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# IEEE 802.11 Standards: Wi-Fi 6 and beyond

**Wi-Fi<sup>®</sup> networks: in use today for Emergency Services**

**New Amendments: Markets, use cases and key technologies**

**2019 October – JPL Workshop**

**Presenter: Dorothy Stanley, IEEE 802.11 Working Group Chair, [dorothy.stanley@hpe.com](mailto:dorothy.stanley@hpe.com)**

“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 802.11 systems are commonly used for emergency and disaster recovery communications

Liberty Global Teams to Provide Free WiFi in Puerto Rico

<https://www.multichannel.com/news/liberty-global-teams-provide-free-wifi-puerto-rico-416351>

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

[https://papers.ssrn.com/sol3/papers.cfm?abstract\\_id=3142393](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3142393)



**C-DOT's Satellite Wi-Fi (C-Sat-Fi®)**

C-DOT Satellite Wi-Fi (C-Sat-Fi) is an innovative integration of VSAT Technology with C-DOT BBWT\* Wi-Fi Terminals. The satellite connectivity is used as Backhaul link for the complete village. C-DOT BBWT Wi-Fi such as Solar Wi-Fi is used for Hotspot and C-DOT Long Range Wi-Fi is used as Point to Point & Point to Multi Point links to cover the complete village.

The Satellite and internet bandwidth can be provided by any existing Satellite operators and ISPs.

The system is optimized to support concurrent VOIP/Voice calls. Local content servers are placed to provide static content locally over C-DOT Manoranjan platform and reducing the use of expensive satellite bandwidth and making the bandwidth available for basic connectivity.

The Services can be offered by either ISPs, or VLEs by enrolling under CSC

**Architecture for network with C-DOT Satellite Wi-Fi to extend broadband to users**

**Network Elements include:**

- Wi-Fi Access point to create Wi-Fi hotspot around area
- Satellite Remote station (VSAT modem or smartLNB for the backhaul connectivity).

\*BBWT: Broadband Wireless Terminal supporting IEEE 802.11 a/b/g/n/AC 2x2 up to 4x4 MIMO technology

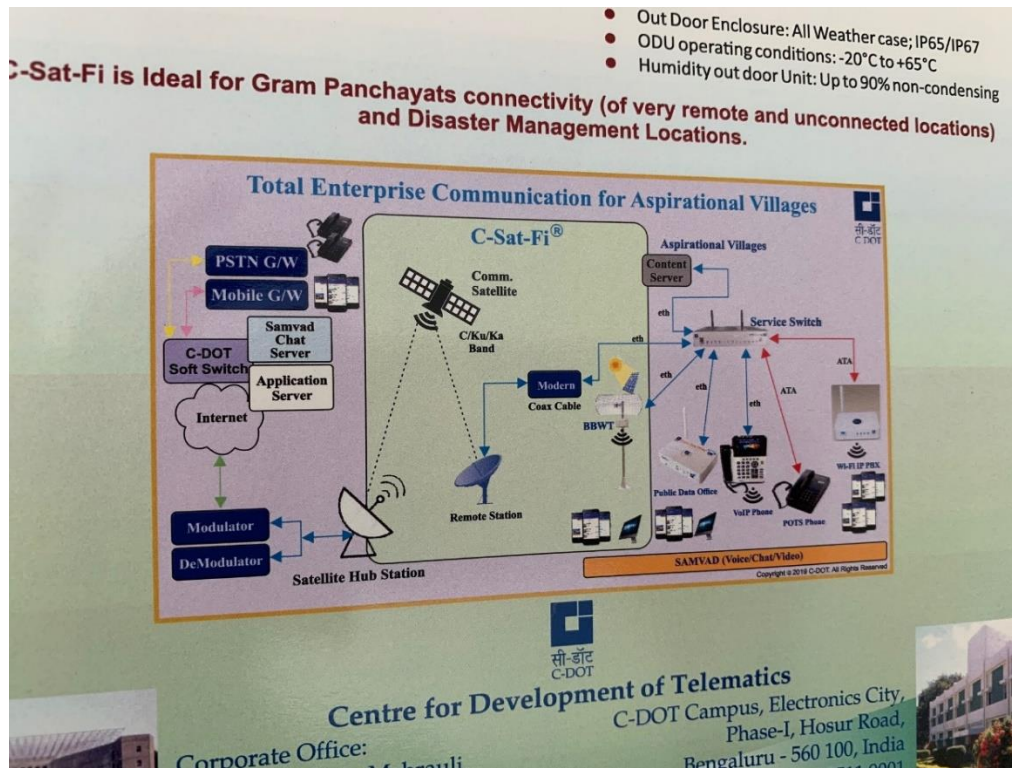
**Digital Connectivity using Satellite Wi-Fi**


Architecture for this network with Wi-Fi to extend broadband from POP location (satellite backhaul location) / village headquarter and using Wi-Fi as a backhaul to connect bigger areas, using point to point Wi-Fi as backhaul.

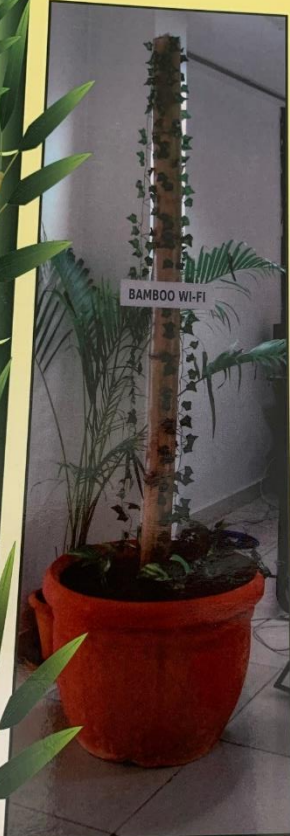
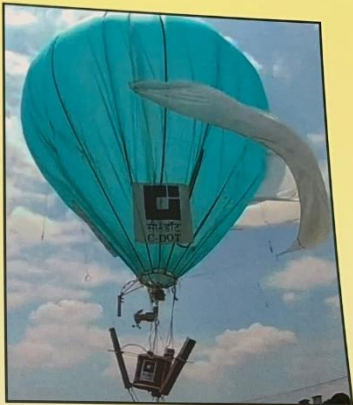
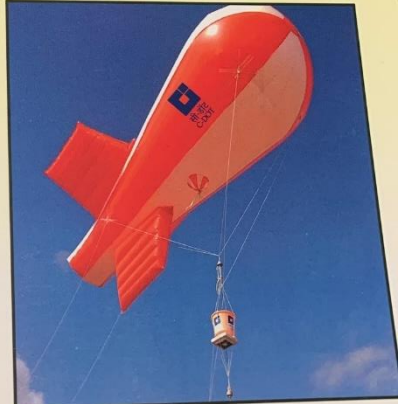
The diagram illustrates the network architecture. It shows an Internet Cloud for Voice, Data, and Video connected to a Modulator and Demodulator. This is linked to a Communication Satellite via a C-Ka/Ku Band. The satellite connects to a Remote Station (VSAT modem or smartLNB for the backhaul connectivity). The Remote Station is connected to a Station (Cable Modem or LNB & In). The Station is connected to a Router, which is connected to a Switch. The Switch is connected to a Server. The Server is connected to a Network of devices (Laptop, Tablet, Smartphone, etc.). The Network is connected to a Wi-Fi Access Point, which is connected to a Wi-Fi Client (Laptop, Tablet, Smartphone, etc.).

