# Motion Detection Under Ubiquitous Wi-Fi

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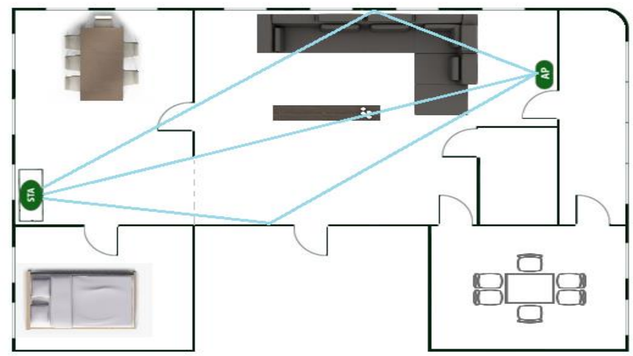
***Abstract-*** *This article deals with a feasibility study on the detection of human movements in indoor scenarios based on radio signal strength variations. The sensing principle exploits the fact that the human body interacts with wireless signals, introducing variations of the radiowave fields due to shadowing and multipath phenomena. As a result, human motion can be inferred from fluctuations of radiowave power collected by a receiving terminal. In this paper, Experimental tests are performed in an indoor environment by using a Wireless device as a Wi-Fi access point and a laptop with dedicated software as a receiver. Simple detection strategies for real-time operation are implemented to process the received signal strength measurements. The achieved results confirm the potentialities of the simple system here proposed to reliably detect human motion in operational conditions.*

***Keywords***- Motion Detection Use Cases, Wi-Fi fundamental building block, Wi-Fi sensing network into a radar array,How will Wi-Fi sensing be used? What do we need to make Wi-Fi sensing happen?

## I. INTRODUCTION

Since its introduction in 1999, Wi-Fi has become ubiquitous. As Wi-Fi is now found everywhere, with new applications being developed to serve new use casesincluding residential, enterprise, and the IoT. One particularly innovative application of Wi-Fi technology, which may not be immediately apparent but has become possible way the technology is used, is motion detection.

Simply put, the propagation characteristics of Wi-Fi radio wave signals can now be used to detect the presence, motion, and activity of people. This can include people entering, exiting, or moving within a defined area such as a room. The ability to detect motion using Wi-Fi is ushering in a new set of use cases and applications, creating new categories of services and business models based on motion detection that can, in many cases, be applied anywhere Wi-Fi exists today.




In this post, I summarize the action recognition from wi-fi.

A. Motion Detection Use Cases
B. Wi-Fi fundamental building block
C. Wi-Fi sensing network into a radar array
D. How will Wi-Fi sensing be used?
E. What do we need to make Wi-Fi sensing happen?

A. Motion Detection Use Cases

Some use cases for Wi-Fi based motion detection are emerging in many markets, including residential, health care, and enterprise.

Application Use Cases

i. Home security: Automatically detect when cleaning or home repair staff arrive and depart.
ii. Health Care: Detect when in-home care personnel arrive or if an elderly person remains stationery for an extended period of time.
iii. Smart Building: Motion based HVAC (Heating, ventilation, and air conditioning) and lighting control.

a. KPIs for Motion Detection

Several key performance indicators are critical for motion detection and are no less relevant for Wi-Fi based motion detection. Some of the key indicators are:

- Accuracy: The ability to determine with a high level of confidence the presence of a person entering or leaving an area while minimizing false positives.

This puts greater importance on having good Wi-Fi coverage around the home, in order to avoid dead spots where detection may not be possible.

- Precision: The ability to distinguish between different movement patterns, such as walking, falling, or breathing, for instance.
- Speed: Detection needs to be fast and timely. Any security action needs to be detected in seconds, not minutes.

B. Wi-Fi fundamental building block

While disturbances in the field of most forms of radio frequency (RF) technologies can be used to detect motion, implementing it would typically require dedicated hardware. Conversely, in most cases no additional or specialized hardware is required to support motion detection using Wi-Fi. Furthermore, the widespread use of Wi-Fi makes it the ideal platform for implementing motion detection as an 'over the top' service.

