

Technical White Paper

Sensing Without Sensors: Why Wi-Fi is the Smart Choice



Maddy Marsh

Abstract

Wi-Fi® sensing is a rapidly emerging technology that transforms existing Wi-Fi infrastructure into a non-invasive spatial awareness sensor capable of tracking motion. With recent advancements in edge artificial intelligence (AI), Wi-Fi sensing models and algorithms can potentially run on lower-cost Wi-Fi MCUs directly and take advantage of existing Wi-Fi infrastructure. This whitepaper explores the purpose and advantages of Wi-Fi sensing, and how advancements in embedded processing and software are making implementation easier than ever in a variety of applications. The paper explores industry activity and how standardized bodies like the Wi-Fi Alliance and IEEE are approaching standardization and interoperability of the technology. The paper also explores the hardware and software solutions that TI Wi-Fi is developing to enable these emerging use cases.

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1 Introduction

As the world grows increasingly dependent on smart, connected devices, innovative use cases continue to emerge. Wi-Fi sensing is one such technology gaining traction in the Internet of Things (IoT) market. Unlike traditional sensors that require dedicated hardware, Wi-Fi sensing leverages the existing wireless infrastructure already present in most buildings and devices, making a more cost-effective and scalable design for activity detection and environmental awareness.

Traditionally, Wi-Fi has served a single purpose: transmitting data wirelessly between devices. Data packets carry useful information like internet traffic, video streams, or web pages. Wi-Fi sensing changes this tradition by repurposing Wi-Fi signals for an entirely different application—detecting and analyzing movement without capturing the data the movements carry. Rather than focusing on the information inside data packets, Wi-Fi sensing analyzes the quality and characteristics of the Wi-Fi channel that carries those data packets.

As a Wi-Fi radio transmits packets through the air, the signals encounter obstacles in the path of the signal—like walls, furniture, or people—and reflect in complex patterns. The reflections change measurably when an object or person moves within the signal path. These changes can be captured through channel state information (CSI), which is a detailed measurement of physical-layer properties like signal amplitudes and phase across OFDM subcarriers already available in standard Wi-Fi radio data. CSI essentially characterizes the current state of the Wi-Fi channel between a transmitter and a receiver to provide a data stream that reflects the environment around the channel. By continuously analyzing CSI measurements, systems can detect subtle changes in the environment and make inferences about the movement or activity occurring.

