IEEE 802.11: Wi-Fi 6 and Beyond

Overview of 802 Standards Committee, 802.11 Working Group

802.11ax and amendments under development

802.11 and 5G

2019-08-27

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"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, explanation, or interpretation of the IEEE." IEEE-SA Standards Board Operation Manual (subclause 5.9.3)

IEEE Standards Association

IEEE Standards drive the functionality, capability, and interoperability of a range of products and services that affect the way people live, work, and communicate.

Individual membership

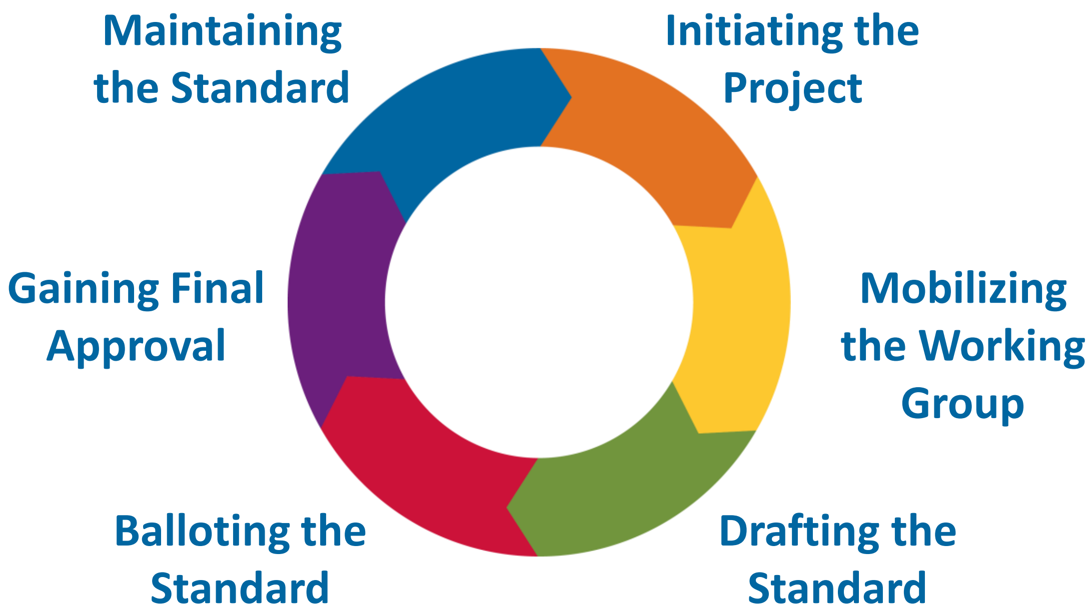
6,879 individual members in 90 countries

Corporate Memberships

187 member corporations in 23 countries

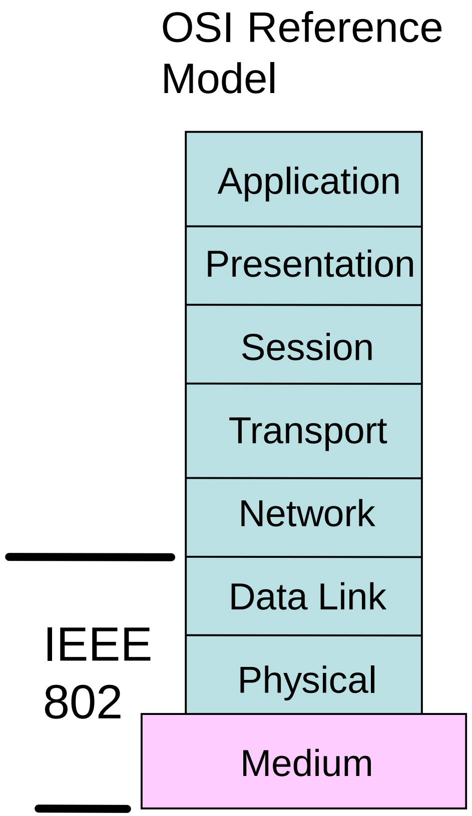
Standards Developers

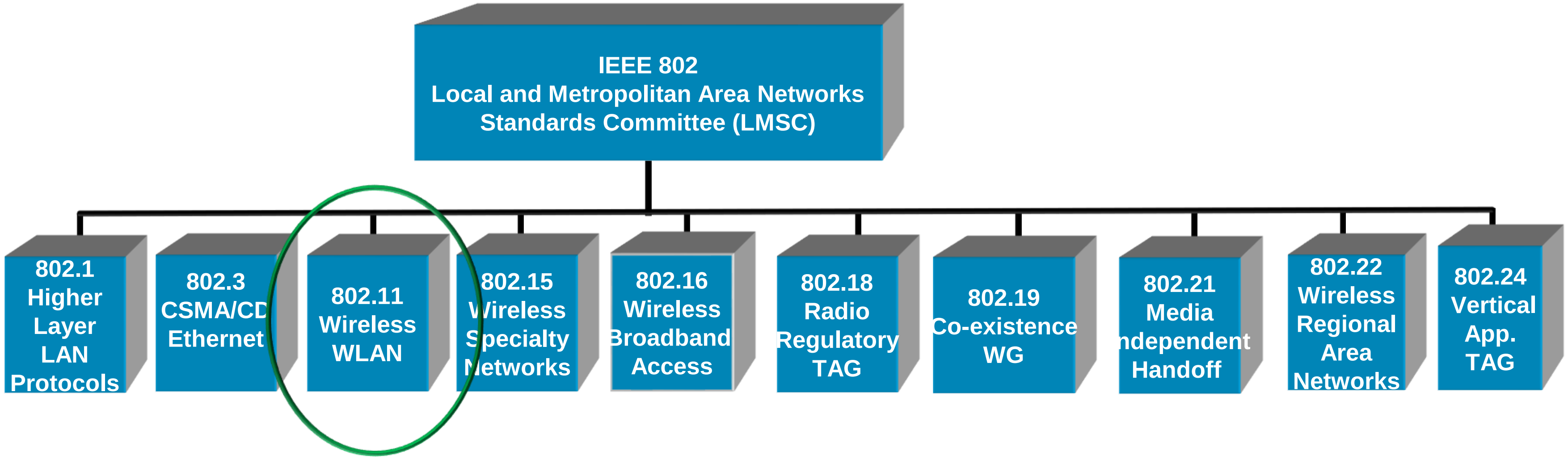
~20,000 participants;
all interested parties are welcome



The IEEE 802.11 Working Group is one of the most active WGs in 802

- Focus on **link and physical layers** of the network stack
- Leverage IETF protocols for upper layers





IEEE 802.11 WG Voting Members: 300+

802.1 Working Group: Time Sensitive Networking, an enabling technology for Industry 4.0

Enables ability to carry data traffic of **time-critical and/or mission-critical applications** over a bridged Ethernet network shared by applications having different Quality of Service (QoS) requirements, i.e., time and/or mission critical TSN traffic and non-TSN best effort traffic.

Provides **guaranteed data transport** with bounded low latency, low delay variation, and extremely low data loss for time and/or mission critical traffic.

TSN achieves **zero congestion loss** for critical data traffic by reserving resources for critical traffic, and applying various queuing and shaping techniques.

See https://1.ieee802.org/tsn/application-of-tsn/
https://mentor.ieee.org/802.11/dcn/19/11-19-1298-01-00be-ieee-802-1-tsn-an-introduction.pdf
https://ieeexplore.ieee.org/document/8412457
https://ieee.app.box.com/v/TSNIndustrial

802.3 Working Group: Ethernet

IEEE P802.3ca 25 Gb/s and 50 Gb/s Ethernet Passive Optical Networks Task Force.
IEEE P802.3cg 10 Mb/s Single Pair Ethernet Task Force.
IEEE P802.3ch Multi-Gig Automotive Ethernet PHY Task Force.
IEEE P802.3ck 100 Gb/s, 200 Gb/s, and 400 Gb/s Electrical Interfaces Task Force.
IEEE P802.3cm 400 Gb/s over Multimode Fiber Task Force.
IEEE P802.3cn 50 Gb/s, 200 Gb/s, and 400 Gb/s over greater than 10 km of SMF Task Force.
IEEE P802.3cp Bidirectional 10 Gb/s, 25 Gb/s, and 50 Gb/s Optical Access PHYs Task Force.
IEEE P802.3cq Power over Ethernet over 2 Pairs (Maintenance #13) Task Force.
IEEE P802.3cr Isolation (Maintenance #14) Task Force.
IEEE P802.3cs Increased-reach Ethernet optical subscriber access (Super-PON) Task Force.
IEEE P802.3ct 100 Gb/s and 400 Gb/s over DWDM systems Task Force.
IEEE P802.3cu 100 Gb/s and 400 Gb/s over SMF at 100 Gb/s per Wavelength Task Force.
IEEE 802.3 Greater than 10 Gb/s Automotive Ethernet Electrical PHYs Study Group.
IEEE 802.3 Multi Gigabit Automotive Optical PHY Study Group.
IEEE 802.3 Improving PTP Timestamping Accuracy Study Group.
IEEE 802.3 10SPE Multidrop Enhancements Study Group.
IEEE 802.3 New Ethernet Applications Ad Hoc.
IEEE 802.3 SCC18 Ad Hoc.

See http://www.ieee802.org/3/index.html
https://ieee.app.box.com/v/TSNAuto

Type of Groups in 802.11

Type of Group	Description
WG	Working Group
SC	Standing Committee
TG	Task Group
SG	Study Group
TIG	Topic Interest Group
AHG	Ad Hoc Group

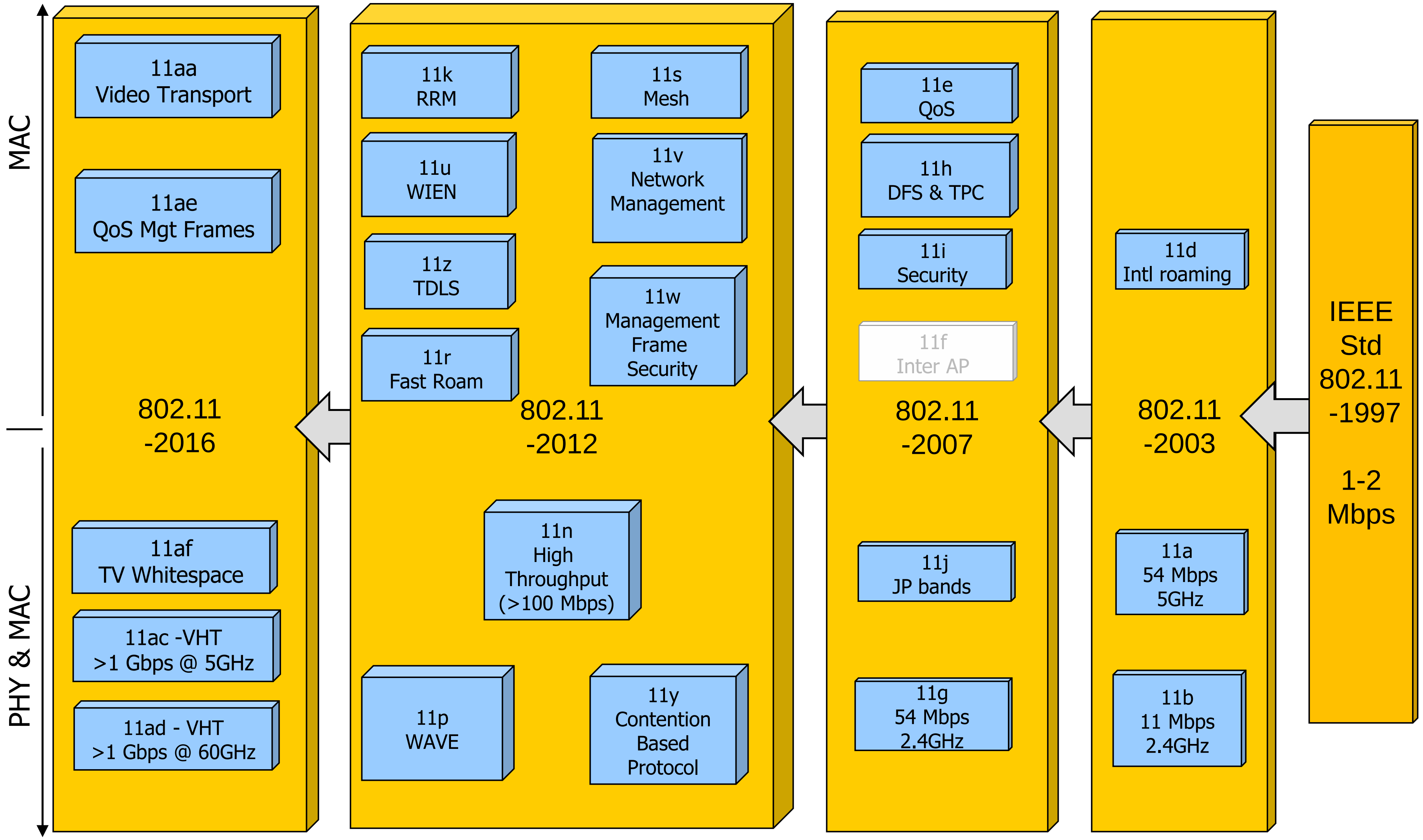
IEEE 802.11 Subgroups

Type	Group	WG & Infrastructure
WG	WG11	The IEEE 802.11 Working Group
SC	AANI	Advanced Access Networking Interface (AANI)
SC	ARC	Architecture
SC	COEX	Coexistence
SC	PAR	PAR review
802 SC	JTC1	ISO/IEC JTC1/SC6

