IEEE 802.11: Future of Wi-Fi Standards

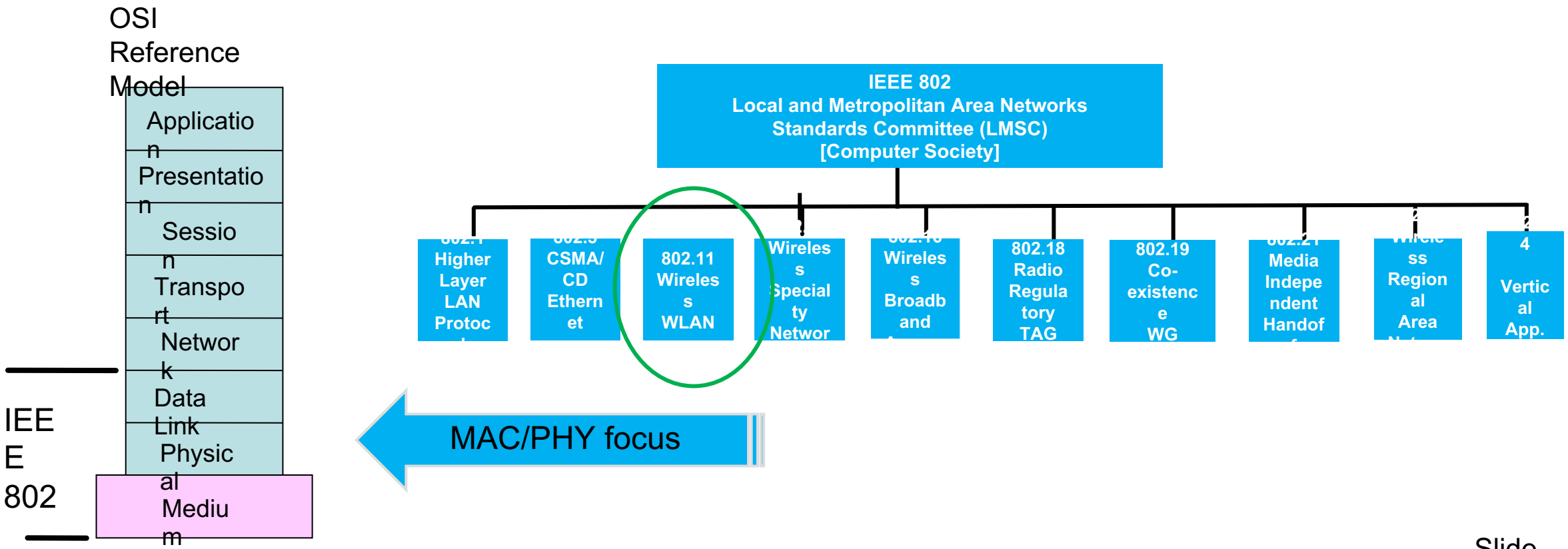
IEEE 802.11 standard & amendment status
6GHz: 802.11ax, 802.11be technology & beyond
New work areas, 802.11az & ranging

2023 February
Presenter: Dorothy Stanley, IEEE 802.11 Working Group Chair

IEEE 802 LAN/MAN Standards Committee standard development covers both Wireless & Wired Media

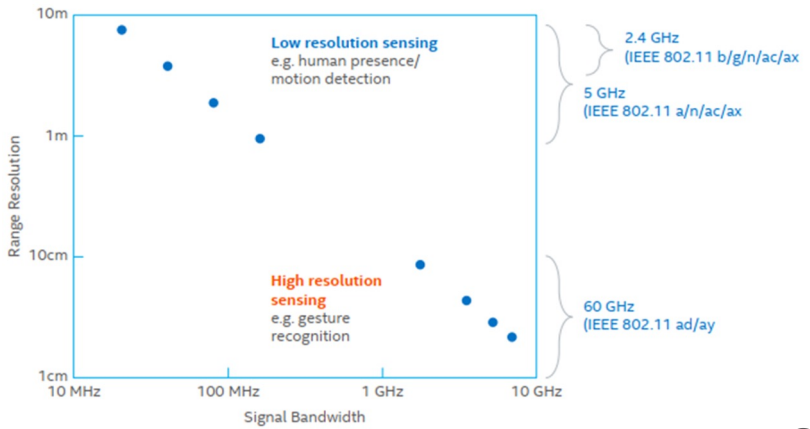
Focus on **link and physical layers** of the network stack

Leverage IETF protocols for upper layers



New 802.11 Radio technologies are under development to meet expanding market needs and leverage new technologies

- 802.11az – 2nd generation positioning features (2022)
- 802.11bb – Light Communications
- 802.11bc – Enhanced Broadcast Service
- 802.11bd – Enhancements for Next Generation V2X (2022)
- 802.11be – Extremely High Throughput in 2.4, 5 and 6 GHz bands, aka Wi-Fi 7
- 802.11bf – WLAN Sensing
- 802.11bh – Randomized MAC Addresses
- 802.11bi – Enhanced Data Privacy
- P802.11bk – 320 MHz Ranging



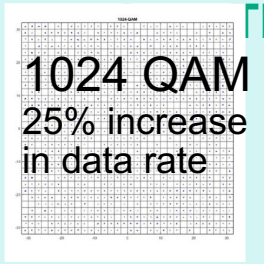
IEEE802.11 Wi-Fi standard evolution

802.11n (2009) Wi-Fi 4	802.11ac (2013) Wi-Fi 5	802.11ax (2021) Wi-Fi 6 6E	802.11be (est. 2024) Wi-Fi 7
• 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	• 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	• 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	• 2.4GHz, 5GHz and **6GHz** supported • Wider channels (40, 80, 160, 240, **320MHz**) • Better modulation (**4096-QAM**) • 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

Products implementing 802.11ax-2021 are in the market now: Wi-Fi 6, 6E
2022: 2.3 Billion Wi-Fi 6 devices, 350 Million Wi-Fi 6E, 4.4Billion devices total