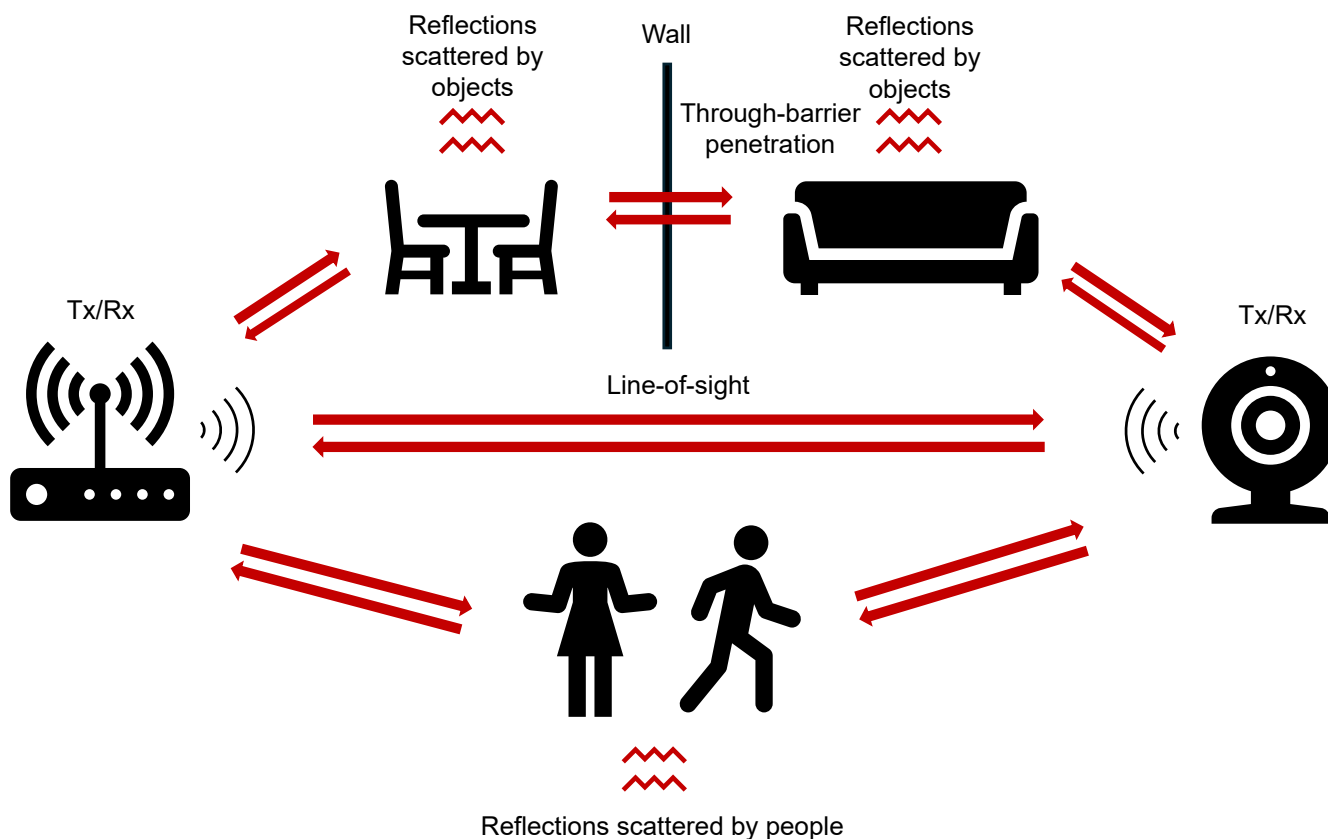


Figure 1-1. Flow Diagram

The raw CSI data requires sophisticated analysis to extract meaningful insights. This is where Edge AI—the ability to run AI models locally, near the source of the data—plays a critical role. Machine learning models trained on CSI patterns can learn to recognize specific activities, detect presence or absence of people, monitor vital signs, or identify gestures. These tools enable developers to train models efficiently on resource-constrained devices and deploy these models in final products.

2 What Are the Benefits of Wi-Fi Sensing?

Wi-Fi sensing offers several compelling advantages that make the technology attractive for product developers. First, the technology leverages the existing Wi-Fi protocol and infrastructure—channel state information can be calculated from the legacy long training field (L-LTF) that is native to 802.11 transmission preambles. An 802.11 frame is transmitted with an L-LTF containing known symbols across all subcarriers. This enables the receiver to extract the channel state represented as an array of complex numbers, one per subcarrier. In the case of OFDM transmissions in a 20MHz channel, there are fifty-two such subcarriers, resulting in fifty-two complex numbers in the channel state. Ordinarily, the channel state is used in the receiver to decode the data payload then discarded, but in the case of Wi-Fi sensing the individual channel state is of interest. By comparing the way the channel state varies from frame to frame, sensing the physical changes in the radio frequency channel is possible between the transmitter and receiver, which correspond to the movement of objects or other physical changes.

CSI is thus a native capability of 802.11 OFDM, requiring no protocol modifications or additional hardware. This means Wi-Fi sensing can be potentially enabled to reuse existing Wi-Fi networking without additional system costs on any modern Wi-Fi chip, creating a more cost-effective way to add sensing capabilities to connected devices.

Additionally, Wi-Fi signals can operate regardless of ambient lighting conditions, and because Wi-Fi signals can penetrate physical barriers, Wi-Fi sensing does not require a direct line-of-sight. A smart plug in a bedroom, for example, can detect movement in the hallway outside—a capability impossible with traditional motion sensors. Personal data privacy is one of the most important advantages which is preserved with Wi-Fi sensing as Wi-Fi sensing relies entirely on standard wireless signals, eliminating the need for cameras or other invasive monitoring equipment.

These advantages have opened new applications across the IoT market, enabling Wi-Fi to provide additional options for enabling sensing that can be more cost-effective. In home security or video surveillance, Wi-Fi sensing provides a through-wall capability that detects occupancy in areas where cameras have blind spots. Smart HVAC, lighting, and appliance systems use Wi-Fi sensing for energy optimization—a smart thermostat, for instance, can detect a prolonged absence and reduce the air conditioning until a resident returns home. From energy savings to enhanced security to health monitoring, Wi-Fi sensing is enabling technology for smarter and more spatially aware products.