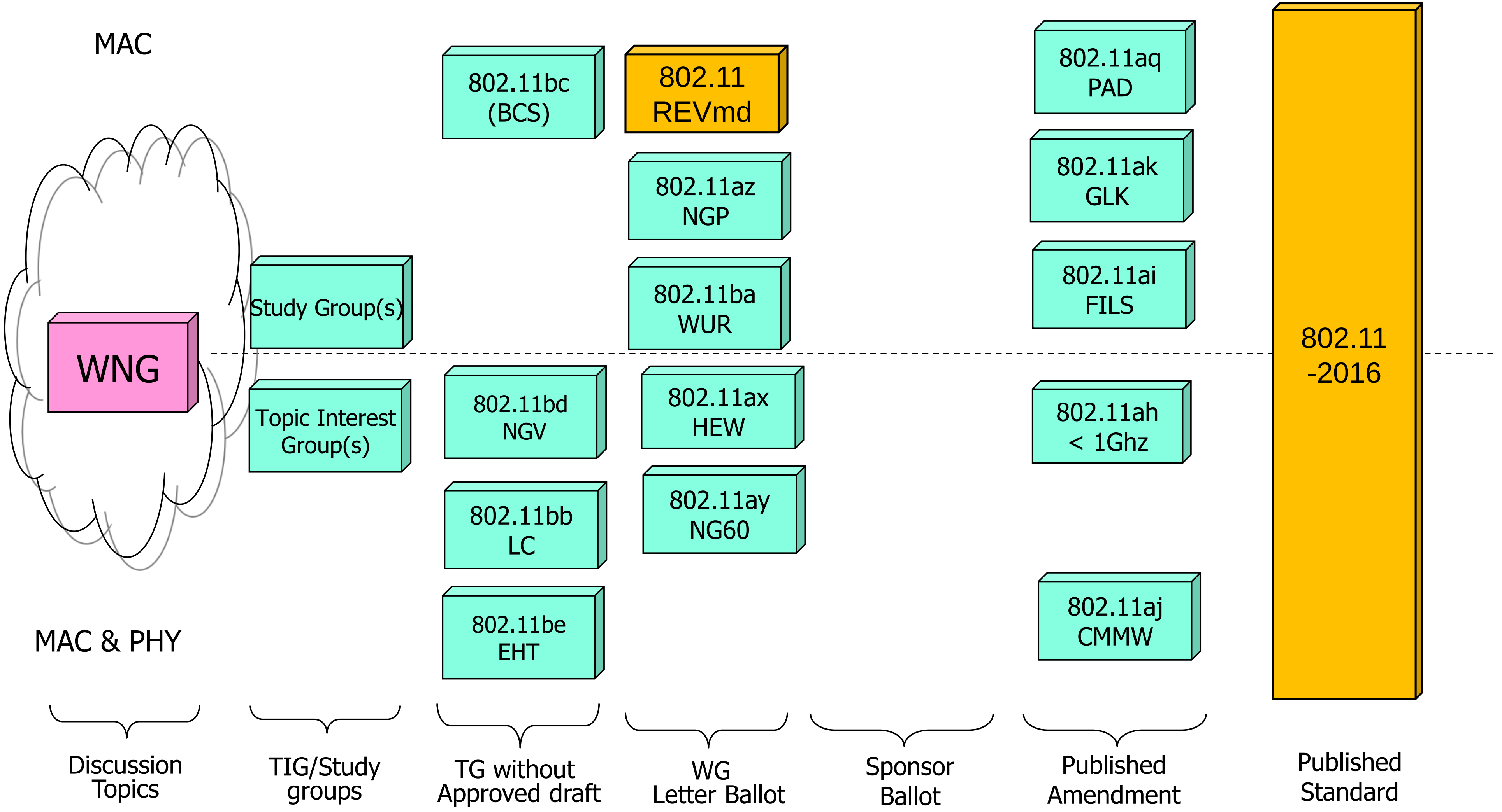
Type	Group	New Work
SC	WNG	Wireless Next Generation
SG	Various	Study Groups
TIG	Various	Topic Interest Groups

Type	Group	Amendments/Revision
TG	AX	High Efficiency Wireless LAN (HEW)
TG	AY	Next Generation 60 GHz (NG60)
TG	AZ	Next Generation Positioning (NGP)
TG	BA	Wake-up Radio
TG	BB	Light Communication (LC)
TG	BC	Enhanced Broadcast Service (BCS)
TG	BD	Enhancements for Next Gen V2X (NGV)
TG	BE	Extremely High Throughput
TG	MD	Revision (REVmd)

Development of the IEEE 802.11 Standard is ongoing since 1997



IEEE 802.11 Standards Pipeline



Market demands and new technology drive IEEE 802.11 innovation

–Demand for throughput

– Continuing exponential demand for throughput **(802.11ax and 802.11ay, 802.11be)**

– Most (50-80%, depending on the country) of the world’s mobile data is carried on 802.11 (WiFi) devices

–New usage models / features

– Dense deployments **(802.11ax),** Indoor Location **(802.11az),**

– Automotive (IEEE Std 802.11p, Next Gen V2X), Internet of Things **(802.11ah)**

– Low Power applications **(802.11ba)**

–Technical capabilities

– MIMO (IEEE Std 802.11n, 802.11ac, **802.11ay**) and OFDMA (**802.11ax**)

– 60 GHz radios **(802.11ay)**

–Changes to regulation

– TV whitespaces (IEEE Std 802.11af), Radar detection (IEEE Std 802.11h), 6GHz (**802.11ax, 802.11be**)

– Coexistence and radio performance rules (e.g., ETSI BRAN, ITU-R)

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

802.11ax – High Efficiency WLAN - 2.4, 5 (and 6) GHz bands.

802.11be – Extremely High Throughput

802.11ay – Support for 20 Gbps in 60 GHz band.

802.11bd – Enhancements for Next Generation V2X, 802.11p DSRC evolution

802.11ah – Sub 1GHz operation

802.11az – 2nd generation positioning features.

802.11ba – Wake up radio. Low power IoT applications.

802.11bb – Light Communications

802.11bc – Enhanced Broadcast Service

802.11ax is focused on improving performance in dense environments

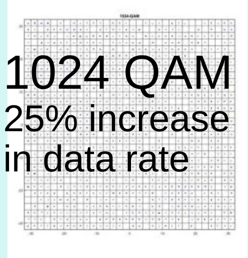
- Existing 802.11 WLAN systems serve dense deployments: 2019 Super bowl: 24TB* of data carried on WLAN network
- 802.11ax aims to further improve performance of WLAN deployments in dense scenarios
  - Targeting at least 4x improvement in the per-STA throughput compared to 802.11n and 802.11ac.
  - Improved efficiency through spatial (MU MIMO) and frequency (OFDMA) multiplexing.
- Dense scenarios are characterized by large number of access points and large number of associated STAs deployed in geographical limited region
  - e.g. a stadium or an airport.

Access to Internet, latest airlines' announcements, and digital media such as movies and sport events

* https://www.extremenetworks.com/resources/slideshare/wi-fi-engagements-from-super-bowl-liii/

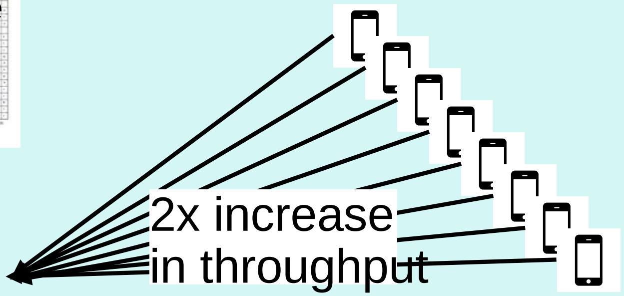
Categories of Enhancements

Spectral Efficiency & Area Throughput

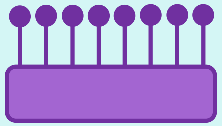


1024 QAM
25% increase in data rate

DL/UL MU-MIMO
w/ 8 clients

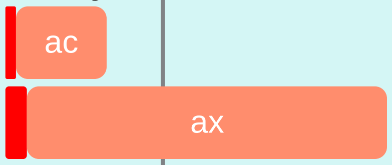


8x8 AP



2x increase in throughput

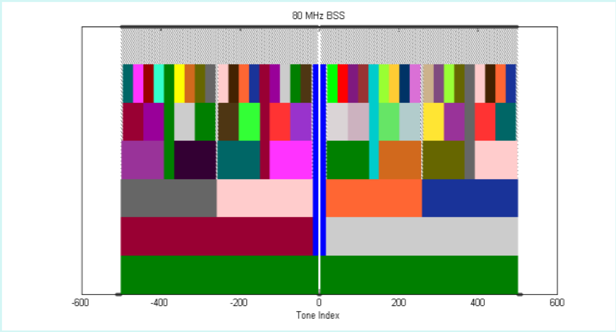
Long OFDM Symbol



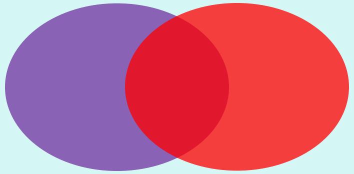
Up to 20% increase in data rate

High Density

OFDMA

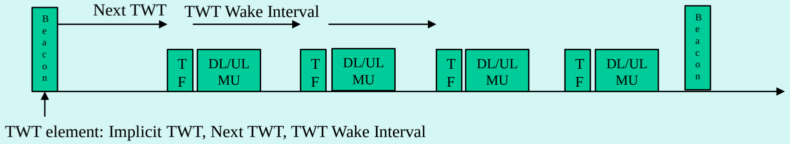


Spatial Reuse



Power Saving

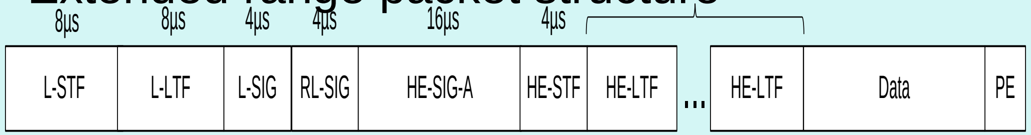
Scheduled sleep and wake times



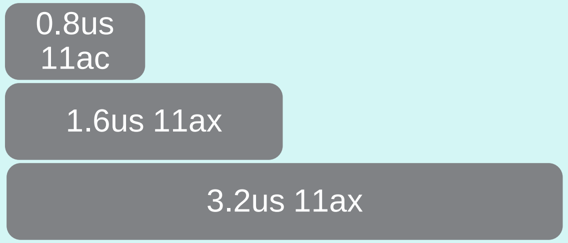
20 MHz-only clients

Outdoor / Longer range

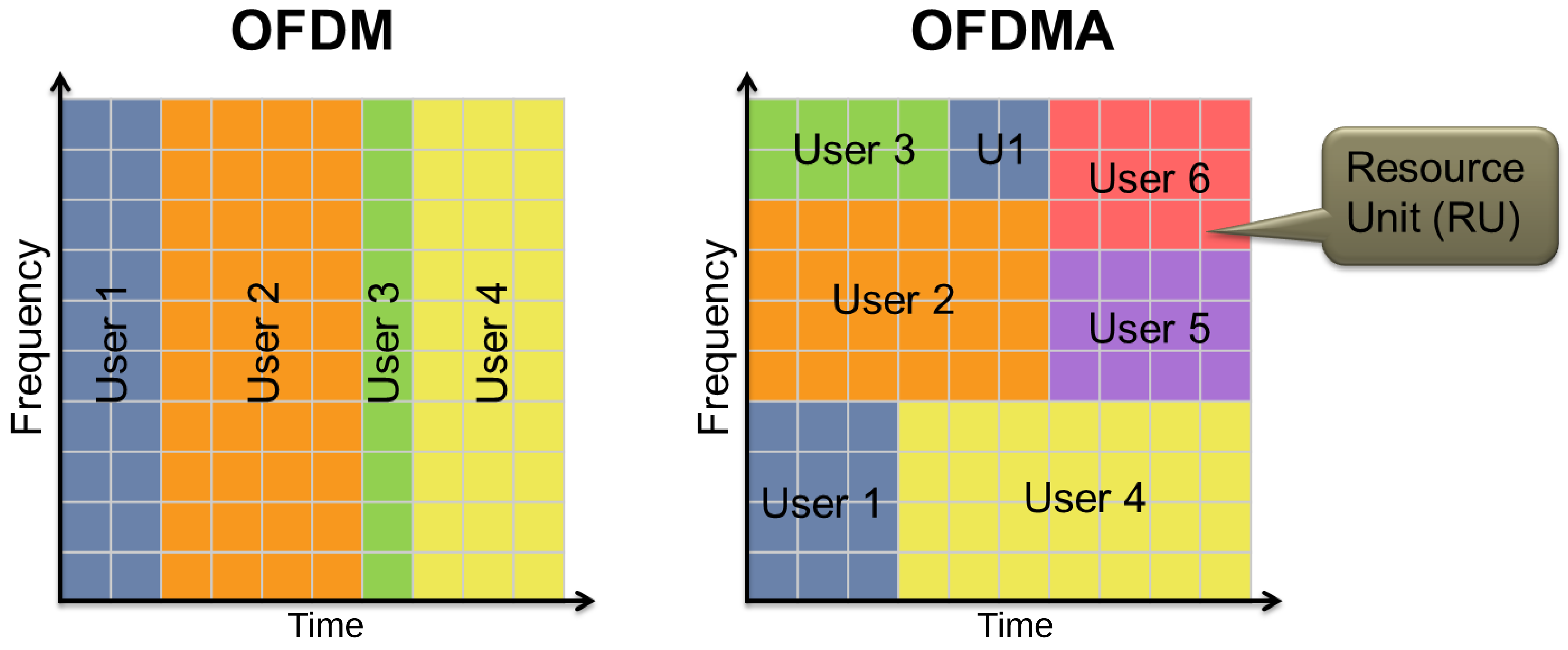
Extended range packet structure



Enhanced delay spread protection- long guard interval

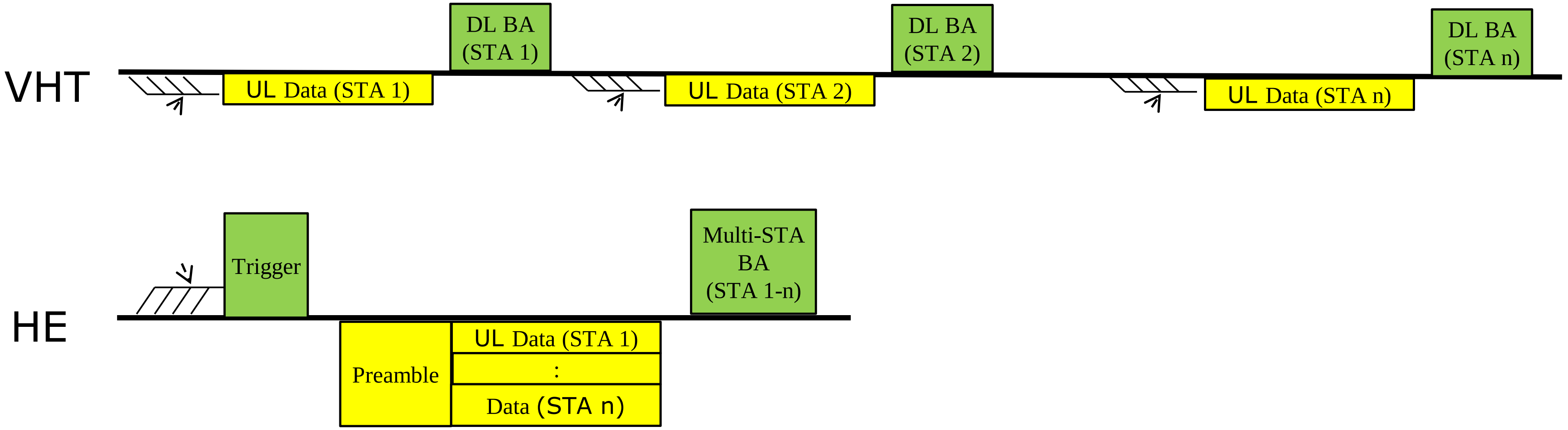


OFDMA enables further AP customization of channel use to match client and traffic demands