Spectral Efficiency & Throughput



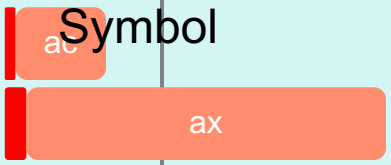
1024 QAM
25% increase in data rate

DL/UL MU-MIMO w/ 8 clients

8x8 AP

2x increase in throughput

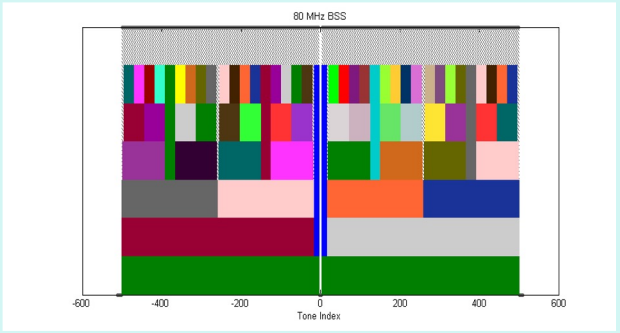
Long OFDM Symbol



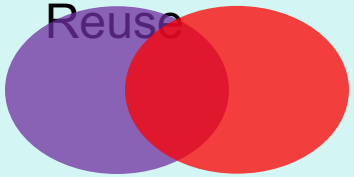
Up to 20% increase in data rate

High Density

OFDMA

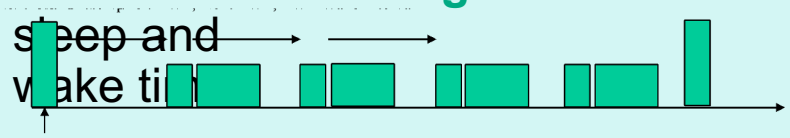


Spatial Reuse

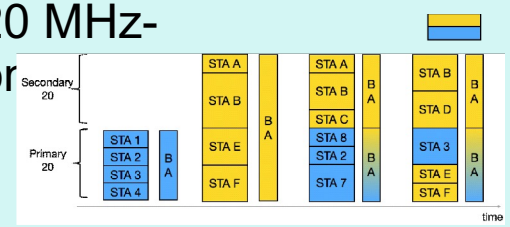


Power Saving

Scheduled sleep and wake ti

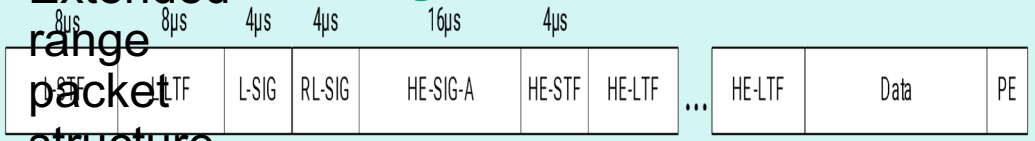


20 MHz-or



Outdoor / Longer range

Extended range packet structure



Enhanced delay spread protection-long guard interval

0.8us 11ac

1.6us 11ax

3.2us 11ax

P802.11be features support increased throughput and performance

Throughput and spectral efficiency

- 320 MHz bandwidth operation
- 16 Spatial Streams and 4096-QAM (Quadrature Amplitude Modulation)
- Multi-band/multi-channel aggregation and operation (MLO)
- Multiple Resource Unit Operation (MRU)
- MIMO protocol enhancements, Enhanced Sounding protocol

Low latency

- Multi-band/multi-channel aggregation and operation (MLO)
- Target Wait Time (TWT) enhancements and Restricted-TWT
- TXOP Sharing
- Stream Classification Service Enhancements
- National Security and Emergency Preparedness (NSEP) priority access operation

Enhancements re: 6 GHz support

- Static Puncturing to avoid pre-defined 20 MHz subchannels, supports efficient 6GHz operation
- GCMP-256 support (High performance cipher)

Use Cases:

- Home, enterprise, industrial, IoT
- Outdoor
- AR/VR
- 4K and 8K video streaming
- Remote office
- Cloud computing
- Video calling and conferencing

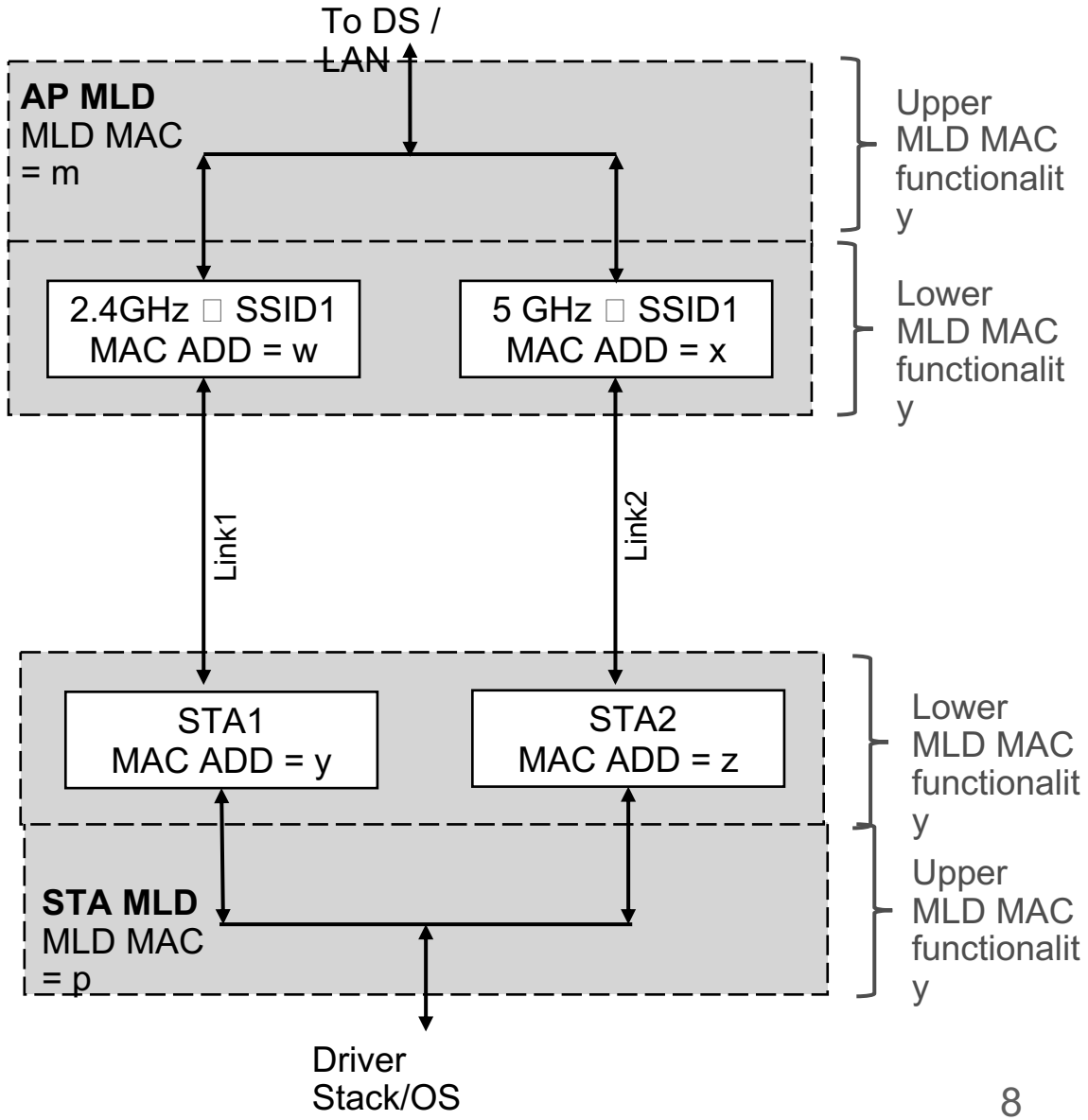
Use of 320 MHz channels provides Extremely High Throughput in a single channel