Wi-Fi sensing enabled devices for occupancy detection

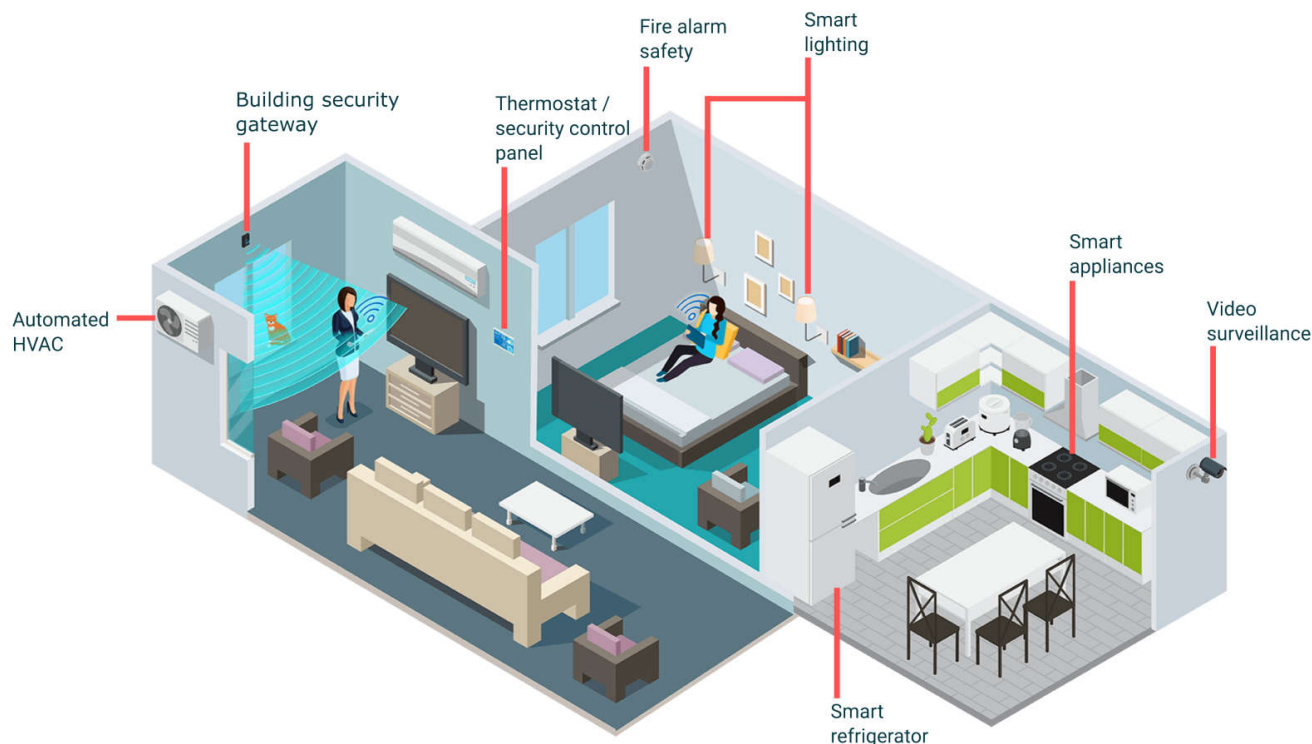


Figure 2-1. Smart Home

With Wi-Fi sensing gaining attention in the smart device market, there are important trade-offs to understand before product deployment. Compared to other technologies, like radar that excels at precise position and velocity measurement, Wi-Fi sensing trades localization accuracy for the ability to work through obstacles and with the existing infrastructure.

Power consumption is another consideration as Wi-Fi sensing requires continuous packet transmission over a certain period, consuming significantly more power than ultra-low-power sensing alternatives such as passive infrared. As a result, Wi-Fi sensing today is generally not optimized for battery-powered designs.

Additionally, Wi-Fi sensing requires two devices—a sender and receiver pair—to extract CSI data, a fundamental architectural constraint. Environmental factors can play a significant role—for example, dense obstacles in a room can weaken signals and the physical placement of the sender and receiver directly impacts sensing accuracy. Developers must carefully consider device placement and adapt algorithms for specific environments, an area of active research and development at TI.

