Wi-Fi Sensing

Detecting Motion for Security, Aging in Place, and More

A Technical Paper prepared for SCTE by

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1. Introduction

Wi-Fi sensing uses functionality already present in Wi-Fi radios to detect motion. The immediate use cases for home security are certainly valuable by themselves, but the future of sensing holds immense promise for elder care, aging in place, advanced medical applications, IoT control, immersive gaming, and more. Imagine being alerted to a change in behavior of a remote relative, or even potentially detecting a fall or other life-threatening condition. Imagine a doctor being able to have real-time information about a patient's breathing or heart rate - all with the patient comfortably at home with no expensive, dedicated medical hardware. Imagine these solutions not requiring a professional installation, relying solely on the devices already deployed in a customer's home. This paper covers the base technology behind Wi-Fi sensing, current applications, deployment best practices, and near-future use cases.

2. Wi-Fi Sensing Technology Overview

Wi-Fi sensing is the ability to detect motion inside an area covered by Wi-Fi. Current implementations use Channel State Information (CSI) to detect this motion.

"*CSI characterizes how wireless signals propagate from the transmitter to the receiver at certain carrier frequencies. CSI amplitude and phase are impacted by multi-path effects including amplitude, attenuation, and phase shift. Each CSI entry represents the Channel Frequency Response (CFR)*

$$H(f;t) = \sum_{n}^{N} a_n(t) e^{-j2\pi f \tau_n(t)},$$

where $a_i(t)$ *is the amplitude attenuation factor,* $\tau_i(t)$ *is the propagation delay, and* f *is the carrier frequency*" [1].

In short, CSI is the sum of all information needed by an access point (AP) or station (STA) in order to decide how best to transmit a wireless frame. In a completely static environment (e.g., an AP and a STA in a shielded chamber – see Figure 1), CSI should have extremely low variability, as all direct and reflective RF paths are constant and there are no external interferers. In this simplified example, CSI is on a scale from 1 to 10, with 10 being perfect signal conditions.

Figure 1 – RF Shielded, static environment, demonstrating consitant CSI

If a person were to walk through this chamber (Figure 2), these RF paths would encounter attenuation, reflection, refraction, etc., thus affecting the CSI. By observing the changes in CSI on the receiver, one can infer motion.

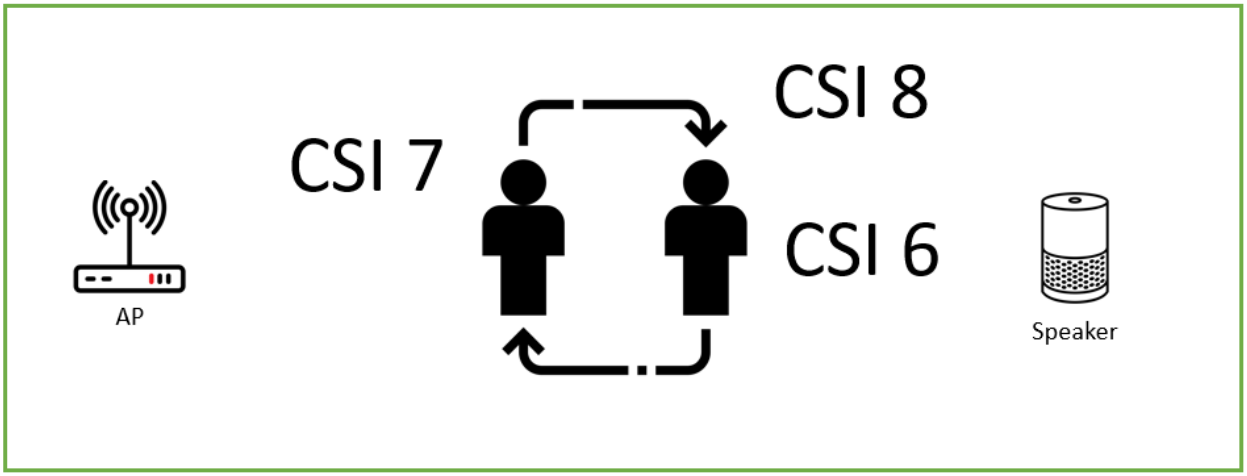

Figure 2 – RF absorbtion of a human walking through the envitonment causes changes in CSI

Wi-Fi sensing relies on significant Wi-Fi utilization over multiple devices. It is not currently good enough to have a single AP and a mobile device to enact sensing. An "ideal" residential deployment would have several static APs and STAs (e.g., smart speakers / Wi-Fi doorbells / Wi-Fi thermostats) deployed at the boundary of the coverage area. Mobile devices within this area currently cannot participate in sensing, other than to provide a user interface for configuration or motion reporting.