- Doubles the data rate from 802.11ax previous maximum of 160 MHz
  - 160 MHz: Single stream device: 1200 Mbps (1.2Gbps), 2x2 stream is 2400 Mbps, 4x4 is 4800 Mbps
  - 320 MHz: Single stream device: 2400 Mbps (1.2Gbps), 2x2 stream is 4800 Mbps, 4x4 is 9600 Mbps
- 320 MHz bandwidth channels are only applicable in 6 GHz band: two adjacent 160 MHz channels.
- Two types of channelization are defined: 320 MHz-1 and 320 MHz-2.
  - 320 MHz-1 has channel center frequencies numbered 31, 95, and 159.
  - 320 MHz-2 has channel center frequencies numbered 63, 127, and 191.

Channels	1	5	9	13	17	21	25	29	33	37	41	45	49	53	57	61	65	69	73	77	81	85	89	93	97	101	105	109	113		117	121	125	129	133	137	141	145	149	153	157	161	165	169	173	177	181	185	189	193	197	201	205	209	213	217	221	225	229	233
20	##	##	##	##	##	##	##	##	##	##	##	##	##	##	##	##	##	##	##	##	##	##	##	##	##	###	6475	###	###		###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###
40	5965		6005		6045		6085		6125		6165		6205		6245		6285		6325		6365		6405		6445		6485		6525		6565		6605		6645		6685		6725		6765		6805		6845		6885		6925		6965		7005		7045		7085			
80	5985				6065				6145				6225				6305				6385				6465				6545				6625				6705				6785				6865				6945				7025							
160	6025								6185								6345								6505								6665								6825								6985											
320-1	6105																								6425																6745																			
320-2									6265																6585																				6905																	

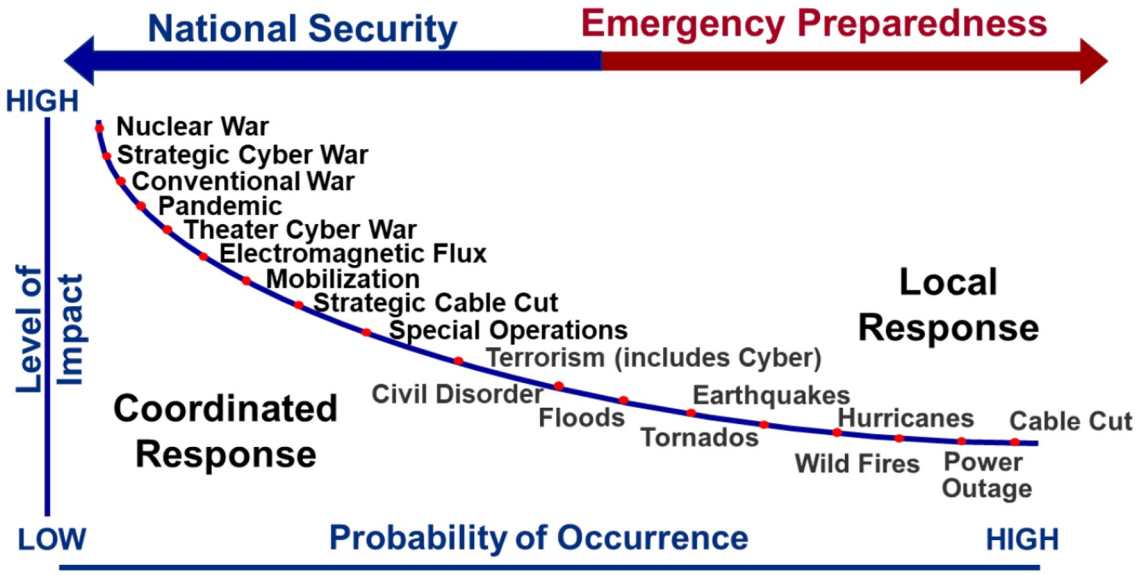
Multi-Link Operation (MLO) enables more than one link between an AP and STA in a BSS

- New AP and STA MLDs are defined which contain MAC functionality for more than one link in a BSS.
- An example of STA MLD associated to an AP MLD with two links (2.4 GHz and 5 GHz) on SSID1 is shown on the right.
- Upper MLD Functions include Association, Security Association establishment and Link selection
- Lower MLD functions include Channel Access, Control frame processing, frame transmission, power save state management
- Benefits include the ability to direct frames to one or both of the links.



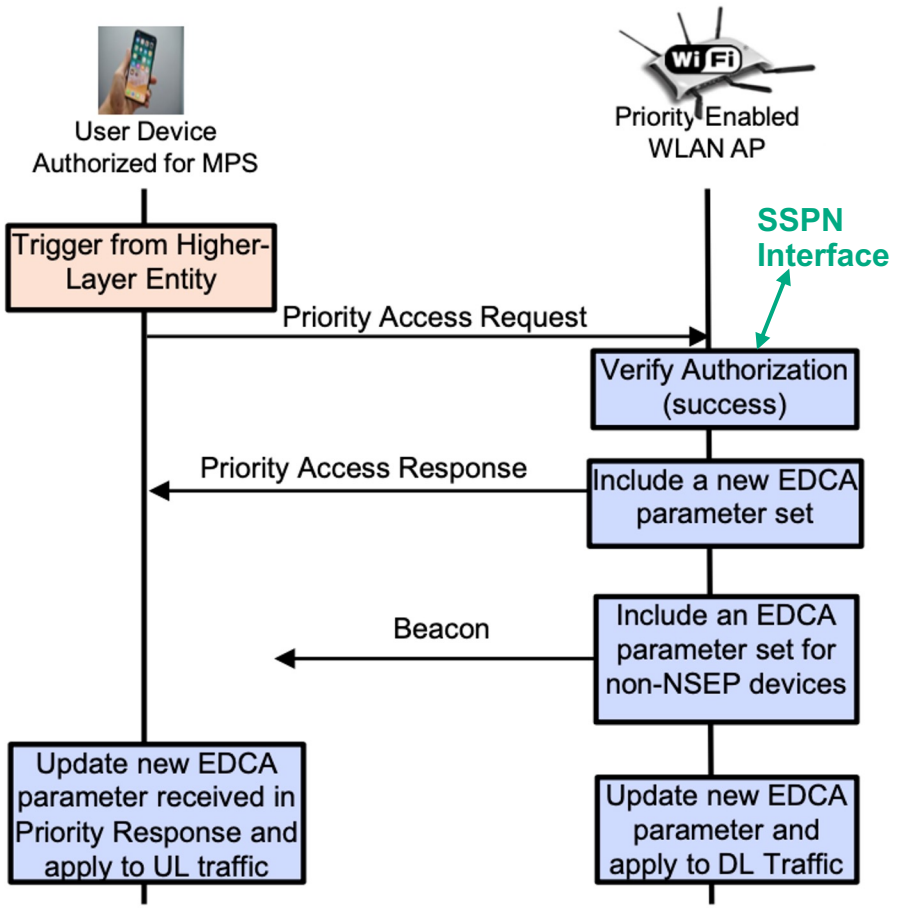
National Security and Emergency Preparedness (NSEP) communication services provide priority for voice and data exchanges on public networks.

