).

REGIONAL MARKET DYNAMICS

The ISAC market is being developed in 2024, mostly in R&D circles, but there are already regional differences emerging. These depend on spectrum allocations mostly, and in which markets FR1 and FR2 spectrum are currently utilized. As discussed earlier, it is most likely that ISAC—in the cellular domain—will be deployed in new frequencies, rather than coexisting in current consumer-oriented 5G bands, meaning that new spectrum allocations will be necessary. Regardless, there are already pre-standards trials and tests, most of them in China, paving the way for a better understanding of ISAC in the market and what its implications will be.

CELLULAR

Cellular ISAC developments are heating up in standards bodies, with ETSI and 3GPP leading the market. In theory, cellular is competing against Wi-Fi for sensing, but the two domains are currently developing independently, due to the monumental technical and development effort required to make either of these a commercial reality. The cellular groups combine a diverse group of stakeholders from around the world that will influence how the official standard will be. At the same time, there are market activities around the world, indicating an appetite for sensing in the cellular domain. This section will not focus on academic projects taking place in 2024, but pre-standards trials and early system tests.

MARKET ACTIVITIES

The ETSI ISAC ISG is expected to produce its first use case documents in early 2025, followed by more diverse and complete specifications. Following on from this work, 3GPP will likely take over the biggest share of the development work and complete its specification in Release 20 and Release 21, meaning that the earliest, fully standardized commercial ISAC systems will likely appear in the market after 2030. However, there are a few pre-standards trials and early deployments already taking place in the market, predominantly in China.

China Mobile has announced the deployment of 500 cell sites supporting ISAC in 2025, in the 4.9 GHz band, focusing solely on five use cases to start with: low-altitude economy, low-altitude security, ground-air integration, water way monitoring, and sea surface monitoring. This will include drone tracking, geofencing, and drone communication, and the mobile operator will provide communication services to start with, followed by sensing services to regulators, government entities, and even the companies that operate the drones themselves. The use case is particularly interesting for secure areas that need to avoid drones and UAVs and could create a new revenue stream for mobile operators. It is notable that China Mobile has chosen this frequency for the commercial trial to ensure that no interference takes place between its sensing and consumer communication businesses, and to test the concept in a commercial setting. Moreover, the Chinese operator hopes to deploy ISAC technology in ports to enable collision avoidance between ships and bridges.

In China, ISAC is considered a strategic priority by the government, pushing ahead in commercial trials in 2025, and augmented by the dominance of the drone company DJI that is also headquartered in Shenzhen.

SPECTRUM CHOICES

Spectrum will likely dictate how ISAC will be deployed, but in early discussions with key stakeholders and mobile operators, it appears as if current services—especially for consumers—should not be disrupted or affected, meaning that ISAC will likely be deployed in new frequencies. The following sections discuss market developments regarding ISAC spectrum. Low band (<1 GHz) is ignored because it is not physically possible to integrate a large antenna array to allow beam-forming and mMIMO, hence making sensing not practical in a size- and cost-effective manner.

Mid-Band (1 – 6 GHz)

Mid-band 5G is the global mainstream deployment model, which is now deployed across most, if not all, developed markets. In some markets, mobile operators will likely reach saturation in FR1 spectrum, especially if they have deployed FWA in this band. It is unlikely that ISAC will be deployed in these frequencies, but there are academic and research projects looking at system co-existence for ISAC using orthogonal signals. However, it remains questionable whether mobile operators would refarm some of their <6 GHz communication bandwidth for sensing at this stage.

Allocating spectrum to mobile terrestrial services was a focus of the WRC-23 conference and will also be the focus of WRC-27, where 6G spectrum will likely be decided. For example, a major factor in securing additional spectrum for IMT at WRC-27 is the anticipated introduction of 6G technology. To support the deployment of 6G, WRC-23 agreed to examine the frequency bands of 4,400 – 4,800 MHz, 7,125 – 8,400 MHz (or portions of these ranges), and 14.8 – 15.35 GHz for International Mobile Telecommunications (IMT). This is crucial for potential 6G stakeholders, as it allows them to concentrate on developing 6G technology within the specified spectrum ranges under study. Leading the charge in 6G development, with ongoing trials and studies, are China, Japan, South Korea, India, Europe, and the United States.

