IEEE Computer Society
802 LAN/MAN Standards Committee:
Connecting the World

Part II – IEEE 802 Wireless Standards

20 January 2021

Dorothy Stanley
Patrick Kinney
Paul Nikolich
Foreword

Per IEEE-SA Standards Board Bylaws, Nov 2019
At lectures, symposia, seminars, or educational courses, an individual presenting information
on IEEE standards shall make it clear that his or her views should be considered the personal
views of that individual rather than the formal position of IEEE.

Dorothy Stanley (dorothy.stanley@hpe.com)
• Chair, IEEE 802.11 Working Group
• HPE Fellow and head of standards strategy @ Aruba

Patrick Kinney (pat.kinney@kinneyconsultingllc.com)
• Chair, IEEE 802.15 Working Group
• Co-Chair / Chief Editor, ISA100.11a (ISA’s first standard on wireless industrial networks
• President, Kinney Consulting LLC

Paul Nikoich (p.nikolich@ieee.org)
• Chair, IEEE 802 LAN / MAN Standards Committee
• Chair, IEEE Technical Activities Board Committee on Standards
• Independent Consultant and Partner, YAS Broadband Ventures LLC
• IEEE Fellow
IEEE 802 LAN/MAN Standards Committee

- 2020 is our 40th Anniversary
- Standards for
  - Local Area Networks (LAN)
  - Metropolitan Area Networks (MAN)
  - Regional Area Networks (RAN)
  - Personal Area Networks (PAN)
  - Wireless Specialty Networks (WSN)

IEEE 802 produces high quality, market relevant standards
IEEE 802.11 Wireless LAN

Factors for 802.11 Market success

MAC/PHY Technology: 802.11ax and 6GHz: Wi-Fi 6, 6E
Extremely High throughput: 802.11be

Applications: Broadcast services, Positioning and Sensing

Presenter: Dorothy Stanley, IEEE 802.11 Working Group Chair
802.11 standards success

Regulatory support
Starting with 2.4 GHz, 5GHz, ongoing 6GHz
60GHz, sub 1 GHz spectrum availability

Low cost, accessible technology
Enables virtuous innovation cycle
Low barrier to entry for new services and business models
Enables significant economic growth and societal development

Market focused standards development
Consensus based, open process for standards development
Responsive to market, technology evolution
Internet access + mobile devices + IETF based protocol support

Backwards Compatibility
Deployed base can evolve per end customer needs
Customized products are developed using IEEE 802.11 systems for remote connectivity, disaster management, targeting developing countries.

Example: India Centre for development of Telematics
Example: Hughes Systems

Hughes Satellite-Enabled Community Wi-Fi Hotspots
Provide Affordable Internet Access Across Vast Areas of Russia; 1,300 Community Wi-Fi Hotspots enable Internet connectivity for more than 300,000 people
IEEE 802.11 systems are commonly used for emergency and disaster recovery communications

Liberty Global Teams to Provide Free WiFi in Puerto Rico


Wireless Network Recovery Following Natural Disaster: Puerto Rico after Hurricane Maria including “cellular backhaul being provided via WiFi”

### IEEE 802.11 Wi-Fi standard evolution

<table>
<thead>
<tr>
<th>Standard</th>
<th>Wi-Fi Generation</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11n (2009)</td>
<td>Wi-Fi 4</td>
<td></td>
</tr>
<tr>
<td>802.11ac (2013)</td>
<td>Wi-Fi 5</td>
<td></td>
</tr>
<tr>
<td>802.11ax (early 2021)</td>
<td>Wi-Fi 6 6E</td>
<td></td>
</tr>
<tr>
<td>802.11be (est. 2024)</td>
<td>Wi-Fi 7</td>
<td></td>
</tr>
</tbody>
</table>

- **802.11n (2009)**
  - Wi-Fi 4
  - 2.4GHz and 5GHz supported
  - Wider channels (40MHz)
  - Better modulation (64-QAM)
  - Additional streams (Up to 4)
  - Backward compatibility with 11a/b/g
  - Standard supports up to 600Mbps

- **802.11ac (2013)**
  - Wi-Fi 5
  - 5GHz only
  - Wider channels (80, 160MHz)
  - Better modulation (256-QAM)
  - Additional streams (Up to 8, implemented up to 4)
  - Backward compatibility with 11a/b/g/n
  - Standard supports up to 7Gbps