Increased efficiency for (high percentage of traffic) short data frames

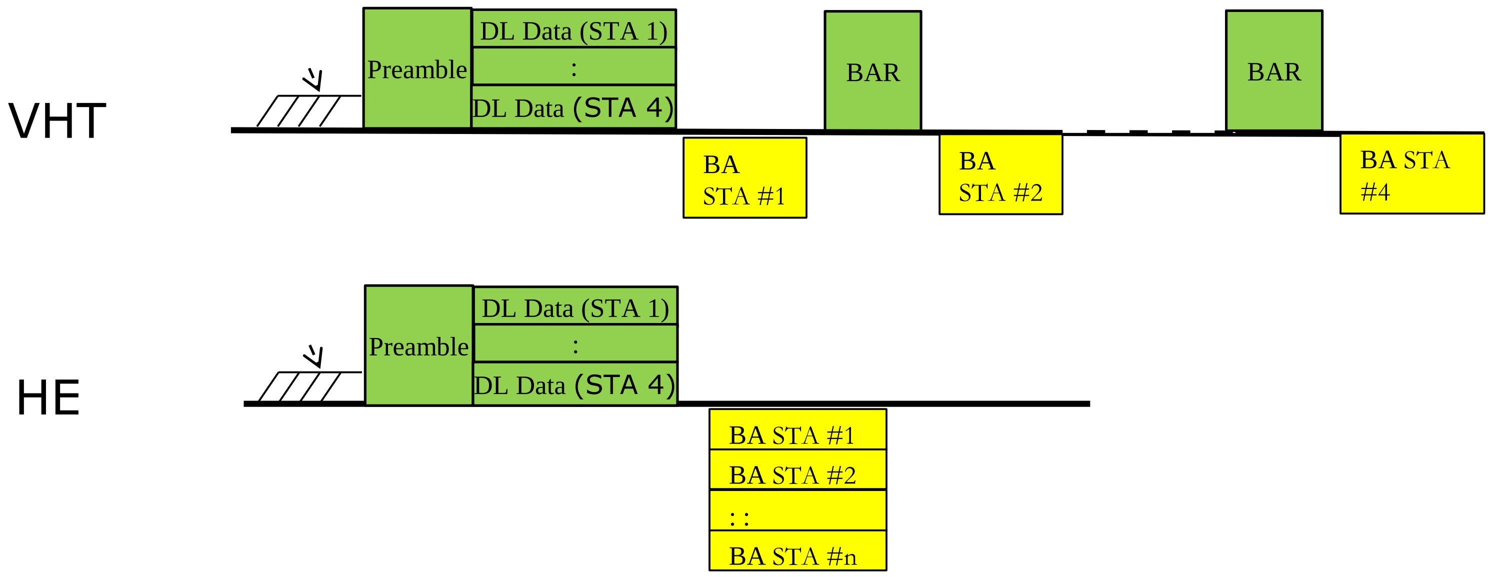
UL/DL multi-user links in 802.11ax will support more efficient UL data



- In a VHT UL sequence, STAs compete for medium access and send sequentially
- In an HE UL sequence, the AP triggers simultaneous transmissions in multiple STAs

802.11ax Data exchange sequences: Multi-user downlink

- In a VHT DL MU sequence acknowledgements are serialized
- In an HE DL MU sequence acknowledgements are allocated UL resources and transmitted simultaneously



Target Wake Time

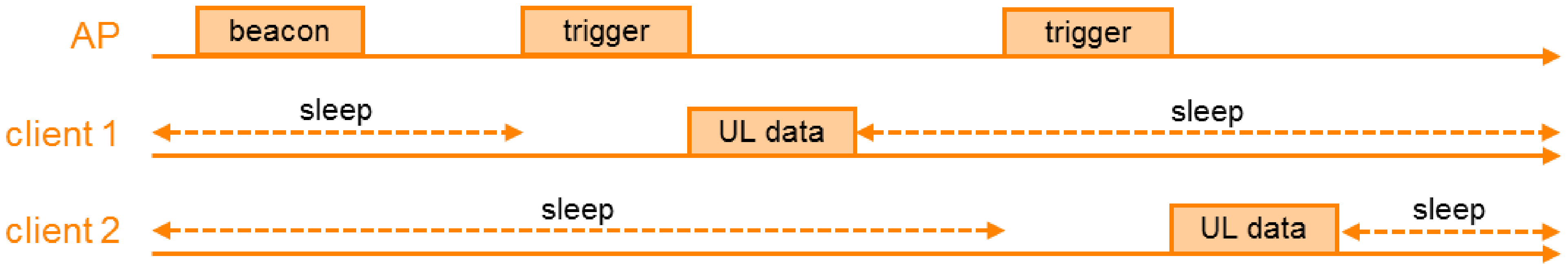
Schedule Sleep and Wake Times

– With the Target Wake Time (TWT) feature, an 802.11ax AP can schedule devices to sleep for long times, depending on anticipated traffic load

– Devices can be scheduled to wake up individually or as a group (taking advantage of MU technologies) to quickly and efficiently exchange data before going back to sleep again

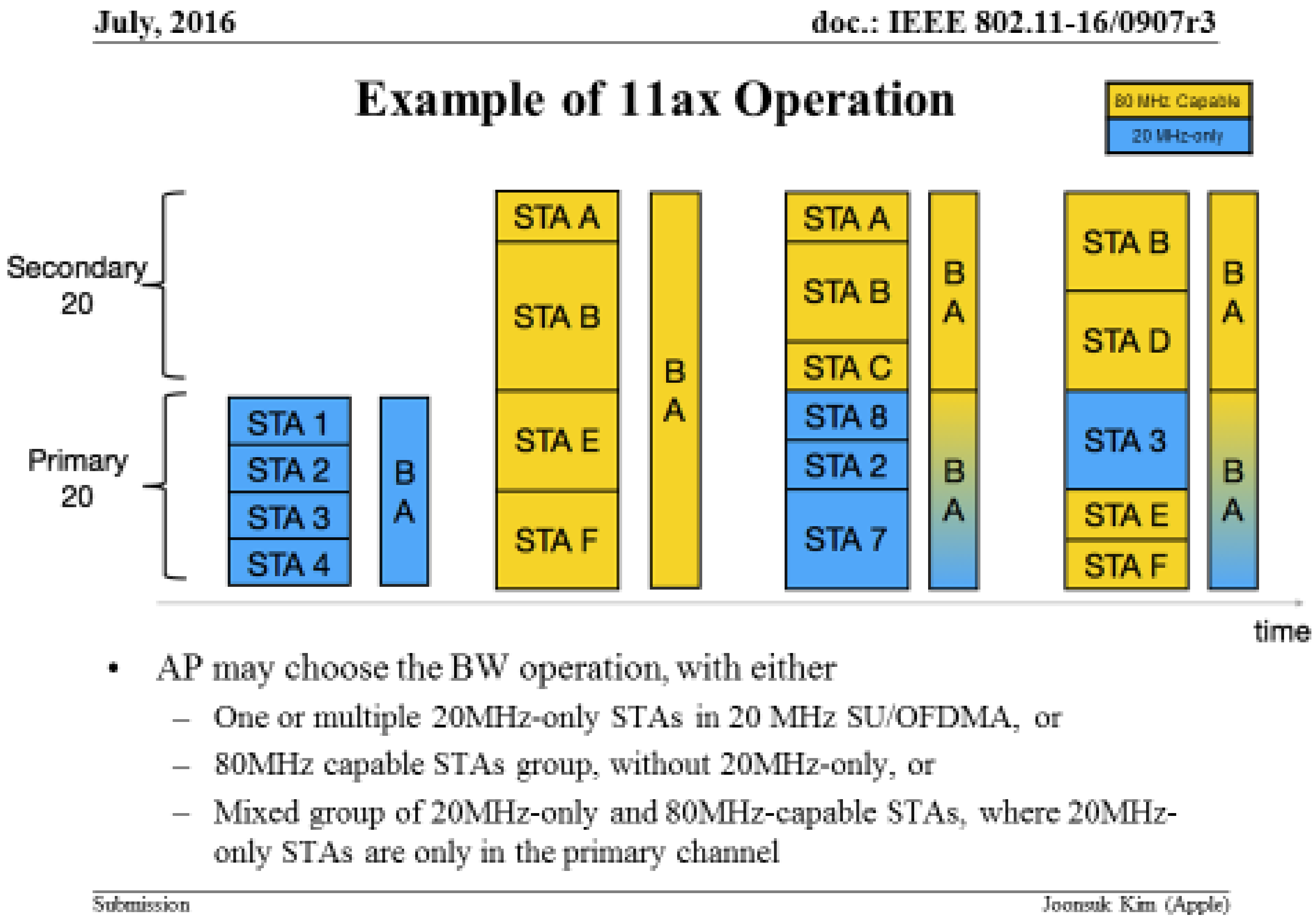
– The primary goal is to reduce power consumption for battery-powered devices like smartphones and IOT sensors. In addition, OTA efficiency will improve

– The AP can send data to the client device(s) at the scheduled wake-up time, or it will send out a trigger frame prior to the scheduled wake-up time to clear the channel for data from the client device

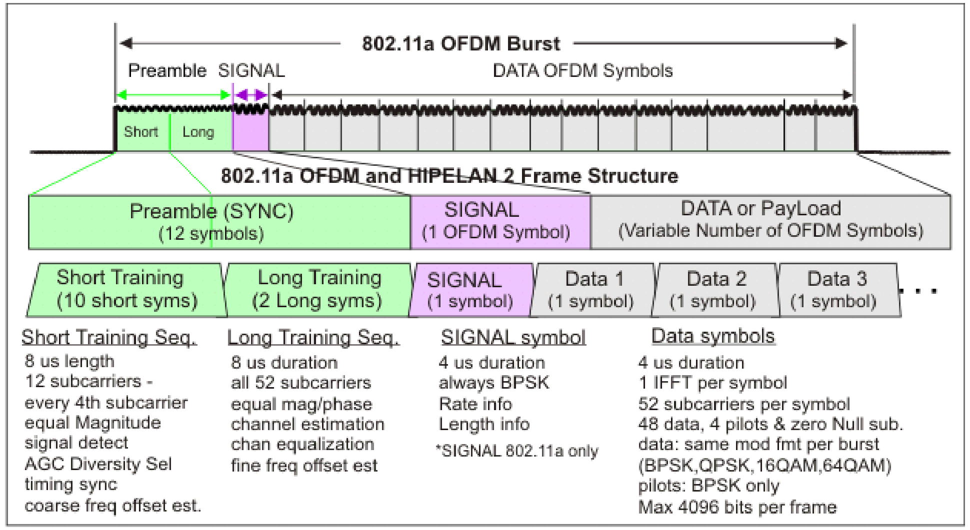


20 MHz-only Clients

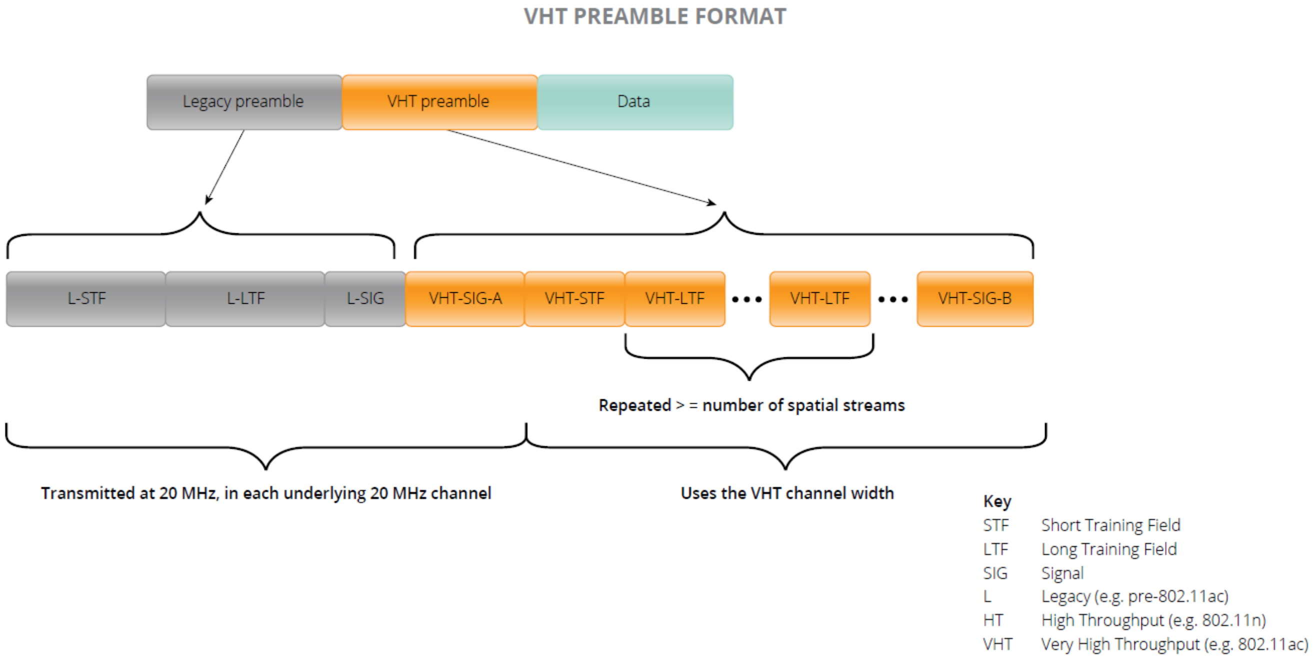
- Provide support for low power, low complexity devices (IOT): wearable devices, sensors and automation, medical equipment, etc.
- Such devices do not need high bandwidth operation
- In actuality, this only applies to 5 GHz, as only 20 MHz support is mandatory in 2.4 GHz
  - "Normal" clients still required to support 80 MHz in 5 GHz