Moving toward WRC-27, the focus will shift toward the 4 GHz band, and ABI Research expects that harmonization of this band for IMT has a high probability of occurrence across Europe, Africa, Russia, and Asia Pacific. For the Americas region, the 4,400 – 4,940 MHz band is currently identified for aeronautical mobile telemetry for flight testing by aircraft stations, so interoperability studies will first need to be conducted. Nevertheless, this band may be a key spectrum allocation for 6G and ISAC.

High-Band (6 GHz to THz)

There is also considerable market activity in the higher bands, above 6 GHz. At the Mobile World Congress (MWC) 2023 event in Shanghai, China announced that it would be allocating the upper part of the 6 GHz frequency band (6,425 – 7,125 MHz) for IMT services in effect from July 1, 2023. This follows the country's earlier allocation of the lowest 100 MHz (5,925 – 6,125 MHz) of the 6 GHz band for the private 5G network operated by the country's premier state-owned aerospace manufacturer, Commercial Aircraft Corporation of China (COMAC). This move has put China up against some of the other spectrum developments in the world, where several countries have identified the entire 6 GHz band (5,925 – 7,125 MHz) for license-exempt access, thereby supporting other wireless access technologies such as Wi-Fi. This spectrum band would also be ideal for ISAC, hinting that China may have a head start in deploying cellular in FR3.

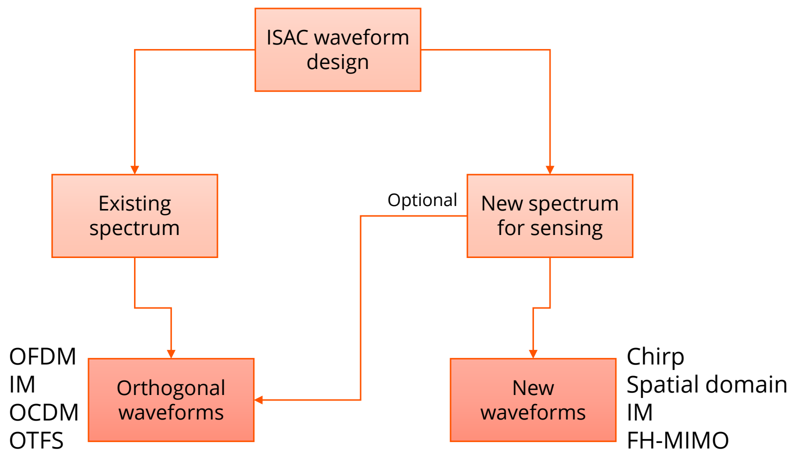
There is also considerable activity in mmWave sensing and discussions about sensing in the Terahertz (THz) range. These frequencies introduce major bandwidths for ISAC and are largely unexplored in most markets. However, their propagation characteristics would translate into a very dense deployment to cover a large enough area, something that cannot be justified in the current state of the technology. Nevertheless, deployment of ISAC may be driven by the business case, meaning that initial deployments may be more localized and not following coverage requirements, like 5G had to adhere to. ISAC may be deployed in both mid- and high frequencies at once, depending on the use case requirements.

ORTHOGONALITY

A literature survey of academic and R&D studies focused on ISAC waveforms indicates that orthogonal signals will likely be utilized for the new integrated systems.[5] Most of the new waveform studies for communication-designed ISAC systems include OFDM, Index Modulation (IM), Orthogonal Chirp Division Multiplexing (OCDM), Orthogonal Time Frequency Space (OTFS). All of these include orthogonality as a foundation concept. There are proposals for sensing-designed waveforms to be introduced, but these will likely have to be optimized for communications, rather than the opposite, which is more likely. These choices are summarized in Figure 3.