Customized products are developed using IEEE 802.11 systems for remote connectivity, disaster management, targeting developing countries.

Example: India Centre for development of Telematics



**Innovative Wi-Fi Products** 

**Bamboo Wi-Fi** **Balloon Wi-Fi**



# Market demands and new technology drive IEEE 802.11 innovation

## Demand for throughput

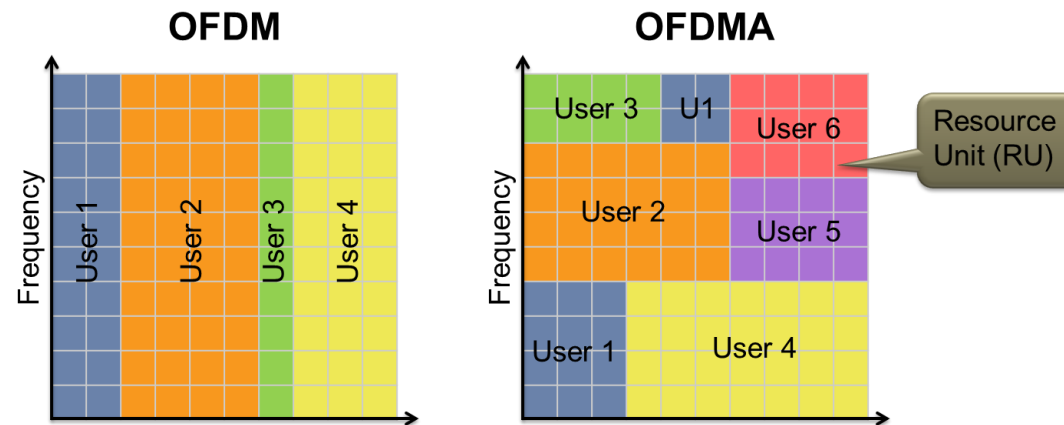
Continuing exponential demand for throughput

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

**802.11ax/Wi-Fi 6 – Increased throughput in 2.4, 5 (and 6) GHz bands.  
Increased efficiency.**

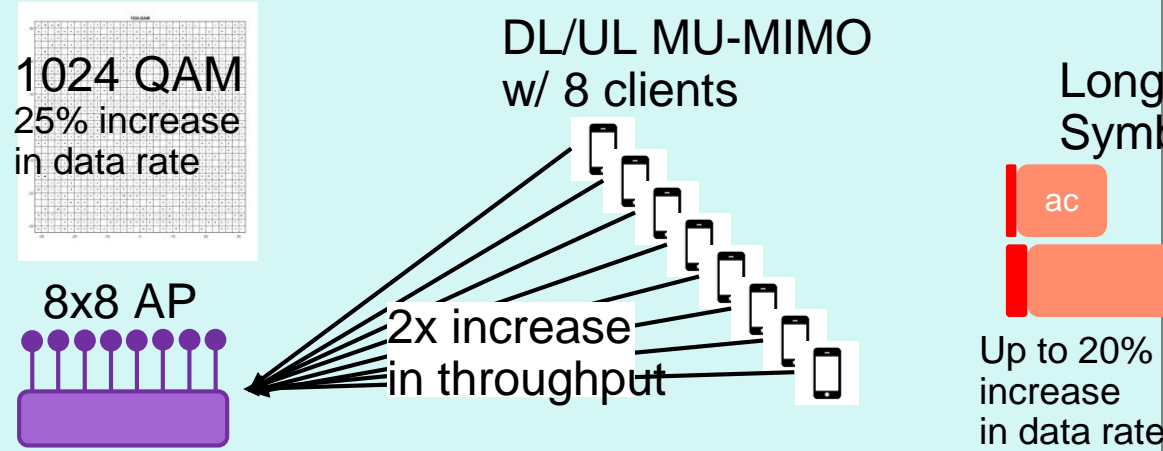
**802.11ay – Support for 20 Gb/s rates in 60 GHz band**

**New: 802.11be – Extremely High Throughput**

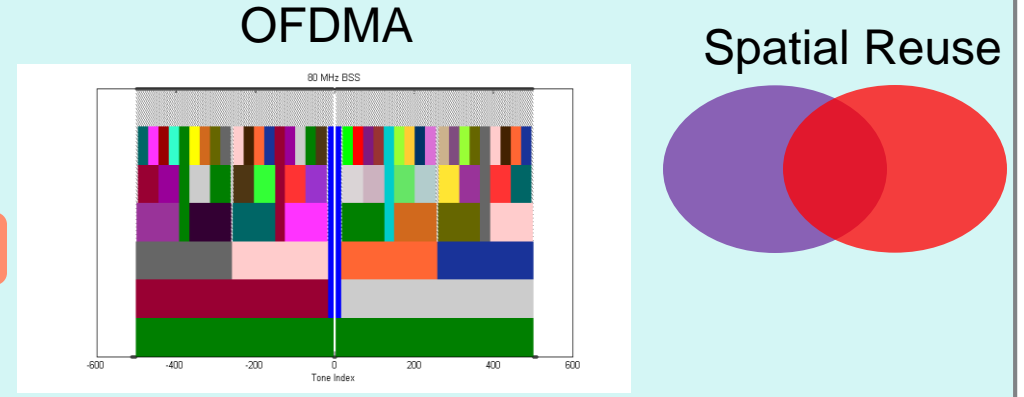


# Categories of Enhancements in 802.11ax (Wi-Fi 6)

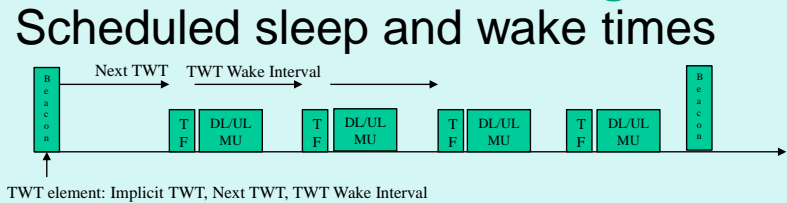
## Spectral Efficiency & Area Throughput