- **Emergency Preparedness Communications Service (EPCS)** priority access is intended to bring capabilities to 802.11-based networks to support such priority (NSEP) services.
- EPCS priority access provides system resources for *authorized* devices to increase their probability of successful communication during periods of Wi-Fi network congestion.
- Use Case (with a real example): In the aftermath of Hurricane Katrina, T-Mobile offered free Wi-Fi access to everyone through their network that included Wi-Fi hotspot locations. In such situations, the survivors need network access but also the search and rescue workers, firefighters ,etc. EPCS gives priority wireless medium access to the rescue workers and firefighters when there is Wi-Fi congestion.
- This is an optional feature; anticipated to be used in managed networks (enterprise, operator hotspot, and similar.)



National Security/ Emergency Preparedness Operation

- A user device (MLD capable) begins the EPCS setup using a EPCS Priority Access Request frame.
- The AP MLD verifies that the user device is authorized (via SSPN)
  - and then sends a EPCS Priority Access Response frame with SUCCESS status code and an EDCA (and MU-EDCA if applicable) parameter set per setup link.
  - If the authorization does not succeed or for any other reason the AP MLD deems the user device should not use EPCS, the AP MLD sends EPCS Priority Access Response frame with EPCS_DENIED_UNAUTHORIZED or EPCS_DENIED_OTHER_REASON respectively.
- After set-up, the new EDCA parameter set(s) is used by the user device on its respective link(s). The AP MLD may also adjust its non-EPCS EDCA parameters and broadcast them in Beacon for non-NSEP devices.
- At any point, any one of the endpoints can send a EPCS Priority Teardown frame to disable the EPCS mode of operation.
- Also see https://mentor.ieee.org/802.11/dcn/22/11-22-1074-01-0wng-priority-access-fcc-r-o-and-additional-use-cases.pdf

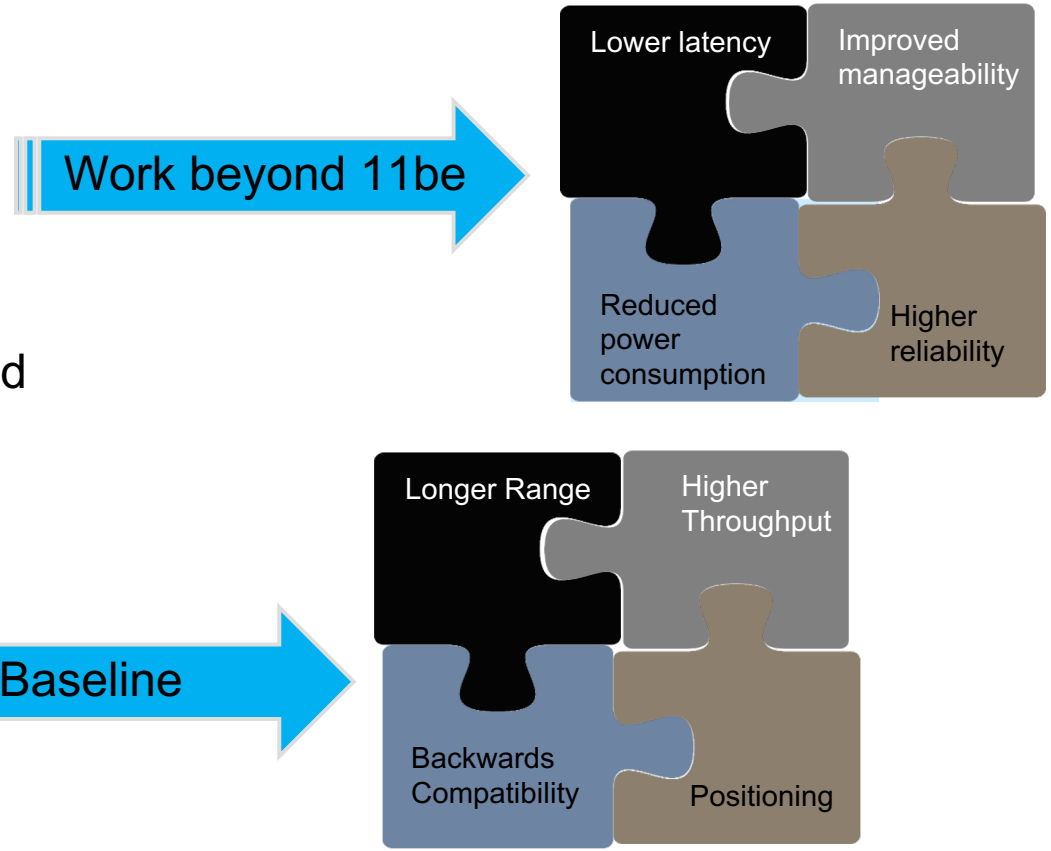


UHR SG: Ultra High Reliability Study Group was approved in July 2022 to define scope and purpose of next MAC/PHY project

The Study Group will investigate technology to

improve reliability of WLAN connectivity,
reduce latencies,
increase manageability,
increase throughput including at different SNR levels, and
reduce device level power consumption

The Task Group to start work in November 2023



AIML TIG: Investigate WLAN support of Artificial Intelligence/ Machine Learning

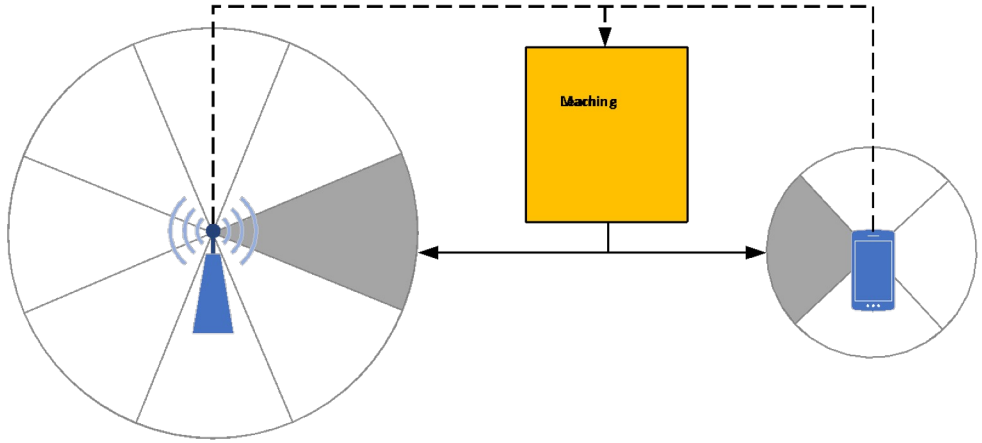
Use of AIML for 802.11 applications is an active area of work in the research community. See Applying ML to 802.11: Current Research and Emerging Use Cases