- **802.11ax (early 2021)**
  - Wi-Fi 6 6E
  - 2.4GHz, 5GHz and 6GHz supported
  - Wider channels (80, 160MHz)
  - Better modulation (1024-QAM)
  - Additional streams (Up to 8, implemented)
  - Backward compatibility with 11a/b/g/n/ac
  - Standard supports up to 9.6Gbps

- **802.11be (est. 2024)**
  - Wi-Fi 7
  - 2.4GHz, 5GHz and 6GHz supported
  - Wider channels (40, 80, 160, 240, 320MHz)
  - Better modulation (4096-QAM)
  - Additional streams (Up to 16)
  - Backward compatibility with 11a/b/g/n/ac/ax
  - Standard targets throughput minimum of 30Gbps, expect 40Gbps+

(Ratification date) Products available in the market typically ~2 years prior
Wi-Fi connects vehicles and international infrastructures in space

**Wi-Fi in Space: Wi-Fi enables next generation space exploration**

“The first Wi-Fi network in space was installed in January 2008 using Wi-Fi 4, the IEEE 802.11n standard.”

“In May 2020, Wi-Fi connected vehicles in space for the first time when the Japanese HTV-9 cargo transfer vehicle—operated by the Japan Aerospace Exploration Agency (JAXA)—demonstrated a high-definition, live video streaming application using Wi-Fi during its final approach to the Space Station.

“...it is hard to imagine the Space Station without Wi-Fi.” Chatwin Lansdowne, Subsystem manager for the IEEE 802.11-based wireless communications system, International Space Station
WFA Wi-Fi 6E Interoperability certification is now available: IEEE 802.11ax in the 6GHz band

Certification Announced 2021-01-07

Press release
Paper: Wi-Fi 6E: Wi-Fi® in the 6 GHz band
Wi-Fi 6E Highlights
Wi-Fi 6E Video animation
List of certified devices

Wi-Fi 6E brings Wi-Fi® into 6 GHz

<table>
<thead>
<tr>
<th>Features</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>More, contiguous</td>
<td>Gigabit speeds</td>
</tr>
<tr>
<td>spectrum</td>
<td></td>
</tr>
<tr>
<td>Wider channels</td>
<td>Extremely low latency</td>
</tr>
<tr>
<td>Less interference</td>
<td>High capacity</td>
</tr>
</tbody>
</table>

Significant Global Regulatory activity is ongoing for 6GHz WLAN operation

Regulators globally have/are deliberating 6GHz operation for economic, societal benefit

Countries/regions include

Argentina, Brazil, Canada, Chile
Columbia, Costa Rica, Honduras
Jordan, Mexico
Peru, South Korea
UAE, USA, EU, UK

Numerous Applications in 6GHz are envisioned

21st century factory: automation, robotics, parts tracking management and information services, connectivity aircraft

See
https://ecfsapi.fcc.gov/file/103050193427226/Boeing%20oral%20ex%20parte%20notice%20on%20legal%20advisors%203%204%202020.pdf

A Substantial Need Exists to Permit Unlicensed Use Inside Aircraft Using the U-NII-5 Through U-NII-8 Bands

- Airlines and their passengers want to use wireless devices to access video, audio and internet content and for inflight IoT
  - Boeing aircraft already use both the 2.4 and 5 GHz unlicensed bands to support the needs of passengers and flight crew
  - Access to more unlicensed spectrum is needed to accommodate new applications and continuously growing demand
The 802.11be Extremely High Throughput amendment builds on 802.11ax, including 6GHz support

Extremely High Throughput (EHT)

Operation in 2.4 GHz, 5 GHz, and 6 GHz bands

Higher throughout – Project goal of at least 30 Gbps; expect 40+Gbps with 320MHz channels, 4096 QAM, 16x16 MU-MIMO

Support for low latency communications

Continued improvements in spectral efficiency

Targeted completion in 2024

Use Cases:
- Home, enterprise, industrial, IoT
- Outdoor
- AR/VR
- 4K and 8K video streaming
- Remote office
- Cloud computing
- Video calling and conferencing
IEEE 802.11ax meets the MAC/PHY requirements for 5G IMT-2020 Indoor Hotspot and Dense urban test environments defined by ITU-R

Simulation conforming to the ITU-R evaluation methodology shows that performance of IEEE 802.11ax systems meet or exceed MAC and PHY requirements for the 5G Indoor Hotspot and Dense Urban test environments.