Figure 3: Waveform Design According to Spectrum

Sources: IEEE ComSoc Survey Paper,[5] ABI Research



Although it is possible that new waveforms will be considered for 6G, it is probable that similar waveforms will be considered for backward compatibility. ABI Research expects that orthogonal waveforms, a family of technologies very familiar to the cellular domain, will be used for ISAC as well, meaning that existing communication-only networks may be transitioned to ISAC. This includes several benefits, but also challenges, as illustrated in Figure 4.

Figure 4: SWOT Analysis for Using Orthogonal Signals for Communication and Sensing

Source: ABI Research

Technical	**STRENGTHS** ▪ Currently being used in cellular networks globally ▪ Possible to fine-tune existing waveforms (OFDM) to introduce sensing capabilities ▪ Plethora of waveforms based on orthogonal comms/sensing signals being proposed as alternatives	**WEAKNESSES** ▪ Potential lower performance compared to sensing-optimized waveforms ▪ May require refarming of communication spectrum for use in <6 GHz bands ▪ Complex integration and optimization of communication and sensing payloads on a single system
Commercial	**OPPORTUNITIES** ▪ Utilize existing cell sites for sensing without the need for major densification ▪ Reuse existing cellular systems for deploying, optimizing, and managing sensing infrastructure ▪ Monetize spectrum selectively, using spectrum for sensing where needed	**THREATS** ▪ CSPs currently risk-averse and will not likely invest in new equipment or infrastructure without clear & strong ROI ▪ Adjacent markets will have more experience with non-communication and non orthogonal based waveforms for radar-like usage

[5] *IEEE ComSoc: Integrated Sensing and Communication Waveform Design: A Survey*

ABI Research expects orthogonal waveforms to become the mainstream technology for ISAC, but will likely meet technical and commercial challenges for new deployments, as with any new technology being developed.

WI-FI

MARKET ACTIVITIES

With the 802.11bf standard in its advanced stages and Wi-Fi sensing having seen commercial deployment, there are already discernable regional dynamics to the technology. These regional dynamics are expected to become more pronounced as a greater number of players enter the market alongside the maturing of the technology, and as regulatory divergence exacerbates the differences in the operating environment for Wi-Fi sensing.

Within the official IEEE TGbf for 802.11bf (see Section 2.2.2.), the most prolific contributors are from Mainland China, with Huawei being the most active, alongside multiple Chinese universities. Indeed, the Chair of the TGbf is Tony Xiao Han of Huawei. Other key members of the TGbf include LG Electronics, Ericsson, and Meta. Outside of the TGbf, the second primary platform for industry collaboration to standardize and devise best practices for Wi-Fi sensing is at the Wi-Fi Sensing Work Group within the Wireless Broadband Alliance (WBA). Significant work from this group, to date, includes its support for testing methodology and deployment guidelines published in 2022. Much of this work group originates from the United States, including companies such as Origin and Cognitive (more on these two below), as well as CableLabs, Cisco, and Comcast. Alongside these, Turkey's state-owned telecommunications company, Turk Telekom, and the Indian Centre for Development of Telematics (C-DOT) are also key members.

Within the software development vendor landscape, one of the largest major commercializing companies is Origin Wireless, a U.S.-based vendor that has been one of the most successful at commercializing the technology. The company was initially founded in 2013 by Dr. K.J. Ray Liu, an ex-University of Maryland Professor who, in 2009, was commissioned by DARPA to solve communication problems in submarines, for which he developed an early Wi-Fi sensing prototype. Origin Wireless' first commercial product was launched in 2019, and since then, it has formed major commercial partnerships with companies that include Aloe Care, Verizon, Airties, and Verisure. Going forward, the company aims to begin monetizing CPD Wi-Fi sensing sometime in the coming 24 months, and aims to launch a Single Point System (SPS) command module for the central command of all Internet of Things (IoT) devices in the home for Wi-Fi sensing in 2025. Outside of this, the past year has also seen Origin Wireless attempt to exert a greater influence on Wi-Fi sensing research. For example, in 1Q 2024, it Launched Origin Research, and became involved in Deutsche Telekom's tech incubator hubraum. January 2024 also saw Origin raise US$15.9 million in its Series B extension round, with the leading investors consisting of companies with which Origin has existing partnerships, including Verisure and Verizon.