802.11 PHY standards are backwards compatible with prior generations within a spectrum band



802.11a and HIPERLAN/2 Frame Structure



- 802.11a Preamble is included in 802.11a, 802.11n, 802.11ac, 802.11ax 5GHz encoded frames
- Very minimal common preamble provides backward compatibility and enables preamble detection at low energy levels for improved coexistence

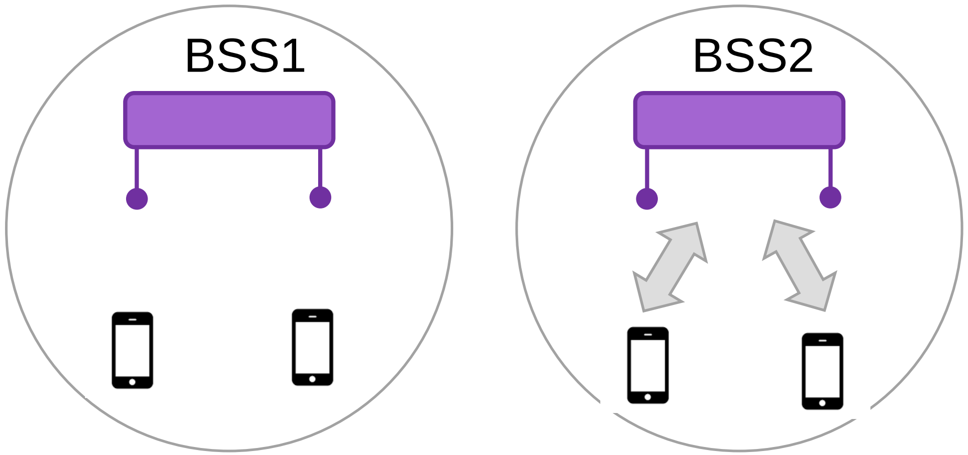
802.11be is a new amendment that builds on 802.11ax

Extremely High Throughput (EHT)
Higher throughout – up to 30 Gbps
Support for low latency communications
Operations in 2.4 GHz, 5 GHz, and 6 GHz bands
Targeted completion in 2023

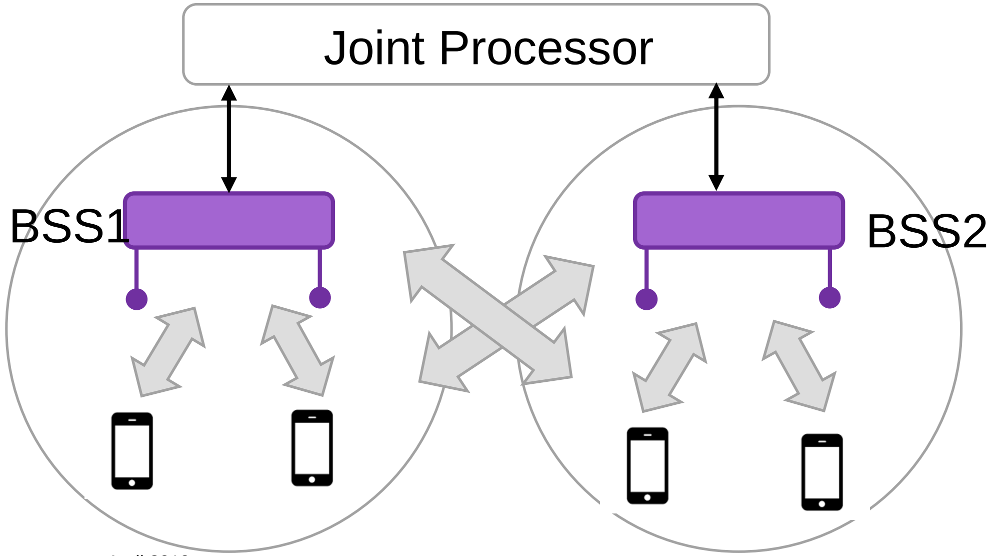
Use Cases:
- AR/VR
- 4K and 8K video streaming
- Remote office
- Cloud computing
- Video calling and conferencing

802.11be features under consideration

- 320MHz bandwidth and more efficient utilization of non-contiguous spectrum
- **Multi-band/multi-channel aggregation and operation**
- 16 spatial streams and MIMO protocols enhancements
- **Multi-AP Coordination (e.g. coordinated and joint transmission)**
- Enhanced link adaptation and retransmission protocol (e.g. HARQ)
- Adaptation to regulatory rules specific to 6 GHz spectrum
- Refinements of 802.11ax features



11ax MU-MIMO: BSS1 defers to BSS2, when both are operating on same channel



Distributed MU-MIMO:
BSS1 and BSS2 transmit simultaneously

Additional Spectrum in 6GHz for 802.11/Wi-Fi operation is under regulatory review

There is a need for additional unlicensed spectrum, as identified in Wi-Fi Alliance Spectrum Needs Study

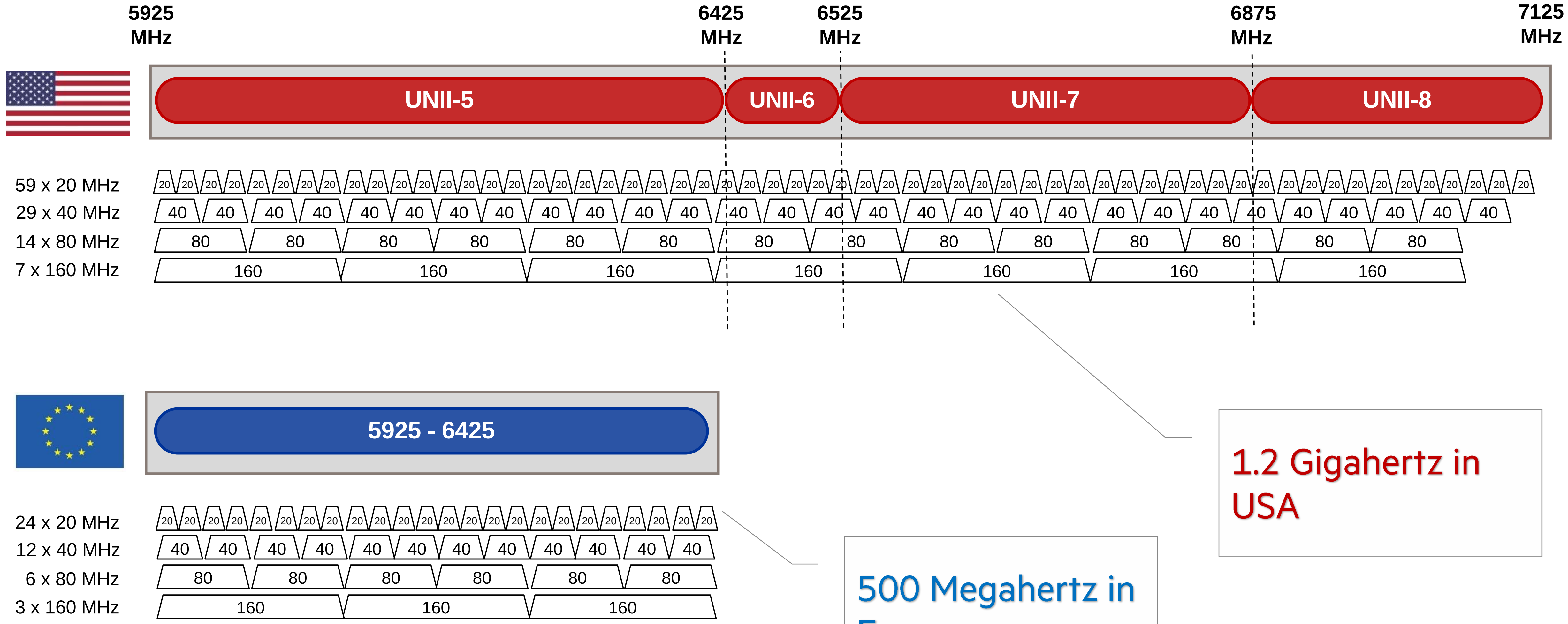
HPE Aruba is major contributor to the significant Global Regulatory advocacy underway

- US: FCC Part 15 regulations (R&O in late 2019/early 2020)

- Europe: EC Decision/National Regulations in 5925-6425 MHz
  - Report A: Assessment of compatibility and coexistence (March 2020)
  - Report B: Harmonized technical conditions (July 2020)

- APAC: National Regulations (AUS, NZL, J, KOR, VET, MLS, INS, others)

Bands & Channelization Under Study in US & EU/CEPT



1.2 Gigahertz in USA

500 Megahertz in Europe

802.11ad 60 GHz radio technologies are in the market today

- 11ad amendment published in 2012, 11ay amendment expected in 2020
- Supports short range, very high speed communications
- Provides multi-gigabit performance for in-room connectivity
- WiGig Wireless Docking stations on the market now
- From http://www.wi-fi.org/discover-wi-fi/wigig-certified :

Multi-gigabit, low latency connectivity. Coming in 2016.

Industry momentum and user anticipation of 60 GHz technology is growing. WiGig CERTIFIED™ products operate in the 60 GHz frequency band and deliver multi-gigabit speeds, low latency, and security-protected connectivity between nearby devices. Popular use cases for WiGig® include cable replacement for popular I/O and display extensions, wireless docking between devices like laptops and tablet, instant sync and backup and simultaneous streaming of multiple, ultra-high definition and 4K videos.

Data rates*

MCS	Data Rate (Mb/s)
1	385
2	770
3	962.5
4	1155
5	1251.25
6	1540
7	1925
8	2310
9	2502.5
9.1	2695
10	3080
11	3850
12	4620
12.1	5005
12.2	5390
12.3	5775
12.4	6390
12.5	7507.5
12.6	8085

*SC data rates as proposed to be modified in TGmc, see https://mentor.ieee.org/802.11/dcn/16/11-16-0670-06-000m-base-mcs-and-length-calculation-for-extended-mcs-set.docx

60 GHz Fixed Wireless Use Case: Affordable 5G Performance

“the 14 GHz of contiguous spectrum in the band offers more bandwidth than any other licensed or unlicensed mmWave band. Further, the 60 GHz band has chipsets and technology currently available on the commercial market.”

“In the U.S., unlicensed mmWave frequencies available for 5G primarily cover the band from 57 – 71 GHz, called the V-Band, or 60 GHz band. This band offers 14 GHz of contiguous spectrum, which is more than all other licensed and unlicensed bands combined7. **This makes the 60 GHz band an excellent alternative to licensed mmWave frequencies for smaller providers, as it can be used to deliver 5G performance for the minimal cost of available 60 GHz infrastructure products.**

https://go.siklu.com/hubfs/Content/White%20Papers/Maravedis%20Industry%20Overview:%205G%20Fixed%20Wireless%20Gigabit%20Services%20Today.pdf

https://www.fiercewireless.com/wireless/60-ghz-band-particularly-appealing-for-fixed-wireless-report