<table>
<thead>
<tr>
<th>Metric (Indoor Hotspot)</th>
<th>ITU-R Evaluation Method</th>
<th>Minimum Requirement</th>
<th>802.11ax Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Peak data rate</td>
<td>Analytical</td>
<td>DL/UL : 20/10 Gbps</td>
<td>DL/UL : 20.78 Gbps</td>
</tr>
<tr>
<td>2 Peak spectral efficiency</td>
<td>Analytical</td>
<td>DL/UL : 30/15 bits/s/Hz</td>
<td>DL/UL : 58.01 bits/s/Hz</td>
</tr>
<tr>
<td>3 User experienced data rate</td>
<td>Analytical for single band and single layer; Simulation for multi-layer</td>
<td>Not applicable for Indoor Hotspot</td>
<td>Not applicable</td>
</tr>
<tr>
<td>4 5&lt;sup&gt;th&lt;/sup&gt; percentile user spectral efficiency</td>
<td>Simulation</td>
<td>DL/UL : 0.3/0.21 bits/s/Hz</td>
<td>DL/UL : 0.45/0.52 bits/s/Hz</td>
</tr>
<tr>
<td>5 Average spectral efficiency</td>
<td>Simulation</td>
<td>DL/UL : 9/6.75 bits/s/Hz/TRxP</td>
<td>DL/UL : 9.82/13.7 bits/s/Hz/TRxP</td>
</tr>
<tr>
<td>6 Area traffic capacity</td>
<td>Analytical</td>
<td>DL : 10 Mbit/s/m&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Required DL bandwidth = 170 MHz with 3 TRxP/site</td>
</tr>
<tr>
<td>7 Mobility</td>
<td>Simulation</td>
<td>UL : 1.5 bits/s/Hz</td>
<td>UL : 9.4 bits/s/Hz</td>
</tr>
<tr>
<td>8 Bandwidth</td>
<td>Inspection</td>
<td>100 MHz, scalable</td>
<td>20/40/80/80+80/160 MHz</td>
</tr>
<tr>
<td>9 User plane latency</td>
<td>Analytical</td>
<td>DL/UL : 4 ms</td>
<td>DL/UL : 80 us</td>
</tr>
</tbody>
</table>
New Usage Models/Features

Indoor Location
802.11az – 2nd generation positioning features

Automotive
802.11bd – Enhancements for Next Generation V2X

Internet of Things, Low Power applications
802.11ba – Wake-up Radio

Target Wait Time for Low power devices (11ah, 11ax)

802.11p seamless evolution
802.11bc defines Enhanced Broadcast Services

Client end devices broadcast information to an AP, e.g. in an IoT environment, to other STAs so that any of the receiving APs act as an access node to the Internet. Uplink, downlink services include IoT, local content delivery.
Next Generation Positioning P802.11az project is the evolutionary roadmap of accurate 802.11 location (FTM) appearing first in previous revisions of the 802.11 standard:

- Accurate indoor Navigation (sub 1m and into the <0.1m domain).
- Secured (authenticated and private) positioning – open my car with my smartphone, position aware services (money withdrawal).
- Open my computer with my phone/watch.
- Location based link adaptation for home usages (connect to best AP).
- Navigate in extremely dense environments (stadia/airport scenarios).
802.11bf WLAN sensing

- WLAN sensing is the use of received WLAN signals to detect features of an intended target in a given environment.
  - Measure range, velocity, angular, motion, presence or proximity
  - Detect objects, people, animals: Enables touchless applications
  - Use in room, house, car, enterprise environments

- Target frequency bands are between 1 GHz and 7.125 GHz (MAC Service interface) and above 45 GHz (MAC/PHY)

- Some use cases

  ![Smart home](https://www.cse.ust.hk/~qianzh/research/sensing-2.jpg)


  ![Gaming control](https://www.bp.blogspot.com/-4T0eZ8yEAbM/AAAZ46A4AIAI/EC/166216605.png)


- Note: The specification of applications that make use of WLAN sensing measurements is beyond the scope of P802.11bf.
Wi-Fi /802.11 technologies continue to be a foundation for innovative solutions

**Project Owl: IBM-backed project**  
**Creates Wi-Fi Network for Natural Disasters**

“Project Owl managed to create a live internet network across one square mile using 23 DuckLinks, communicating via the system in areas without cell reception.”