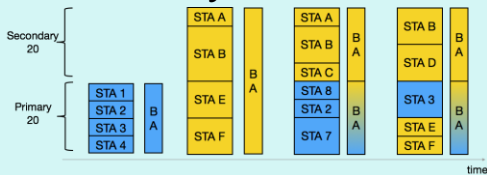
## High Density



## Power Saving

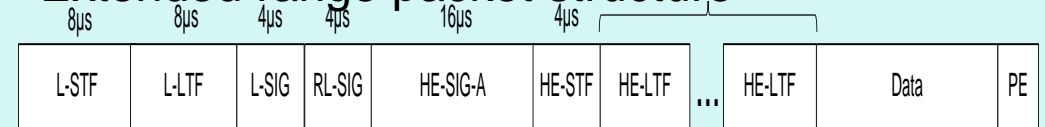


## 20 MHz-only clients

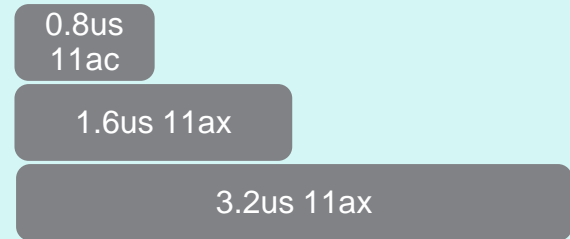


## Outdoor / Longer range

### Extended range packet structure



Enhanced delay spread protection-long guard interval



# IEEE 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	5 <sup>th</sup> 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 <sup>2</sup>	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]

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# 802.11ay is defining next generation 60GHz: 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

# 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/>





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# 802.11be is a new amendment that builds on 802.11ax

## Extremely High Throughput (EHT)

Higher throughput – 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:

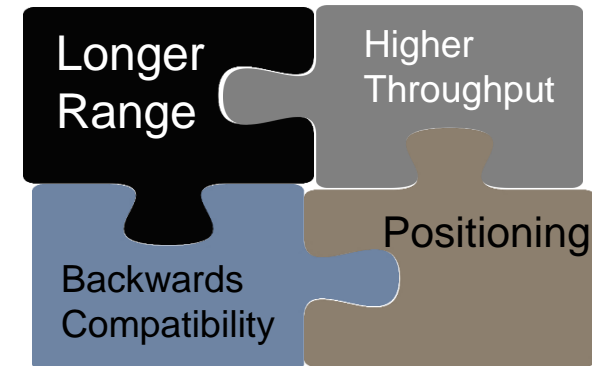
- AR/VR
- 4K and 8K video streaming
- Remote office
- Cloud computing
- Video calling and conferencing

# New Usage Models/Features

**Indoor Location**  
802.11az – 2nd generation positioning features

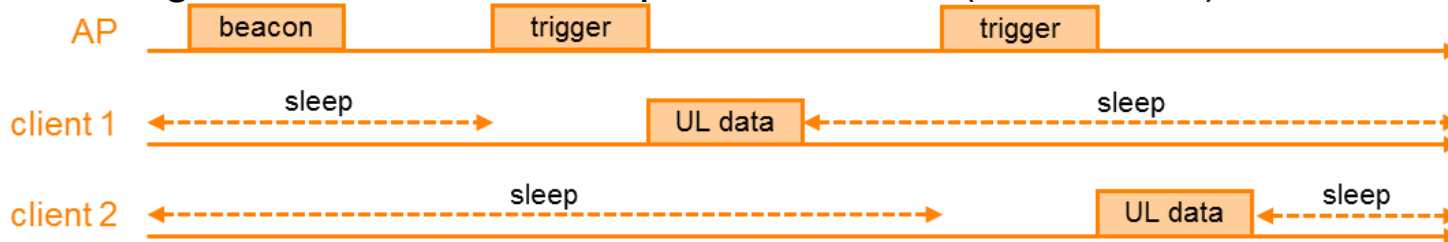
**Automotive**  
802.11bd – Enhancements for Next Generation V2X