60 GHz Mesh Backhaul Wireless Use Case: Deploying Today

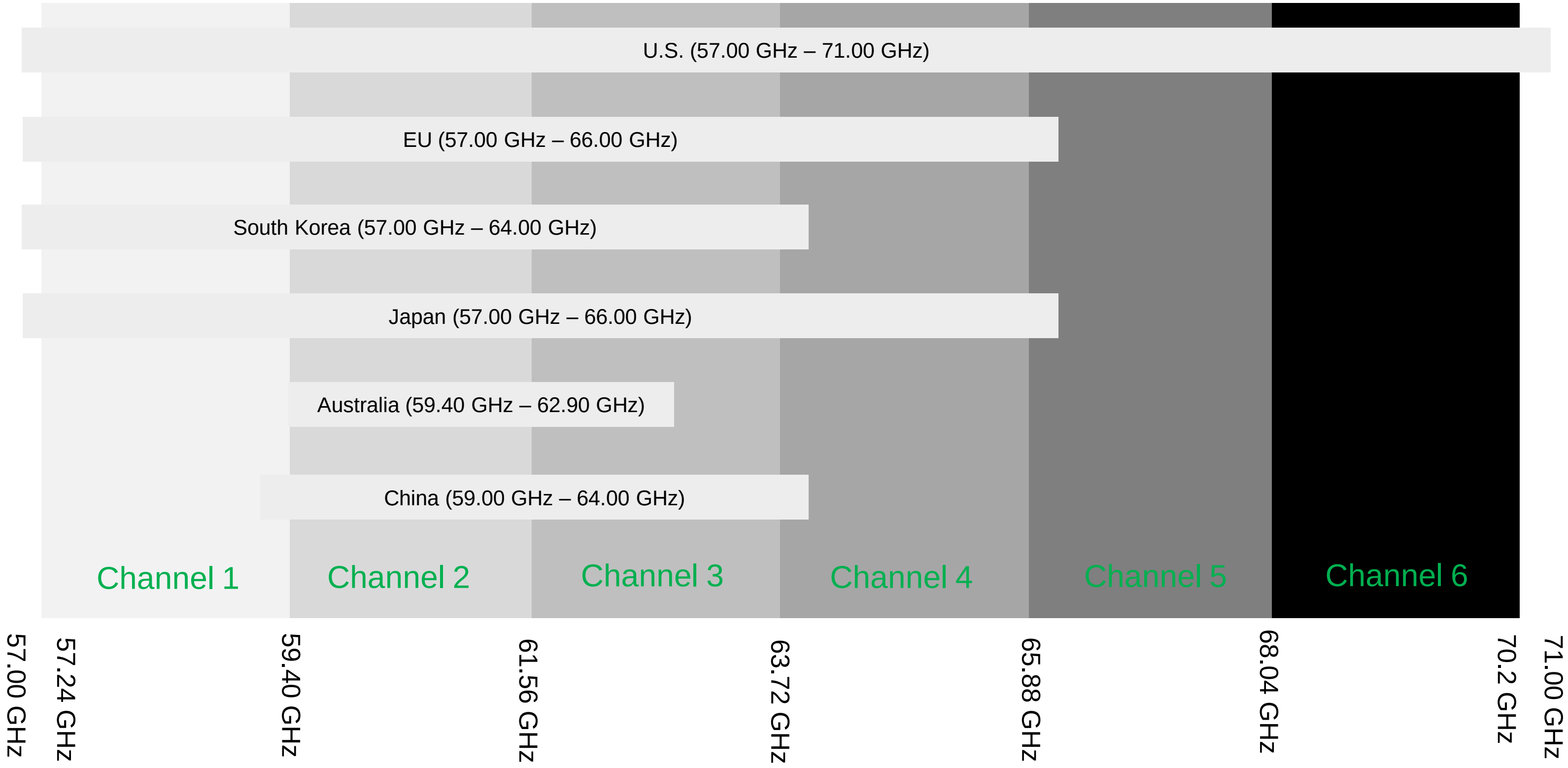
"Leading Wi-Fi and wireless network solution vendor Cambium Networks announced today that they will be incorporating Facebook's Terragraph technology into a new series of Cambium Networks ***60 GHz radio products*** *called cnWave™. The news comes as Terragraph appears to be ramping up go-to-market activities with trials underway in Hungary and most recently in Malaysia."*

"Terragraph is essentially a 60 GHz-based meshed (or multi-hop, multi-point) backhaul radio system for deployment at street level in cities."

https://wifinowevents.com/news-and-blog/cambium-networks-to-incorporate-facebook-terragraph-tech-into-new-60-ghz-products/

60 GHz Worldwide Spectrum

- Worldwide, unlicensed, spectrum availability
- 4 bands available in EU and Japan
- Recently expanded spectrum in U.S. from 57 – 71GHz, additional countries also considering expansion



802.11ay is defining next generation 60 GHz: increased throughput and range

20Gbps+ rates are defined
License- Exempt bands above 45Gbps
Completion in 2020; First chipsets announced

Use Cases:

- Ultra-Short Range
- 8K UHD - Smart Home
- AR/VR and wearables
- Data Center Inter Rack connectivity
- Video / Mass-Data distribution
- Mobile Offloading and MBO
- Mobile Fronthauling
- Wireless Backhauling (w. multi-hop)
- Office Docking
- Fixed Wireless

Key additions :

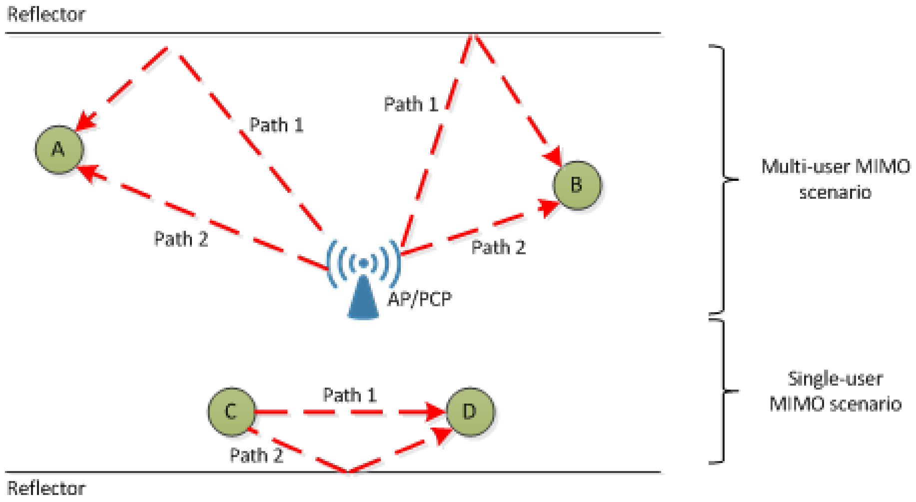
- SU/ MU MIMO, up to 8 spatial streams
- Channel bonding
- Channel aggregation
- Non-uniform constellation modulation
- Advanced power saving features

802.11ay builds on 802.11ad with MIMO and channel bonding features

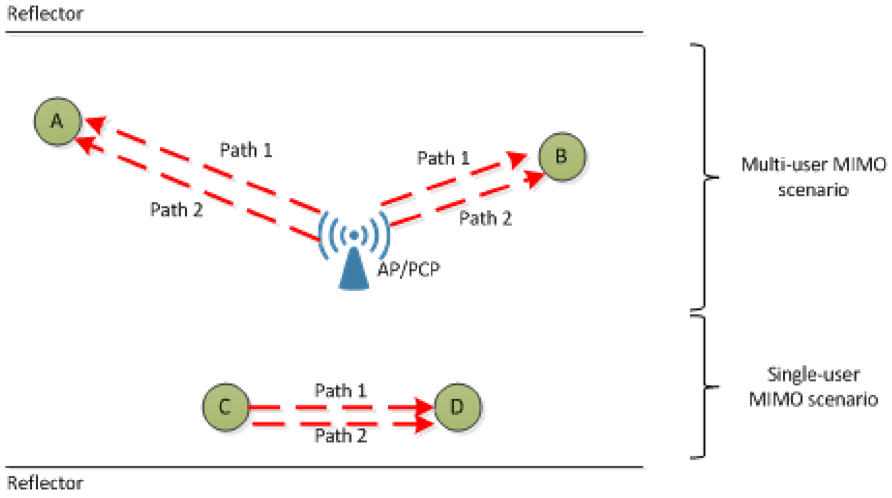
- Channel bonding and aggregation requires new:
  - Channelization
  - Packet format
  - Channel access mechanisms

- Single User and downlink MU MIMO
  - Distribute capacity across users
  - Unique requirements given directionality
  - Exploit antenna polarization
  - Changes to the beamforming protocol

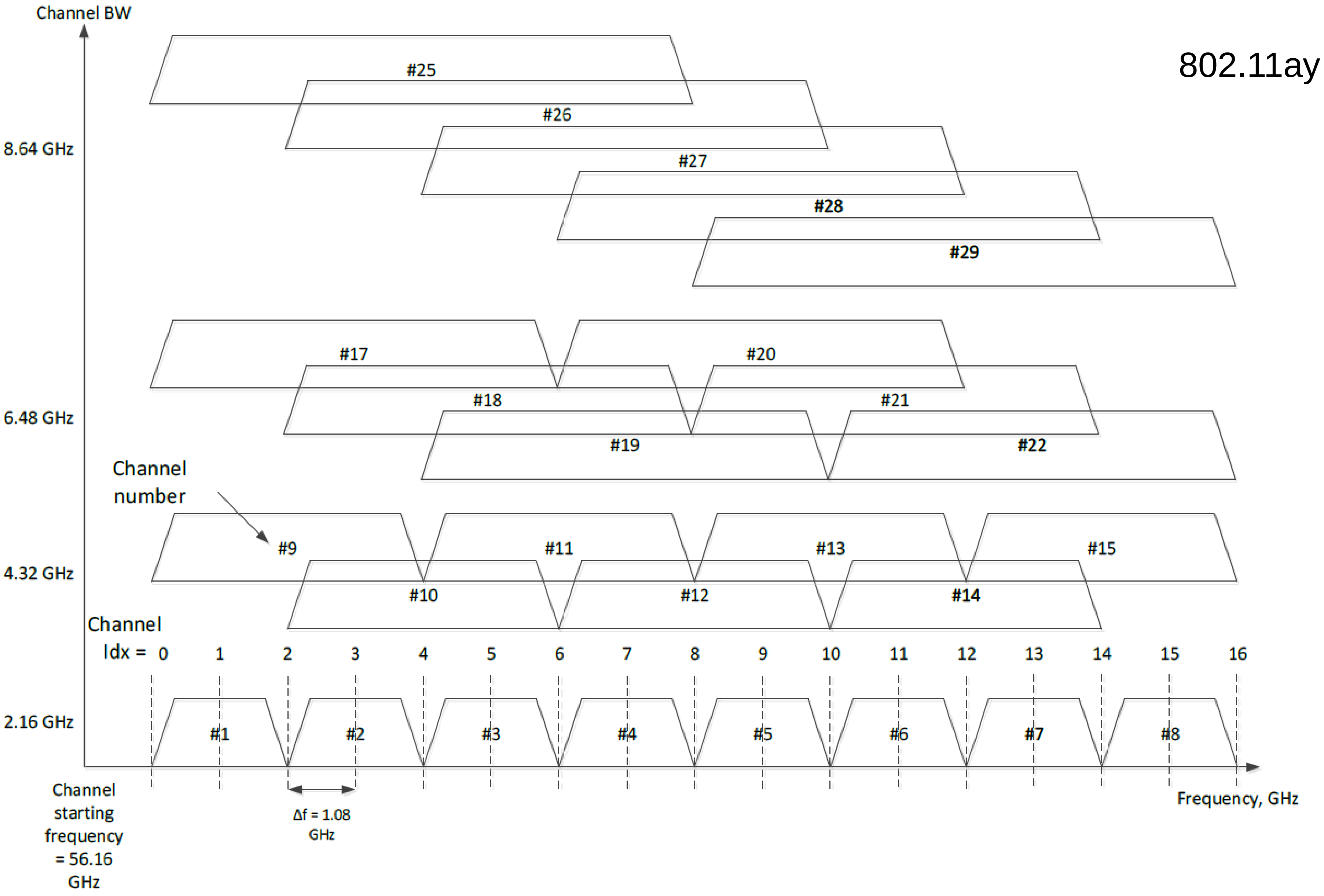
Example without polarization



Example with polarization

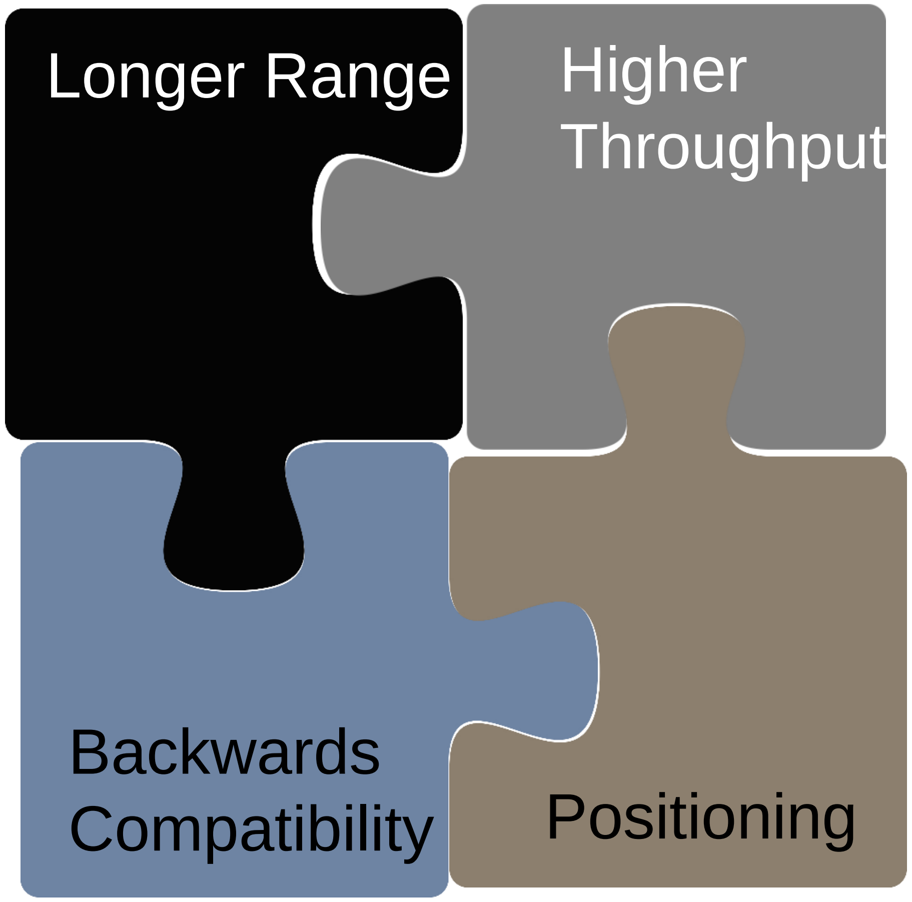


802.11ay defined channelization



802.11bd defines an evolution of 802.11p for V2X

- **802.11p is largely based on 802.11a.**
- **802.11bd defines MAC/PHY enhancements from 802.11n, ac, ax, to provide a backwards compatible next generation V2X protocol.**
- **Higher Throughput**
  - OFDM frame design
  - Higher MCS, LDPC coding
  - Packet aggregation
- **Longer Range**
  - Mid-amble design
  - Repeated transmission mechanism
  - More robust channel coding
- **Support for Positioning**
- **Backward Compatibility**
  - Backward compatible frame format design, Version indication