“…..create a special Wi-Fi network spanning more than 100 square miles that can be used to connect victims and first responders.”
Useful Links & Thank you!

• 802.11 home page: http://ieee802.org/11/
• Help if you want to contribute: http://www.ieee802.org/11/help.html
• 802.11 document server: https://mentor.ieee.org/802.11/documents
• Wi-Fi Alliance http://www.wi-fi.org/
• Get 802.11 standards:
  • http://standards.ieee.org/about/get/802/802.11.html
  • http://www.techstreet.com/ieee
Standards from the IEEE 802.15 Wireless Specialty Networks (WSN) Working Group

2021 January
Presenter: Patrick Kinney, IEEE 802.15 Working Group Chair
The Wireless Specialty Networks (WSN) work group, 802.15, develops standards for many diverse applications requiring special networks not found in the LAN or WAN marketplace. These applications range from RFID active tags to body-implantable devices, from utility meters to pipeline monitoring, and from kiosks requiring short range with very high throughput to long range, broadband networks.
IEEE 802.15 Standards

- IEEE 802.15.3
  High Data Rate Multi-Media Networks

- IEEE 802.15.4
  Low Rate Networks

- IEEE 802.15.9
  Key Management Protocol

- IEEE 802.15.10
  Layer 2 Routing Protocol

- IEEE 802.15.12 (not yet approved)
  Upper Layer Interface for IEEE 802.15.4 Low Rate Networks

- IEEE 802.15.6
  Body Area Network

- IEEE 802.15.7
  Optic Communication Using Visible Light

- IEEE 802.15.8
  Peer Aware Communications

- IEEE 802.15.13 (not yet approved)
  Multi Gigabit per second Optic Communications

- IEEE 802.15.16t (not yet approved)
  Air Interface for Broadband Wireless Access Systems
IEEE Std 802.15.3

Very fast join, and upload or download (<1 sec)

Public Area

User Devices: Smartphone, Mobile pad,

Private Area

User Devices: Wireless Storage

100 Gb/s data rate for data centers or wireless videos

Toll Gate

Kiosk

Wireless Memory

Dual SDD

IEEE Std 802.15.4 along with IEEE 802.15.9 and IEEE 802.15.10 as ancillary standards

Using a mesh configuration to extend connectivity beyond the range of a single device while maintaining the device’s battery life of over 10 years has always been a key aspect of 802.15.4.

Connectivity and efficient use of bandwidth have always been at the core of the IEEE 802.15.4 standard. The IEEE 802.15.4 standard defines occupied bandwidths over a large range, i.e. from narrow band (NB) to ultra wide-band (UWB).

- Devices complying with the NB sections of the standard can exhibit transmit ranges of up to 20 km.
- Devices designed as per the UWB sections of the standard can demonstrate range determination accuracies, in support of location awareness, down to 10 centimeters.

The IEEE 802.15.9 and IEEE 802.15.10 standards provide a key management protocol and a layer 2 routing protocol, respectively, for IEEE 802.15.4 devices.
Technologies supported by IEEE Std 802.15.4

Physical Layer
- Ultra Wide Band (UWB)
- Narrow Band (NB)

Media Access Control sublayer
- Security
- Time Slotted Channel Hopping (TSCH)
- Mesh Networking

Link Layer Control sublayer
- Key Management Protocol (KMP) via IEEE Std 802.15.9
- Layer 2 Routing for Mesh Networking (L2R) via IEEE Std 802.15.10
Applications using the 802.15.4 standard (1)

**Sensing and Controller applications**

- Smart Utility Meters (e.g. electric, gas, water) using mesh networks to replace the need for wired connectivity
- Pipeline integrity (e.g. water, petroleum, gas) using NB for long ranges
- Railway in applications such as positive train control
- Industrial Automation sensors and controllers (e.g. Wireless HART, or ISA 100) using TSCH for deterministic behavior
- Commercial building lighting control networks using mesh networks to eliminate the need to run extra cables for connectivity
- Consumer electronics such as cable/set top boxes, integrated A/V and home theatre control
- Home Automation applications such as remote controls, lighting, and HVAC controls
Applications using the 802.15.4 standard (2)

**Ranging applications**
- Automotive wireless key devices
- Network device locations
- Access Control

**RFID applications**
- Industrial asset tracking
- Augmented Reality (AR)
  - UWB is sufficiently accurate to allow the tracking software to incorporate AR to let users visualize where their items are on a screen
802.15.6 Body Area Network (BAN)

A standard for a short range, low power, and highly reliable wireless communication for use in close proximity to, or inside, a human body.