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



802.11p seamless evolution

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



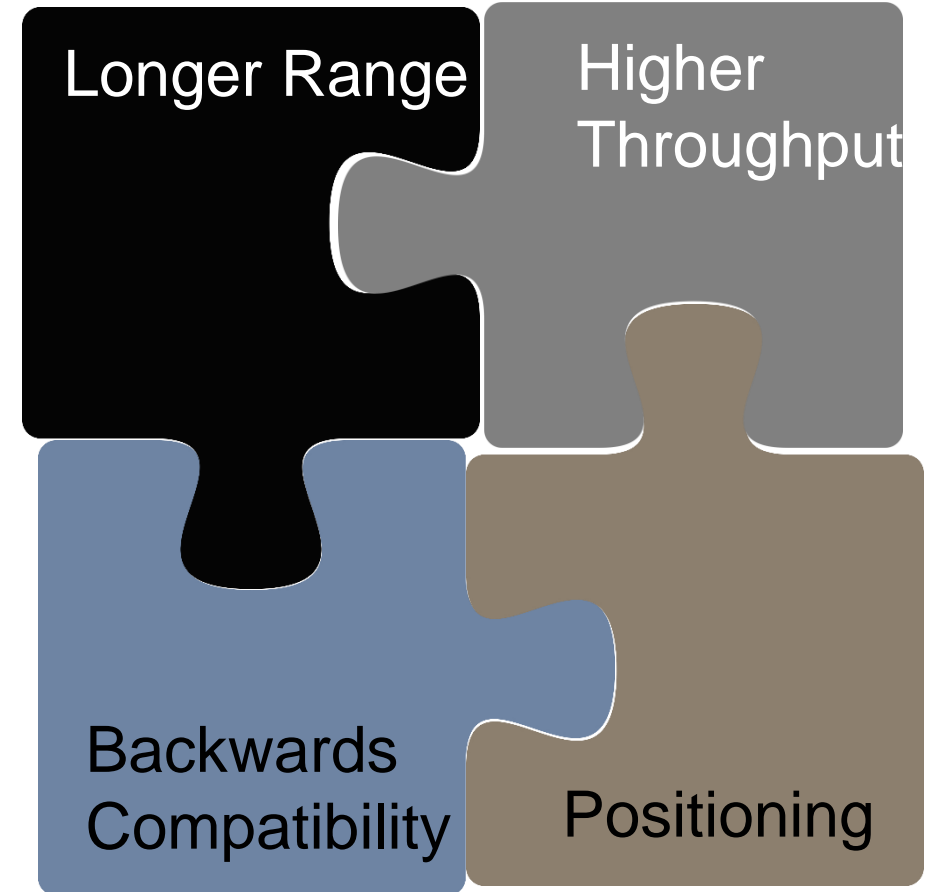
# 802.11az Next Generation Positioning

- 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 <math><0.1\text{m}</math> 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).



# 802.11bd 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



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

- 802.11ax – Increased throughput in 2.4, 5 (and 6) GHz bands. Increased efficiency.
- 802.11ay – Support for 20 Gbps in 60 GHz band
- 802.11be – Extremely High Throughput
  
- 802.11az – 2<sup>nd</sup> generation positioning features
- 802.11ba – Wake up radio. Low power IoT applications.
- 802.11bb – Light Communications
- 802.11bc – Enhanced Broadcast Service
- 802.11bd – Enhancements for Next Generation V2X
  
- Random and Changing MAC Addresses – Topic Interest Group
- Sensing – Topic Interest Group

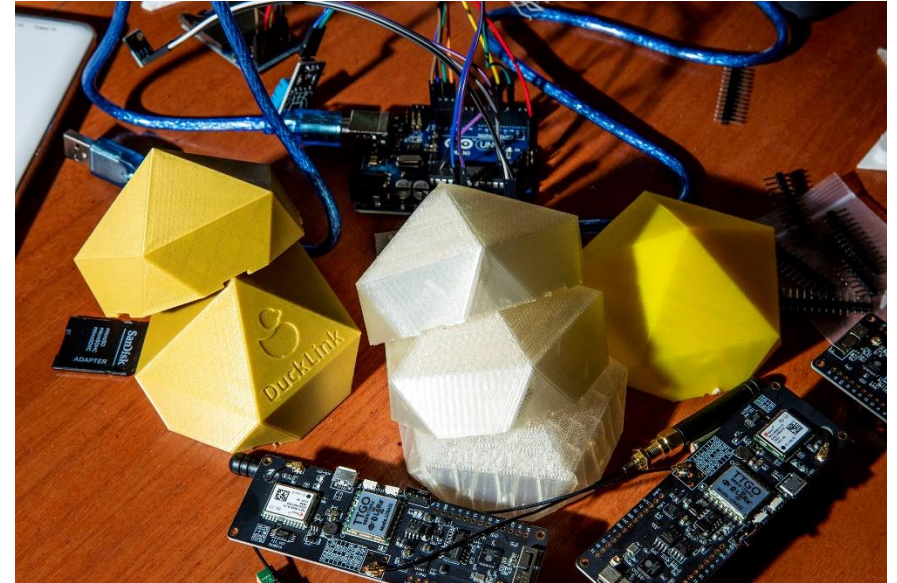


# Wi-Fi /802.11 technologies continue to be a foundation for innovative solutions

## 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.”



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Thank You

Questions

# IEEE Today at a Glance

*Global Reach*

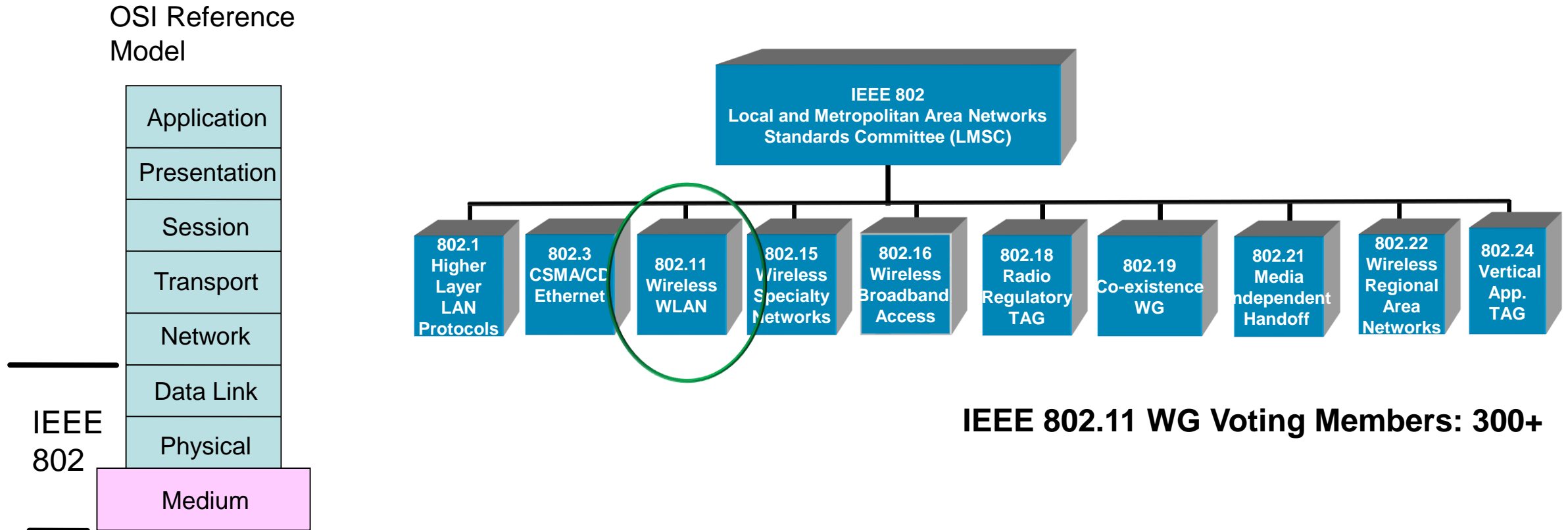


*Technical Breadth*



# 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



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## 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>