Table 2-1. Advantages and Considerations of Wi-Fi Sensing

Advantages	Considerations
- Leveraging existing Wi-Fi infrastructure – no additional hardware or protocol modifications required - Works in any lighting conditions - Penetrates physical barriers and walls – no line-of-sight required - Preserves privacy with no cameras or invasive monitoring equipment necessary - Enables diverse spatial awareness applications (for example, home security, occupancy detection, energy optimization, and health monitoring)	- Lower localization accuracy compared to radar - Requires continuous packet transmission (high power consumption) - Requires sender and receiver pair architecture - Sensitive to environmental factors and obstacles – device placement impact accuracy - Requires careful algorithm tuning for specific environments

3 What Industry Activity is Currently Happening?

Wi-Fi sensing technology has existed for over a decade, but implementations have been largely proprietary with exclusive hardware support until standardization efforts began. In the early days of Wi-Fi sensing, many researchers began learning how to repurpose Wi-Fi signals for location sensing and motion detection. A few years later, developers created Wi-Fi sensing designs to detect human falls. When this technology finally reached the consumer market in 2019, the IEEE intervened to study the technology and eventually established the 802.11bf standard as the official WLAN sensing standard in 2020. The 802.11bf standard is not required to perform Wi-Fi sensing with current infrastructure, but the standard offers optional extensions that enable enhanced capabilities.

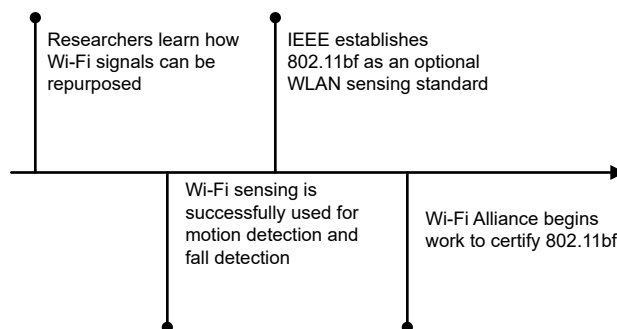


Figure 3-1. Timeline of Wi-Fi Sensing Developments

The 802.11bf standard extends Wi-Fi sensing capabilities by adding standardized mechanisms for control and coordination. The standard defines how WLAN sensing devices inform other stations of their WLAN sensing capabilities, request and configure sensing-enabled transmissions, and exchange sensing feedback and information.

With interest in Wi-Fi sensing growing among developers, the Wi-Fi Alliance has begun designing the framework to certify the 802.11bf standard implementations. The certification program aims to promote interoperability between devices from different vendors and accelerate market adoption.

4 How is Texas Instruments Addressing the Growth of Wi-Fi Sensing?

Texas Instruments enables Wi-Fi sensing adoption through both hardware and software innovations. The CC3551E is a Wi-Fi 6 and Bluetooth® Low Energy 5.4 wireless MCU built for sensing applications. The MCU combines an Arm® Cortex®-M33 processor with an embedded neural processing unit (NPU) that enables high-performance, power-efficient AI acceleration through custom data path extensions (CDE).

The architecture of the CC3551E distributes workloads, using the primary M33 processor for handling standard application code and the wireless networking stack, while the NPU executes the machine learning algorithms and complex operations for CSI data analysis in parallel. The device natively extracts CSI data from standard Wi-Fi signals exchanged with connected peers and exposes this data through an API that the application can access and pass to the NPU for further analysis.

Extracting CSI data is only the first step. Developers need tools to analyze, test, and deploy AI models with minimal programming expertise. Texas Instruments addresses this through two complementary approaches. Experienced developers seeking full control over a Wi-Fi sensing implementation can develop custom designs with proprietary sensing capabilities and market differentiation. For developers wanting to experiment with Wi-Fi sensing applications without deep expertise in model development, Texas Instruments provides CCStudio™ Edge AI Studio.

TI's CCStudio™ Edge AI Studio is a collection of graphical and command line tools that simplifies and accelerates edge AI development on Texas Instruments embedded devices like the CC3551E. The tools include a model composer, model analyzer, model selection tool, and model maker, enabling designers to quickly evaluate models and the performance of those models without physically connecting to an evaluation board. Developers can also train models on their own data for environment-specific optimization, then deploy those models through integrated tools that handle model compression and on-device AI processing for the CC3551E.

With a wide variety of development paths, CCStudio™ Edge AI Studio enables a broader range of developers to bring innovative applications to market.

