IETF 95-Wireless Tutorial: IEEE 802.11

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Abstract

The document contains slides prepared for the IETF 95 Wireless Tutorial related to IEEE 802.11 status. A discussion of areas of mutual interest is included.

See the prior Wireless tutorial (2014) prepared by Donald Eastlake, http://ietf.org/edu/technical-tutorials.html#wireless

This presentation represents my views, not those of my employer, the IETF or IEEE 802 or sub-parts of those organizations

Topics and Agenda

- **Some information about the IEEE 802 standards development process**
- **IEEE 802.11 status and projects under development**
- **Areas of mutual interest**
- **References, including past liaison documents**
- **Q&A**

IEEE-SA Individual and Corporate Standards Development

Open, consensus-based process

- **Open – anybody can participate (payment of meeting fees may be needed)**
- **Individual standards development**

  Each individual has one vote

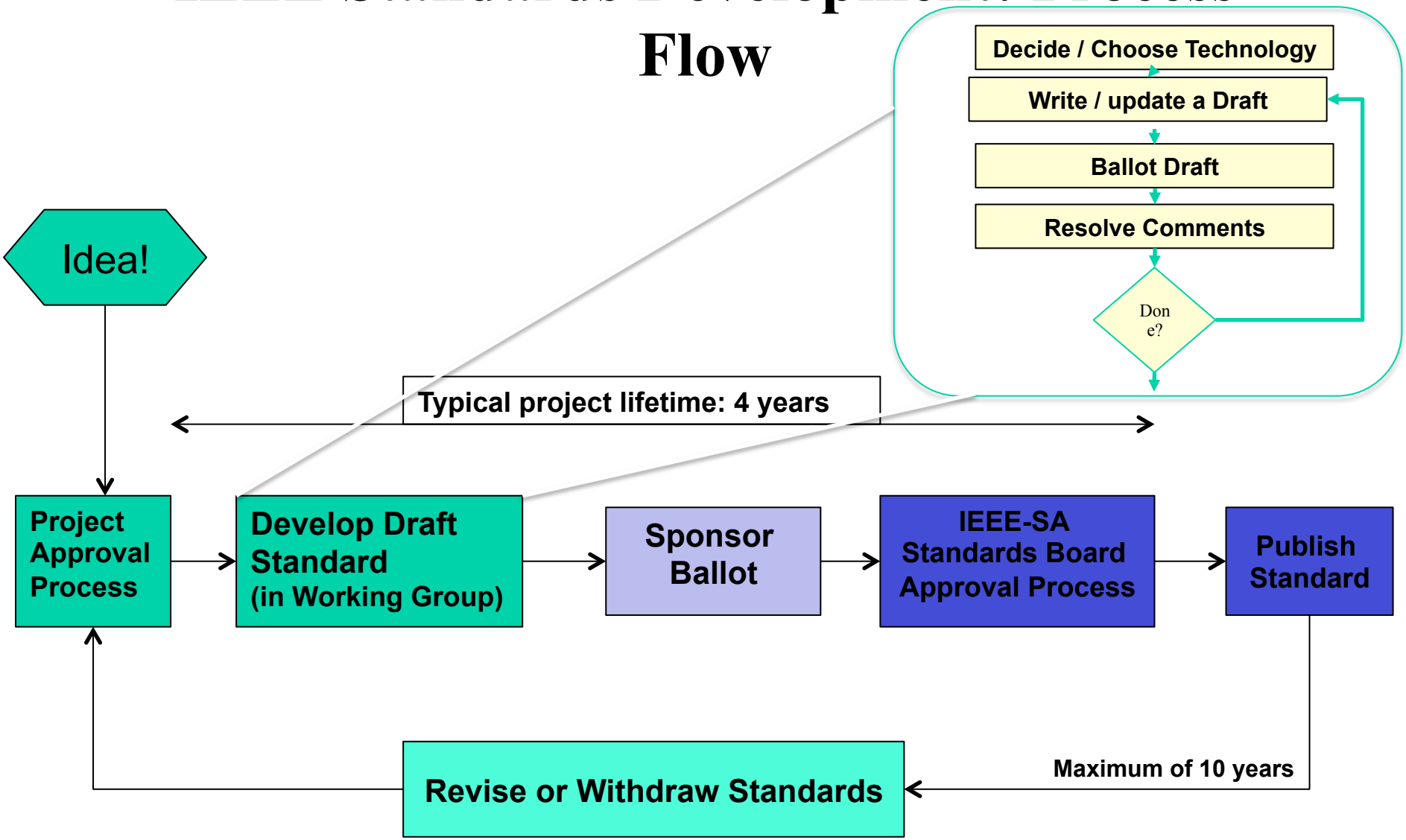
  Corporate standards development

  One company/one vote
- **Results frequently adopted by national, regional, and international standards bodies**

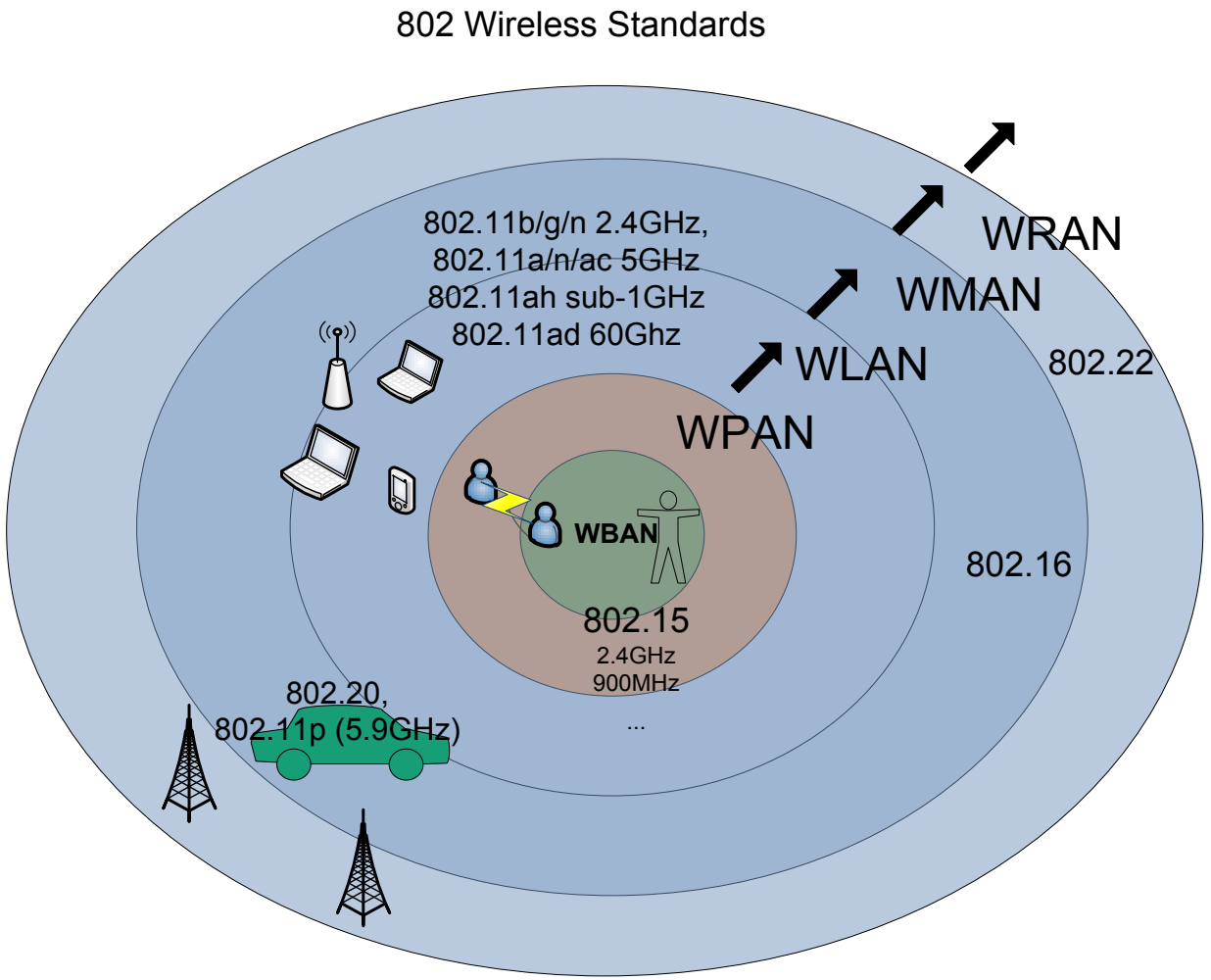
  IEEE 802 standards are submitted to ISO/IEC JTC1 SC6

