Technology: WLAN IEEE 802.11ad, WiGig

Abstract

Wireless Local Area Networks (WLAN) describe a bunch of very popular technologies for wideband data communication serving a vast number of use-cases and applications in different industrial and non-industrial environments. The most common WLAN technologies use different frequency bands, in the first place in the 2.4 GHz and 5 GHz ranges which are widely available for commercial and private in almost any region of the world. These bands are used by the WLAN evolution stages 4 and 5. Due to the fact that these frequency bands are shared with other technologies, there a limitations especially in terms of usable bandwidth and channels. Even though modern coding schemes and high-order modulation increased effective bandwidth constantly, especially in the 5 GHz bands, there is a need for higher throughput for a bunch of applications. This need was addressed within WLAN evolution stage 6 allowing very high throughput and multiple transmit and receive paths (also referred to as multiple input multiple output (MIMO)) as well as beamforming in order to increase the bandwidths available to the user.

But there are a bunch of applications requiring even more bandwidth than the low-GHz spectrum can provide. For example, the transmission of uncompressed high-definition video data demands for extremely high data rates up to Gigabits per seconds in the WLAN environment. For these applications, the requirements in terms of spatial coverage are manageable because most of the connections are indoors and often line-of-sight, so shielding effects by walls or

Source: Shutterstock

IEEE 802.11 physical layer evolution

Release Date	Standard	Wi-Fi Alliance Naming	Frequency Band	Max. Data Rate per Stream
1999	802.11b	Wi-Fi 1	2.4 GHz	11 Mbit/s
1999	802.11a	Wi-Fi 2	5 GHz	54 Mbit/s
2003	802.11g	Wi-Fi 3	2.4 GHz	54 Mbit/s
2009	802.11n	Wi-Fi 4	2.4 + 5 GHz	600 Mbit/s
2013	802.11ac	Wi-Fi 5	5 GHz	6.9 Gbit/s
2013/2016	802.11ah/af	-	< 1 GHz	35 – 234 Mbit/s
2021	802.11ax	Wi-Fi 6/6E	2.4/5/6 GHz	9.6 Gbit/s
2012	802.11ad	-	60 GHz	8 Gbit/s

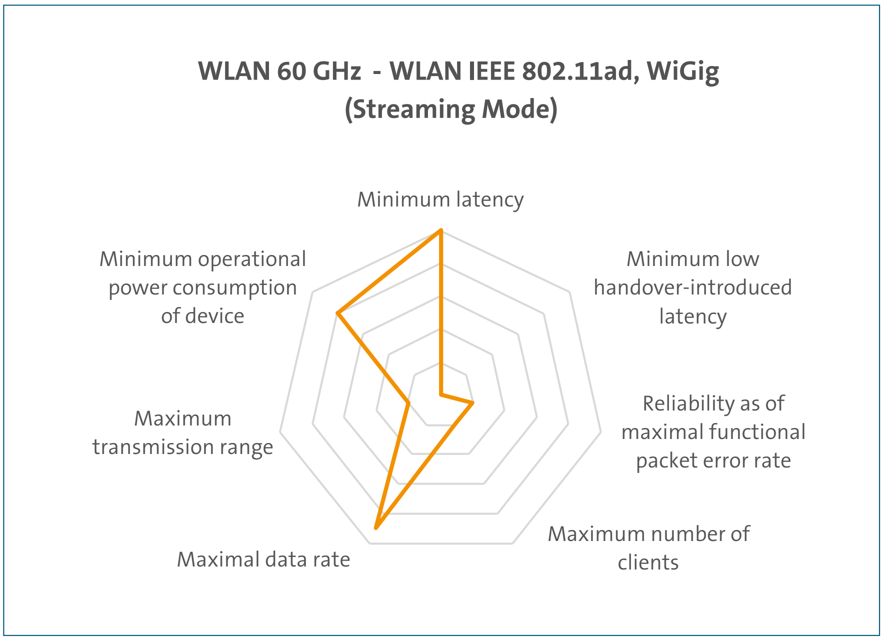
Table 1: IEEE 802.11 physical layer evolution

ceilings are not relevant. Hence, using very high frequency ranges is an option. The disadvantage of higher attenuation as oxygen absorption at the 60 GHz frequency range can be turned into the advantage of providing a very accurate spatial sharing of the spectral resources. Furthermore, small wavelengths allow compact designs and performant antenna systems in the scale of a few millimetres.