802.11bd: Next Generation V2X Use Cases

5.9 GHz band mainly, and optionally 60GHz;
Completion in 2021
http://www.ieee802.org/11/Reports/tgbd_update.htm

V2X Use Cases:

- Suport all defined DSRC/802.11p use cases, including Basic safety message (safety, range, backward compatibility, fairness)
- Sensor sharing (throughput)
- Multi-channel operation (safety channel + other channels)
- Infrastructure applications (throughput)
- Vehicular positioning & location (LoS and NLoS positioning accuracy)
- Automated driving assistance (safety, throughput)
- Aerial vehicle IT application (video)
- Train to train (high speed)
- Vehicle to train (high speed, long range)

Key additions :

- Higher throughput (2x) than 802.11p
- Longer range (3dB lower sensitivity level)
- Support for positioning
- Backward compatibility with 11p

802.11ay, 802.11ad (60GHz) and 802.11ax (2.4GHz, 5(6)GHz) technology can be leveraged to meet 5G requirements

- Today’s 4G networks include 802.11 technologies
  - For offload: “More traffic was offloaded from cellular networks (on to Wi-Fi) than remained on cellular networks in 2016” (Cisco VNI)
  - For Wi-Fi calling
- Wi-Fi carries most public & private Internet traffic worldwide
  - Between 50-80% depending on country.
- 5G radio aggregation technologies will natively incorporate Wi-Fi
  - 802.11/Wi-Fi is a Peer Radio Access Technology in the 5G Architecture

802.11ax
8Gb/s (OFDMA, U/L MU-MIMO)
5G Hotspot Mobile Broadband

802.11ay/aj
60GHz
n*20Gb/s (Aggregation+MIMO)
Device connectivity

802.11ah (Sub 1 GHz) + 11ba
900 MHz Indoor IoT PANs
Wearables, sensors, smart home

802.11ax meets the MAC/PHY requirements for 5G Indoor Hotspot test Environment defined by IMT-2020

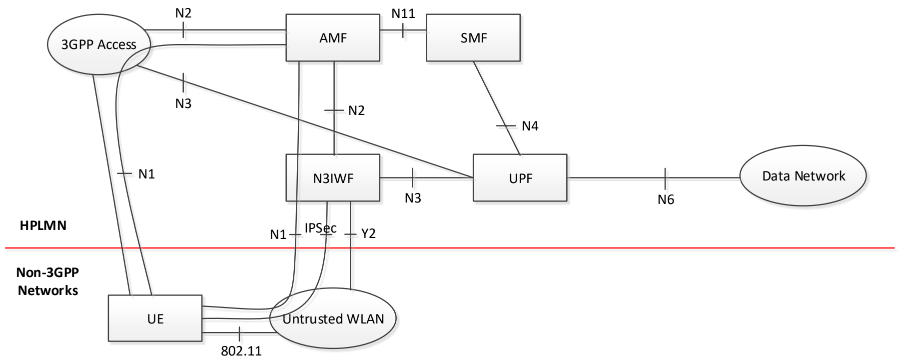
- Analysis and simulations confirm that performance of IEEE 802.11ax MAC/PHY meet or exceed 5G requirements for the 5G Indoor Hotspot use case
- Similar studies are underway for the Dense Urban test environment

	Metric	ITU-R Evaluation Method	Minimum Requirement	802.11ax Performance
1	Peak data rate	Analytical	DL/UL : 20/10 Gbps	DL/UL : 20.78 Gbps [Note 1]
2	Peak spectral efficiency	Analytical	DL/UL : 30/15 bits/s/Hz	DL/UL : 58.01 bits/s/Hz [Note 2]
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 [Note 3]
5	Average spectral efficiency	Simulation	DL/UL : 9/6.75 bits/s/Hz/TRxP	DL/UL : 9.82/13.7 bits/s/Hz/TRxP [Note 3]
6	Area traffic capacity	Analytical	DL : 10 Mbit/s/m^2	Required DL bandwidth = 170 MHz with 3 TRxP/site. [Note 4]
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 [Note 5]

See https://mentor.ieee.org/802.11/dcn/19/11-19-1284-00-AANI-summary-of-802-11ax-self-evaluation-for-imt-2020-embb-indoor-hotspot-and-dense-urban-test-environments.docx

802.11/Wi-Fi is a Peer Radio Access Technology in 5G System

Untrusted WLAN Access (3GPP Rel-15 onwards)



– 5G System is Access Agnostic: UE devices can register and access 5G services without the need of licensed based access;

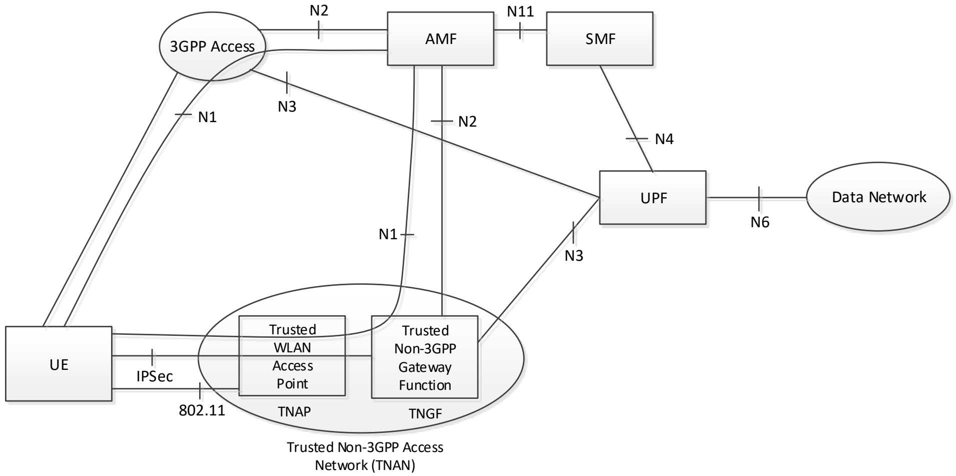
– Unified EAP based authentication mechanism for all accesses;

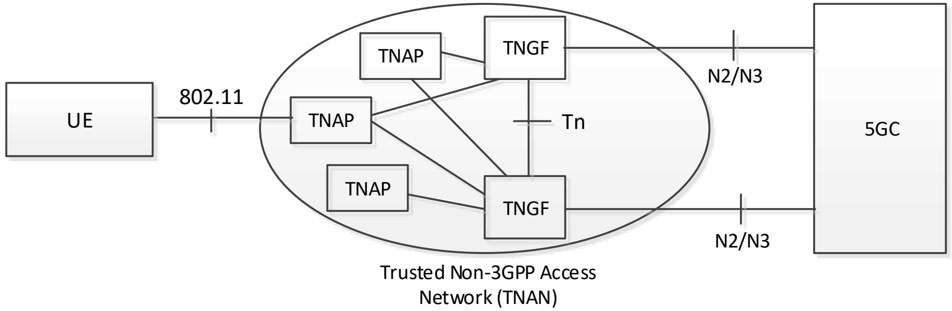
– Unified transport mechanism over WLAN access for both trusted and untrusted use cases;

– Policies based mechanism for access selection and traffic selection, steering and splitting;

– Unified QoS mechanism for both cellular and WLAN access.

Trusted WLAN Access (3GPP Rel- 16 onwards)





802.11 and cellular radio technologies are largely complementary in meeting the comprehensive 5G service vision

- WLAN access is integral part of the into the 5G system architecture developed by 3GPP

- 5G architecture is a functional based architecture
  - This provides the flexibility that both core network anchoring and the RAN based anchoring from 4G system are seamlessly supported in 5G system architecture

- <u>802.11 defined technologies – 2.4/5/6/60GHz and cellular radio technologies are essential – and largely complementary - in meeting the comprehensive 5G service vision</u>

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

802.11ax – High Efficiency WLAN - 2.4, 5 (and 6) GHz bands.

802.11be – Extremely High Throughput

802.11ay – Support for 20 Gbps in 60 GHz band.

802.11bd – Enhancements for Next Generation V2X, 802.11p DSRC evolution

802.11ah – Sub 1GHz operation

802.11az – 2nd generation positioning features.

802.11ba – Wake up radio. Low power IoT applications.

802.11bb – Light Communications

802.11bc – Enhanced Broadcast Service

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

Bandwidth	PHY Rate
1 MHz	150Kbps – 4Mbps
2 MHz	650Kbps – 7.8Mbps
4 MHz	1.35Mbps – 18Mbps
8 MHz	2.9Mbps – 39Mbps
16 MHz	5.8Mbps – 78Mbps

- **Long range** indoor/outdoor connectivity up to 1 km, over 8K clients per AP
- **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 is defining the **Wi-Fi Certified HaLow** certification program
- Japan: 802.11ah Promotion Council
- **New market entrants** emerging to develop the technology

802.11ah use cases are broad: Consumer, Industrial, Agricultural

- **Industrial Automation**
  - Smart robots with local imaging
- **Agriculture, Horticulture, City farming**
  - Large number of devices supported
  - See http://www.methods2business.com/applications
- **Process Automation**
  - Predictive maintenance, logistics, inventory tracking
- **Healthcare in hospital and home settings**
- **Home and Building automation**
  - Energy and asset management
  - Remote operation/self diagnosis
  - Whole home coverage for battery operated sensors
- **Retail: Electronic shelf labels**

Sub 1 GHz Spectrum availability in various countries

– Australia (13 MHz), 915-928 MHZ

– China (32 MHz), 755-787 MHz

– Europe (7 MHz), 863-868 MHz and 917.4-919.4 MHz

– Japan (13 MHz), 915.9-929.7 MHz

– New Zealand (13 MHz), 915-928 MHZ

– Singapore (8 MHz), 866-869 MHz and 920-925 MHz

– South Korea (12 MHz), 917-923.5 MHz and 940.1 to 946.3 MHz

– USA (26 MHz), 902-928 MHz

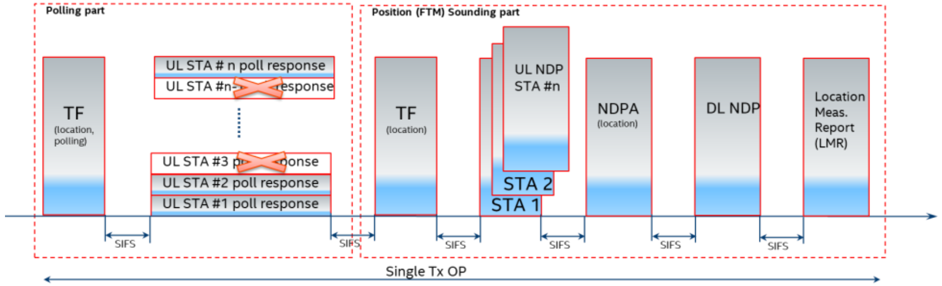
  – 902-928MHz is also available in Canada and countries in South America, i.e. ITU Region 2, with some exceptions

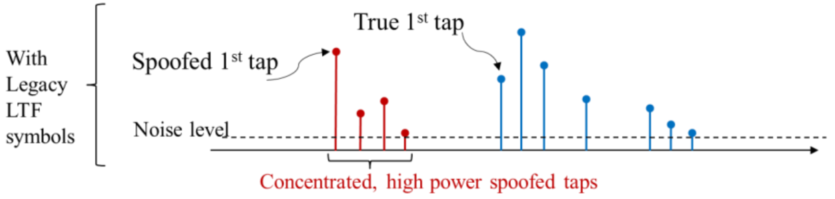
802.11az Next Generation Positioning

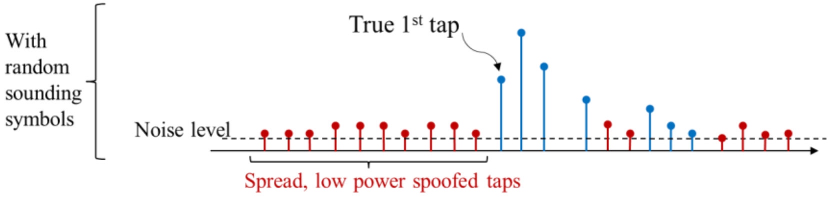
- Next Generation Positioning P802.11az project is the evolutionary roadmap of accurate 802.11 location (FTM) appearing first in previous revisions of the 802.11 standard:
    - Accurate indoor Navigation (sub 1m and into the <0.1m domain).
    - Secured (authenticated and private) positioning – open 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).