- Indicates 802.11

IEEE Standards Development: Process Flow



IEEE 802 Wireless



IEEE 802.11 Scope

Wireless local area networks

Typical range up to 100m, can be much higher with directional antennas

Generally use unlicensed spectrum

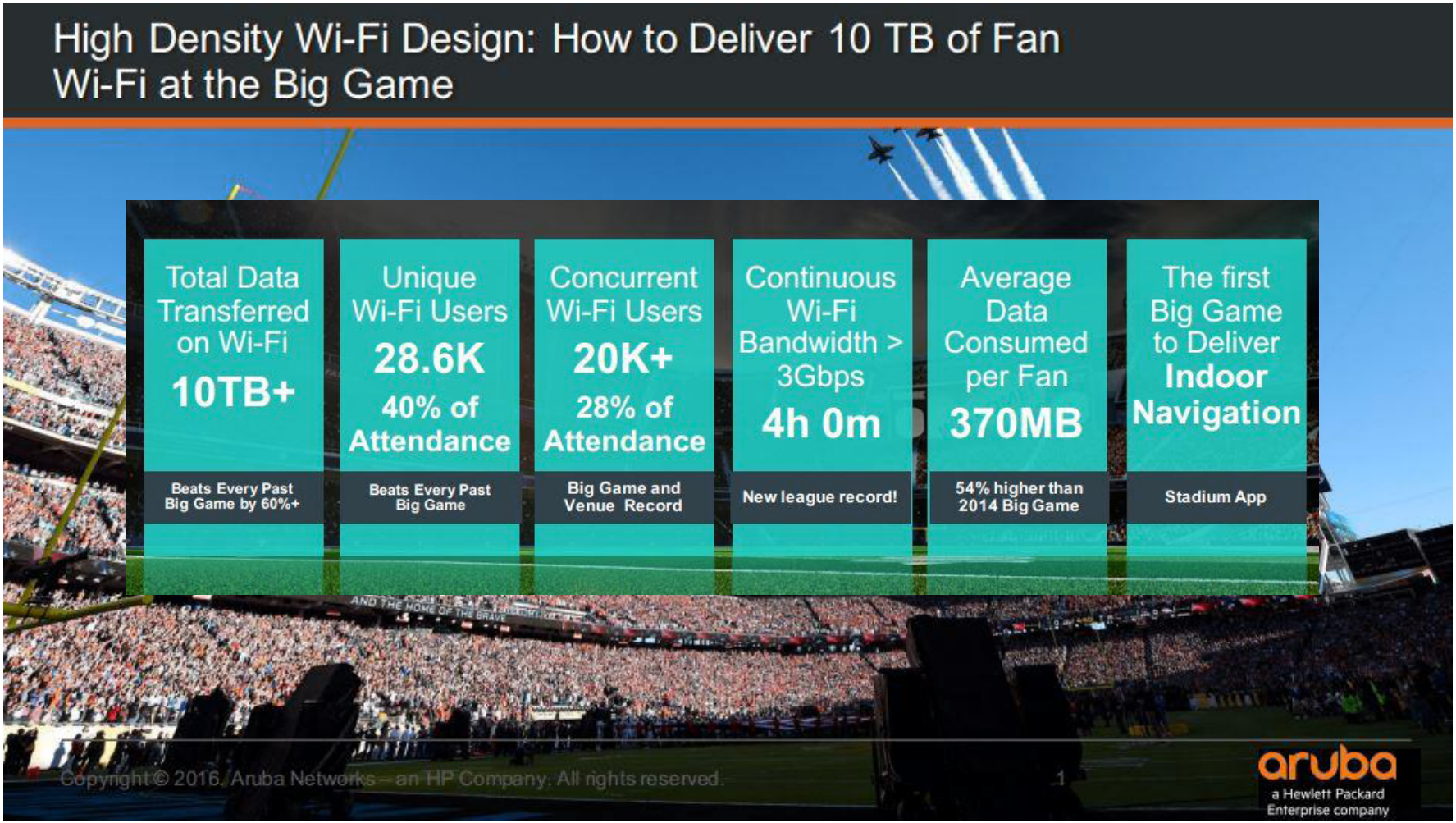
Exception for 802.11y: "lightly licensed"

Exception for TV whitespace

Ubiquitous Deployments: Broadband network access, public venue access, sensor networks, mesh networks, automotive.

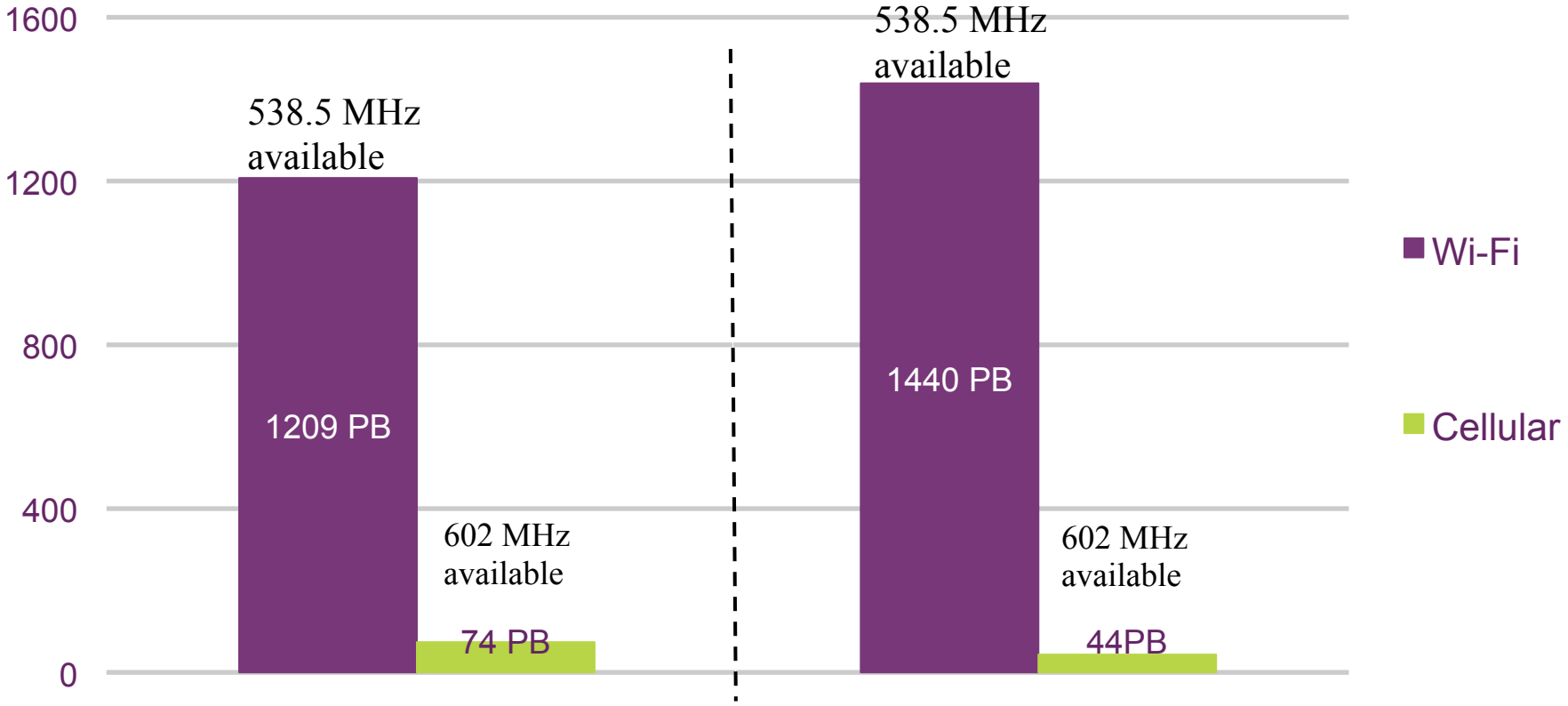
Photo credit: Slide 36 in Donald's presentation

802.11 technology is serving high density applications today



In 2014 Wi-Fi traffic was 16 times cellular one

UK Data carried in PB per month



Source: Andy Gowans (UK regulator) presentation:
https://mentor.ieee.org/802.18/dcn/16/18-16-0016-01-0000-ofcom-future-spectrum-requirements.pptx