Wi-Fi motion detection works due to the way that 2.4GHz and 5GHz RF radio waves propagate and react to stationary and moving objects in their operating environment. Every signal path exhibits a unique signature as it travels through the medium (or channel), changing slightly as it is absorbed or reflected by objects. Every device that receives a Wi-Fi signal provides feedback to the source of the signal; the access point (AP), router or gateway (GW). This feedback contains information about the channel's characteristics, in wireless communications this is normally referred to as the Channel State Information (CSI) and it contains information that allows the transmitter to optimize its operation based on what the receiver 'sees'.

The AP, router or GW analyzes the CSI data, to identify patterns that describe changes in the channel. More advanced algorithms can then determine if the reported disruptions are caused by someone entering or moving within a Wi-Fi field. Importantly, RF propagation delays and angles can also be calculated from this information, which provides the means to pinpoint the location of the object (or person). A visual representation of this CSI, plotted over time in the frequency domain, is shown in Figure 1. Motion events are detected by recognizing disturbance in the channel, as shown in Figure 2.

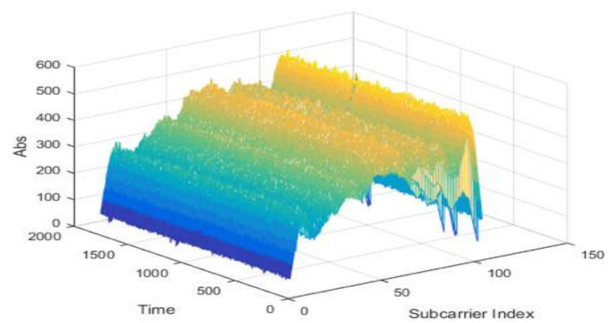



Figure 1. Channel Information across frequency and time

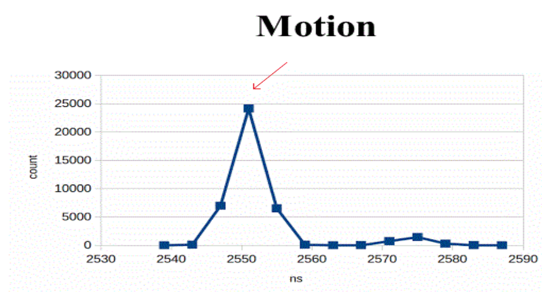



Figure 2. Motion events in a channel subcarrier

While the AP or GW will process this data locally in order to optimize its own operations, it can also grant access to the CSI data to a trusted 3rd party application who would use software algorithms to identify movement. Depending on the type of motion detection solution, these algorithms may run locally on the AP/GW, or remotely on a cloud platform.

I. High order MIMO - improving motion detection performance

Although it is realized through software, Wi-Fi motion detection is enabled by the hardware. Several factors can dramatically improve the KPIs of accuracy, precision, and speed of motion detection, all of which rely on good performance being provided by the underlying hardware platform.

MIMO (Multiple-Input, Multiple-Output) is a proven technology that significantly increases Wi-Fi performance, coverage and usable bandwidth in all environments. With MIMO, a multi-antenna GW or AP sends and receives data and channel information across multiple streams to client devices.

Because of the reflective and refractive properties of any environment, transmitted radio waves bounce off walls, objects, and people, which creates a multi-path transmission, as represented in Figure 3.MIMO leverages multi-path, which improves range, coverage, and speed. To illustrate how this is achieved in practice, consider Quantenna's high order 8-stream MIMO device, which delivers more than 2x improvement in speed than a 4-stream device. MIMO is also the foundation for beam forming, which is a technique used to improve radio performance by focusing the RF energy towards the client(s) and thereby improving range and performance. Beam forming further improves the range that can be achieved, which is critical in this scenario because motion detection is not effective without adequate Wi-Fi coverage. Higher order MIMO based on Quintana's chipset also delivers greater insights into the multipath environment, thanks to the more detailed CSI data the chipset produces. The result is even better motion detection performance.