Two other the most significant Wi-Fi sensing software developers are based in Canada. The larger of the two, Cognitive Systems, has commercialized its Wi-Fi Motion sensing solution, which enables applications that include home monitoring, wellness monitoring, and smart home automation. Its most important partnership is with value-added service platform provider Plume, with its HomePass Sense and Workpass Flow features based on Cognitive's Wi-Fi sensing technology solution. The Plume partnership helped Cognitive significantly expand its serviceable market, and today, more than 100 ISPs globally are using Cognitive Systems' sensing solution for home security via Plume's platform. Cognitive also has plans to integrate Wi-Fi sensing directly into chipsets in the future for client-side sensing, which, if successful, will help greatly expand the reach of the company's technology. The second significant Canadian Wi-Fi sensing developer is Aerial Technologies, although the company has yet to fully commercialize its solution, as it is still in the testing phase of its platform.

A fourth major commercializing developer is nami, a Singaporean-based company that received US$10.5 million Series A funding in July 2023 from an assortment of investors, including Verizon Ventures, AMAVI Capital, and INSPiRE, a fund backed by the Japanese government dedicated to supporting research on Wi-Fi sensing's application for the healthcare sector. nami has gone to market in the healthcare and security verticals, and major partners include Alarm.com, which uses Wi-Fi sensing as a failsafe, and the consumer electronics vendor Philips. nami's commercial strategy differs from that of Origin or Cognitive in that it prioritizes equipment vendor partnerships over those with service providers, and the company reports that around 100,000 devices supporting the company's Wi-Fi sensing technology have been shipped to date. One of its Wi-Fi sensing solutions with a coverage area of approximately 1,500 square feet (about half the area of a tennis court) would retail for between US$60 and US$100. Beyond products currently on the market, nami is actively testing its advanced Wi-Fi sensing for aged care within healthcare facilities in Japan, in partnership with the Japanese government.

SPECTRUM

The additional spectrum that the 6 GHz band offers is highly valuable for Wi-Fi sensing, as it opens much needed extra bandwidth for achieving simultaneous communication and sensing activities without impairing the performance of either. Given this, regional differences in unlicensed spectrum access are likely to exert a significant influence on the regional dynamics of Wi-Fi sensing. Regions with larger sections of the 6 GHz band made available as unlicensed are likely to witness faster adoption of Wi-Fi sensing, as sensing activities will interfere less with communications. On the other hand, regions without or with only partial access to 6 GHz will face greater spectrum challenges, potentially resulting in impaired sensing performance or interference with Wi-Fi communications.

While the debate over the fate of 6 GHz is ongoing, early discussions of assigning additional spectrum for unlicensed Wi-Fi use, with a particular focus on the 7 GHz spectrum, have already begun. For example, the Federal Communications Commission (FCC) Technological Advisory Council in the United States has already published its preliminary view of spectrum bands in the 7.125 – 24 GHz range. With the bandwidth requirements of Wi-Fi only expected to grow, expanding unlicensed spectrum access further may prove to be vital to ensuring that communications and sensing can operate simultaneously.

BUSINESS AND SERVICE MODELS

ISAC monetization is arguably the most important aspect for the success of the new concept, coming at a time when the cellular market is experiencing a slowdown, particularly in 5G monetization. This has failed to attract the interest and revenue opportunities in the enterprise market, and several mobile operators are now arguing that 6G will likely be an upgrade, an evolution of 5G, rather than a completely new technology refresh. ISAC can become the next leap ahead in cellular networks and introduce completely new use cases and applications, but the telecoms market needs to start planning the business case, and not on a "build it and they will come" basis.

