White Paper

Implementing IEEE 802.11ah in Industrial, Indoor Settings

142-00100-080A

Table of Contents

Considerations for IEEE 802.11ah Indoor Usage

Over the years, many wireless technologies have promised to minimize physical wiring in industrial and indoor applications like office buildings and college campuses. However, these spaces have unique characteristics and requirements that make that promise hard to fulfill in practice. In such applications, wireless communication requires high reliability, limited jitter, and low latency over hundreds of meters of area.

Today, the proliferation of sub-GHz technologies is improving the range and coverage of wireless communication. While many consider the wireless networking protocol IEEE 802.11 to be best for outdoor coverage, this protocol is well positioned for many indoor environments too. 802.11ah uses sub-GHz radio that can easily penetrate building materials and diffract obstacles to reduce dead spots and provide relatively high throughput for IoT applications. This white paper explores how IEEE 802.11ah meets important requirements related to network coverage, latency, throughput, power optimization, and material penetration for mid-range, mid-latency wireless communication in industrial, indoor settings.

Network Coverage

Wireless network coverage refers to the area in which wireless signals are transmitted. In-building wireless coverage is impacted by multiple factors, including building materials, layout, surrounding environment, and user position.

When planning a Wi-Fi project, one of the first decisions relates to access points. Typically, the number of wireless access points in the space depends on the area, environment, use case, and wireless technology.

The following information needs to be assessed to install Wi-Fi access points properly and provide the best possible wireless coverage:

- Coverage area/floor plan
- Shape of the area/floor plan
- Building/wall material
- Number of users
- Capacity/throughput requirements per user/application

Latency

The advent of Industry 4.0 initiated the modernization of industrial spaces. To remain competitive, facilities managers need to:

- Continuously monitor product quality
- Adequately synchronize processes to optimize their efficiency
- Cope with dynamic market demands by supporting more flexible and adaptive production processes

There is research on the suitability of IEEE 802.11ah for low-latency, time-critical control loop systems where control loops (i.e., controllers connected to access points) and monitoring sensors are connected to the same host. Control loop systems monitor and regulate devices, instrumentation, and machines used in industrial or manufacturing settings. Seferagi’c et. al. experimented with cycle time and how many station connections (i.e., sensors) could be supported in a cycle. In the end, the best-case scenario was 310 sensor stations transmitting 64-byte packets per second alongside a control loop with a cycle time (Tcyc) of 512ms. Control loop cycle time represents the time between two consecutive transmissions of a measured value from the access point to the controller.

Findings also showed that:

- It is feasible to have 75 monitoring sensors using a single control loop with Tcyc = 32ms
- For 3 control loops with Tcyc = 32ms, packet loss is 0.0208 percent
- 4 control loops with Tcyc = 64ms can reliably operate alongside 70 monitoring sensors

Overall, these findings indicate that there is a relationship between latency and how many stations/sensors transmit data on the network; the number of stations per access point requires thoughtful consideration in applications where latency is critical.

Others can achieve this kind of result by reducing the beacon interval, the intervals at which the access point sends out beacon messages, to limit latency and jitter. Allowing two or more transmission opportunities within a cycle provides enough robustness for at least 99.99 percent of packets to transmit successfully.

Even though reducing the beacon interval enables the realization of control loops, it introduces significant setbacks including increased energy consumption for monitoring sensors and reduced overall throughput. IEEE 802.11ah solves many of the latency challenges facing traditional Wi-Fi with some constraints on energy and power consumption.

Throughput

In recent years, there has been a tremendous proliferation of IEEE 802.11-based wireless local-area networks (WLANs), and the broader acceptance of IEEE 802.11 has resulted in mass and diverse employments (e.g., homes, offices, streets, campuses). Today, many different devices (e.g., smartphones, laptops, tablets, wearables) utilize the IEEE 802.11 standard operating in 2.4GHz/5GHz frequency band to connect to the Internet. IEEE 802.11 (i.e., a/g, n, or ac) was not originally designed for IoT specifications; however, the new IEEE 802.11ah standard aims to organize communication between various IoT applications such as smart grids, smart meters, smart houses, healthcare systems, and smart industry.

Power Optimization

Collecting and distributing data within an industrial space via physical wiring presents numerous complications. Wiring is difficult to install in hard-to-reach places and can disrupt the movement of mobile assets (e.g., indoor traffic, automated guided vehicles). Physical wiring is fault prone due to degradation, and between materials and labor costs, it can be an expensive endeavor too. Besides the obvious physical benefit of reducing excessive wiring, wireless networks also introduce several logical benefits that minimize downtime.