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# 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)

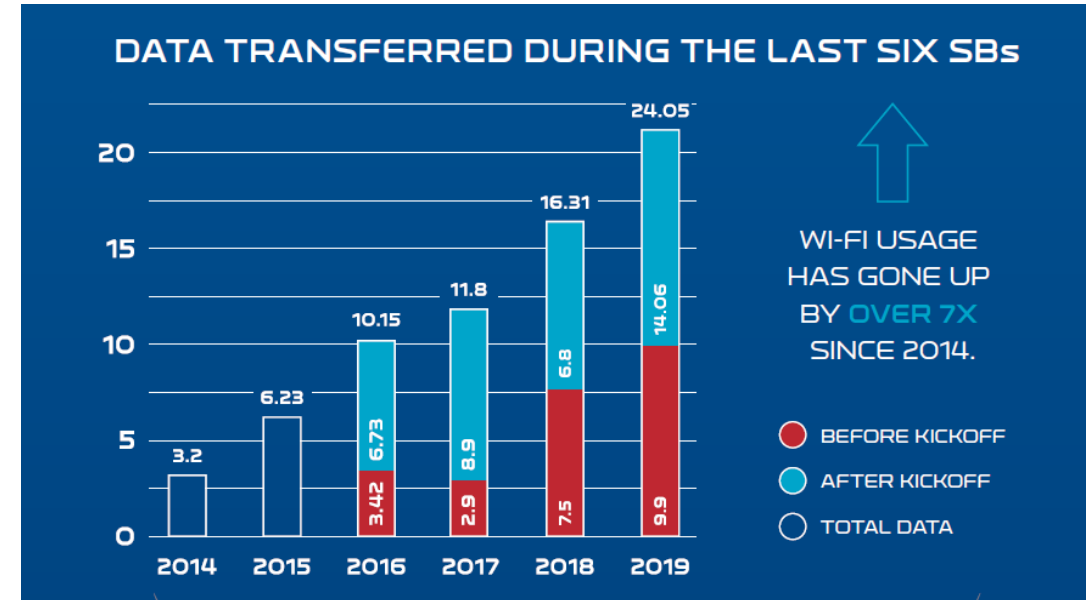


# Indoor Hotspot: Wi-Fi **today** can meet the needs of indoor and outdoor hotspots: for a single home user ..... or a whole stadium of users

## 2019: Super Bowl 53 smashes Wi-Fi record with 24 TB of traffic at Mercedes-Benz Stadium

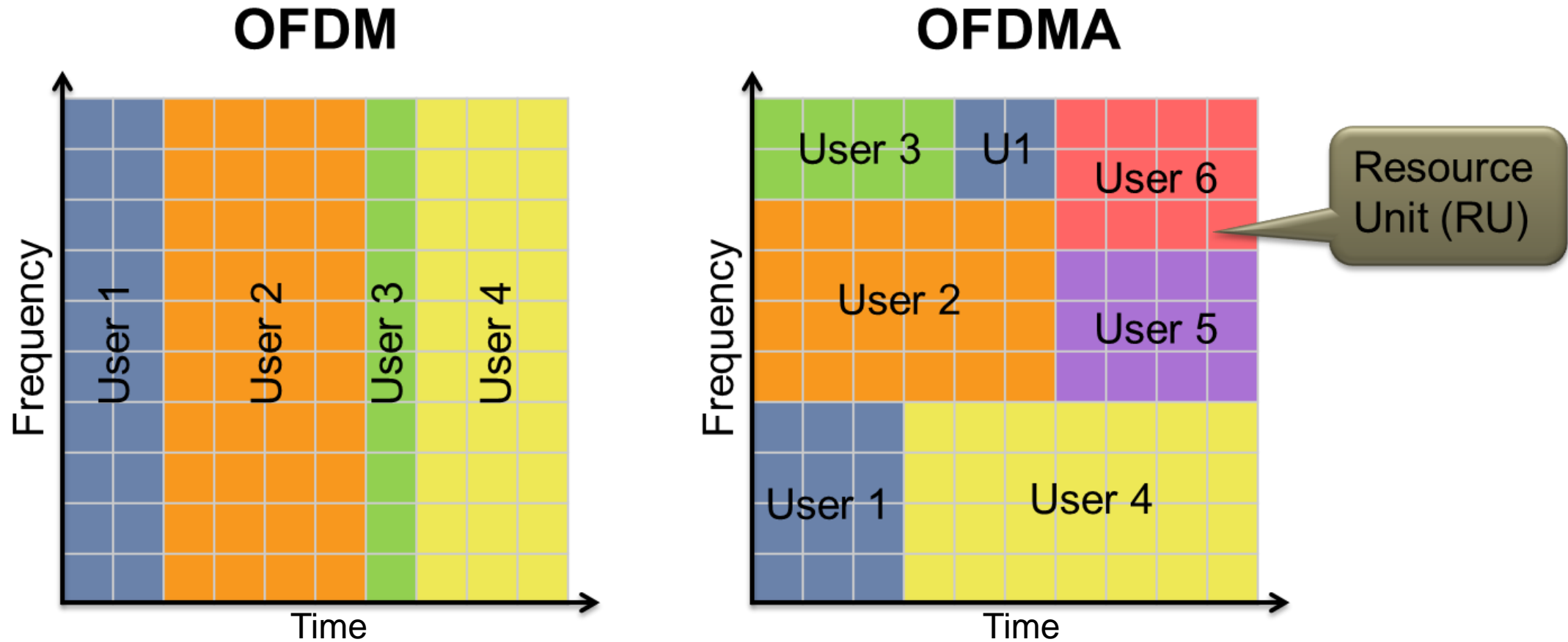
Average Wi-Fi data use per connected fan also set a new record, with the per-fan mark of 492.3 megabytes per user eclipsing last year's mark of 407.4.