2.1. IEEE 802.11bf

Current Wi-Fi Sensing deployments, while based on 802.11 standards, are all unique in their implementations as the process for turning CSI information into inferred motion is proprietary. The IEEE has formed a task group to standardize sensing. This will be a critical step in helping wide adoption and has the potential to include moving STAs into the sensing cluster. Additionally it will enable a cross-platform mix of devices to participate seamlessly.

"Task Group bf is expected to develop an amendment that defines modifications to the IEEE 802.11 medium access control layer (MAC) and to the Directional Multi Gigabit (DMG) and enhanced DMG (EDMG) PHYs to enhance Wireless Local Area Network (WLAN) sensing (SENS) operation in license-exempt frequency bands between 1 GHz and 7.125 GHz and above 45 GHz.

This amendment enables:

- *Stations to inform other stations of their WLAN sensing capabilities*
- *Request and setup transmissions that enable WLAN sensing measurements to be performed*
- *Exchange of WLAN sensing feedback and information"* [3]

Draft 0.1 for initial comment collection was released in April 2022, and final 802 EC approval is scheduled for July 2024.

3. Wi-Fi Sensing Use Cases

The uses cases listed below are presented in chronological order from where we are today, to where this technology could take us in the future.

3.1. Home Security

Home security is the simplest implementation of Wi-Fi sensing, as it merely detects some level of motion in the coverage area. While it will be the most basic use case described here, it is not without significant challenges – primarily in false signal detection. These include:

- Fans, robotic vacuums, or other household devices that move on their own
- Pets
- Outdoor motion (e.g., a tree on a windy day)

Addressing these false detections is achievable. Fans and devices with consistent repetitive motion can be identified and filtered out. Most pets will have a much lower effect on CSI than a human, so a minimum motion level could be set. Outdoor motion can be an issue but could also be useful in the proper context. For example, outdoor motion on the second floor of a house may be ignored, while outdoor motion on the ground floor could trigger an alert as a possible trespasser.

3.2. Aging in Place

The next evolution of Wi-Fi sensing will address aging in place, which is the ability for people to retain independence and stay in their homes for longer than is currently possible. There are currently 5.8 million people over age 65 in the United States with Alzheimer's or related dementias [2]. These diseases are progressive in nature, with increasing levels of care needed the further along the person is. Technology designed for aging in place can help delay the transition to memory care facilities by offering minimally invasive remote monitoring by a relative or healthcare professional. Several specific uses for Wi-Fi sensing include:

- Fall detection
- Sleep monitoring
- Lack of motion alerts
- Boundary crossing alerts

3.3. Advanced Medical Applications

Wi-Fi sensing is also being developed for dedicated medical applications, beyond the residential deployments covered above. Heart rate and breathing detection have already been shown as achievable, but these have deployment considerations that initially make them only appropriate for controlled environments. For example, envision a hospital bed with an AP on the ceiling above the patient and a STA directly beneath them on the floor. These APs would not be used to service other non-medical STAs and would exist as a separate network from anything providing data services.

While this level of medical application is only possible today in a specific healthcare environment, Wi-Fi sensing technology should advance to the point where these same services are achievable in the home.

3.4. Future Innovations

We've only begun to glimpse the full potential of Wi-Fi sensing, as we're only in the very first years of innovation. And considering there are over 20 Billion Wi-Fi devices deployed today, there's an incredible base upon which to develop new uses for Wi-Fi sensing. The following represents a small sample of what is technically possible.

3.4.1. Gesture Sensing

As seen in section 2.1 above, the 802.11bf task group is working to enable sensing at frequencies above 45 GHz. In this range, gesture recognition becomes possible at very small motion ranges. We've seen advances in IoT control where most home devices can be controlled with a voice command, and sensing will enable an even more natural level of control. If you want all the lights off in a room, just gesture towards the light switch as if you were turning it off.

3.4.2. XR Integration

The natural evolution from gesture recognition is full XR (AR/VR/MR) integration, without the need for on-body sensors or dedicated tracking systems. This will increase immersivity while decreasing hardware costs and battery utilization, making XR systems lighter and more powerful. Potentially, the only hardware needed would be the head-mounted display (HMD).

4. Conclusion

Wi-Fi sensing represents a paradigm shift in how we leverage existing and future Wi-Fi deployments. Home security applications available today are just the very beginning. The biggest impacts will be in home healthcare, granting more independence and a better quality of life for far longer than ever possible before. On top of home and health, the potential value to entertainment markets is enormous, and the field for not-yet imagined sensing innovations is limitless.

Abbreviations

AP	access point
AR	augmented reality
CSI	channel state information
EC	engineering change
GHz	gigahertz
HMD	head-mounted display
IEEE	Institute of Electrical and Electronics Engineers
RF	radio frequency
STA	station
VR	virtual reality
WBA	Wireless Broadband Alliance
XR	extended reality

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