In industrial scenarios there are also some applications demanding very high bandwidths paired with low distances to cover. One example is a kiosk application transferring huge amounts of data between a mobile part and the network infrastructure, e.g. to transfer high-resolution video and photo data of a mobile camera to a fixed personal computer or network terminal. Further applications for the technology are wireless connections from terminal devices (e.g. laptops) to docking stations, video transmission from a mobile device to a TV screen or anywhere else as far as high throughput is needed within short distances.

All these requirements are addressed by the standard 802.11ad released by the Institute of Electrical and Electronics Engineers (IEEE) as a part of the 6th generation of WLAN standards. Due to the cooperation with the Wireless Gigabit Alliance and the Wi-Fi Alliance, the technology is also known as “WiGig”.

Technology Briefly



Note: Scale value “5” = best performance; scale value “0” = not specified. Source: cetecom advanced

The properties in this diagram have been defined by consensus within WCM-Working Group 2.

In addition to a consensual definition, the property values refer to requirements described in reference use cases. This is done to ensure a degree of comparability between wireless communication systems.

The reference use cases have been described by the WCM-Working Group 1, providing specific requirements for:

- Realtime / Ultra low latency communication (e.g. discrete manufacturing)
- Streaming/high data rate (e.g. video streaming)
- Massive Industrial Internet of Things (mIIoT) / Sensor Networks (e.g. valve status)

Property Definitions

Minimum Latency

Nominal achievable latency for the given reference use case and the associated functional packet error rate (FPER) property.

- Assuming that all clients are able to fulfill this latency requirement at the same time
- The latency is measured from reference input interface to reference output interface of the wireless communication system (e.g. Layer2/3)
- The latency and FPER of the spider diagram need to be achievable at the same time as they are linked together

Minimum Handover-Introduced latency

Minimum latency added to the nominal latency when a handover of a single device occurs for the given use case. Handover assumes operation of all devices of the usecase with the associated FPER.

Reliability as of maximal Functional Packet Error Rate, where Functional PER:

Percentage of data that is delivered later than the nominal latency for a given reference use case due to errors on the channel, late channel access, scheduling, or whatever other reason.

- Assuming that all clients are at the maximum range and at line of sight
- Assuming that all devices have to fulfill the same latency requirement (provided by the minimum latency property)
- Assuming that all clients fulfill the same FPER requirement
- FPER and latency of the spiderdiagram need to be achievable at the same time as they are linked together

Maximum number of clients

The maximum supportable number of clients for the given reference use case. This means the number of clients servable by one access point/base station/node in a meshed network/relay.

- Assuming that all devices in that scenario have the same communication requirements
- The available spectrum for the property is defined by the maximum bandwidth supported by the technology.
  It needs to be in line with the data rate property
- Per default the frequency regulation of Germany is referenced

Maximum Data Rate

The maximum/peak user data rate (payload) achievable per device for the given reference use case. Assuming that all devices in that scenario have the same communication requirements.

Minimum Operational Power Consumption of Device

Mean power consumption in Watt [W] for the given reference use case.

- This references the power consumption of a known device/node for that use case
- The time duration for the averaging is defined by the use case

Maximum Transmission Range

Maximum distance from a single transmitter to a single receiver

- Assuming maximum allowed transmission power (EIRP)
- Assuming typical receive antennas for the application
- The frequency band is also defined by the application
- Assuming line of sight communication

The “Technical Parameters” chart in the “Detailed Technology Description” section provides further information on these properties and other Key Performance Indicators (KIPs).

A brief description of the reference use cases can be found in the Appendix.

Disclaimer: This graph is based on the information provided by the authors of this chapter – a list of authors can be found at the end of the publication – available at the time of publication. It reflects an approximate performance of the communications system at a high level, based on the requirements specified in reference use cases.

This performance may of course vary depending on the degree of customization possible in defining the specific requirements for each industrial application and on the specific implementation. Thus, dialogue between the industrial user and wireless experts is encouraged to explore all possibilities.

High-level Technology Description

Topology

Being part of the IEEE 802.11 ecosystem, IEEE 802.11ad basically has the same topology as the well-known WLANs operating in the 2.4 GHz and 5 GHz bands. So the system is divided into master and slave devices, whereas the master devices are managing the frequency bands for the entire system. Mitigation techniques like Adaptivity, listen-before-talk and Dynamic Frequency Selection are applied by the devices as far as required for the used frequency bands. The hand-over procedure from one access point to another is controlled by the slaves (clients). Besides the described master-slave topology, peer-to-peer connections between clients are possible. The IEEE 802.11ad extension is not technically compatible with the WLAN standards in the 2.4 GHz and 5 GHz bands. It can be operated stand-alone but tri-band devices are capable to cover 2.4, 5 and 60 GHz, so seamless integration of IEEE 802.11ad into the 802.11 ecosystem is supported.