CELLULAR

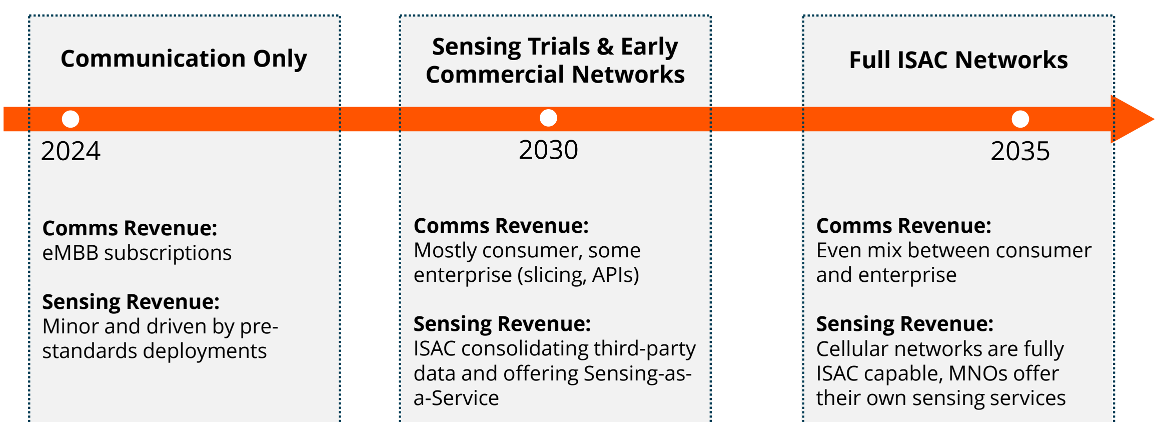
The discussion about ISAC is still premature and it is difficult, if not impossible, to uncover what monetization opportunities it will bring for mobile operators. Nevertheless, as discussed above, ISAC can place them in a completely new market position and even help them redefine their role. The cellular network is effectively a distributed connected computing environment, and they can use it, in this case, for something much more than communication. The same goes for Wi-Fi, which can be used in the home or other indoor environments for much more than communications. The following sections illustrate a possible future roadmap for ISAC in these two markets.

MONETIZATION OPPORTUNITIES

In the cellular domain, pre-standards trials are already allowing operators to test new waters and enter new markets. Figure 5 illustrates a potential future roadmap for ISAC monetization opportunities.

Figure 5: Potential Roadmap for ISAC Monetization Opportunities

Source: ABI Research



They key question for sensing is if and when it will be able to provide a similar $/Hertz (Hz) ratio compared to current Enhanced Mobile Broadband (eMBB) deployments. Assuming that a 5G cell site sector spectral efficiency is 5 Bits per Second (bps)/Hz and that a 100 MHz channel is utilized, translates to a 500 Megabits per Second (Mbps) instantaneous capacity in each sector. In terms of monetization, this capacity can provide adequate data connectivity for tens, if not hundreds of subscribers at any given time. Assuming also that a sensing use case will likely utilize at least 100 MHz for adequate accuracy means that mobile operators will only consider sensing with a very strong business case. If this does not exist, then they will likely prefer to assign spectrum to eMBB capabilities instead.

KEY END MARKETS AND CHALLENGES

Mobile operators will need to prioritize certain enterprise verticals in their ISAC deployments, much like they are doing today with their enterprise connectivity strategies. For ISAC, they will need to focus on use cases that only cellular can effectively cater to. In early pre-standards trials, these markets include drones/UAVs and other verticals that operate on the Wide Area Network (WAN), where public cellular can adequately provide sensing capabilities by reusing the cellular grid. Adding sensing capabilities will surely cost, but there is no other market entity that can provide a similar sensing service. Of course, it will be many years before full sensing capabilities are brought to market, but mobile operators must focus on verticals where no similar capabilities exist, including transportation and even public safety.