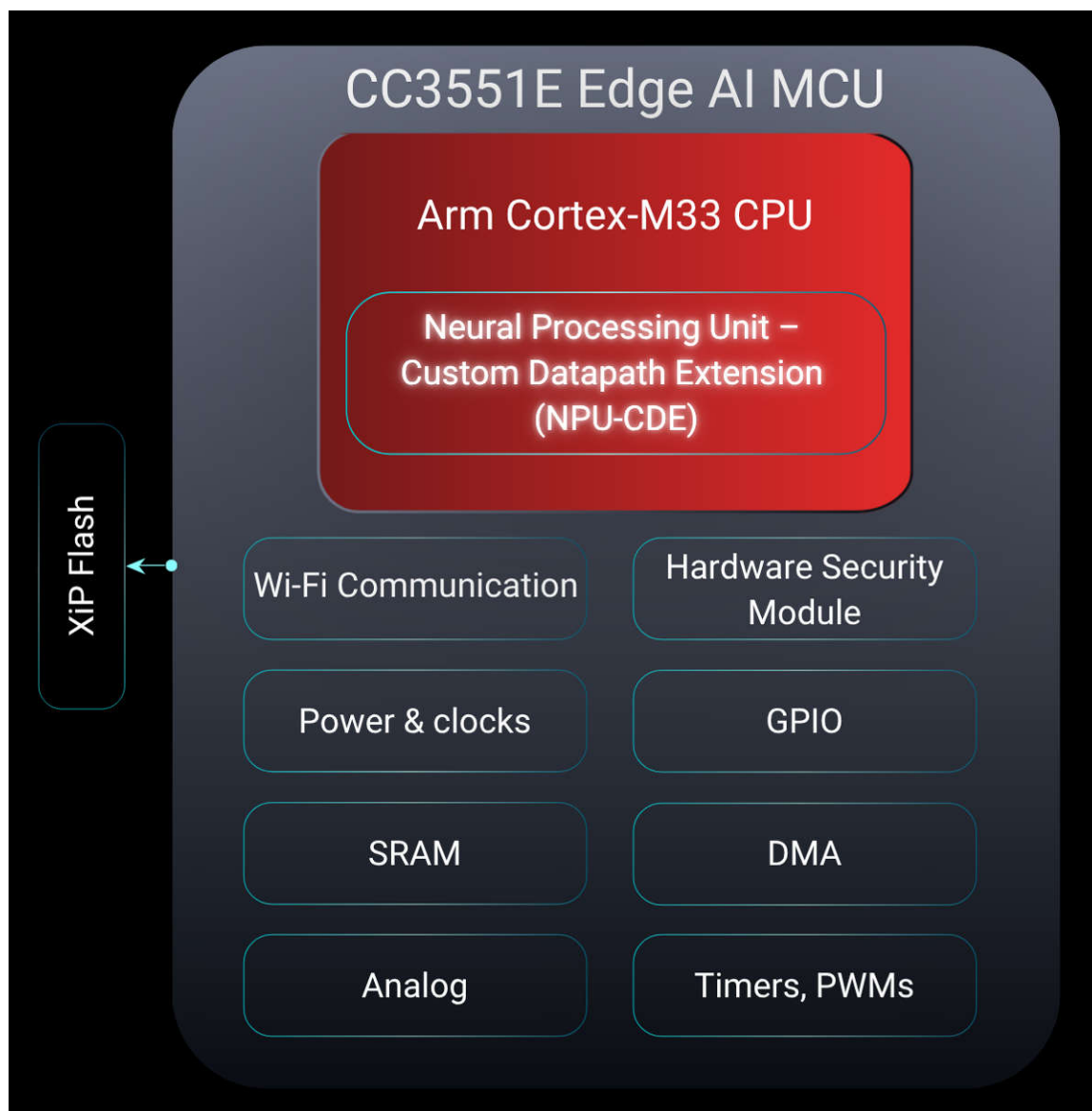


Figure 4-1. Edge AI + CC3551E Block Diagram

5 Additional Resources

- Explore TI's [CC3551E](#) – Wi-Fi 6 + BLE 5.4 combo wireless MCU
- Get started with TI's [LP-EM-CC35X1](#) evaluation kit
- Learn about TI's [Edge AI Wi-Fi Sensing use case](#)

6 Conclusion

Although Wi-Fi sensing is still in the early stages, the potential of Wi-Fi sensing to reshape spatial awareness applications is becoming clear, particularly regarding the ability to add intelligent sensing capabilities without requiring dedicated hardware or cameras. With standardization efforts like the 802.11bf standard, improved hardware such as the CC3551E with integrated AI acceleration, and intuitive software tools like CCStudio™ Edge AI Studio, the barrier to implementing Wi-Fi sensing has never been lower. Designers of any experience level can now experiment with sensing applications, train models on their own data, and deploy designs tailored to their specific environments. As more developers become familiar with the technology, the industry can expect

Wi-Fi sensing to become a standard feature across smart home devices, industrial IoT systems, and connected applications. With each successive generation of Wi-Fi devices and supporting tools, Wi-Fi sensing continues to open new possibilities for privacy-preserving, cost-effective sensing capabilities.

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