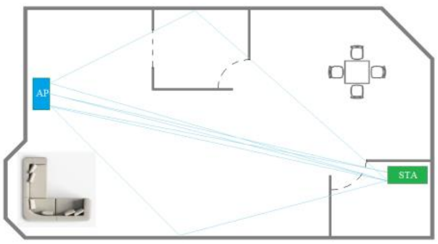



Figure 3. A representation of Multipathtransmission using MIMO

In practice, the channel information is converted by the Wi-Fi chipset from RF energy into digital bits, for subsequent processing. The more bits used and made available to motion detection software, the higher the resolution. A chipset with 16 or even 12-bits CSI data as opposed to 8-bits will result in greater motion accuracy. Also, higher channel bandwidths will improve accuracy. As a result, the bandwidths supported by the Wi-Fi 5 and Wi-Fi 6 standards improve not only Wi-Fi throughput, but also motion detection accuracy. For example, simply doubling the Wi-Fi channel bandwidth from 40MHz to 80MHz can improve motion location accuracy by 40%.

II. AI in motion

A growing number of AP/GW manufacturers are now delivering advanced motion detection services based on Quantenna's expertise in developing MIMO and Multi-user MIMO (MU-MIMO) chipsets. While the basic premise of Wi-Fi based motion detection is simple, delivering the accuracy, precision and speed needed to make it practical is a challenge few chipset manufacturers are able to address. The application of Artificial Intelligence (AI) is adding a higher level of analysis, enabling greater detail and even higher reliability.
Detecting disturbances in RF energy is now a proven and effective method of implementing motion detection, as demonstrated by the growing number of partners working with Quintana. Access to the rich CSI data Quintana's technology enables is bringing MIMO and AI together in exciting new ways.

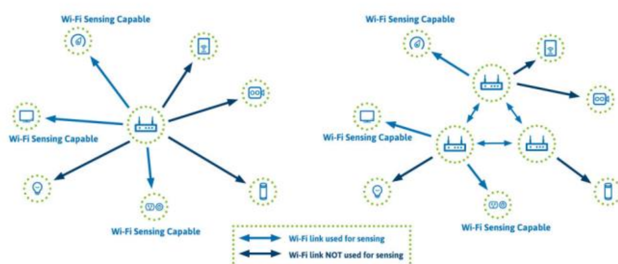
Wi-Fi continues to evolve and is no longer just a wireless networking technology. Wi-Fi motion detection has become a practical, cost-effective technology that addresses real needs in residential security, health care, and enterprise applications. As Wi-Fi performance continues to increase with technologies such as MIMO, beam-forming, and high bandwidth operation, Wi-Fi motion detection performance also benefits.

KEY POINTS

i. Wi-Fi sensing builds upon the mechanisms already used in wireless networks to detect environmental changes.
ii. Possible use cases of Wi-Fi sensing include motion/presence detection, security, elder care, home automation, and gesture recognition.
iii. Work is underway to standardize Wi-Fi sensing, which will pave the way for increased functionality, interoperability, and reliability.

C. Wi-Fi sensing turns your wireless network into a radar array

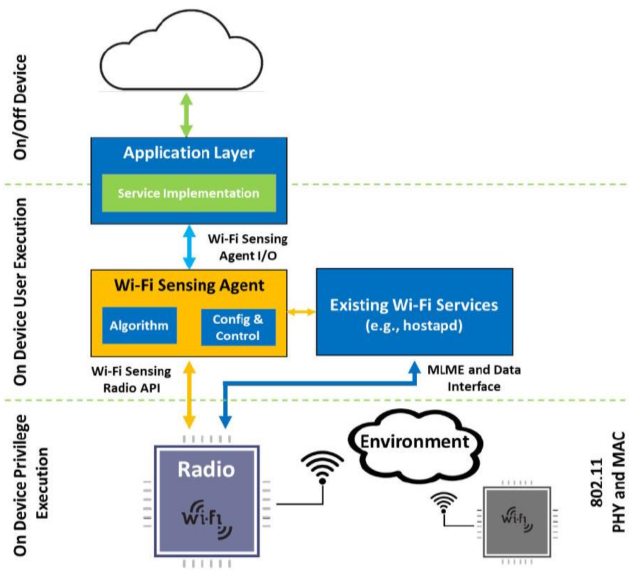
A 2019 study from Deloitte found that U.S. households have an average of 11 connected devices. The wireless radios in those devices typically send information to and receive information from a central access point, creating a star-like topology.