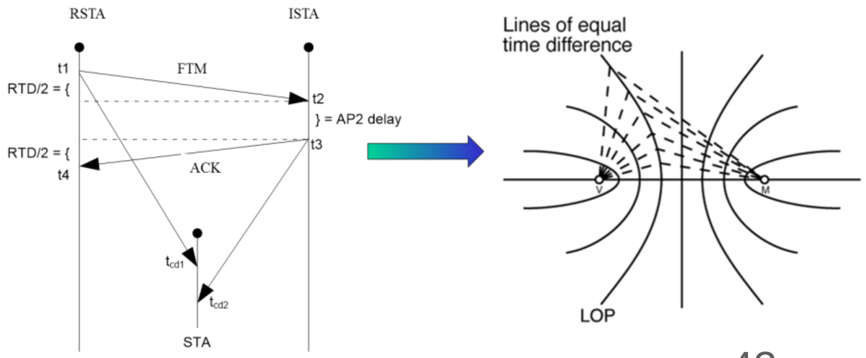
802.11az Key Radio and Positioning Techniques

- 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



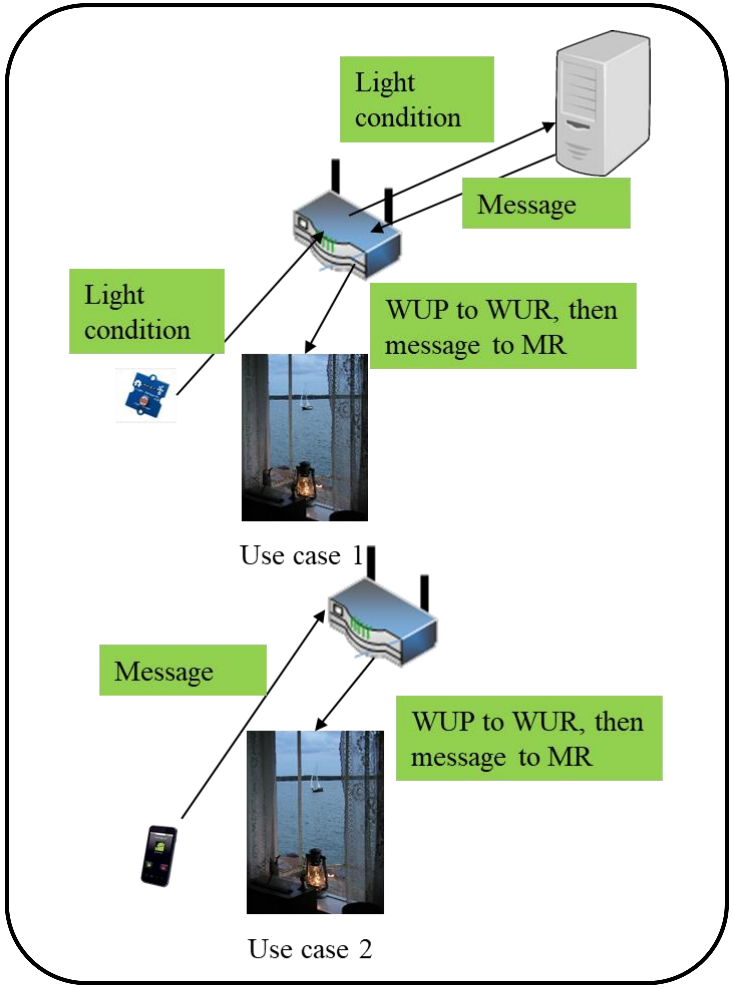




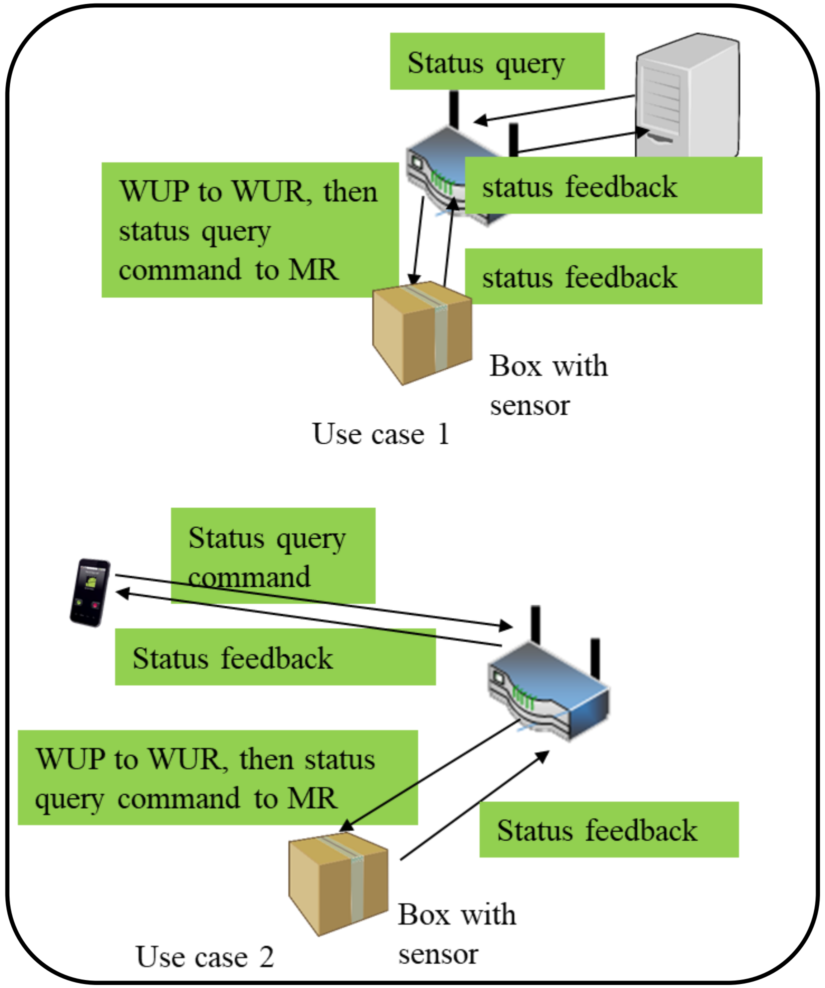


802.11ba Wake-up Radio Main Use Cases

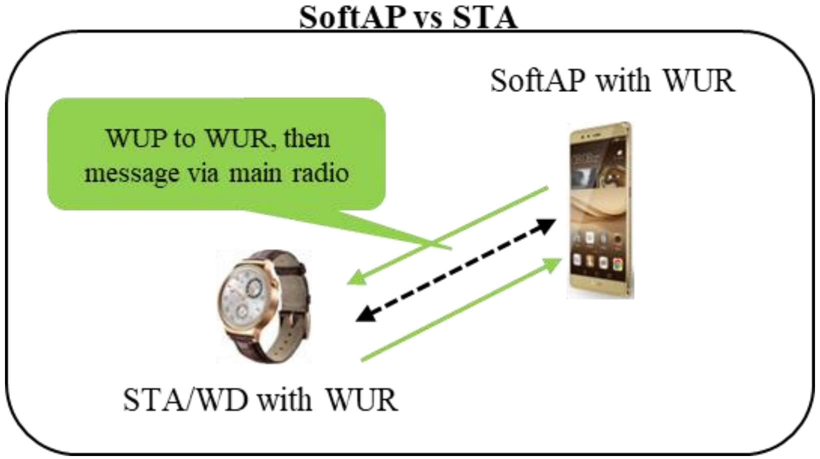
1. Smart Home



2. Warehouse



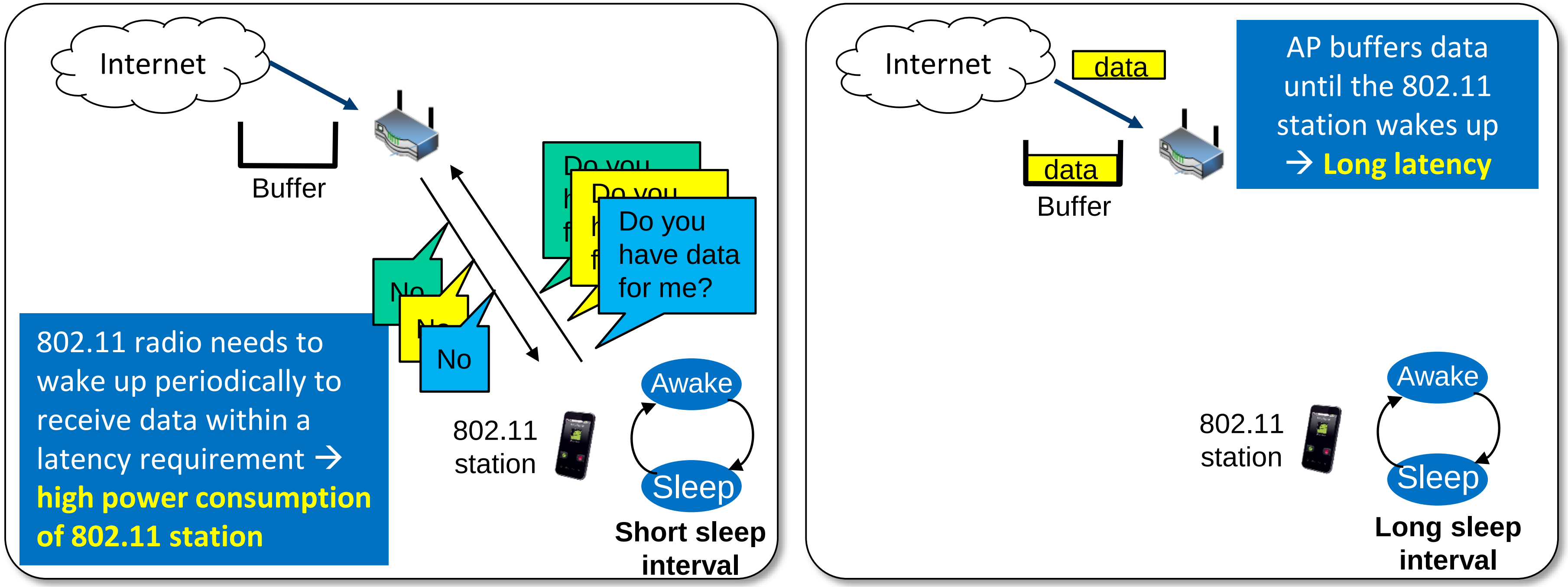
3. Wearables



WUP: wake-up packet
WUR: wake-up receiver
MR: main radio

802.11ba Wake-up Radio

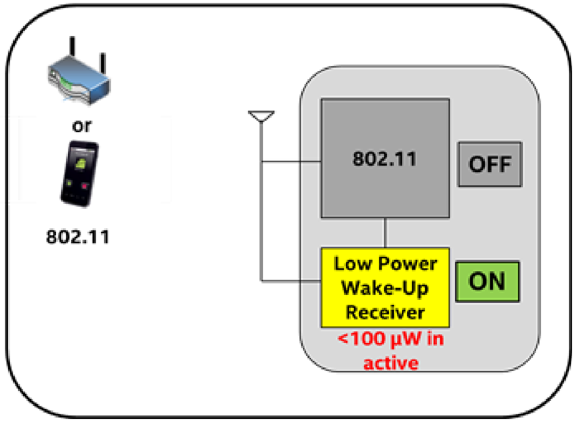
– IEEE 802.11ba improves energy efficiency of IEEE 802.11 stations while maintaining low latency



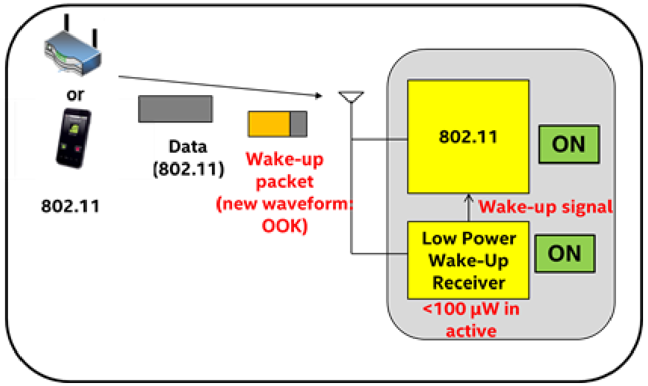
802.11ba Low-power Wake-up Receiver (LP-WUR) as Companion Radio for 802.11

- Comm. Subsystem = Main radio (802.11) + LP-WUR
  - **Main radio (802.11): for user data transmission and reception**
    - Main radio is off unless there is something to transmit
    - LP-WUR wakes up the main radio when there is a packet to receive
    - User data is transmitted and received by the main radio
  - **LP-WUR: not for user data; serves as a simple "wake-up" receiver for the main radio**
    - LP-WUR is a simple receiver (doesn't have a transmitter)
    - Active while the main radio is off
    - Target power consumption < 1 mW in the active state
      - Simple modulation scheme such as On-Off-Keying (OOK)
      - Narrow bandwidth (e.g. < 5 MHz)
    - Target transmission range: LP-WUR = Today's 802.11

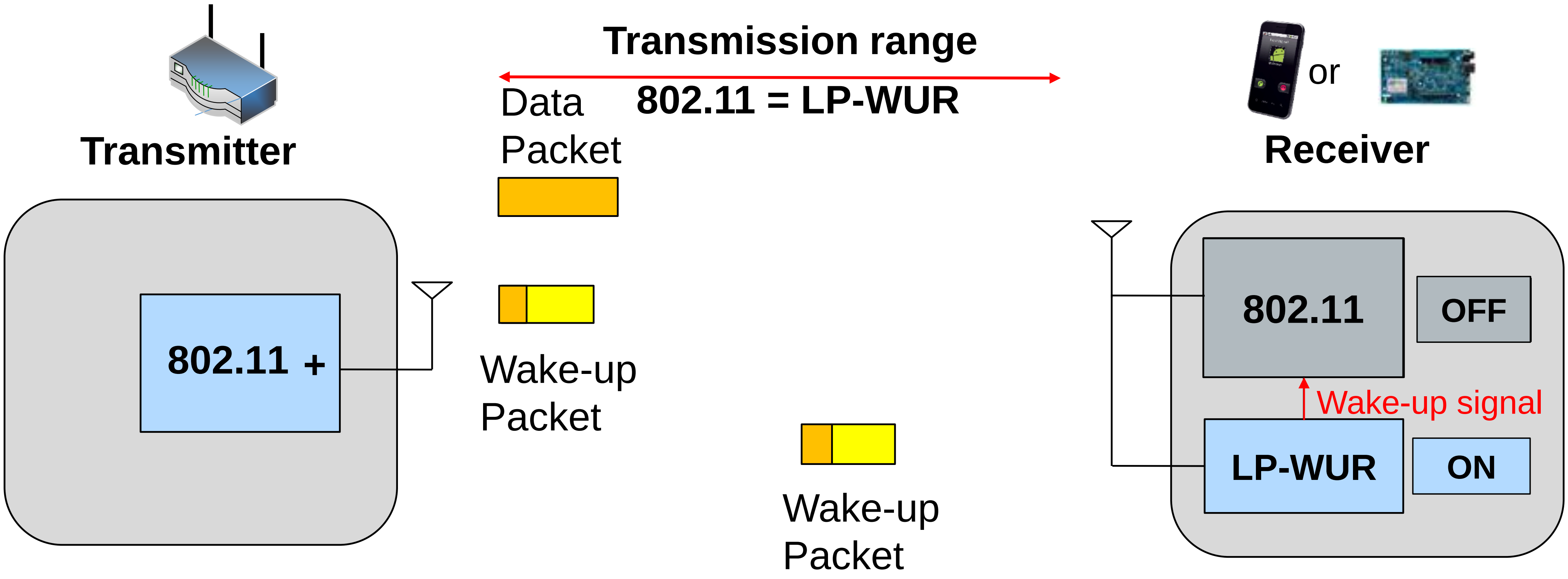
No data to receive



Data to receive



802.11ba Low Power Wake-up Radio Operation



802.11bc is defining Enhanced Broadcast Services

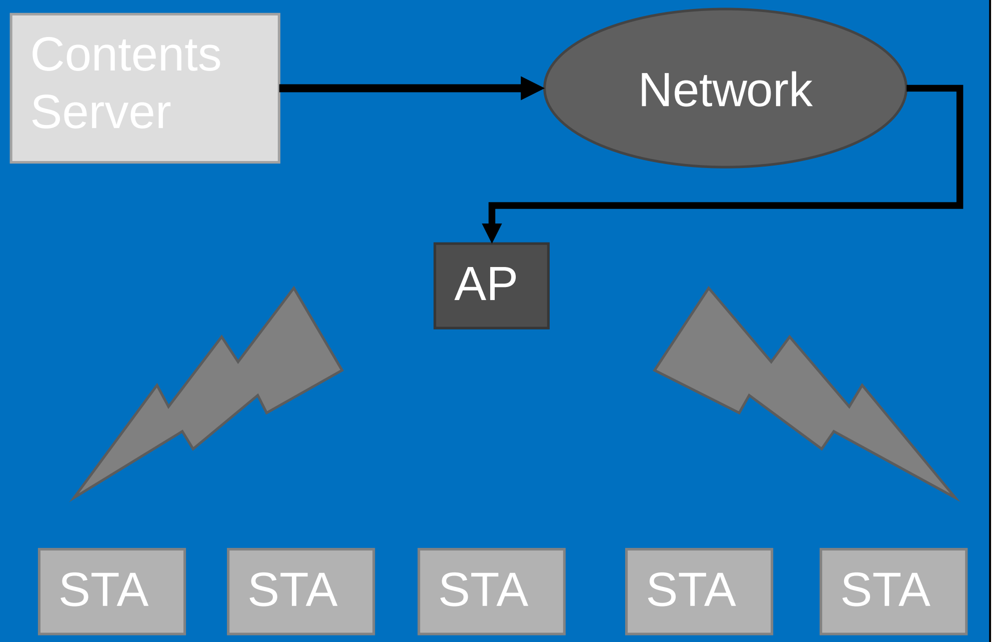
– Enhanced Broadcast Services (eBCS) define broadcast service enhancements within an 802.11-based network.
– Client end devices broadcast information to an AP, e.g. in an IoT environment, to other STAs so that any of the receiving APs act as a access node to the Internet.

802.11bc use cases description

– **Broadcast Downlink**
– Provides enhanced Broadcast Services (eBCS) of data (e.g. videos) to a large number of densely located STAs. These STAs may be associated, or un-associated with the AP or may be low-cost STAs that are receive only.
– **Broadcast Uplink**
– Pre-configured devices (e.g. IoT) automatically connect to the end server through APs with zero setup action required.
– Alternatively, low power IoT devices that are in motion, report to their servers through APs without scanning and associating

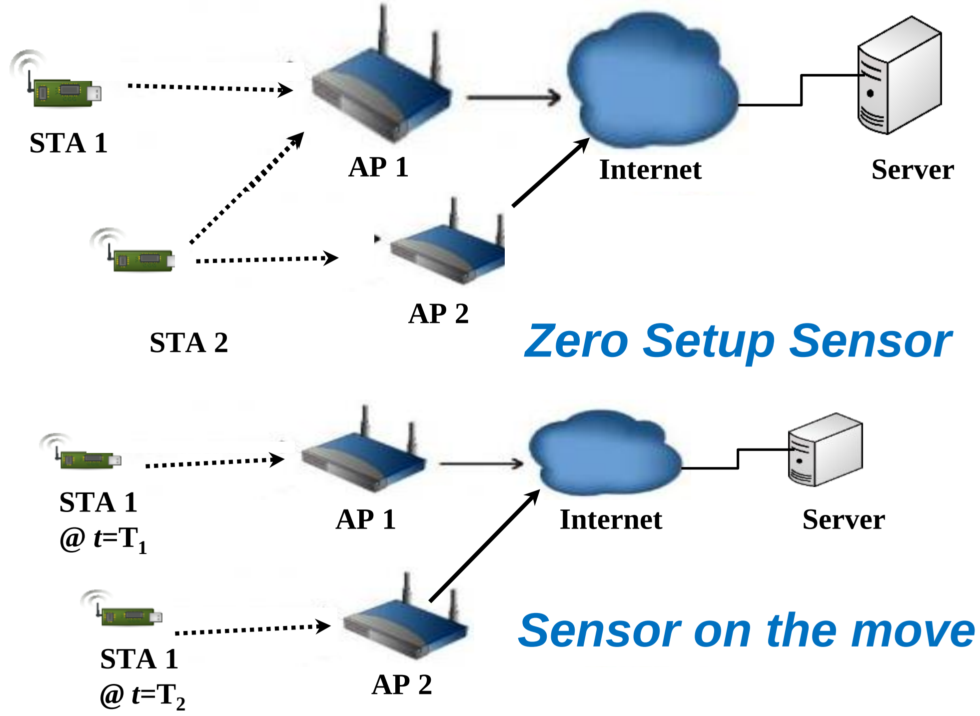
802.11bc use cases

Topology/Architecture



Broadcast Downlink

Topology/Architecture



Broadcast Uplink

802.11bb: Light Communications

5Gbps+ rates are defined
Light Communications

Key additions :

- Uplink and downlink operations in 380 nm to 5,000 nm band
- Minimum single-link throughput of 10 Mb/s
- Mode supporting at least 5 Gb/s,
- Interoperability among solid state light sources with different modulation bandwidths.

Use Cases:

- Industrial wireless applications
- Medical environments
- Enterprise
- Home
- Backhaul
- Vehicle to Vehicle Communication
- Underwater Communication
- Gas Pipeline Communication

802.11bb: Usage Model 1: Industrial wireless

Pre-Conditions

Devices may experience unstable radio frequency (RF) connection due to Electro-Magnetic Interference (EMI) in factories. LC is deployed to provide reliable wireless connectivity for industrial wireless networks.

Environment

All communications are within a large metal building, industrial or automated work cell. The area of these environments range from tens to thousands of square meters, equipped with industrial robot and other equipment. The environment has high levels of EMI. Lighting level of 150 lux is recommended (1500 lux for dedicated work).

Applications

Ultra-high-definition (UHD) video streaming for surveillance or production monitoring (quality control) applications, as well as for video collaboration for team, customer, and supplier meetings. Lightly compressed Video: ~ 1Gbps, delay < 5 ms, $1x10^{-8}$ PER, 99.9% reliability.

Fully connected factory—for real-time communications, application execution, and remote access.

Distance between LC APs ranges from 2~20

Traffic Conditions

Both uplink and downlink traffic is using LC.

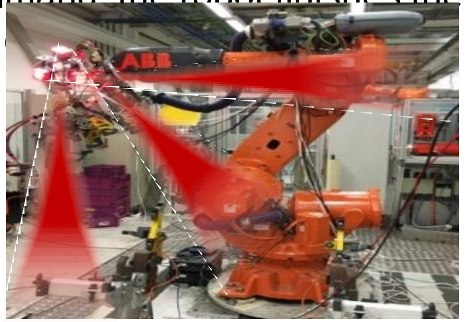
High levels of OBSS interference between LC access points (APs) expected due to very high density deployment.

Potential non-LC interference from surrounding environments such as artificial-light.

Multiple LC modules are deployed on the robot/equipment and on the ceiling/walls to provide multiple light links for a robust connectivity in case a single line-of-sight (LOS) link is blocked.

Use Case

An industrial robot is powered on and ready for operation. Operating instructions are transmitted to the robot via LC. The robot is working (e.g., movement) according to the instructions and provides real-time feedback information and/or video monitoring data for quality control to control center also via LC. Upon command, the robot finishes the task and is ready for the next



802.11bb: Usage Model 2: Wireless access in medical environments

Pre-Conditions
IEC 60601-1-2 standard recommends the minimum separation distance between medical electrical (ME) equipment and RF wireless communications equipment (e.g., wireless local area network (WLAN)) be 30 cm to avoid performance degradation of the ME equipment. LC is deployed to ensure the performance of all ME equipment.

Environment
The size of a operating theater and MRI room ranges from 30~60 m^2. Multiple LC-APs are deployed on the ceiling to provide specialized illumination. The central ~~i~~lluminance of the operating light: 160k and 40k lux. The size of a four beds ward is about 60 m^2, light level: 300 lux on the bed and >100 lux between the beds and in the central area.

Applications
LC-WLAN is used to allow wireless data exchange in medical environments with ME equipment or system. Medical multimedia and diagnostic information can be transmitted to provide telemedicine services; ME equipment can also be wirelessly controlled via LC.
Provide Intranet/ Internet access, audio or video call for doctors, nurses and patients using LC-based devices.

Traffic Conditions
No interference caused by RF radiation.
Both uplink and downlink traffic is ~~are~~ using LC.
High Quality of Service (QoS) and high reliability are required.
Potential non-LC interference from surrounding environments such as artificial-light.

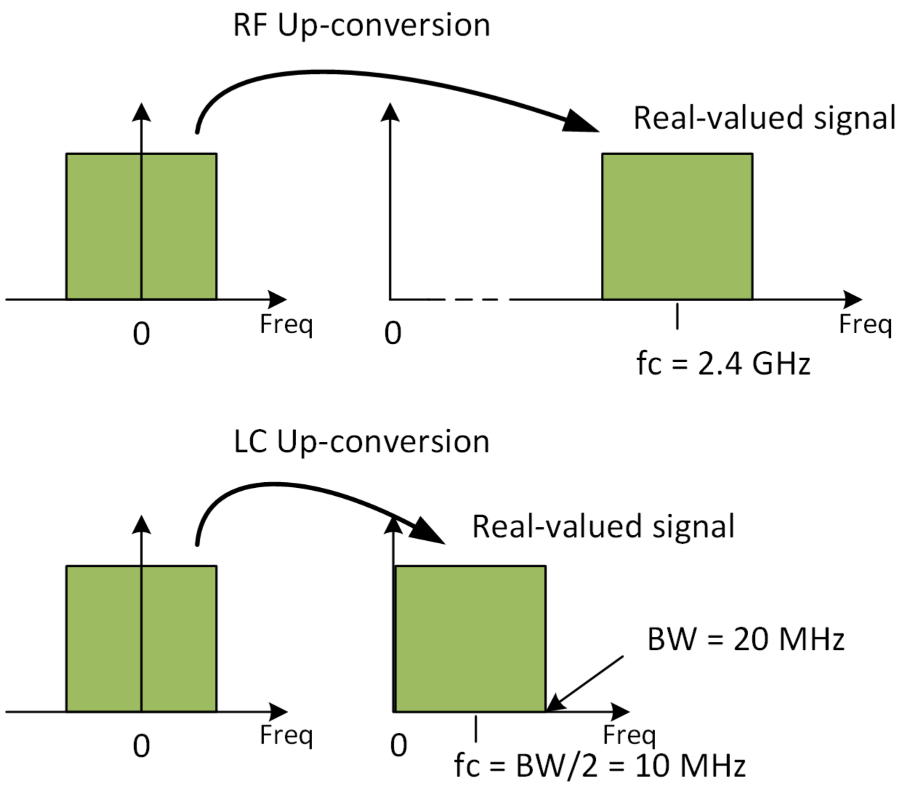
Use Case
Doctors enter an operating theater, turn on the LC enabled LED lights and ME equipment. Doctors can interact with the remote doctors and share information using LC. ME equipment connectivity is also supported by LC. Doctors finish the treatment, then turn off the lights and medical equipment.
A patient is monitored by ME equipment which communicate with the nurses/doctors in control room via LC.

Operating theater

Hospital ward

802.11bb uses light spectrum and existing technological capabilities

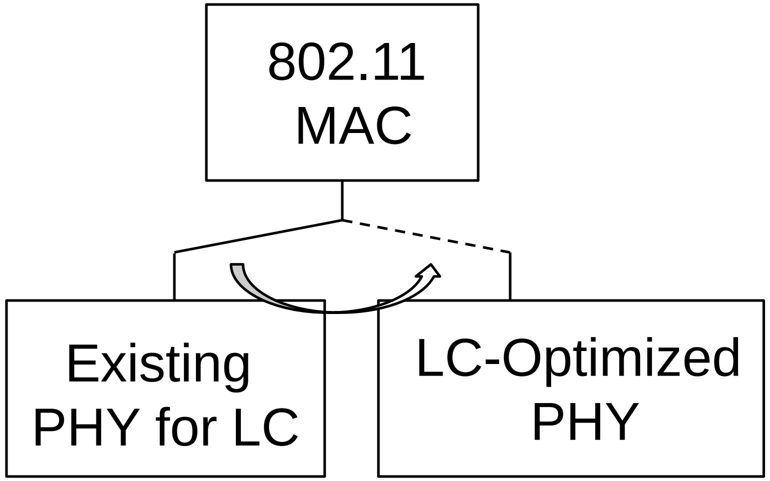
- RF frontend up-converts baseband signals onto e.g. f_c=2.4 GHz.



- LC frontend up-converts baseband onto low IF e.g. f_c=BW/2 + Δ.
  - Δ is to be agreed depending on signal mask design.
- This way, any complex-valued baseband signal (i.e. any existing IEEE 802.11 PHY) can be used to facilitate LC.

802.11bb uses light spectrum and existing technological capabilities

- 802.11 MAC could integrate existing and optimized PHY



- Use existing 802.11 PHY as a common, mandatory OFDM PHY (except 11ad, ay).
- A legacy preamble is prepended to new LC PHYs. Legacy preamble is sent by using an existing 802.11 OFDM PHY. The switch is set in the legacy signaling field.

  a) Legacy 802.11 PHY is used (e.g. 11a/g, n, ac, ax) → reuse 802.11 PHY also for LC

  b) LC-optimized PHY is used (e.g. G.hn/G.vlc) → optimize performance for LC

Thank You

Questions