Wi-Fi Alliance

Founded in 1999 http://www.wi-fi.org/

600+ member companies

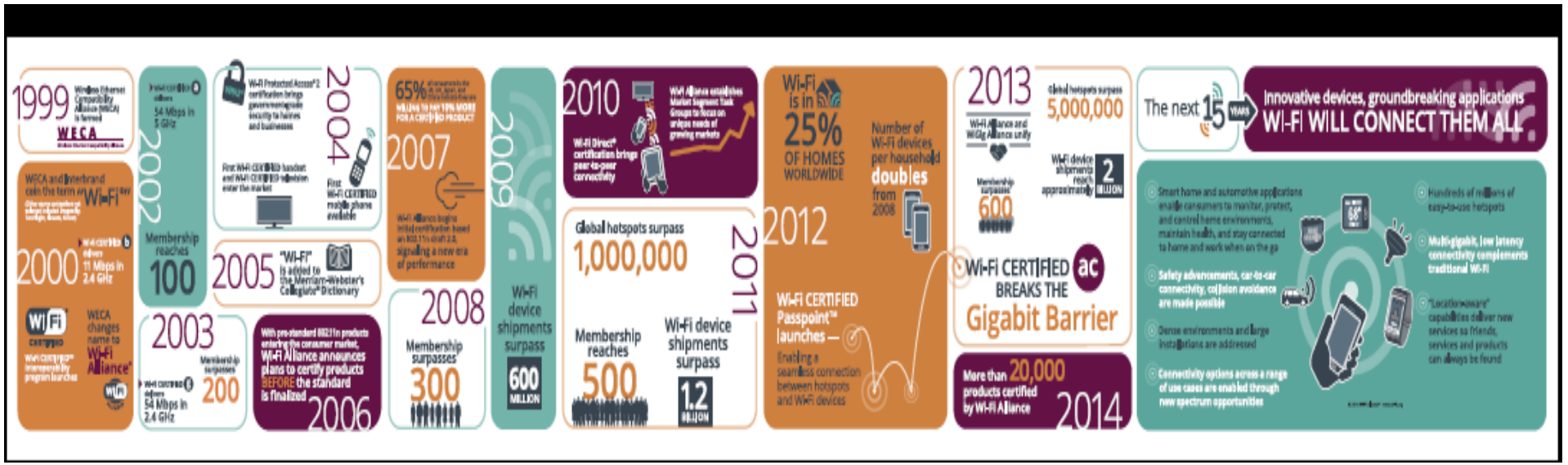
The Wi-Fi Alliance provides:

- *Interoperability certification programs*
  - *Over 30,000 products certified*
  - *Over 7 billion Wi-Fi devices deployed*
- *Market messaging*
- *Includes WiGig certified 60Ghz products (2016)*

First called the "Wireless Ethernet Compatibility Alliance", early alliance slogan was "The standard for Wireless Fidelity"

Over 7,000,000 hot spots world wide

http://www.wi-fi.org/discover-wi-fi/15-years-of-wi-fi



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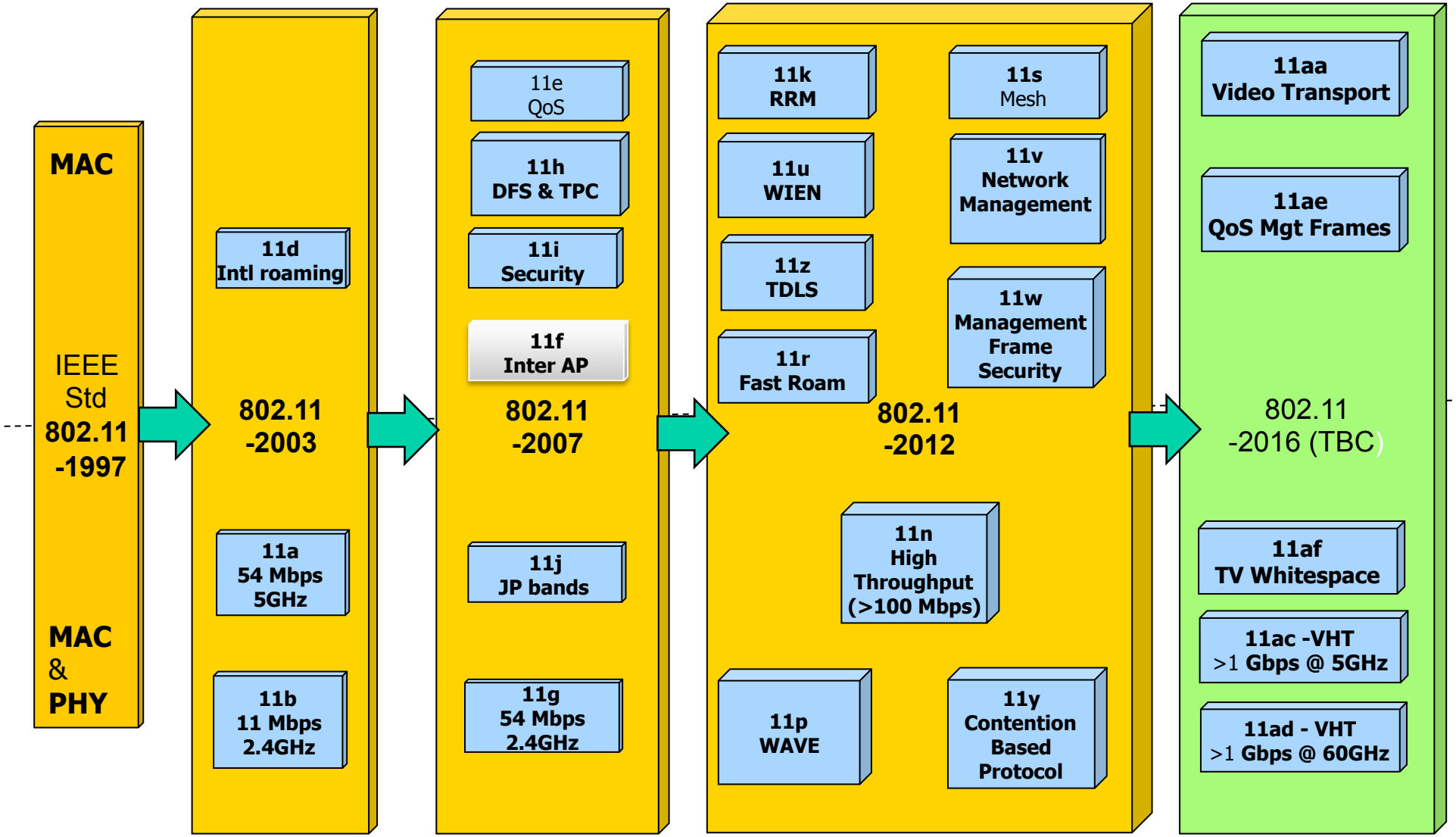
IEEE 802.11 Revisions



Project timelines and Project Authorization documents are publicly available, see http://www.ieee802.org/11/Reports/802.11_Timelines.htm

IEEE 802.11:Types of Groups

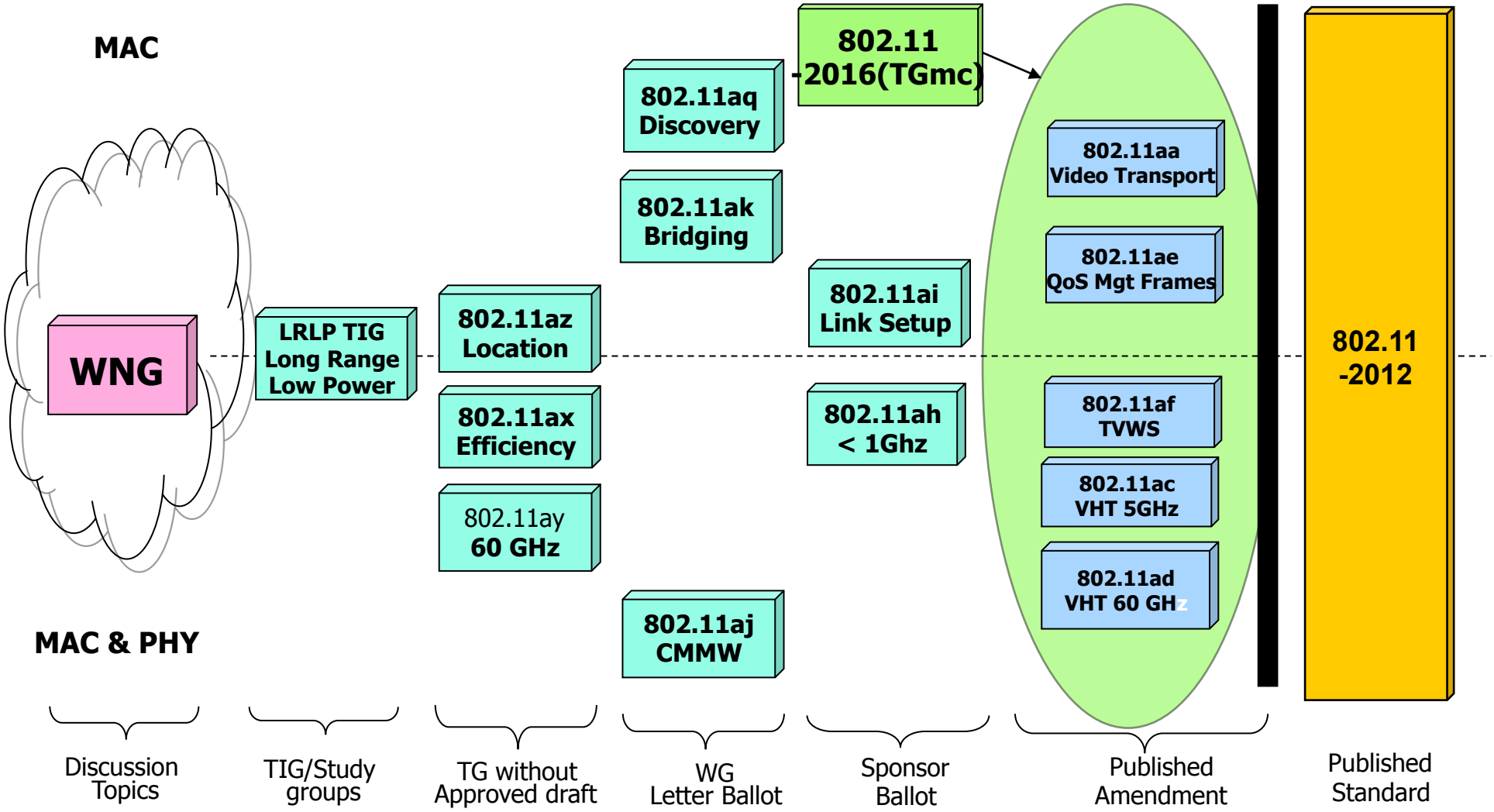
Type of Group	Description	IETF (rough) equivalent
WG	Working Group	IETF Area
SC	Standing Committee	IETF WG
TG	Task Group	IETF WG
SG	Study Group	BOF
TIG	Topic Interest Group	BOF

See RFC 7241, “The IEEE 802/IETF Relationship”

802.11 Groups

Type	Group	Description
WG	WG11	The IEEE 802.11 Working Group
SC	ARC	Architecture
SC	PAR	PAR review
SC	REG	Regulatory
SC	WNG	Wireless Next Generation
802 SC	JTC1	ISO/IEC JTC1/SC6
TG	MC	Revision mc (REVmc)
TG	AH	Operation in 900 MHz bands (S1G)
TG	AI	Fast Initial Link Setup (FILS)
TG	AJ	China Milli-Meter Wave (CMMW)
TG	AQ	Pre-association Discovery (PAD)
TG	AK	General Link (GLK)
TG	AX	High Efficiency Wireless LAN (HEW)
TG	AY	Next Generation 60 GHz (NG60)
TG	AZ	Next Generation Positioning (NGP)
TIG	LRLP	Long Range Low Power (LRLP)

IEEE 802.11 subgroup status



Market demands and new technology drive innovation (Current projects)

Demand for throughput

Continuing exponential demand for throughput (**TGax** and TGay)

~85% of the world's mobile data is carried on 802.11 (WiFi) devices

New usage models / features

Dense deployments (TGax), Indoor Location (TGaz)

Automotive (IEEE Std 802.11p), Internet of Things (TGah)

Technical capability

MIMO (IEEE Std 802.11n, 802.11ac, TGay)

60 GHz radios (TGay)

Changes to regulation

3650 MHz in USA (lightly licensed) (IEEE Std 802.11y)

TV whitespaces (IEEE Std 802.11af), Radar detection (IEEE Std 802.11h)

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

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802.11ah	Sub 1 GHz	Status: WG Ballot complete; SB underway	Completion 2016

Key Project Goals

Define operation of license-exempt IEEE 802.11 wireless networks in frequency bands below 1 GHz excluding the TV White Space bands.

868-868.6 MHz (Europe), 950 MHz -958 MHz (Japan), 314-316 MHz, 430-434 MHz, 470-510 MHz, and 779-787 MHz (China), 917 - 923.5 MHz (Korea) and 902-928 MHz (USA), provides mechanisms that enable coexistence with other systems in the bands including IEEE 802.15.4 and IEEE P802.15.4g

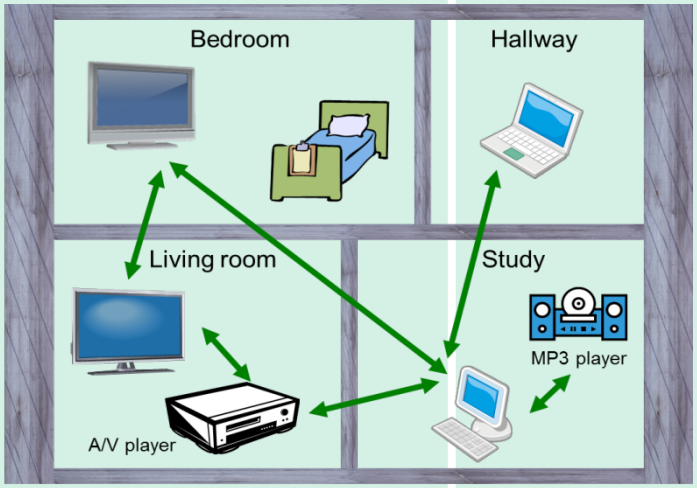
Key Parameters

Use cases

- Extended range WLAN internet access,
- Smart home sensor networking,
- Outdoor access with low data rates – ranch, mountainous areas
- Wearable devices - health, multimedia

Technology

- OFDM PHY
- MAC enhancements
- Transmission range up to 1km
- data rates > 100 kbit/s
- maintain the IEEE 802.11 WLAN user experience for fixed, outdoor, point to multi point applications



For more information: functional reqs; photo from use cases

802.11ai	Fast Initial Authentication	Status: WG Ballot complete; SB underway	Completion 2016

Key Project Goals

Define mechanisms that provide IEEE 802.11 networks with fast initial link set-up methods which do not degrade the security currently offered by Robust Security Network Association (RSNA) already defined in IEEE 802.11. Minimize initial link set-up time.

Key Parameters

Use cases

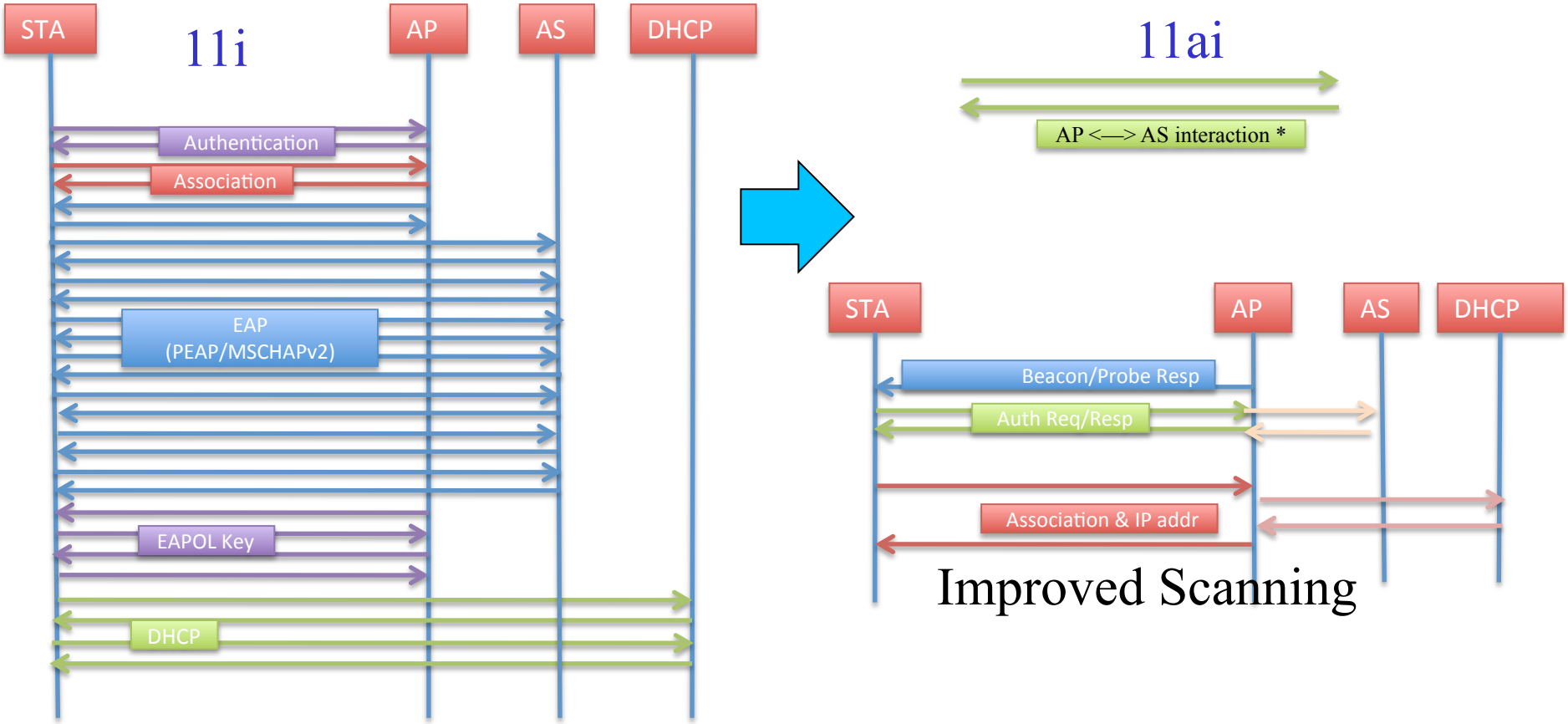
- Large number of mobile users are constantly entering and leaving the coverage area of an existing extended service set (ESS).

Technology

- EAP-RP (ERP): RFC 5296
- EC(DH) authenticated by (EC)DSA
- MAC enhancements for probe response reduction
- MAC enhancements for more efficient scanning

For more information: use cases, functional reqs;

TGai Technical Highlights



*Two authentication options are defined. Public key authentication and shared key authentication using ERP. When ERP is used an optional AP <—> AS exchange is required during the FILS exchange.

802.11aj	China Milli-meter wave	Status: Initial WG Ballot complete	Completion 2017

Key Project Goals

Define defines modifications to the IEEE P802.11ad Physical (PHY) layer and the Medium Access Control (MAC) layer to enable operation in the Chinese 59-64 GHz frequency band and Chinese 45 GHz frequency band. Maintains backward compatibility with 802.11ad when it operates in the 59-64 GHz frequency band

Key Parameters

Use cases

- Similar to 11ad
- Low range, high bandwidth applications

Technology

- Narrower channels to allow for additional channels
- Single Carrier/OFDM
- MAC enhancements

802.11ak	Enhancements For Transit Links Within Bridged Networks	Status: Initial WG Ballot complete	Completion 2017

Key Project Goals

Enables an 802.11 connection to be used as a through link in a general network, not just as a connection to an end station at the edge of a network

There are a large number of new products including home entertainment systems and industrial control equipment that have both an IEEE 802.11 wireless station capability and a wired IEEE 802.3 Ethernet capability. IEEE 802.11 has media operating in the gigabit per second range and has standardized security and quality of service improvements. These developments raise a demand for bridging of IEEE 802.11 media with the same bridging services as other media: as media internal to the network as well as media offering access to the network.

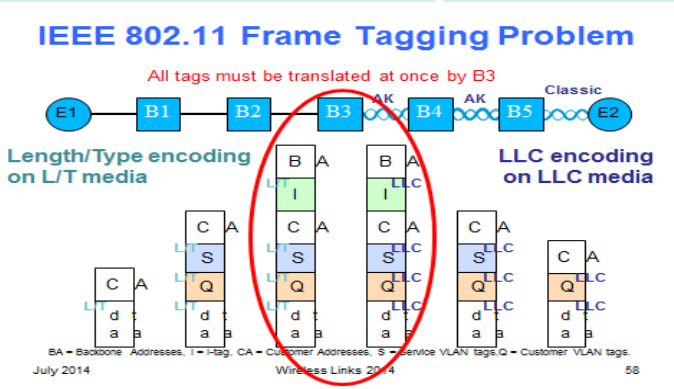
Key Parameters

Use cases

- Fully general mixed 802.11 and wired plug and play in the home
- Data Center top-of-rack to top-of-rack connections for overflow traffic.
- Industrial control
- Enterprise network use

Technology

- GLK, EPD
- MAC enhancements



For more information: see slides 49-60 in Donald's document;

802.11aq	Pre-Association Discovery	Status: Initial WG Ballot complete	Completion 2017

Key Project Goals

Enables delivery of pre-association Service Discovery information by IEEE 802.11 stations (STAs).

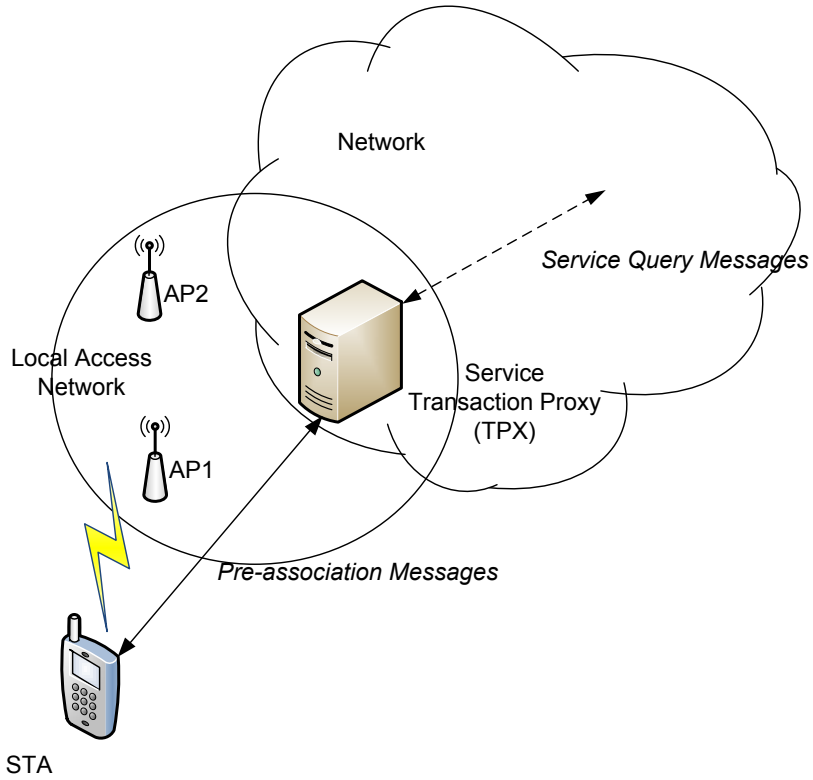
Key Parameters

Use cases
- Printer discovery in a hotel
- Service discovery in a WLAN

Technology
- Container MAC protocol
- Service identification hash nechanism

For more information: use cases, functional reqs;

TGaq Technical Highlights



Container MAC protocol to carry upper layer service discovery protocols (e.g. UPnP, Bonjour)

Provisioning and configuration of services in the access point

Service Transaction Proxy is a logical element connected to the access point

Universal identification of services

Using a hash name

Provide service attributes (e.g. 3D printer capability or point of sale service)

Currently considering request/response or broadcast concept

802.11ax	High Efficiency WLAN	Status: Pre-D1.0; D0.1 available	Completion 2019

Key Project Goals

Improve performance of WLAN deployments in dense scenarios

Targeting at least 4x improvement in the per-STA throughput compared to 11n & 11ac.

Improved efficiency through spatial reuse and enhanced power save techniques.

Key Parameters

Use cases

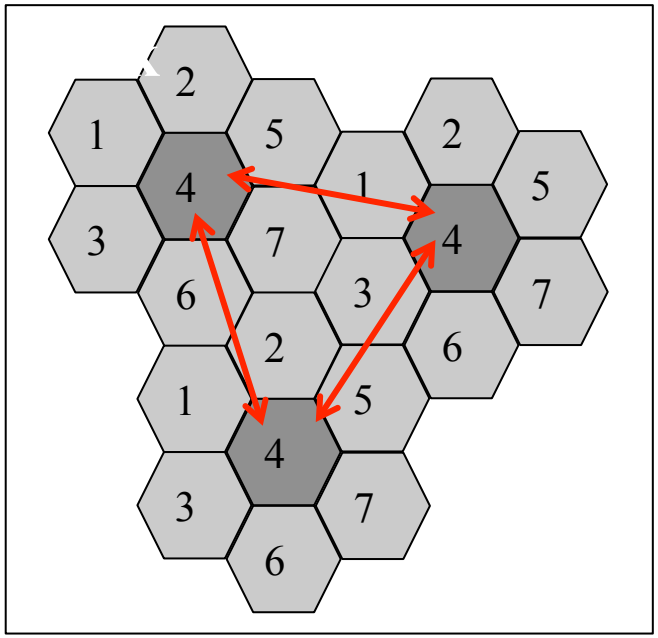
- Focus on dense deployments
- 2.4GHz and 5GHz (1-6GHz)
- Evaluation of performance includes throughput, delay, spectral efficiency, power consumption

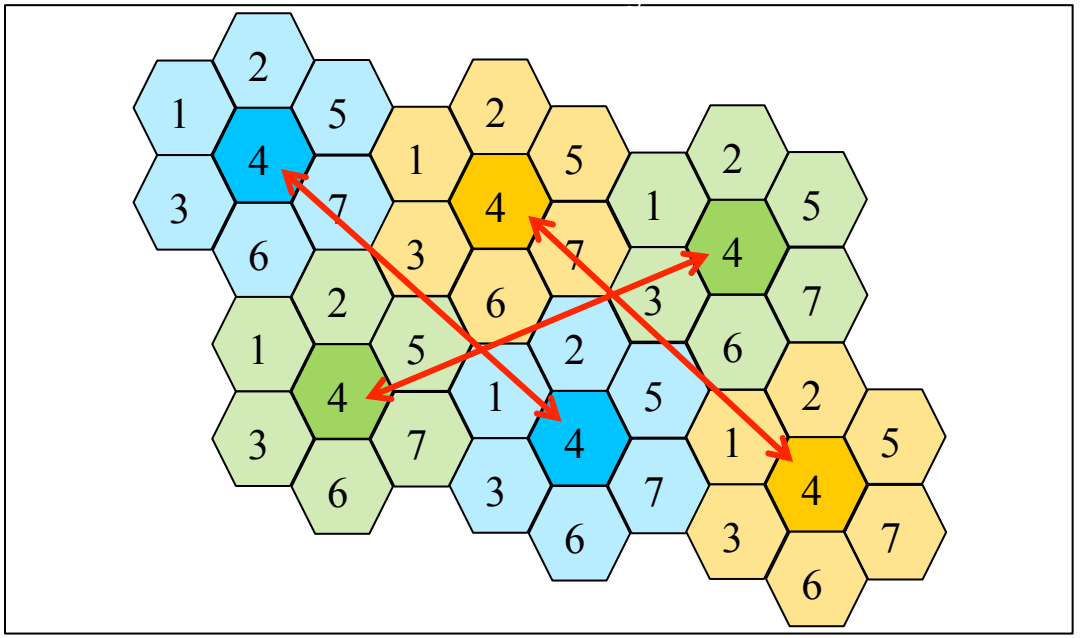
Technology

- Significant MAC changes: Addition of scheduled OFDMA MAC inside of EDCA transmission windows
- PHY changes: OFDMA subdivides 20MHz channel into 9 2+MHz channels
- Bi-directional MU-MIMO and MU-MIMO enhancements
- 1024 QAM
- BSS Coloring spatial re-use
- Compatible with existing devices

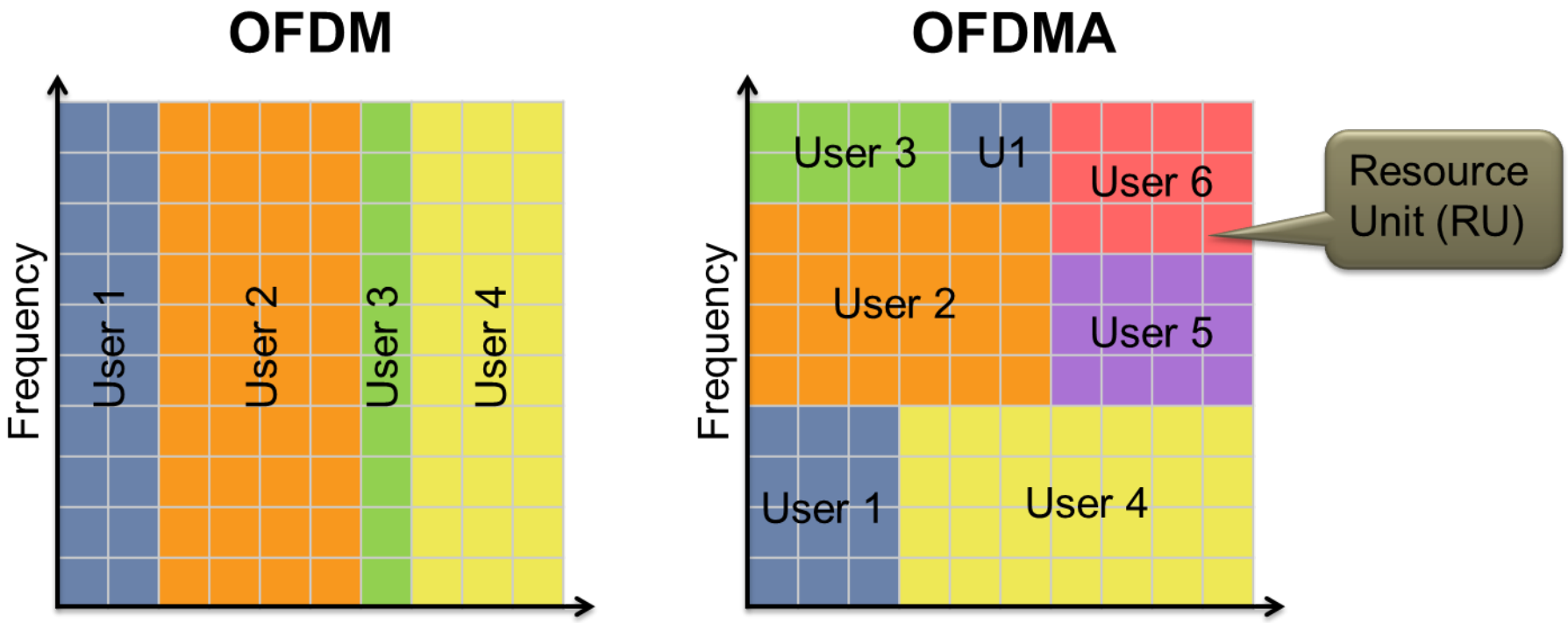
For more information: simulations, functional reqs, specification framework

BSS Coloring enables additional channel re-use





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



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

802.11ay	Next Generation 60GHz	Status: Pre-D1.0; Functional Reqs	Completion 2019

Key Project Goals

Enhanced Throughput for Operation in License-Exempt Bands Above 45 GHz: Increase aggregated throughput, range and reliability
Expected to develop mode of operation capable of supporting a maximum throughput of at least 20 gigabits per second (measured at the MAC data service access point), while maintaining or improving the power efficiency per station.

Key Parameters

Use cases

- Wireless docking
- Wireless display
- Indoor/Outdoor backhaul
- Ultra short range communications
- 8K UHD streaming
- Data Center Inter-rack connectivity
- Video/Mass Data distribution

Technology

- Channel bonding
- MIMO
- Maintain backwards compatibility with existing deployed 60GHz devices
- Note: 802.11ad products coming on the market now, Wi-Fi Alliance 11ad WiGig Certified launching 2016, see link

For more information: channel models, specification framework, use cases document (photos from slide 12

802.11az	Next Generation Positioning	Status: Pre-D1.0; Functional Reqs	Completion 2020

Key Project Goals

Improve location accuracy and scalability; consider new usages such as directionality and ranging

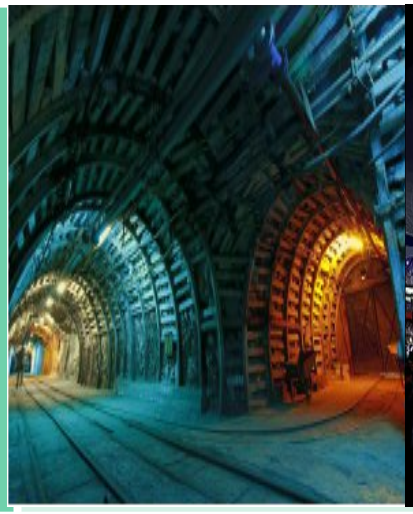
Key Parameters

Use cases

- Indoor location maps and directions
- Micro-location in a store
- Navigation in public buildings
- Industrial positioning: underground mining,

Technology

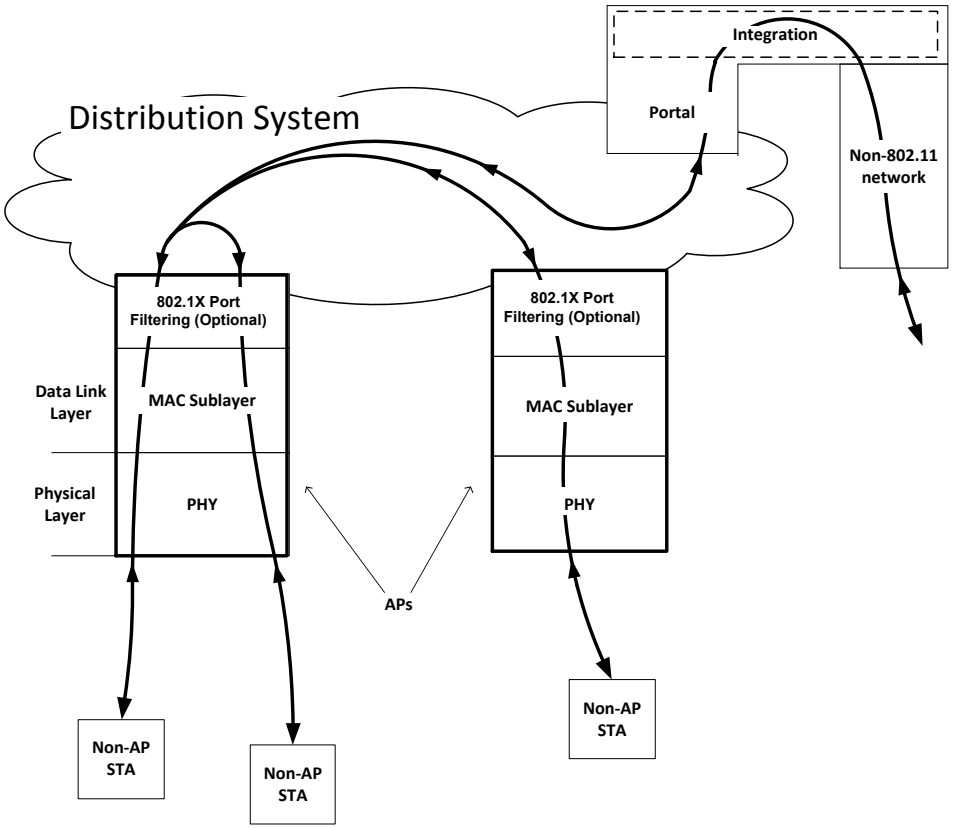
- additional rotational angle



For more information: use cases, functional reqs, ;

Standing Committees (SCs) and Topic Interest Groups (TIGs)

Architecture Standing Committee Overview

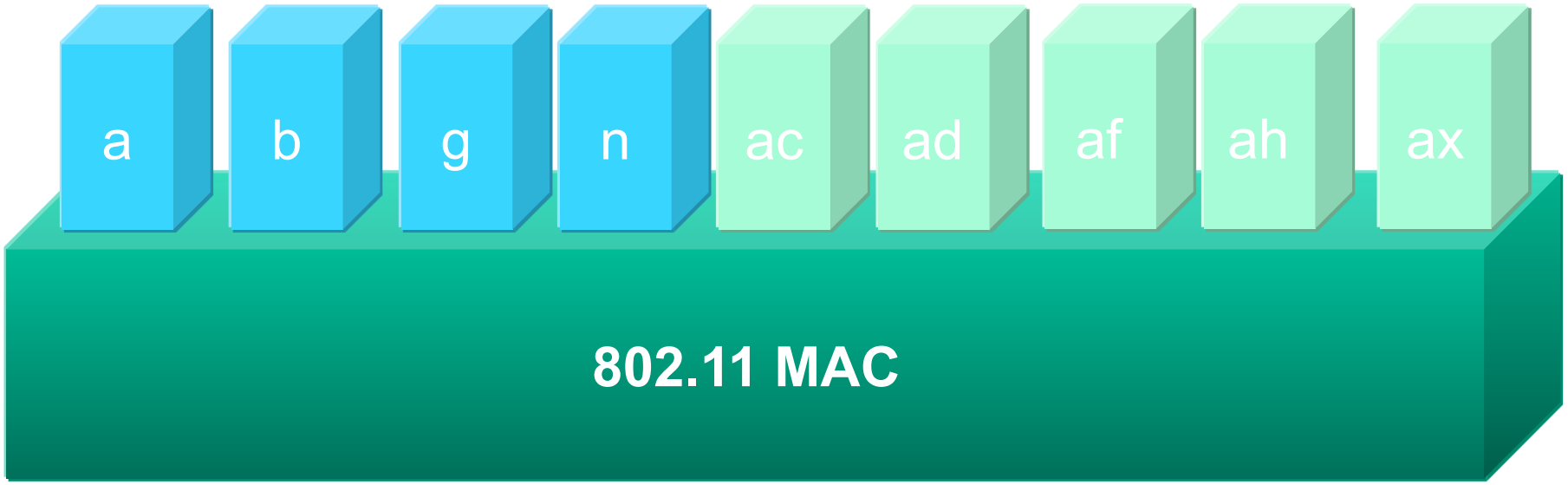


- **Models for STA architecture and related concepts, and overall system architecture, included in the Standard in clauses 4 and 5, generally.**
- **Evolution of the models, either to consider amendments to the Standard, or as clarification is needed**
- **Define how 802.11 technologies fit into 802, 802.1 use cases.**
- **Define MIB and management conventions**

802.11 Architecture Overview

Multiple Over the Air PHY options

One common MAC based on CSMA/CA



802.11/802.15 Regulatory SC and & 802.18 Regulatory Technical Advisory Group

- Wireless standards all depend on the availability of RF spectrum for their deployment
- Spectrum allocations and rules vary worldwide
- The massive growth of wireless applications is forcing regulators to make changes
- The Regulatory SC provides IEEE 802.11 with information about spectrum availability and changes
- Where needed, the group lobbies regulators for changes to accommodate new standards
- Work in transition to 802.18

802.19 Coexistence and related liaison activity

Significant work underway related to LAA coexistence

- **See** https://mentor.ieee.org/802.19/dcn/16/19-16-0037-09-0000-laa-comments.pdf

Liaisons received related to 3GPP LWIP and LWA

- **See 3GPP presentation on LWA and LWIP:** https://mentor.ieee.org/802.11/dcn/16/11-16-0351-01-0000-liaison-from-3gpp-on-lwa-and-lwip.pptx
- **And, related, BRCM presentation on LWA and LWIP:** https://mentor.ieee.org/802.11/dcn/16/11-16-0437-01-0wng-discussion-on-lwa-and-lwip.pptx
- **And 802.11 response:802.11 liaison to 3GPP (with Adrian's edits) re: thank you for presentation on LWA and LWIP and request for further collaboration:** https://mentor.ieee.org/802.11/dcn/16/11-16-0489-02-0000-liaison-to-3gpp-on-lwa-and-lwip.docx

LRLP TIG	Long Range Low Power Topic Interest Group	Status: Developing use cases, requirements, technical feasibility	Completion July 2016

Key Project Goals

Identify use cases and requirements for long range low power applications that are not met by current 802.11 MAC/PHY capabilities and recommend a path forward.