Above: An example home deployment might have one access point or multiple APs in a mesh configuration.

Not every device on the network has to be Wi-Fi sensing-capable.Wi-Fi sensing works by detecting environmental changes between devices. So, when you cross the communication path of a wireless router and game console for instance, an agent running on the router might perceive the disruption and, like radar, determine your location, size, and so on.

Every client added to the network creates additional opportunities to gather environmental data. And of course, all those sensing measurements need to be processed by a device with enough computational horsepower. Access points, or even edge/cloud servers, work well for this purpose.




Above: A typical Wi-Fi sensing system comprises three main components: a Wi-Fi radio, a software agent for signal processing, and an application layer that turns context-aware information into services/features.

According to The Need for Enabling Touchless Technologies, working on an amendment to the standard to support Wi-Fi sensing on the 2.4, 5, 6, and 60 GHz frequency bands. Applications that don't rely on resolution but do need some ranges are best served by the 2.4, 5, and 6 GHz bands. Conversely, the fine resolution required by gesture recognition lends itself to millimeter wave signals.

D. How will Wi-Fi sensing be used?

The ubiquity of Wi-Fi makes the technology an attractive platform for new business opportunities, and there are already several exciting use cases for sensing-capable Wi-Fi networks.

Home monitoring is perhaps the simplest implementation of Wi-Fi sensing. In fact, it's already available through Linksys' Aware Velop Mesh systems. Aware offers adjustable sensitivity, programmable schedules to limit extraneous notifications, and a logged history. If something moves between two of the Velop's nodes and your sensitivity setting is dialed in correctly, the Linksys App lets you know. Motion detection through a service like Aware is fairly basic compared to more advanced Wi-Fi sensing use cases. But remember that Linksys layers this functionality on existing wireless hardware, not a chipset developed with sensing in mind. And compared to the upfront hardwaresystem, Wi-Fi sensing is remarkably affordable.

As Wi-Fi sensing evolves, the technology's performance will improve, allowing it to detect subtler movement from a greater number of sources, and then pinpoint their locations. That's when the potential applications really get wild.

Take elder care, for example. Adding sensing to an existing Wi-Fi network protects the privacy of residents, since they're not on camera, and affords them greater independence. At the same time, machine learning algorithms fed by higher-resolution detection data differentiate between someone sitting down to watch soaps or accidentally falling.

How about home automation? Connected light fixtures, multi-room audio, and climate control systems could come alive and then fade to black as family members enter and leave roomsall withoutcomplexity of passive infrared sensors for motion detection.

The wake-on-approach and lock-on-walk-away use cases are similar in concept. Consumer electronics with Wi-Fi radios might detect a user in proximity and switch on from standby mode. The same mechanism could lock a device when a logged-in user saunters off. Enabling both features would be a boon for the battery life and security of mobile devices.

Intel's IoT group is especially interested in sensing's application to hospitality. "In a hotel, housekeeping goes door to door checking for occupancy before servicing each room," "But imagine if they had the ability, through their Wi-Fi infrastructure, to know if there was someone in the room without being invasive." The idea here would be to deploy housekeeping resources efficiently, keep from disturbing guests, and maintain privacy.

Given enough resolution, Wi-Fi sensing may even be used for gesture recognition, displacing many of today's touch controls, particularly in public places. It goes without saying that COVID-19 has everyone acutely aware of shared surfaces. So, there's an immediate need for touchless alternatives to subway turnstiles, elevator buttons, and airport kiosks.