## 2018: a huge leap from the official 16.31 TB seen at 2018 Super Bowl 52 in Minneapolis at U.S. Bank Stadium



Source: <https://www.extremenetworks.com/resources/slideshare/wi-fi-engagements-from-super-bowl-liiii/>

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

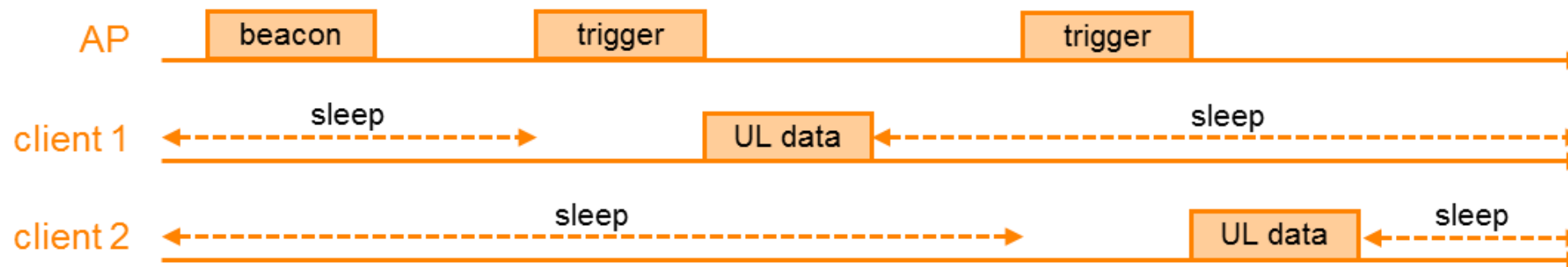


Increased efficiency for (high percentage of traffic) short data frames

# Target Wake Time

## Schedule Sleep and Wake Times

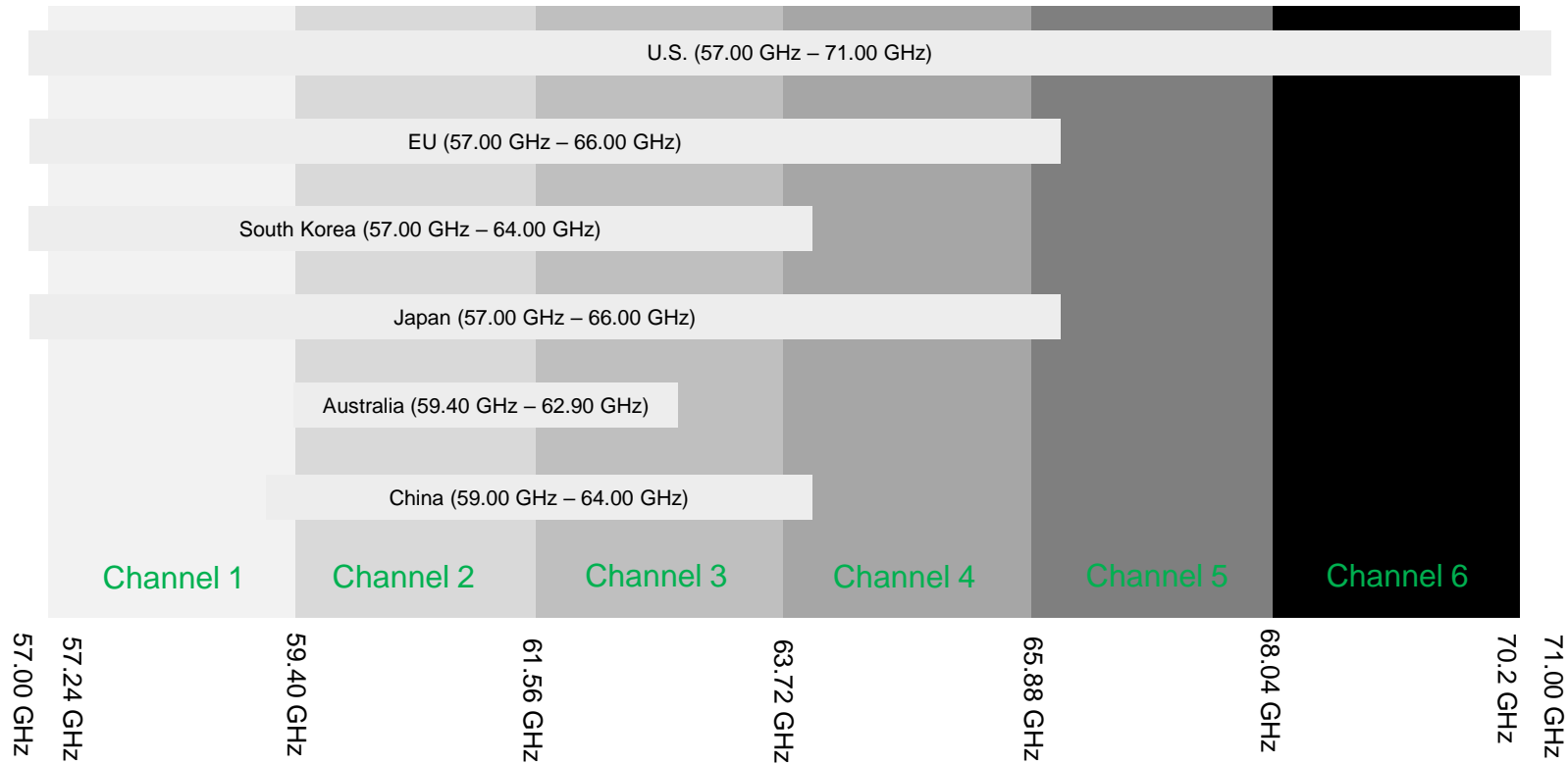
- With the Target Wake Time (TWT) feature, an 802.11ax AP can schedule devices to sleep for long times, depending on anticipated traffic load
- Devices can be scheduled to wake up individually or as a group (taking advantage of MU technologies) to quickly and efficiently exchange data before going back 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





# 60GHz 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



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# 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.”