- Provides communication links in and around the body
- Allows communications between sensors, actuators and processing elements
BAN Applications

Physiological and vital signals monitoring

Neuro-stimulator

Remote control of medical devices

Disability assistance

Elderly People Assistance

Fitness Monitoring

Wearable Audio - Video
IEEE 802.15.7 Visible Light Communication (VLC)

- Access to several hundred THz of unlicensed spectrum
- Avoidance of electromagnetic and RF interference
- Additional security of allowing user to see where the channel is being directed with no eavesdropping beyond walls
- Augment and complement existing services, such as illumination, display, indication, decoration, from existing visible light sources.
IEEE 802.7 VLC Application Scenarios

- Peripheral Interface
  - E-display
  - Contents Machine
  - Sign Board

- Information Broadcast
  - TS Navigation
  - Warning
  - Ad

- RF Prohibited
  - Door Lock
  - Security Banking
  - Digital Hospital

- Visible LAN

Bandwidth Security

Coverage Mobility
The IEEE 802.15.16t project specifies operation in licensed spectrum with channel bandwidths greater than or equal to 5 kHz and less than 100 kHz. A new PHY will be specified, with changes to the MAC as necessary. While frequency independent it focuses on spectrum less than 2 GHz. Aggregated operation in adjacent and non-adjacent channels will be supported.
IEEE 802.15.16t application support

IEEE 802.15.16t will be a standard air interface protocol focused on long range wireless communication requirements of mission critical organizations including electrical utilities, oil and gas, rails, UAVs, government security and others.

802.15.16t will support a wide range of applications:

- Low throughput remote command and control applications referred to as Mission Critical Internet of Things (MC-IoT). These applications are best described by message length, periodicity, reliability, and latency in downlink and in uplink.

- Higher throughput applications, e.g. those data streaming (video/audio). These are best characterized by throughput, latency/jitter, and reliability in downlink and uplink.
Interest Group UWB-Next Generation (1)

The IEEE Std 802.15.4z was approved in 2020. This UWB standard addresses the automotive Wireless Key market as well as other high-volume markets. Application needs include high security (communications and location), low power (button cell battery), short communication packets, accurate and consistent ranging determination. Devices complying to IEEE Std 802.15.4z are in today’s mobile phones, smart watches, and many automobiles.

The IEEE 802.15.4z marketplace is expected to grow significantly in the next 4 - 5 years due to smartphones, smartphone, accessories, automotive wireless keys, as well as IoT devices as shown on the next slide.
Updated Market Forecast for devices using UWB technology

- Based on TSR 2020 UWB Market Report, but UWB Smartphone Accessories for Smartphones will drive a 1:1 chip ratio with Smartphones by 2025, producing an estimated total $2.3B of Chip Revenue Annually.
- UWB is being incorporated into high-end smartphones NOW, as well as accessories.
The Interest Group UWB next generation will be working on its strategy to enhance the IEEE 802.15.4 UWB standard to best enable future device uses such as:

- Increasing the speed of UWB to:
  - Sending files securely to other devices identified by their location
  - Low latency high quality audio, enabling spatial or immersive audio

- Enhancing the location accuracy to:
  - Enable an AR display to help you locate other UWB devices such as smart home devices, including fans, air purifiers, robo-vacuums, around your house
  - Support indoor mapping functions that could potentially guide you to specific stores or kiosks in places like a mall.

- Decreasing the energy usage of UWB ranging allow smart home devices like smart locks to communicate faster and more securely
Key Links

- The Global Impact of IEEE 802’s Standards
- IEEE 802 Home Page
- IEEE 802.3 Home Page
- IEEE 802 Executive Committee Members
- IEEE 802 Document Repository
- IEEE 802 Meeting Calendar

Follow IEEE 802 on LinkedIn
Follow IEEE 802 on Twitter (@IEEE802)
THANK YOU

To get involved with IEEE 802: