

Design of Modern Communication Systems

Lecturer: Dr. Rui WANG



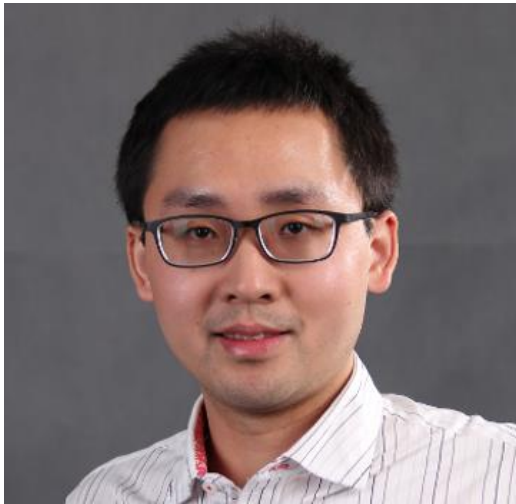
About this course

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About this course

- **Lecture:**

- The design principle of modern wireless communication systems, including IEEE802.11 and 3GPP releases (**we shall focus on PHY and MAC layers**)
- Cutting-edge wireless technologies, e.g., WiFi sensing, 6G and etc.

- **Lab:**

- Simulations of popular wireless communication technologies
- Experiments via software-defined radio

- **Evaluation:**

- Lecture 50% (Assignments + Reports in terms of PPT)
- Lab 50%



Background of IEEE802.11



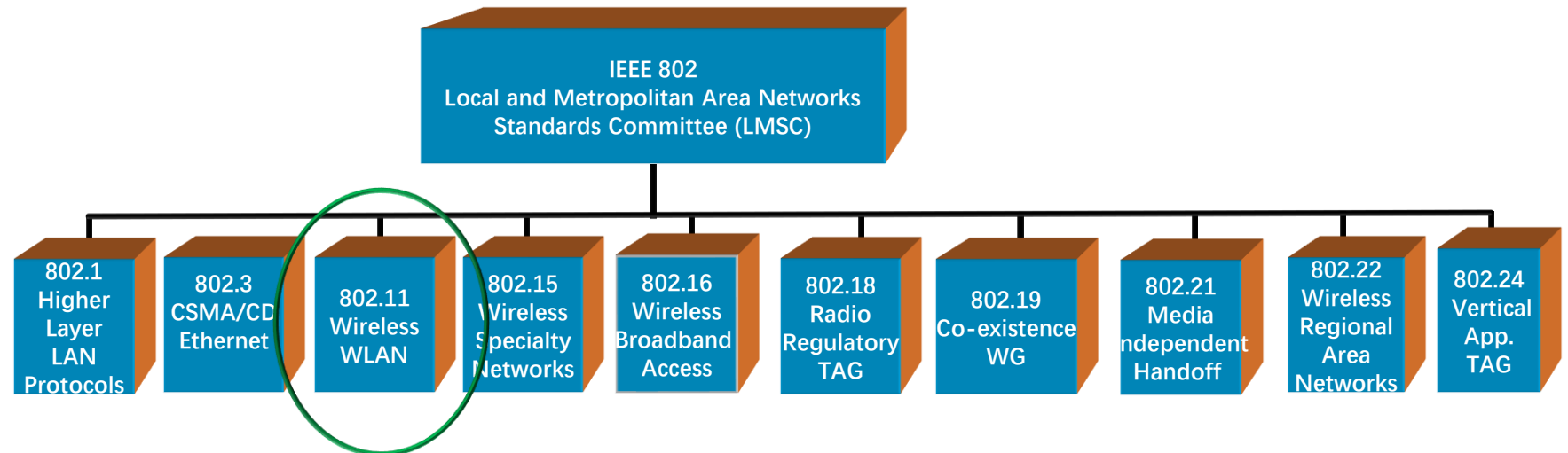
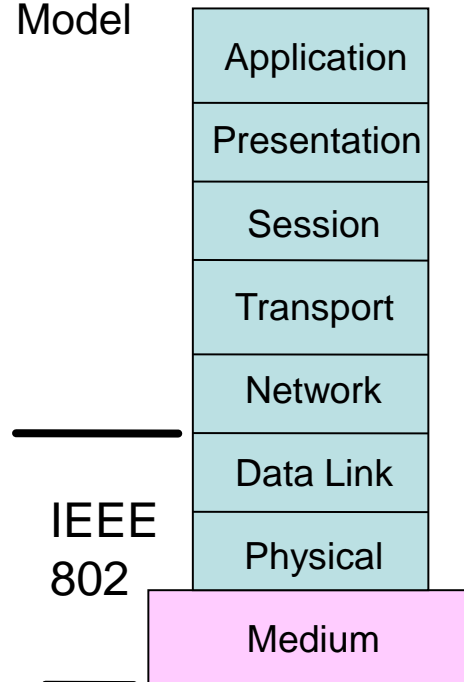
What's IEEE802.11

- “IEEE 802.11 is a set of **media access control** (MAC) and **physical layer** (PHY) specifications for implementing wireless local area network (WLAN) computer communication in the 900 MHz and 2.4, 3.6, 5, and 60 GHz frequency bands. “ --- Wikipedia
- It is created and maintained by IEEE802.11 working group (<http://www.ieee802.org/11/>)
- It is a series of specifications which keep evolving. The version number is can be found in the letters after “802.11”. For example, 802.11**n**, 802.11**ac** and etc.
- Latest version is 802.11**ax**, which is also called as Wi-Fi 6

The IEEE 802.11 Working Group

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

OSI Reference
Model



Main versions at a glance

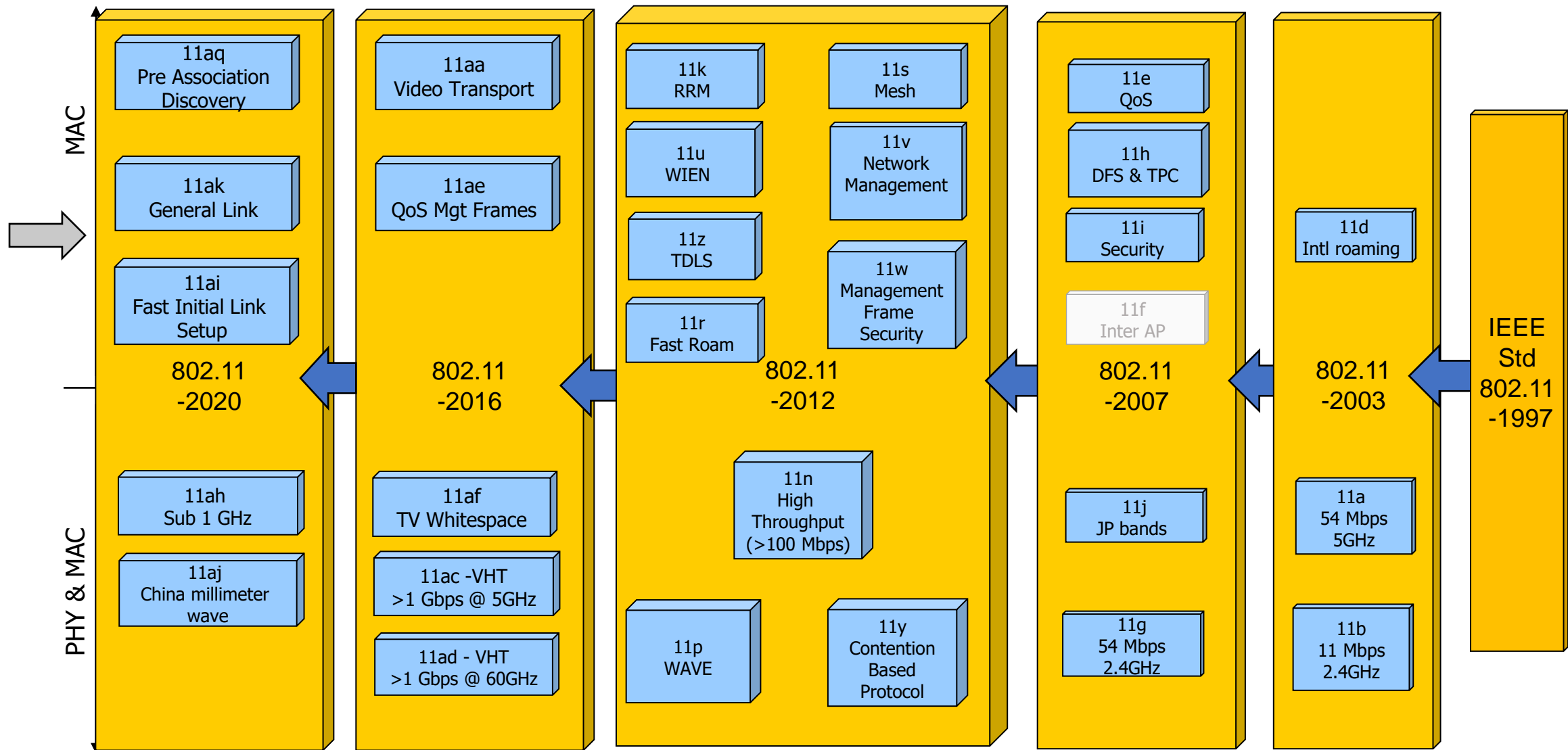
802.11 network PHY standards					
802.11 protocol	Release date	Frequency	Bandwidth	Allowable MIMO streams	Modulation
		(GHz)	(MHz)		
802.11-1997	Jun 1997	2.4	22	N/A	DSSS, FHSS
a	Sep 1999	5	20	N/A	OFDM
		3.7			
b	Sep 1999	2.4	22	N/A	DSSS
g	Jun 2003	2.4	20	N/A	OFDM
n	Oct 2009	2.4/5	20	4	MIMO-OFDM
			40		
ac	Dec 2013	5	20	8	
			40		
			80		
			160		
ad	Dec 2012	60	2,160	N/A	OFDM, single carrier, low-power single carrier

from Wikipedia

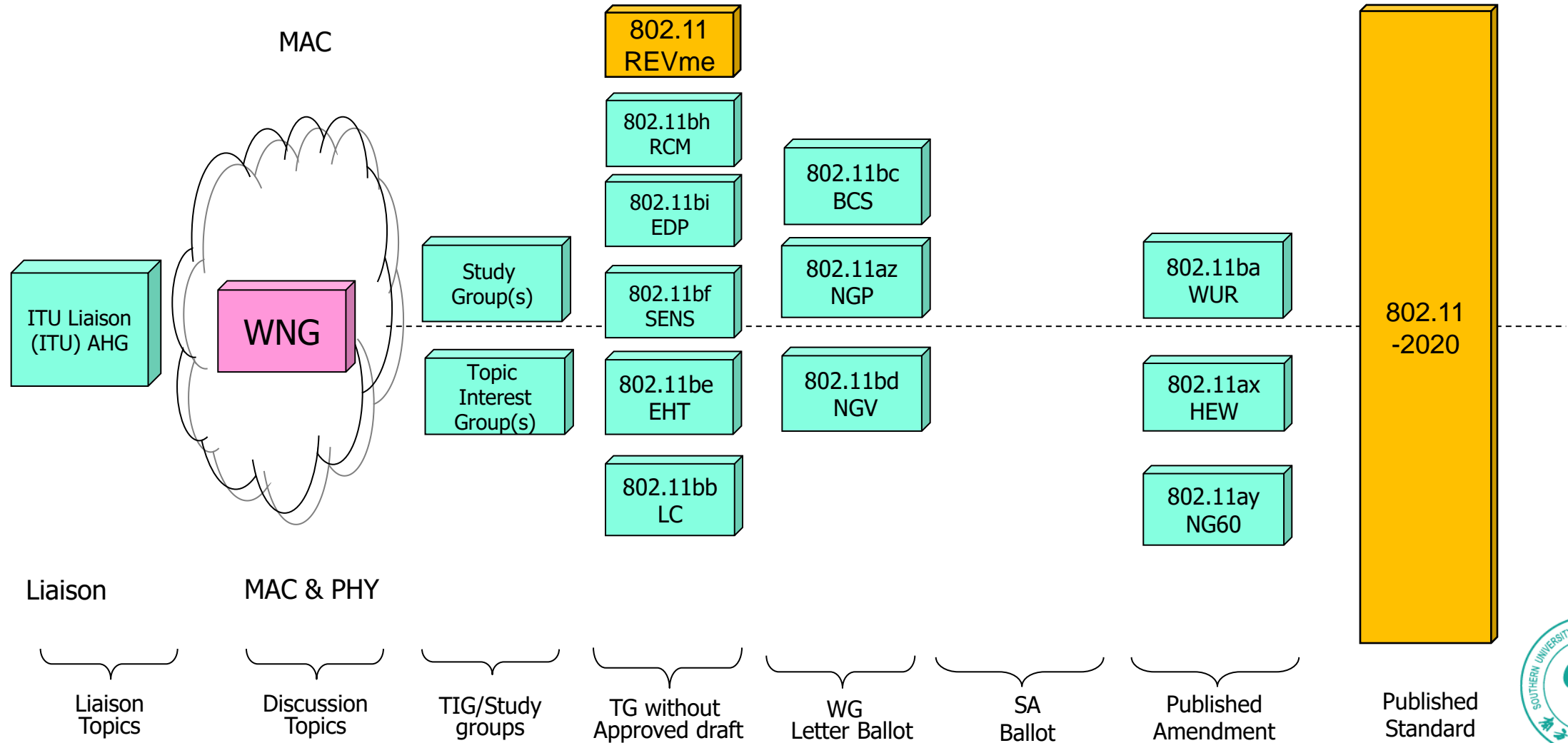
New 802.11 Radio technologies

- **802.11ax** – Increased throughput in 2.4, 5 (and 6) GHz bands. Increased efficiency.
- **802.11ay** – Support for 20 Gbps in 60 GHz band.
- **802.11az** – 2nd 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
- **802.11be** – Extremely High Throughput

Development of the IEEE 802.11 Standard is ongoing since 1997



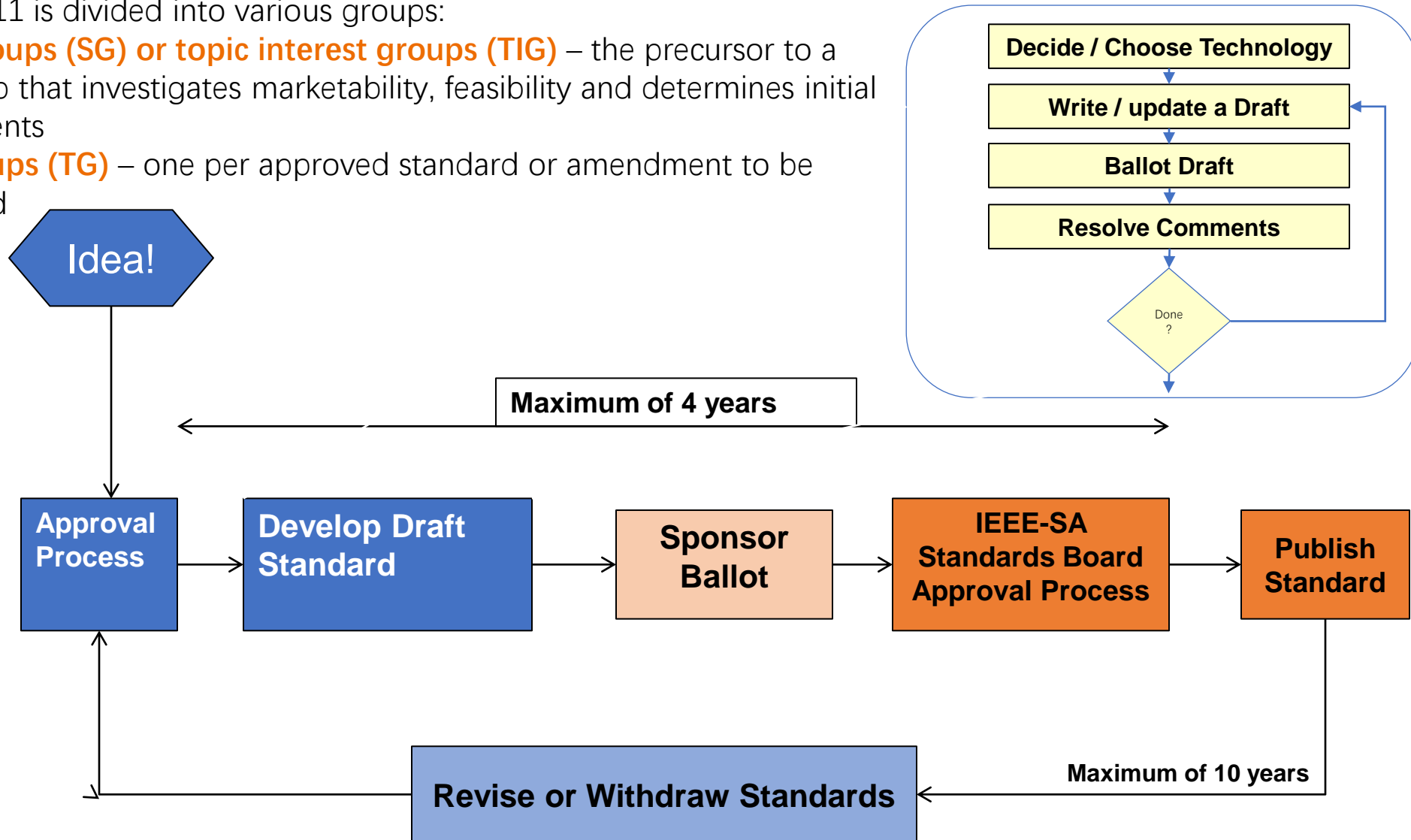
IEEE 802.11 Standards Pipeline (2021)



How to make an 802.11 specification

Work in 802.11 is divided into various groups:

- **Study groups (SG) or topic interest groups (TIG)** – the precursor to a task group that investigates marketability, feasibility and determines initial requirements
- **Task groups (TG)** – one per approved standard or amendment to be developed



Week 1



Key players in the standardization

- In task group, the protocol is discussed via teleconferences & various sessions periodically.
 - Session information: <http://www.ieee802.org/11/Reports/index.html>

IEEE 802.11 WLAN WORKING GROUP SESSIONS							
As our sessions are open to the public, all interested parties are welcome to attend IEEE P802.11 Working Group sessions, for which there is a registration fee, to defray the cost of the session. At Plenary sessions this is administered by the IEEE P802 LMSC organization. Whereas, the Interim sessions are normally managed by our sponsoring host. This is in-addition to your individual hotel accommodation, and travel expenses. Click here to view Example Plenary and Interim Session Agenda .							
Session	Date	Month	File URL or Doc# Report	Minutes	Location	Place	Type
For Year 2017							
161	15 th - 20 th	January	Report		Grand Hyatt	Atlanta Georgia USA	Interim
For Year 2016							
160	7 th - 11 th	November	Report	Minutes	Grand Hyatt	San Antonio TX USA	Plenary
159	12 th - 16 th	September	Report	Minutes	Marriott	Warsaw Poland	Interim
158	25 th - 29 th	July	Report	Minutes	Manchester Grand Hyatt	San Diego CA USA	Plenary
157	16 th - 20 th	May	Report	Minutes	Hilton Waikoloa Village	Waikoloa HI USA	Interim
156	14 th - 18 th	March	Report	Minutes	Venetian	Macau	Plenary
155.5	27 th - 27 th	January	Report	Minutes	Heilongjiang Trade Union Hotel	Harbin China	Interim
155	18 th - 22 nd	January	Report	Minutes	Hyatt Regency	Atlanta GA USA	Interim

- Every technology written into the standard should be voted.
- Members with voting power can be found in <http://www.ieee802.org/11/Voters/votingmembers.htm>
- Most of the voters come from industry, e.g., Qualcomm, Intel, Marvell, Broadcom, Huawei, ZTE, and etc.