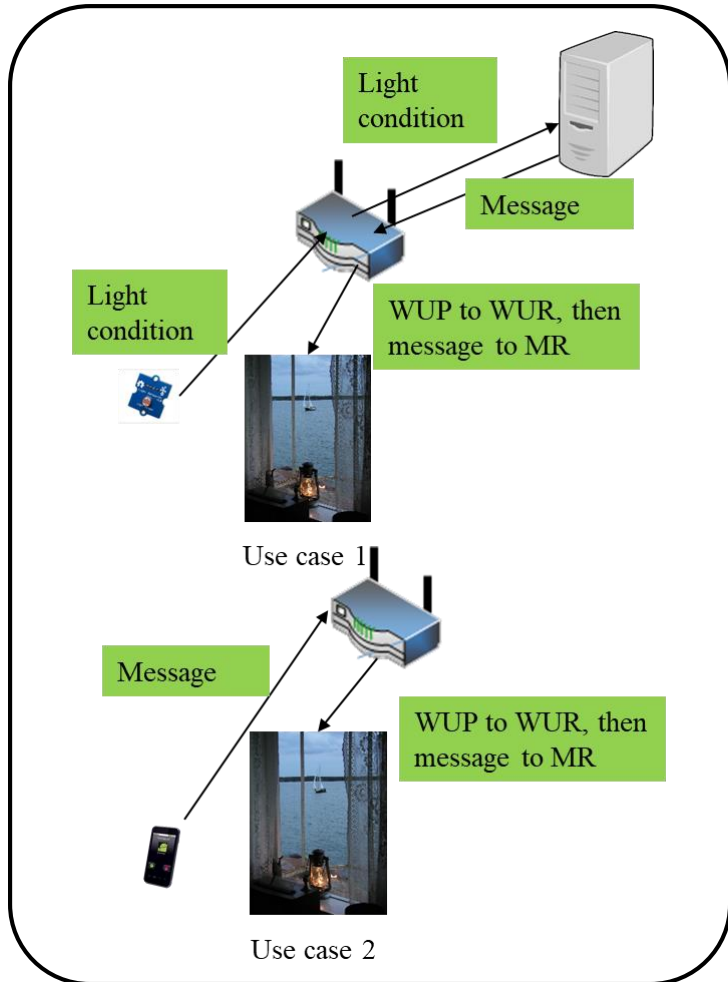
“In the U.S., unlicensed mmWave frequencies available for 5G primarily cover the band from 57 – 71 GHz, called the V-Band, or 60 GHz band. This band offers 14 GHz of contiguous spectrum, which is more than all other licensed and unlicensed bands combined<sup>7</sup>. **This makes the 60 GHz band an excellent 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>

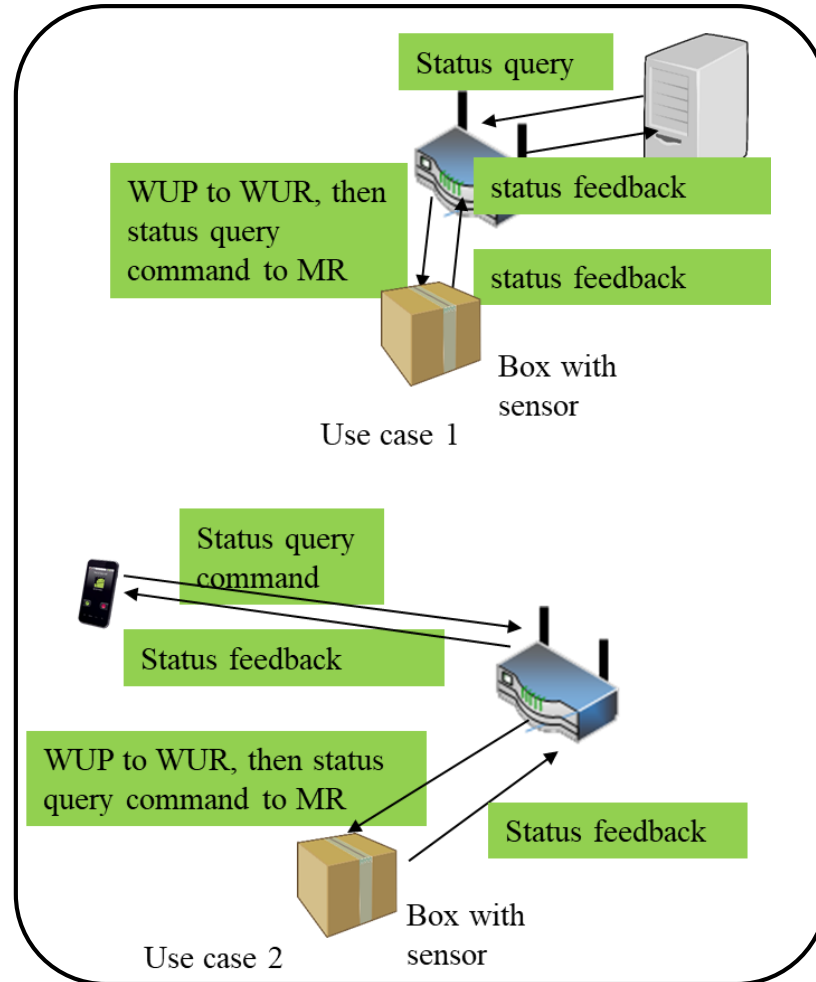
<https://www.fiercewireless.com/wireless/60-ghz-band-particularly-appealing-for-fixed-wireless-report>

# 802.11ba Wake-up Radio: Main Use Cases include Smart Home, Industrial/warehouse and Wearables [11-17/29r10]

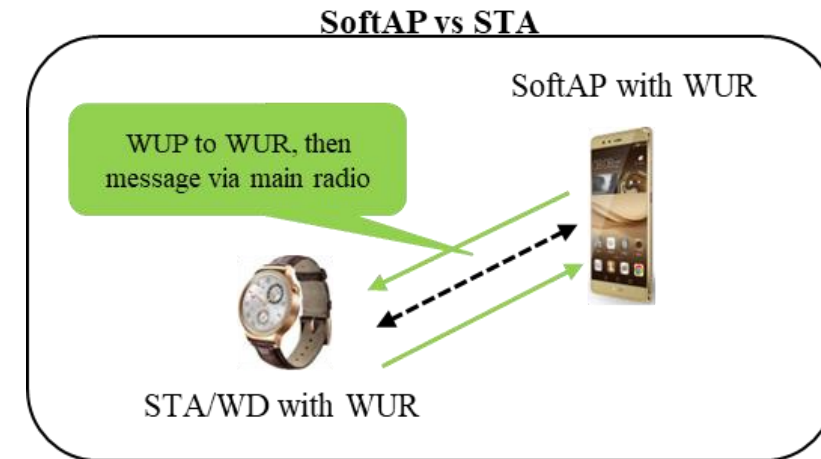
## 1. Smart Home



## 2. Warehouse



## 3. Wearables



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

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# 802.11bb: Light Communications