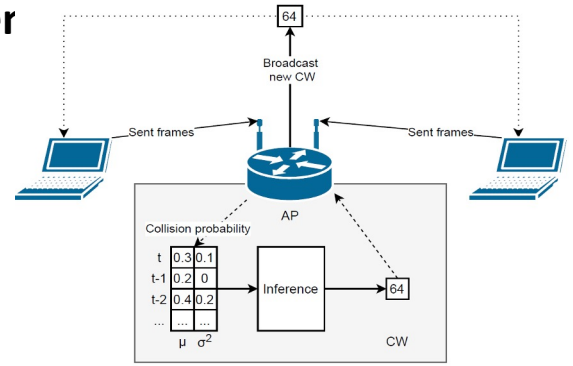
Current applications focus on performance improvement parameter selection for channel access control and link adaptation, multi-user parameters, contention window sizes, channel usage

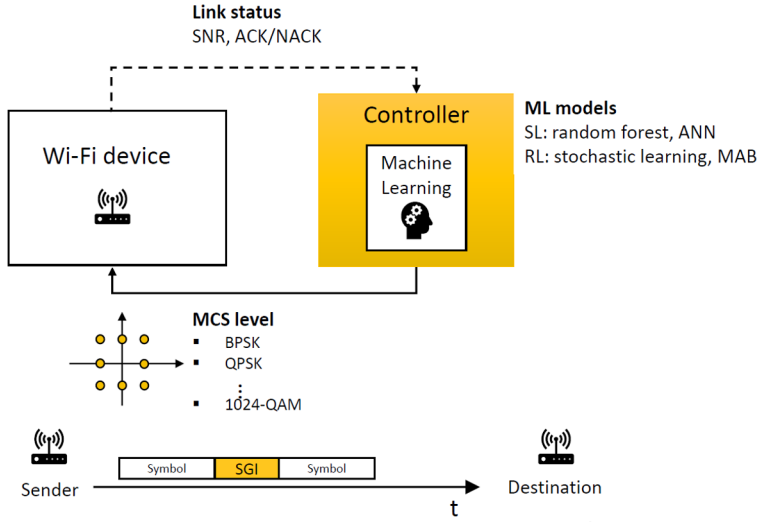
Focus of the 802.11 AIML Topic Interest Group is to

Describe use cases for Artificial Intelligence/Machine Learning (AI/ML) applicability in 802.11 syster

Investigate the technical feasibility of features enabling support of AI/ML.





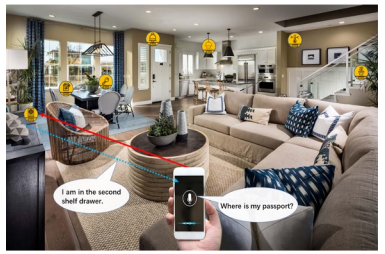


AMP TIG: Investigate WLAN support of Ambient Power

Research into ambient power (energy harvesting) and prototype development has been ongoing using 802.11 based devices

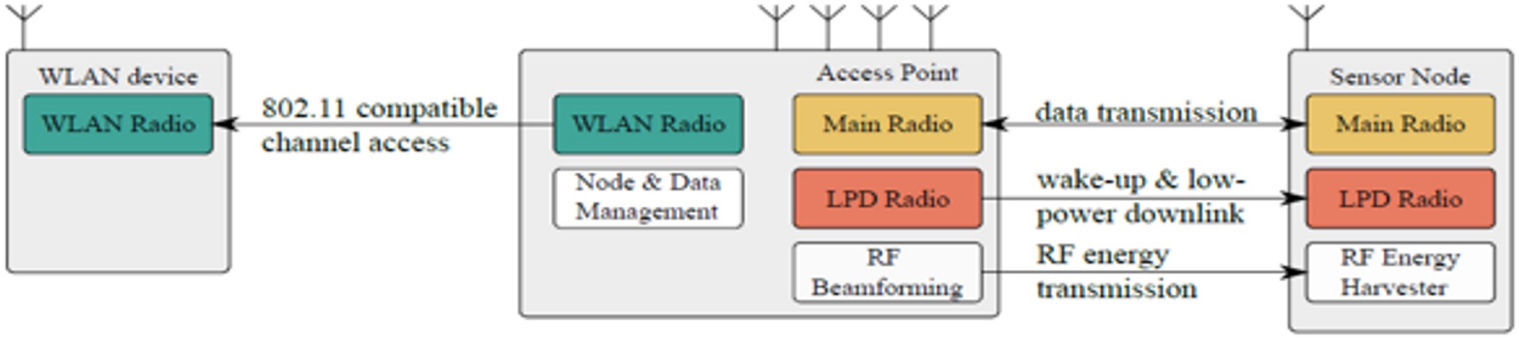
Optimizing M2M Energy Efficiency in IEEE 802.11ah, IEEE GLOBECOM 2015

"the battery dependency of an 802.11ah sensor is significantly lowered by energy harvesting provided that the sensor size and energy harvesting efficiency are sufficient for the utilized ambient energy source."



Low-Power Downlink for the Internet of Things using IEEE 802.11-compliant Wake-Up Receivers, IEEE INFOCOM 2021

Use Cases include Smart Home, Logistics/Warehouse/Inventory, Industrial Wireless Sensor Networks



See https://mentor.ieee.org/802.11/dcn/22/11-22-0645-02-0wng-ambient-power-enabled-iot-for-wi-fi.pptx

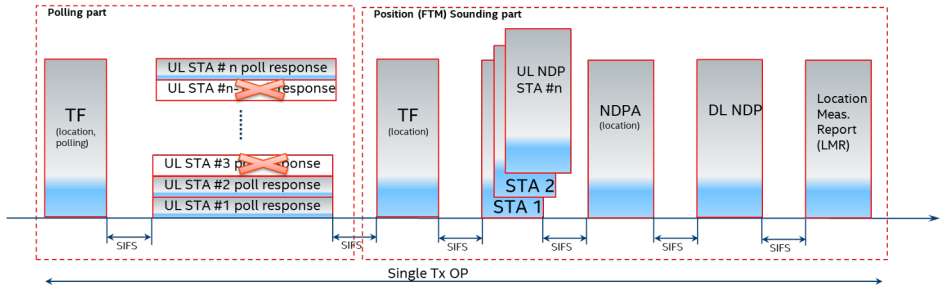
P802.11az Next Generation Positioning (ratified 2022)