The IEEE 802.11ah standard defines two power consumption management modes: activation mode and low power consumption. In the activation mode, the STA keeps the RF module in an open state, and data can transmit continuously when there are upstream and downstream data operations. In low power mode, the STA switches between hibernation and activation. When hibernating, the STA completely shuts down the RF module and stops receiving the signal; even if the access point is transmitting data downstream to the STA, the data can only be cached by the access point. When the STA wakes up, switches to the active mode, and sends a downstream request, the access point can transmit the cached data to the STA.

In a traditional IEEE 802.11 system, access points periodically broadcast beacon frames, and the STA examines the beacon frames to check if there is data to be received. If there is, a PS-Poll must be sent to request that the access point starts a packet transmission. After completing the transmission, STA goes to sleep mode. However, problems arise when there are many STAs in the network. The beacon frames become very long, and if many packets are cached in the access point, the low-power STA may not complete data transmission, causing enormous power consumption.

To solve power consumption concerns, the IEEE 802.11ah standard offers a new traffic information indicator (TIM) diagram and a new page segmentation strategy for beacon frames. When the DTIM beacon is broadcasted, all group STAs need to be woken up to see if there is cached data. Suppose the entire group does not have cached data; in that case, the whole group stays asleep throughout the DTIM cycle until the next TIM beacon arrives, giving STAs more time to sleep. The result is a significant reduction in power consumption.

In addition, IEEE 802.11ah introduces two other optimization strategies:

- **Maximum Sleep Time Expansion:** The maximum sleep time can be extended up to 2,500 times.
- **Target Wakeup Time (TWT):** This mechanism allows AP to arrange STA wakeup time, which makes different stations wake up at different times, thereby reducing competition and collision, improving the system efficiency, and significantly reducing the power consumption of the STA.

Material Penetration

There is a relationship between the wavelength/frequency of a wireless signal and its ability to penetrate through barriers and other materials. As a wireless signal penetrates a medium, the signal is attenuated, losing energy. As the signal penetrates, some of the signals are reflected, refracted, or absorbed. Penetration is directly related to wavelength; smaller wavelengths are more easily reflected or refracted than longer ones. As wavelength increases (and frequency decreases), the wireless signal penetrates deeper. As wavelength decreases (and frequency increases) signal has shallower penetration. Naturally, low-frequency ultrasound has superior penetration. IEEE 802.11ah operates in the sub-GHz frequency band, so it can be ideal for many indoor applications because it can penetrate through dense building materials.

802.11ah Indoor Test

A recent Silex office building test, detailed below, showed that IEEE 802.11ah offers the broader coverage due to the lower frequency band, narrower bandwidth, and more robust coding scheme. It showed at least ten times the range of IEEE 802.11n in the 2.4GHz band. However, it is important to consider that IEEE 802.11ah accommodates lower throughput than IEEE 802.11n when closer to an access point.

For this experiment, the AP-100AH, IEEE 802.11ah access point, and 802.11n (2.4GHz) access point were placed side-by-side in a second-floor conference room, see Figure 1. 17 station test points were set up in the corridor, 10 feet apart, from end to end. Station test points 12, 13, and 14 were closest to the access points. The same test set up was replicated on the third, fourth, fifth, and sixth floors of the Silex building.