Addressing these market opportunities will come with its own set of major challenges. The technical challenges will be addressed by standardization bodies and technical R&D, but as with other cellular concepts that have succeeded commercially, business and use cases need to come first. It is now becoming clear that ISAC will likely be deployed in new spectrum, meaning that its deployment will start from sensing use cases, and then expand to include communication. This would translate to a large Capital Expenditure ()CAPEX requirement, especially if large areas need to be covered with sensing capabilities. This will require a strong and clear business case and clear demand in the market for relevant sensing capabilities.

WI-FI

EXISTING MONETIZATION

Wi-Fi sensing leverages the same unlicensed spectrum resources as Wi-Fi communications, which, unlike in the cellular domain, require no additional costs for access. That said, Wi-Fi sensing still must demonstrate sufficient value to justify dedicating finite unlicensed spectrum resources for its application. The most effective GTM strategies for Wi-Fi sensing currently being implemented are through partnerships with ISPs and through collaboration with equipment vendors in the verticals of security and healthcare. Origin has targeted both these channels, with the company's partnership with Verizon an example of the former and partnerships with Aloe Care and Verisure examples of the latter. The success Origin has witnessed with ISPs has led the company to take several steps to deepen its integration with ISPs over the past 12 months, including joining the prpl Foundation in October 2023, launching the TruPresence product targeted at ISPs in December 2023, and partnering with Airties that same month.

Given the still maturing state of Wi-Fi sensing and existing limitations on its precision and reliability, Wi-Fi sensing solutions are typically monetized in a Subscription-as-a-Service package as part of a broader package of value-added services. For example, the integration of Cognitive Systems' Wi-Fi Motion technology into Plume's platforms has helped the solution be available in more than 60 million homes in which Plume's HomePass and Haystack platforms are deployed. Again, in the belief that the best existing route for Wi-Fi sensing monetization is for the technology to be bundled with other value-added services to create a compelling package for ISPs, Cognitive has also partnered with Domos and Lansweeper, which produce services for improving latency and identifying and classifying devices, respectively.

Straying from the fundamentals of ISAC, several vendors have attempted to bring Wi-Fi sensing to market through the launch of dedicated Wi-Fi sensing infrastructure designed primarily for sensing tasks. The belief is that many consumers have reservations toward depending upon standard Wi-Fi CPE for critical tasks like security and healthcare, but they will have greater confidence in the reliability of equipment that has been designed from the ground up for such applications. Early attempts at dedicated Wi-Fi sensing infrastructure came with the launch of Origin's Hex subsidiary back in 1Q 2021. More recently, in March 2024, domestic appliance vendor Versuni released the Philips Home Safety 5000 Series, which included Wi-Fi sensing motion sensor plugs powered by nami's Wi-Fi sensing technology (since 1Q 2022, nami has been in a strategic partnership with Origin).

FUTURE MONETIZATION

Table 3 in Section 4.1.1. highlights 14 promising future applications for Wi-Fi sensing, with a rating of each application's monetization likelihood in the far-right column. It is notable that many of the applications, such as people counting for commercial buildings or smart meeting rooms, are possible with existing technology today, but have not yet been monetized on a large scale. There are several reasons for this. First, the monetization path is not as clear as residential security and healthcare applications. Whereas most of the current Wi-Fi sensing applications have gone to market as a Subscription-as-a-Service via ISPs or equipment vendors in the healthcare or security verticals, clear partners in the verticals of the proposed future applications are unclear, and standalone subscriptions for the sensing services are unlikely to garner high levels of traction. Second, the attraction of many of the currently monetized applications is that they leverage pre-existing equipment to solve a task that is not being met by existing equipment. In contrast, for many of the proposed future applications, dedicated equipment would be required (especially true for the mmWave applications) and there are often existing alternative technologies that are already suitable for the job. Finally, whereas improvements to security and healthcare are straightforward to monetize for partners, the path to a strong Return on Investment (ROI) is less tangible for the other applications.