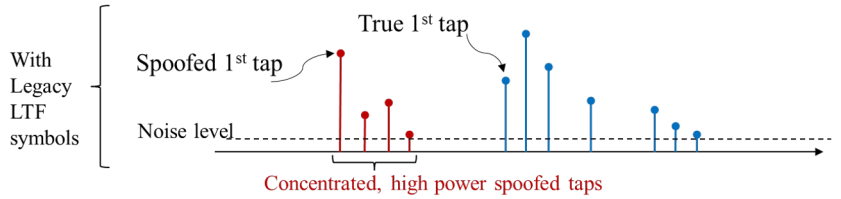
P802.11az project Next Generation Positioning extends accurate IEEE Std 802.11-2016 Fine Timing Measurement capabilities

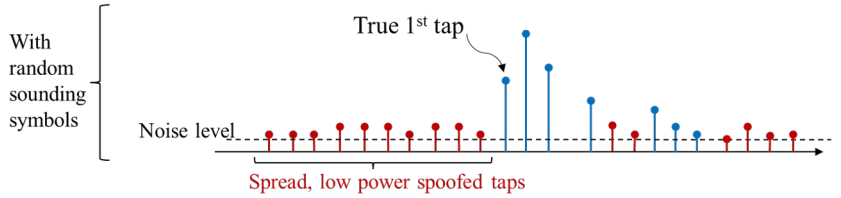
- Accurate indoor Navigation (sub 1m and into the <0.1m domain).
- Enables self-locating networks for easy, fast and cost efficient WLAN deployment for navigation and 6GHz AFC operation.
- Secured (authenticated and private) positioning – open my car with my smartphone, position aware services (money withdrawal).
- Unlock computer with a wearable device, adapt TV content to audience presence.
- Location based link adaptation for home usages (connect to best AP).
- Navigate in extremely dense environments (stadium/airport scenarios).

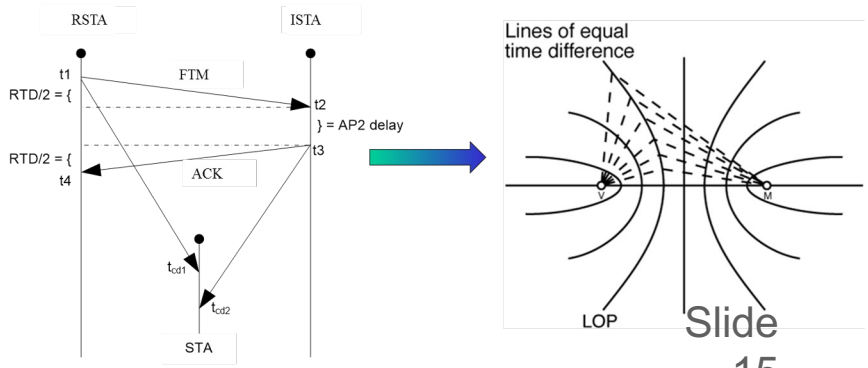
P802.11az Key Radio and Positioning Techniques

- Medium efficient operation via dynamic (demand dependent) measurement rate
- Adaptation to next generation mainstream 802.11ax Trigger Based Operation (MIMO, Trigger Frame, NDP frame)
- Authenticity and privacy and anti-spoofing mechanism via PMF in the unassociated mode and PHY level randomized measurement sequences (HE LTF sequences protection)
- Improved accuracy via MIMO and larger BW available in the <7Ghz band for 11ax
- MIMO enablement for measurement for improved accuracy especially for NLOS or NNLOS conditions
- Passive location with fixed overhead independent of number of users



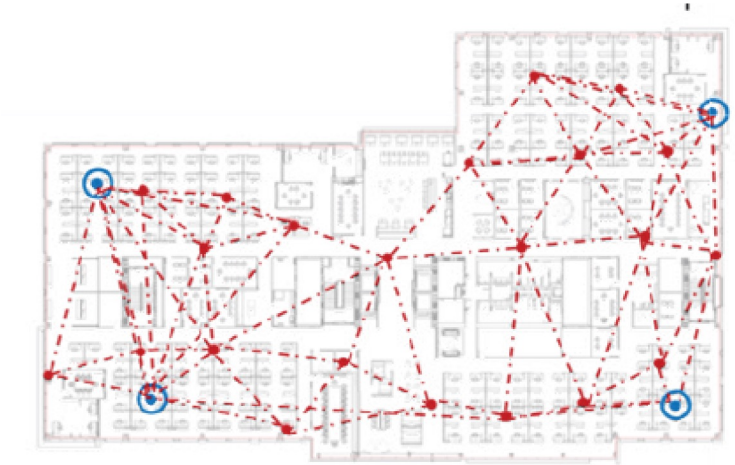






P802.11bk 320 MHz Positioning

- New project to further increase the accuracy of 802.11 based location and proximity determination
- WLAN standardization roadmap towards 0.1m accuracy levels in real world scenarios
- Based on P802.11be 320 MHz channelization and waveforms, reuses the 802.11be PHY
- Takes advantage of WLAN spectrum availability in the <7GHz band and the superior 802.11 link budget
- Attractive for device-to-device, improved self-locating network accuracy, keyless entry and engine-start use cases



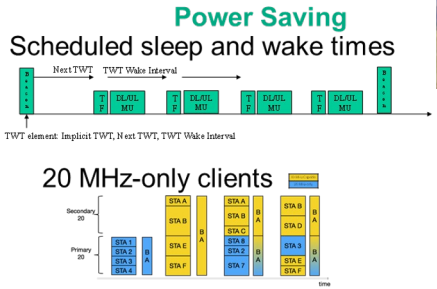
Wi-Fi evolution needs 1200 MHz of global harmonized 6GHz spectrum to support next generation use cases

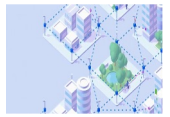
- Future connectivity and economic value increase will depend on Wi-Fi 6E and Wi-Fi 7
- 6 GHz band is uniquely suited (no alternative) to support growing Wi-Fi spectrum needs
- Next use cases: immersive AR/VR/XR for training, industrial, telehealth, automation, 3-D video, also supports dense deployments
- Standard Power Devices with AFC is the most efficient and practical solution to deliver connectivity to underserved areas while coexisting with existing fixed services in the band.

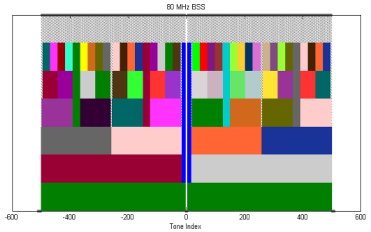
The IEEE 802.11 standard continues to be enhanced to support innovative services and business models

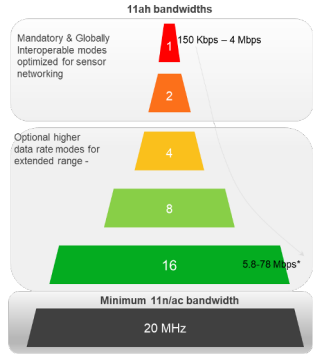
IEEE 802.11 standard development

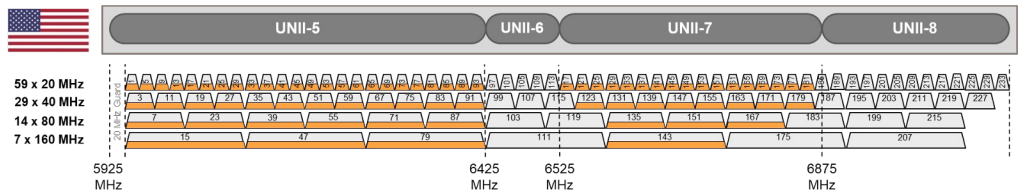
- Defines Wi-Fi operation in sub 1GHz, 2.4, 5 and 6 GHz spectrum bands
- Supports existing and new innovative services, business models, including 5G
- Delivers significant economic value
- Enables economic growth and societal development









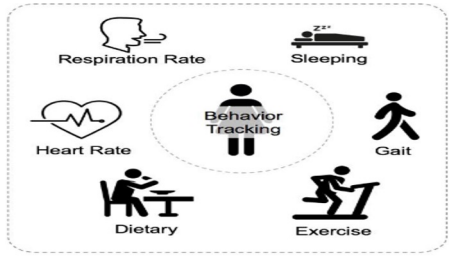


THANK YOU

QUESTIONS

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**



https://www.cse.ust.hk/~qianzh/research/sensing-2.jpg

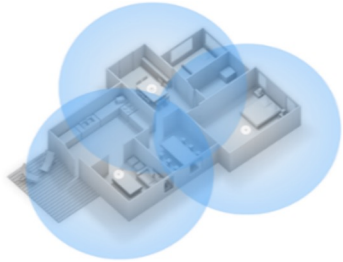
Smart home

https://www.pressebox.com/pressrelease/gb-pronova-gmbh/HoloPro-and-the-magic-of-interactive-control/boxid/129647#

Gesture recognition

http://4.bp.blogspot.com/-_krIAHPdn-8/T02hISBvOnI/AAAAAAAAA1A/jAufr2N8k4c/s1600/Kinect%2BGames.jpg

Gaming control



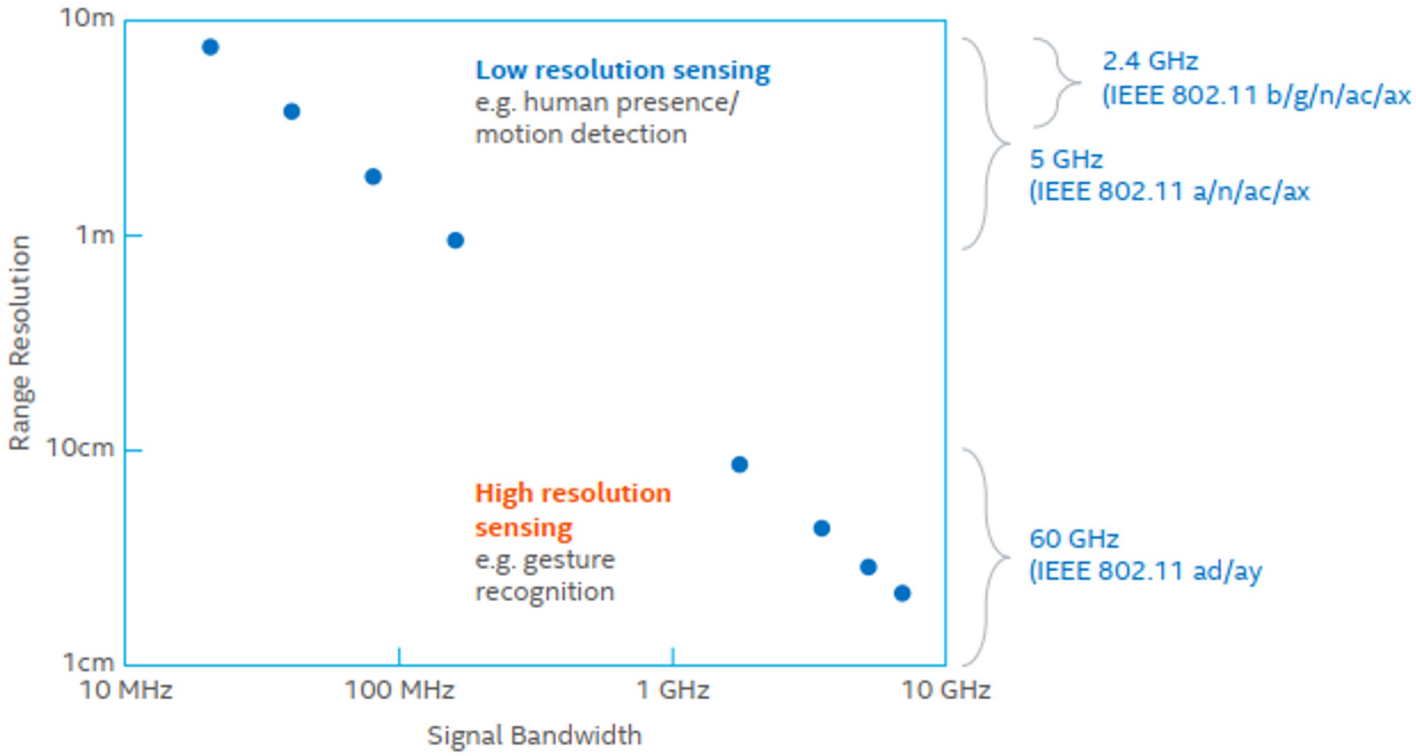
https://www.lastampa.it/tecnologia/news/2018/06/27/news/router-google-wifi-internet-senza-fili-in-ogni-angolo-della-casa-1.34027426

Presence and proximity detection (Home/Enterprise/Vehicle)