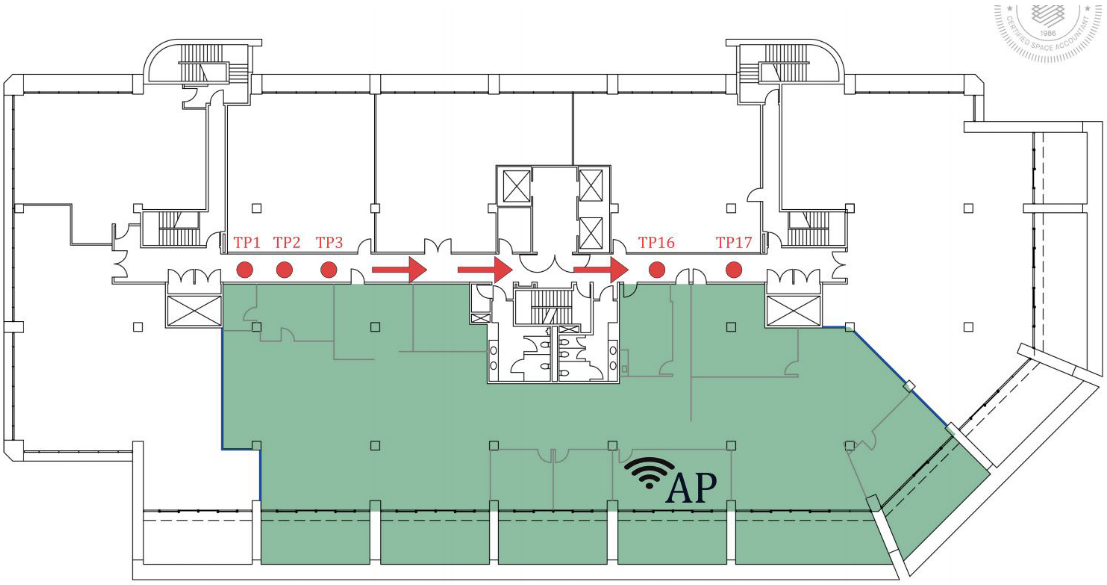

Figure 1: Second floor of the Silex office building; red arrows demonstrate the location of test points, and AP abbreviation identifies each access point location.

Test Environment:

- **Building Size:** 158,670 square feet
- **Floor Size:** 19,834 square feet
- **Floor Count:** 8
- **Wall Type:** Drywall with internal metal rods, ceiling, several fire-grade doors
- **Wireless Interference:** Noisy environment with many existing Wi-Fi networks from the building's different offices

With the AP-100AH 802.11ah access point, wireless connectivity reached the 6th floor—four floors up from the access point. On the other hand, the 802.11n access point was only able to cover a portion of the second floor. Farther from the access point, the combination of distance and wall thickness made it difficult to establish connectivity.

On the second floor, where the access point was situated, 802.11ah fared better in terms of coverage, see Figure 2. Its throughput hovered around 1 to 2.5 Mbps. In comparison, 802.11n peaked at 15 Mbps close to the access point and completely lost connectivity about 80 feet away. For strong coverage with few access points and many stations, 802.11ah would be the best technology choice.

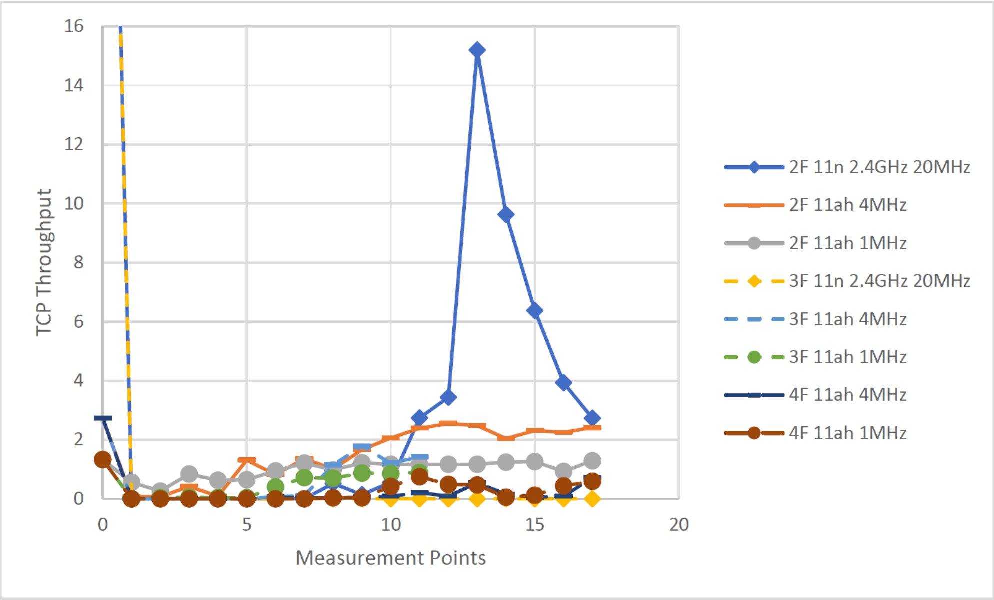

Figure 2: Data throughput at different test points on floor two

Silex test results also showed that the RSSI value of the IEEE 802.11ah was far better than the IEEE 802.11n signal through walls and structures, see Figure 3. One IEEE 802.11ah access point provided network coverage to the building, whereas IEEE 802.11n could not propagate beyond a floor. IEEE 802.11n (blue line) provides more throughput where they are fewer obstacles. However, when considering throughput and network coverage from a single access point, IEEE 802.11ah is more consistent throughout the building.

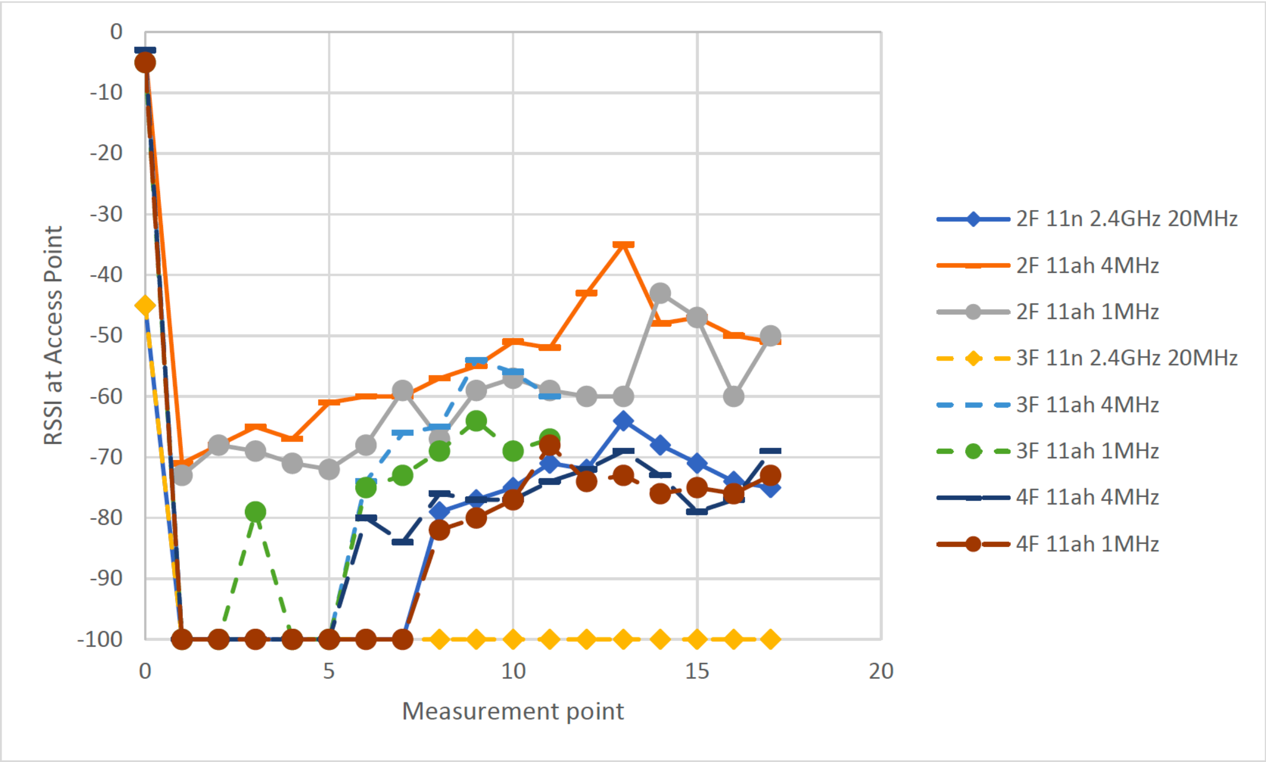

Figure 3: Received signal strength indicator (RSSI) shows wireless wireless signal strength according to the receiver; higher RSSI indicates better signal.

There are many industrial applications where wide-scale coverage and high data throughput are not required. IEEE 802.11ah is ideal for such applications. Furthermore, because these standards are designed for compatibility, customers can supplement their existing IEEE 802.11n infrastructure with IEEE 802.11ah access points to solve challenges that IEEE 802.11n cannot.

Conclusion

IEEE 802.11ah has proven to be a versatile solution for heterogeneous industrial environments. Experiments have shown that IEEE 802.11ah can meet reliability and low-latency demands up to a certain extent, allowing low-latency, coverage, and throughput sufficient for many indoor settings as well as outdoor. IEEE 802.11ah is often exempt from consideration for indoor and industrial applications; our testing shows promise both performance and value for long-range, mid-latency wireless communication.

More resources related to IEEE 802.11ah technology are available on Silex's website.