5Gbps+ rates are defined  
Light Communications  
Use cases

## Use Cases:

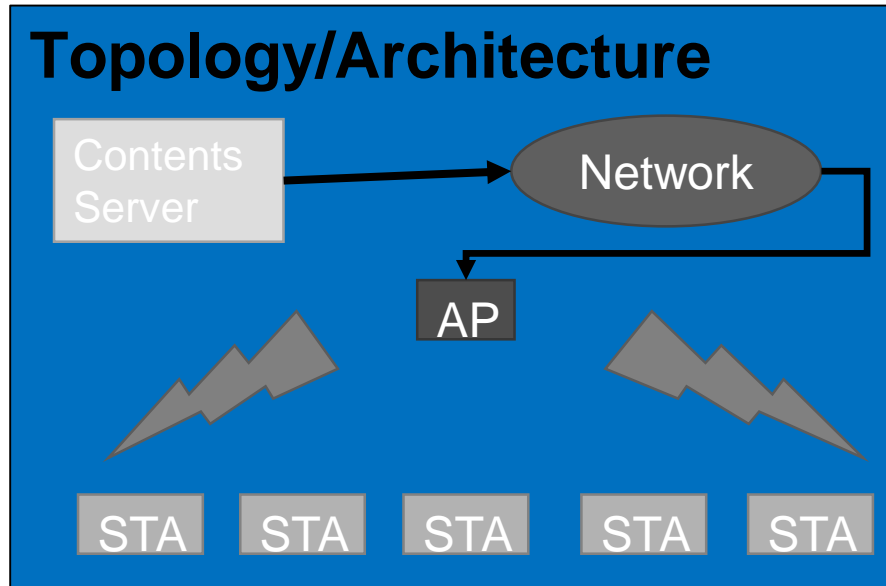
- Industrial wireless applications
- Medical environments
- Enterprise
- Home
- Backhaul
- Vehicle to Vehicle Communication
- Underwater Communication
- Gas Pipeline Communication

## Key additions :

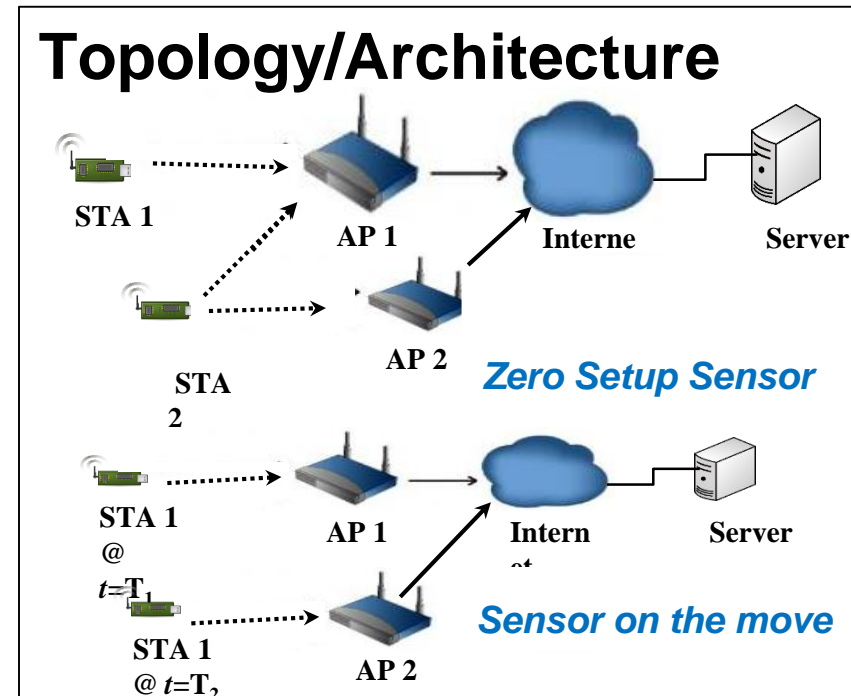
- Uplink and downlink operations in 380 nm to 5,000 nm band
- Minimum single-link throughput of 10 Mb/s
- Mode supporting at least 5 Gb/s,
- Interoperability among solid state light sources with different modulation bandwidths.

# 802.11bc is defining 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 a access node to the Internet.



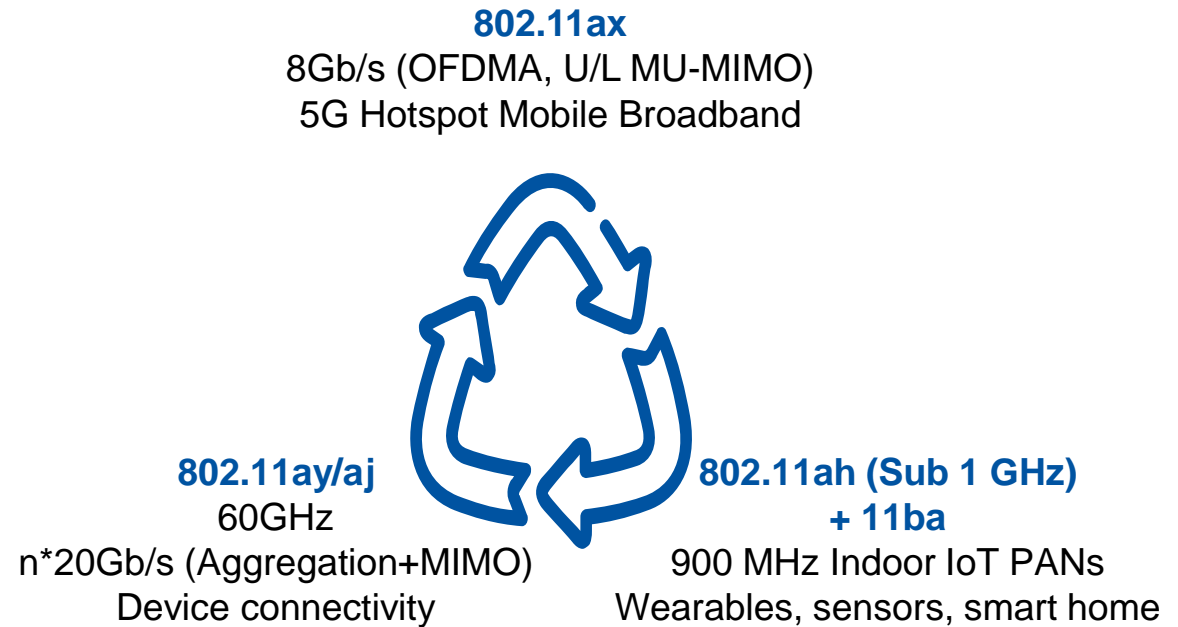
Broadcast Downlink



Broadcast Uplink

# IEEE 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





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## 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
- 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