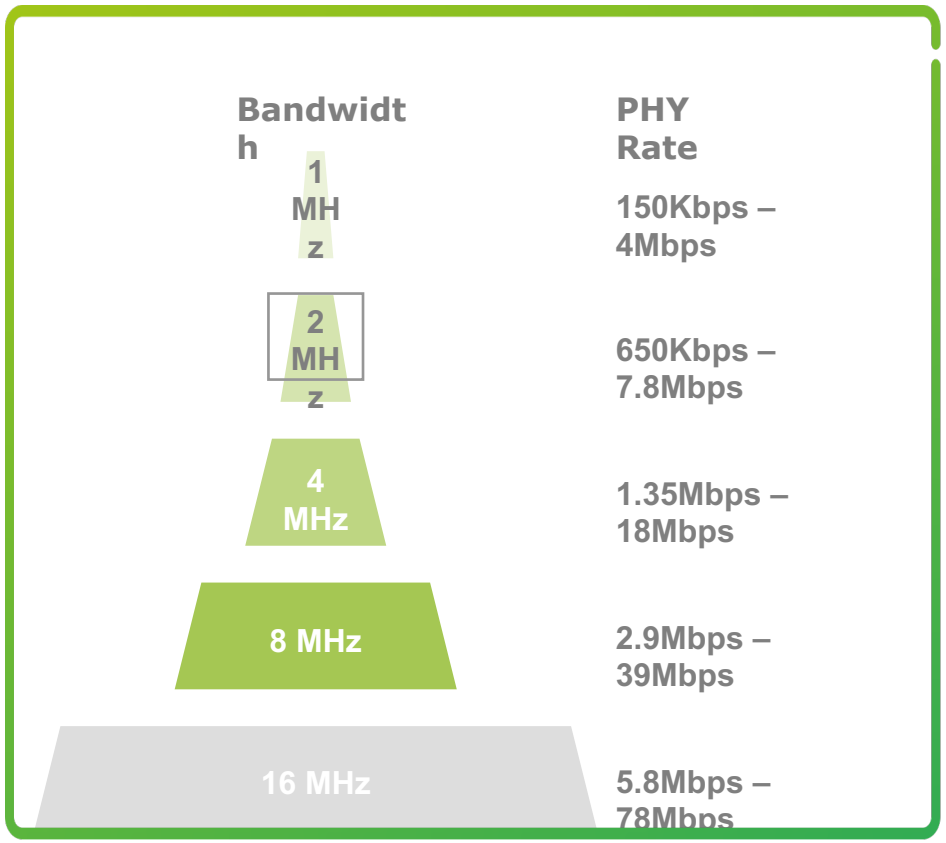
- Note: The specification of applications that make use of WLAN sensing measurements is beyond the scope of P802.11bf.

802.11bf WLAN sensing

- **802.11bf 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
- **Sensing performance metrics include**
  - Accuracy of range, angle and velocity resolution
  - Resolution of range, angle and velocity
  - Coverage range, field of view



IEEE Std 802.11ah-2016 enables Wi-Fi for M2M and IoT applications



Long range indoor/outdoor connectivity up to 1 km

Robust connections for superior penetration through walls and other obstacles in home and industrial environments

Low power consumption for multi-year battery operation

Bidirectional monitoring and control of IoT client devices enable over the air software updates

Moderate data rates **support IETF TCP/IP, discovery protocols**

WFA **Wi-Fi Certified HaLow** certification program
Japan: **802.11ah Promotion Council**
New market entrants emerging to develop the technology

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

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

IEEE 802.11 based products are an essential component for connecting the unconnected: enabling low cost RLAN & hotspot access, rural connectivity, disaster management

Opportunity to transform the connectivity landscape for those who are currently unconnected

July 2021: Africa Telecommunication *Union Recommendation 005-0* to allocate the 5925-6425 MHz band for unlicensed usage. ATU Member States are expected to update their national regulations accordingly.

https://villagetelco.org/deployments/mankosi-south-africa/

Certainty of regulation provides the foundation for industry action to more quickly meet development goals

9. Wi-Fi can support the attainment of the Africa Union's Agenda 2063, where the Africa Union is aiming to double ICT penetration and its contribution to GDP between 2015 and 2023, supported by a 70% increase in broadband accessibility by 2020.

Use cases: Hotspot access, Community Wi-Fi using satellite, optical for backhaul

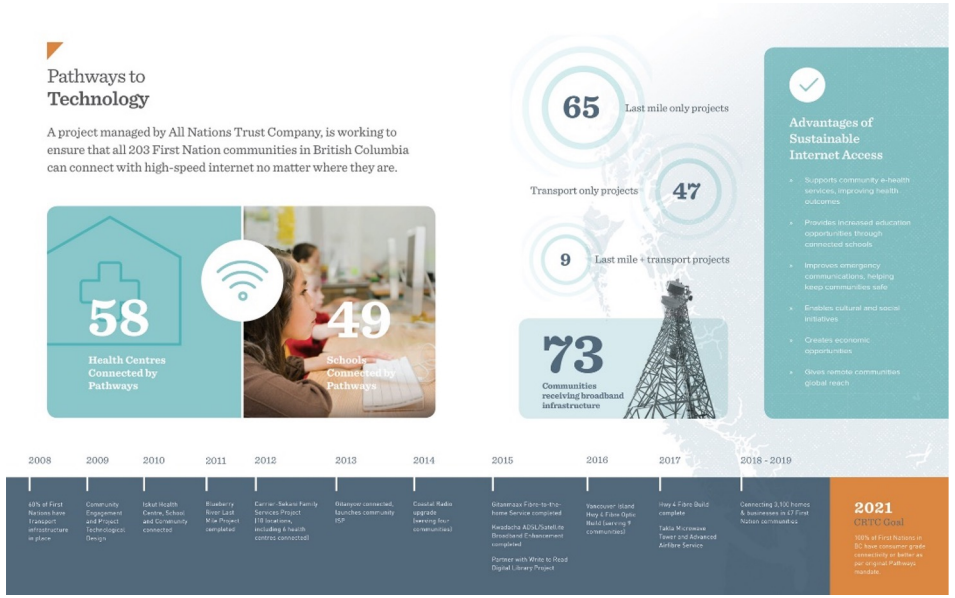
Backhaul Connectivity Initiatives in India – Optical Fiber deployed along railways + Wi-FI connectivity
Backhaul Initiatives in Africa: Optical Fiber along highways, + Wi-Fi Hotspot access

1. To deliver wireless broadband to consumers in Africa, IEEE-based technologies (Wi-Fi 6 based on 802.11ax and beyond, and WiGig based on IEEE 802.11ad/ay) may be able to complement 5G/IMT-2020 (3GPP standards i.e. Release 15 and beyond).

Wi-Fi networks are being deployed globally to extend Broadband wired and wireless backhaul

- Smart Villages in Niger connected via satellite and Wi-Fi Smart Africa).
- Provision of fast, affordable, and reliable access to the internet over Wi-Fi in Rwanda, South Africa, Ghana, and Nigeria
- Wi-Fi reach for schools: Enabling e-learning in Mali
- Wi-Fi Community networks, https://villagetelco.org/deployments/mankosi-south-africa/

- AND in rural, underserved areas in developed countries



Useful Links

- 802 home page: http://www.ieee802.org/
- 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