Interfaces

As the entire 802.11 ecosystem, WLAN 802.11ad is based on the underlying IP network. Interfaces following the definition for local area networks based on IP.

Time Behaviour

The channel access is based on the listen-before-talk mechanism Carrier Sense Multiple Access (CSMA) as typical for the WLAN ecosystem.

Spectrum

IEEE 802.11ad uses the unlicensed frequency band between 57 GHz and 71 GHz. This band is regulated differently in various countries. The entire band is divided into 6 channels, whereas 2 out of these 6 channels are not universally available. In the majority of countries, the channels 1-4 are free to use where channel 2 is the default channel. In the United States, all 6 channels can be used. Regulatory requirements for the European Union are covered by the radio test standard ETSI EN 302 567. The allowed maximum radio frequency (RF) output power is 40 dBm equivalent isotropic radiated power (EIRP) (10 W) with a maximum power spectral density of 23 dBm/MHz. There might be additional regional requirements regarding indoor/outdoor applications.

The channel numbers with its corresponding centre frequencies are as follows:

Channel no.	Center Frequency
Channel no. 1	58.32 GHz
Channel no. 2	60.48 GHz
Channel no. 3	62.64 GHz
Channel no. 4	64.80 GHz
Channel no. 5	66.96 GHz
Channel no. 6	69.12 GHz

Source: IEEE 802.11ad

Coexistence

The used frequency band is also available to other applications, e.g. tank-level probing radar systems, fixed outdoor datalinks or further non-specific short range usage taking into account adequate spectrum sharing mechanisms. Due to the short coverage, coexistence of different technologies will mainly be managed through spatial separation.

Maturity

During the last years, the implementation of the IEEE 802.11ad technology found its way into a number of client devices covering smart phones, laptops, TV screens and wireless docking stations for personal computers. Furthermore, network cards to extend existing devices are available. On the infrastructure side, several IEEE 802.11ad compatible WLAN access points and routers are available. As the “high-bandwith-low-coverage” scenario is still a niche for specific applications, the market penetration of IEEE 802.11ad compatible devices is relatively inert in comparison to the classical WLAN technologies.

Detailed Technology Description

Technical Parameters

Parameter	General KPIs
Protocol	IEEE, IP based
Frequency bands	57 - 71 GHz
Un-licensed frequency band	Yes
International coverage	EU, USA, Canada, South Corea, Japan, Australia, China, Singapur
Real-Time capability	No
Network topology	Base station (BS), point2point
Handover (mobility) support	Seamless roaming within the 802.11 environment
Voice support	Yes, but without QoS
Localization support	Fairly (based on infrastructure position, accuracy < 10m)
Coexistence mitigation mode	LBT, Adaptivity
MiMo capability	No, beamforming supported
Typical range BS - MS	< 10m
Typical latency BS - MS	~ 10 µs
Typical data rate	Up to 8 Gbps
Maximal number of active clients	8
Maximal lifetime when using a battery	Depends on the battery
Expected interference immunity	Poor
Likelihood of coexistence	Poor
Coexistence relevant bandwidth	See hopping waveform
Localization accuracy	cm
Technology maturity level	Mature
Product availability	2012
Standardization	IEEE
Standard availability	2012
Required Infrastructure on site	Access Point, none
Streaming Mode	
Nominal latency	10 µs
Maximal Functional Packet Error Rate	$< 10^{-1}$
Maximum number of clients	8

Parameter	General KPIs
Telegram size	Flexible
Maximal data rate MS downlink	max. 8 Gbps
Maximal data rate MS uplink	max. 8 Gbps
Maximal RF power [EIRP] downlink	40 dBm
Maximal RF power [EIRP] uplink	40 dBm
Mean power consumption in usecase	< 3 W
Maximum transmission range	10 m

Technology Description

802.11ad supports data rates up to 8 Gbit/s in three transmission modes: a robust mode with single carrier modulation, an energy-saving mode for mobile devices and a high-performance mode. Beamforming is applied to optimize the transmission path and compensate high free-space attenuation as well as interference effects.

The physical layer (PHY) includes a Directional Multi-Gigabit (DMG) capability. It applies high-level coding schemes to increase the data rate up to 8 Gbit/s using 64-QAM modulation (Quadrature Amplitude Modulation with 64 states). While the channel bandwidth is 2.16 GHz, six channels are available with some regional restrictions.

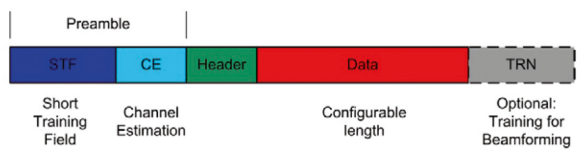


Figure 1: General packet structure in 802.11ad
Source: Rohde & Schwarz. "802.11ad – WLAN at 60 GHz, A Technology Introduction", White Paper http://www.rohde-schwarz.com/appnote/1MA220, accessed April 2022

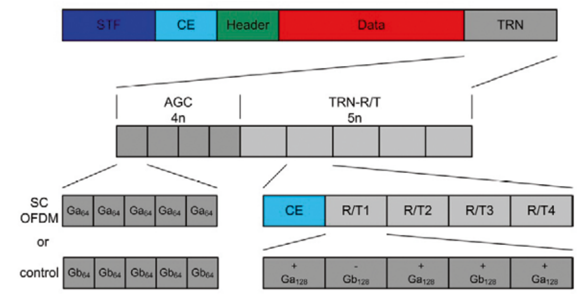


Figure 2: Beamforming training sequence.
Source: Rohde & Schwarz. “802.11ad – WLAN at 60 GHz, A Technology Introduction”, White Paper http://www.rohde-schwarz.com/appnote/1MA220, accessed April 2022

The DMG PHY consist of a Control PHY and a Single carrier PHY. Orthogonal Frequency Division Multiplex (OFDM) isn't supported in this evolution stage. The packet structure consists of a preamble, a header, the data sequence and a training sequence for beamforming. The Control PHY uses a robust modulation and coding scheme (MCS) applying Binary Phase-Shift Keying (BPSK) modulation. Thereby the single carrier modulation is able to use different MCS, according to the desired bandwidth, applying BPSK, Quadrature Phase-Shift Keying (QPSK) or Quadrature Amplitude Modulation up to QAM-64. The energy-saving mode does not use QAM and provides bandwidths up to 2.503 Gbit/s.

To encounter the disadvantages of high free-space loss in the 60 GHz band, IEEE 802.11ad introduces beamforming in real-time. The probability of attenuation effects due to moving objects is very high due to the relatively compact coverage range. In order to avoid loss of transmission in these cases, training sequences for beamforming can optionally be appended to all packages. The technology uses so called Golay complementary sequences for channel estimation (Source: Wireless LAN at 60 GHz – IEEE 802.11ad Explained, Application Note, Agilent Technologies). These sequences have the property that their out-of-phase aperiodic auto-correlation sums to zero. All training fields are transmitted with π/2-BPSK modulation which is a BPSK with the constellation shifted by 90 degrees in phase.

Outlook:

IEEE WLAN 802.11ad was introduced in 2012. Meanwhile, a further evolution was defined under IEEE 802.11ay. 802.11ay builds on 802.11ad and features an increased bandwidth up to 8.64 GHz resulting in a transmission rate up to 40 Gbit/s and introduces high-order modulation up to QAM-256, OFDM and MIMO up to 4 streams. The spatial coverage is extended from a few meters to 300-500 meters.

Application Reference

Application Specific Technology Description

Machine Vision / Bildverarbeitung

Current Situation
The key requirement of this application is to transmit high-definition video data from a camera to a fixed terminal where the data can be processed, analysed and stored. Cameras suited for machine vision applications can use different interfaces to connect to the industrial infrastructure. For example, Universal Serial Bus (USB) 2.0 and USB 3.0 connections are quite popular. For extremely high resolutions and frame rates exceeding 100 fps, network interfaces like Fast Ethernet, Gigabit Ethernet, or, in data-intensive scenarios, 5 or 10 GBit/s Ethernet connections are common (Source: GetCameras, website: https://www.get-cameras.com/How-to-select-a-machine-vision-camera-interface-USB3-GigE-5GigE-10GigE-Vision#, accessed on April 2022). Several cameras can be used within a small area, e.g. in order to reconstruct 3D objects from real-time images.

Pain Point
All mentioned interfaces are wired interfaces with the need to connect the camera device locally to the fixed station. Integration of moving cameras in production processes is therefore hard to set into practise. Wireless connections would have the benefit to solve this problem and allow moving cameras in a production environment, but bandwidth is rather limited as far as existing wideband data transmission technology like WLAN in the 2.4 and 5 GHz bands are used.

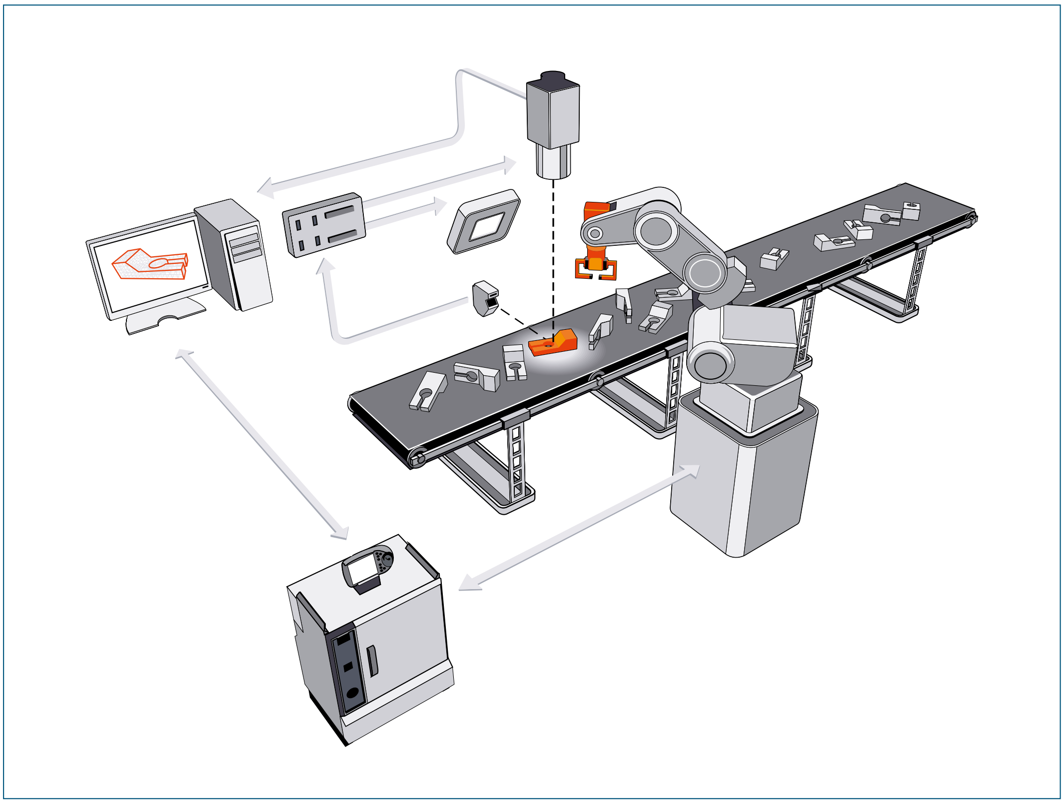


Figure 3: Machine vision
Source: MVTEC, 3D.Vision, website: https://www.mvtec.com/de/technologien/3d-vision, accessed on April 2022

IEEE 802.11ad (WLAN @ 60 GHz)

Pros	Cons
Easy to deploy following IEEE standards	Due to 60 GHz spectrum highly limited in coverage
Un-licensed spectrum only shared by few applications	Massive shielding effects and oxygen absorption
Nearly world-wide spectrum allocation	Relatively high energy consumption
Compact devices and antennas, small form factors	

Source: Own ellaboration

Wireless Solution
WLAN 802.11ad is well-suited to deliver the data of high-resolution cameras to a fixed point. With data rates in the range of several Gigabits per second, equivalent throughput compared with Gigabit networks or even 5 or 10 Gigabit networks can be achieved via a wireless link.

In the concrete example, a camera on a specific point within the assembly line which is monitoring a component during the assembly process can be equipped with a IEEE 802.11ad module instead of a wired Ethernet interface. This allows the camera to move during operation and offers the opportunity of real-time supervision of mobile component carriers or automated vehicles in the production. Any time the camera is moving to another station in the assembly line, it connects to an IEEE 802.11ad-compatible access point that is mounted within the line. Due to the excellent spatial separation which is related to the high-frequency physics of the applied technology, several access points can be mounted at specific points of the assembly line without any spectral conflict or interference between themselves.