E. What do we need to make Wi-Fi sensing happen?

Before we're able to master our appliances with pinches, swipes, and waves, Wi-Fi sensing must experience a renaissance. Right now, a limited number of use cases are possible with commercially available hardware based on existing wireless standards. But there are gaps in the technology begging to be bridged by a broader industry-wide effort.

Work toward that effort is already underway. Last year, the Wireless Broadband Alliance published a white paper detailing the building blocks needed to create Wi-Fi sensing systems. Part of the analysis led by Cognitive Systems, Intel, and the Centre for Development of Telematics (CDOT) included guidance for overcoming apparent gaps.
As an example, Wi-Fi's physical layer (PHY) protocols already perform certain measurements for sensing the surrounding environment. But those measurements weren't exactly designed for the applications targeted by Wi-Fi sensing. If a future standard could specify additional measurement data, sensing accuracy would improve. Meanwhile, the technology's efficiency stands to benefit by exposing each device's sensing capabilities at the medium access control (MAC) layer.

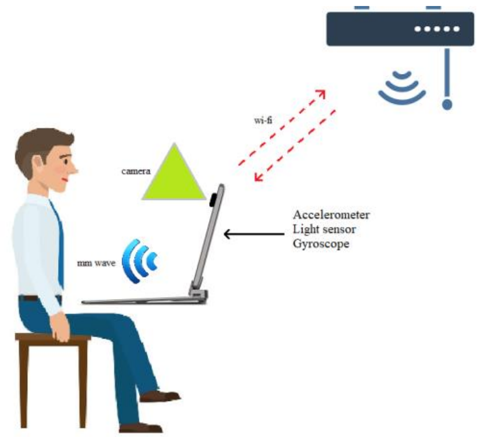
Beyond a handful of other hardware-oriented improvements suggested by the WBA's paper, standardized application programming interfaces (APIs), security considerations, and interoperability tests are also advised.

"Over the last 20 years, Wi-Fi has been used primarily as a communication service," "Sensing, although complementary, is a completely different usage of Wi-Fi. As a result, there is a gap when it comes to testing Wi-Fi sensing features, in terms of knowledge, procedures, and tools. To overcome these limitations, it became clear to Cognitive very early on that industry collaboration and standard support will be required."

I. Standardization is key to Wi-Fi sensing's future

Today's standards and adherent Wi-Fi platforms do limit the scope of Wi-Fi sensing. However, home monitoring systems like Linksys' Aware demonstrate the technology's viability, even before it sees the surge of momentum standardization promises. Now, it appears the work that Cognitive Systems, Intel, and the CDOT put into its whitepaper is bearing fruit.

Companies like Cognitive Systems are to be lauded for driving Wi-Fi sensing using existing hardware, says Intel's Cordeiro. For the market to really take off, though, more needs to be done. "The standards work is important because that's what gets us the right solutions at the radio level, the protocol level, and the API level for innovation to be able to happen."




Above: Combining measurement data from a laptop's accelerometer, light sensor, gyroscope, and millimeter wave radio could enable health analytics and remote health monitoring functionality.

With everything going on right now, we're all spending more time in front of connected devices. Imagine if the PC you work and game in front of was able to measure your heart rate, your breathing rate, evaluate your stress level, and remind you to take breaks. "Use cases like that are really resonating with people," continues Cordeiro. "We have these Wi-Fi devices out there for communications. But look at all the other use cases that go beyond communications and how they stand to benefit society. For us to be able to bring this to market at scale, with the right reliability and quality, the industry needs to come together. That happens through the standards process."

Expect Wi-Fi sensing to become a more familiar concept as standardization progresses. Most recently, Cognitive Systems and its partnering WBA members defined a second phase project for the Wi-Fi sensing group, which involved developing a test methodology around Wi-Fi sensing and home monitoring. The group has defined several KPIs that can be used to evaluate a system and some test procedures for how they can be measured. Since sensing is a very different Wi-Fi application, the group hopes that this work will form the foundation of how to test and eventually certify a Wi-Fi sensing system.

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