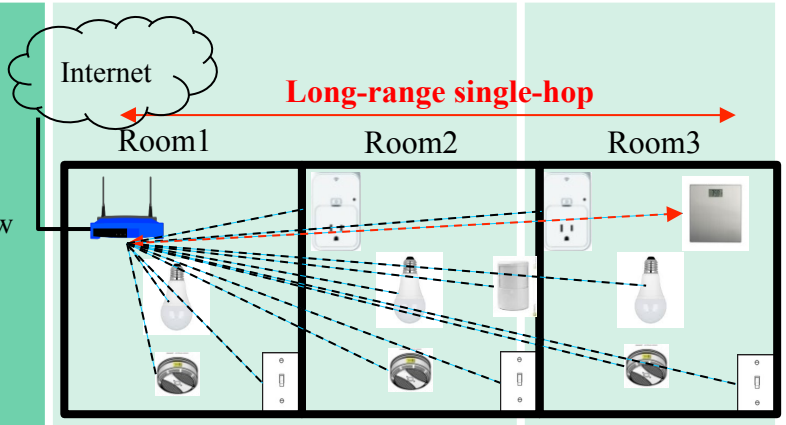
Key Parameters

Use cases

- Smart grid
- IoT, energy management, sensors
- Smart home, digital health
- Leverage deployed WLAN internet access infrastructure

Technology

- 2.4 GHz band
- Asymmetrical STA and AP (enables simple client device implementation)
- Optimize for long range or low power
- Extend 11ah long range functionality to higher bands



For more information: Output report document, Figure from example use case document;

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IETF- IEEE 802 Liaison Activity

Joint meetings, agenda and presentations

http://www.iab.org/activities/joint-activities/iab-ieee-coordination/

2016-02-01 teleconference held;

Request for tutorial on 802 wireless (.11, .15) technologies, see http://ietf.org/meeting/95/tutorials.html ; note prior presentation from Donald Eastlake: http://www.ietf.org/edu/documents/WirelessLinks2.pdf

Next teleconference and Sept F2F meeting dates are TBD

RFC 7241, "The IEEE 802/IETF Relationship" has been published (RFC4441 update)

https://datatracker.ietf.org/doc/rfc7241/

IEEE 802 Liaisons list is available

http://ieee-sa.centraldesktop.com/802liaisondb/FrontPage

802 EC "IETF/IAB/IESG" 802 EC Standing Committee

Formed March 2014, Pat Thaler as chair

Topic: Multicast

Multicast issues were

- **discussed at the IETF-IEEE 802 meeting Sept 29th 2015 and**
- **a presentation given at the November 2015 IETF meeting, see** ttps://mentor.ieee.org/802.11/dcn/15/11-15-1261-02-0arc-mulicast-performance-optimization-features-overview-for-ietf-nov-2015.ppt
- **Further actions: ietf mailing list has been established for ongoing discussion, will include additional 802. wireless groups, see** http://www.ieee802.org/11/email/stds-802-11/msg01838.html
- **Internet draft describing use cases, issues, etc. under development**

Insights

- Multicast used for multiple types of traffic including ARP/ND, routing protocols, video applications, and these might need to be transmitted at different MCS
- Implementations might consider APIs to allow MCS differentiation
- RFC 6775, Neighbor Discovery Optimization for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs) defines a registration mechanism for accomplishing proxy ND
- Current Proxy ND support does not address Secure ND, see RFC 3971

Available internet drafts and related documents

- http://datatracker.ietf.org/doc/draft-mcbride-mboned-wifi-mcast-problem-statement/
- http://www.ipv6council.be/IMG/pdf/20141212-08_vyncke_-_ipv6_multicast_issues-pptx.pdf

Topic: Multicast - 2

- **PIM:** http://datatracker.ietf.org/wg/pim/charter/
  - The Working Group charter includes: "Optimization approaches for IGMP and MLD to adapt to link conditions in wireless and mobile networks and be more robust to packet loss."
  - And a work item (April 2016) "submit solutions for IGMP and MLD to adapt to wireless link conditions"
- **New internet draft:** https://tools.ietf.org/id/draft-perkins-intarea-multicast-ieee802-00.txt
  - *"This document describes some performance issues that have been observed when multicast packet transmission is attempted over IEEE 802 wireless media. Multicast features specified for IEEE 802 wireless media related to multicast are also described, along with explanations about how these features can help ameliorate the observed performance issues. IETF protocols that are likely to be affected by the observed performance issues are identified, and workarounds are proposed in some cases. The performance of multicast over wireless media often can be quite different than the performance of unicast. This draft describes the nature of the differences and the effects on representative IETF protocols. We also describe some efforts that have been made by IEEE 802 Wireless groups to ameliorate the performance differences."*

Additional topics of mutual interest

- **Quality of Service and DSCP code mapping**
  - RFC 7561: Mapping PMIPv6 QoS Procedures with WLAN QoS Procedures, see http://datatracker.ietf.org/doc/rfc7561/
  - https://tools.ietf.org/html/draft-szigeti-tsvwg-ieee-802-11-01.
- **White-Space database access**
  - RFC 7545: **Protocol to Access White-Space (PAWS) Databases, see https://datatracker.ietf.org/doc/rfc7545/**
- **CAPWAP protocol and extensions**
- **RADIUS Extensions**
- **Additional EAP methods**
- **EAP Method Requirements**
- **IEEE 802.11 uses IANA registry to define domain parameter sets for DH.**

References

- http://www.ieee802.org/11/
- **Documents:** https://mentor.ieee.org/802.11/documents

EU Spectrum for 802.11ah

	Frequency Band	Power / Magnetic Field	Spectrum access and mitigation requirements	Modulation / maximum occupied bandwidth	ECC/ERC Deliverable	Notes
h1.1	863-870 MHz	25 mW e.r.p.	≤ 0.1% duty cycle or LBT (notes 1 and 5)	≤ 100 kHz for 47 or more channels (note 2)		FHSS
h1.2	863-870 MHz	25 mW e.r.p. Power density: -4.5 dBm/100 kHz (note 7)	≤ 0.1% duty cycle or LBT+AFA (notes 1, 5 and 6)	Not specified		DSSS and other wideband techniques other than FHSS
h1.3	863-870 MHz	25 mW e.r.p.	≤ 0.1% duty cycle or LBT + AFA (notes 1 and 5)	≤ 100 kHz, for 1 or more channels modulation bandwidth ≤ 300 kHz (note 2)		Narrow /wide-band modulation
h1.4	868-868.6 MHz	25 mW e.r.p.	≤ 1% duty cycle or LBT +AFA (note 1)	No spacing, for 1 or more channels (note 2)		Narrow / wide-band modulation. No channel spacing, however the whole stated frequency band may be used
h1.5	868.7-869.2 MHz	25 mW e.r.p.	≤ 0.1% duty cycle or LBT+AFA (note 1)	No spacing, for 1 or more channels (note 2)		Narrow / wide-band modulation. No channel spacing, however the whole stated frequency band may be used
h1.6	869.4-869.65 MHz	500 mW e.r.p.	≤ 10% duty cycle or LBT+AFA (note 1)	No spacing, for 1 or more channels		Narrow / wide-band modulation The whole stated frequency band may be used as 1 channel for high speed data transmission

EU Spectrum for 802.11ah [2]

h1.7	869.7-870 MHz	5 mW e.r.p.; 25 mW e.r.p.	No requirement ≤ 1% duty cycle or LBT+AFA (note 1)	No spacing for 1 or more channels		Narrow / wide-band modulation. No channel spacing, however the whole stated frequency band may be used
h2	870-876 MHz	25 mW e.r.p.	≤ 0.1% duty cycle. For ER-GSM protection (873-876 MHz, where applicable), the duty cycle is limited to ≤ 0.01% and limited to a maximum transmit on-time of 5ms/1s	≤ 200 kHz		This frequency band is also identified in Annexes 2 and 5
h2.1	870-875.8 MHz	25 mW e.r.p.	≤ 1% duty cycle. For ER-GSM protection (873.0-875.8 MHz, where applicable), the duty cycle is limited to ≤ 0.01% and limited to a maximum transmit on time of 5ms/1s	≤ 600 kHz		The frequency band is also identified in Annexes 2 and 5
h3	915-921 MHz	25 mW e.r.p.	≤ 0.1% duty cycle. For ER-GSM protection (918-921MHz, where applicable), the duty cycle is limited to ≤ 0.01% and limited to a maximum transmit on-time of 5ms/1s	≤ 200 kHz		The frequency band is also identified in Annexes 10 and 11
h3.1	915.2-920.8 MHz	25 mW e.r.p. except for the 4 channels identified in note 9 where 100 mW e.r.p. applies	≤ 1% duty cycle (note 10). For ER-GSM protection (918-920.8MHz, where applicable), the duty cycle is limited to ≤ 0.01% and limited to a maximum transmit on-time of 5ms/1s	≤ 600 kHz except for the 4 channels identified in note 9 where ≤ 400 kHz applies		The frequency band is also identified in Annexes 10 and 11

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Systems using digital modulation techniques may operate in the 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz bands. The minimum 6 dB bandwidth shall be at least 500 kHz.

The maximum peak conducted output power of the intentional radiator shall not exceed the following:

For systems using digital modulation in the 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz bands: 1 Watt. As an alternative to a peak power measurement, compliance with the one Watt limit can be based on a measurement of the maximum conducted output power. Maximum Conducted Output Power is defined as the total transmit power delivered to all antennas and antenna elements averaged across all symbols in the signaling alphabet when the transmitter is operating at its maximum power control level. Power must be summed across all antennas and antenna elements. The average must not include any time intervals during which the transmitter is off or is transmitting at a reduced power level. If multiple modes of operation are possible (e.g., alternative modulation methods), the *maximum conducted output power* is the highest total transmit power occurring in any mode.