Table 3 also lists a range of Wi-Fi sensing applications that rely on the superior sensing granularity and more precise positioning that mmWave can offer. Although mmWave may have plenty to offer sensing, due to its poor propagation properties, it has been sidelined for communication applications, meaning that there is a virtual absence of mmWave Wi-Fi equipment in residential and enterprise environments. Therefore, given that one of the main advantages that Wi-Fi sensing has over alternative motion detection technologies is that it can leverage existing Wi-Fi infrastructure, the majority of ISAC-based Wi-Fi sensing monetization initiatives have been and will continue to be based around sub-7 GHz frequencies. The mmWave Wi-Fi sensing radios that we do see monetized are going to predominantly be dedicated to the task of sensing. For example, when equipment vendor Mercku installed mmWave radios into its CPE, they only targeted sensing tasks.

CHALLENGES

Aside from the issues discussed above, there are a range of other significant challenges that ISAC Wi-Fi sensing must overcome before it can reach widespread acceptance. The first is the potential for the additional sensing task to degrade the quality of communication activities. As Section 3.1.2. outlines, this will pose a greater challenge in regions with relatively restricted access to unlicensed spectrum. Research has concluded that consumers prioritize communications over sensing, so developers must ensure that communications performance is protected if they are going to successfully implement Wi-Fi sensing.

A second major challenge is privacy, and as advances in Wi-Fi sensing raise our awareness of how 802.11 RF waves can be measured to infer movement, privacy concerns are steadily increasing. Concerns have now reached a level that multiple research initiatives are actively exploring how to disrupt Wi-Fi sensing measurements. One notable example is an European Union (EU)-sponsored project at the University of Brescia called CSI-MURDER, which is exploring methods for distorting CSI signals so that they cannot be read. To effectively allay these concerns, future Wi-Fi sensing development should consider how to guaranteed privacy for consumers.

RECOMMENDATIONS

Both cellular and Wi-Fi ISAC are still in the very early stages of maturity, and although there is clearly significant untapped potential from the technologies, clear GTM strategies are still unclear. As ISAC gradually transitions from a theoretical concept to a viable marketable solution in the coming years, the industry must ensure that the economics of the technology remain front and center. Developers of ISAC applications should prioritize use cases that are driven by customer demand and offer strong ROI over those that are technologically impressive, but detached from the needs of the market and for which the high costs of adoption will prevent widespread adoption. We have already seen this today with the greater focus on the development of sub-7 GHz Wi-Fi sensing solutions over those in the mmWave.

Outside of economic concerns, there are a range of additional steps that the industry should take to help stimulate the advancement of ISAC. The first is to collaborate on driving standardization for both cellular and 802.11 ISAC independently, which will help provide a marketing boost to the technologies and a framework for the industry to coalesce around. It is also important that industry associations and ecosystem vendors conduct ISAC technology trials to demonstrate the technology's potential for positioning tasks, which will help raise awareness and boost confidence in the technology. Alongside this, ecosystem vendors should look to build strategic partners with organizations active in their target markets, such as with insurance companies for healthcare, to support the alignment of their R&D roadmaps with market demands.

In the cellular domain, there are two considerations: that Communication Service Providers (CSPs) are currently reluctant to invest heavily in a new concept and technology, and at the same time, they will need a strong business case to introduce sensing in a commercial environment. According to ABI Research's understanding, it is most likely that ISAC waveforms will be based on orthogonality, perhaps even reusing many parts of current 5G waveforms. It is important for 3GPP and the research community to coalesce behind a single waveform choice and drive that forward. This will allow the gradual introduction of sensing in cellular frequencies, allowing CSPs to deploy the new concept with a low investment, reusing existing cell sites.

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