802.11ax is focused on improving performance in dense environments

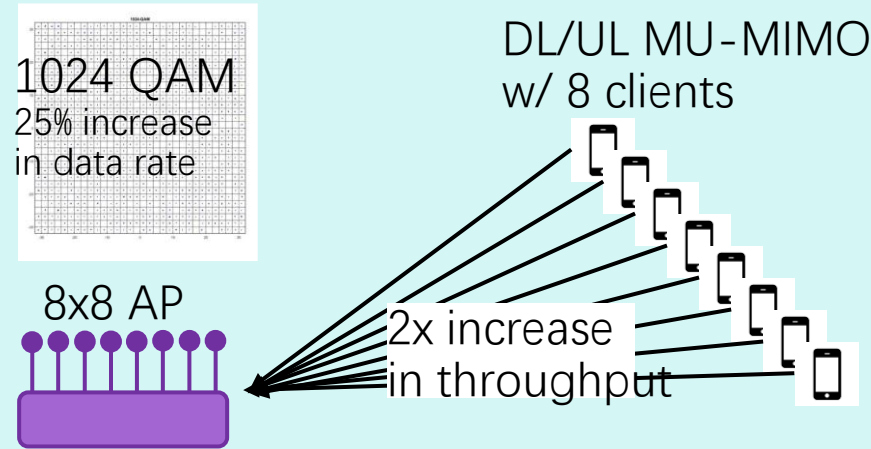
- Existing 802.11 WLAN systems serve dense deployments:
2019 Super bowl: 24TB of data carried on WLAN network
- 802.11ax aims to further improve performance of WLAN deployments in dense scenarios
 - Targeting at least 4x improvement in the per-STA throughput compared to 802.11n and 802.11ac.
 - Improved 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.



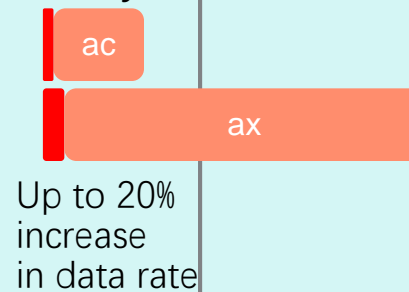
Access to Internet, latest airlines' announcements, and digital media such as movies and sport events

802.11ax Categories of Enhancements

Spectral Efficiency & Area Throughput

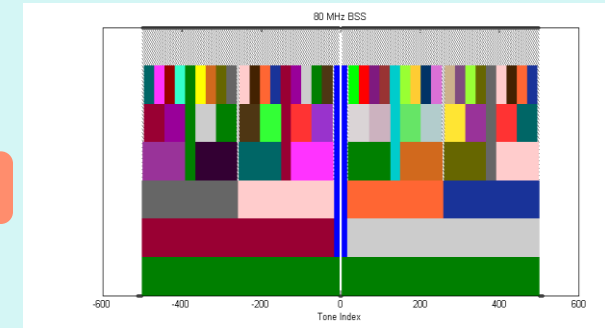


Long OFDM
Symbol

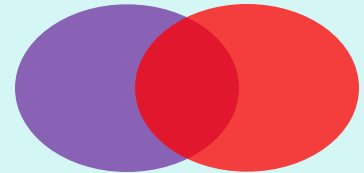


High Density

OFDMA

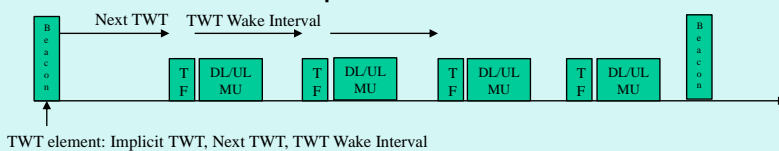


Spatial Reuse

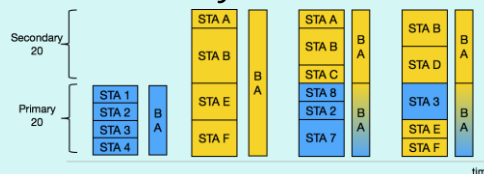


Power Saving

Scheduled sleep and wake times

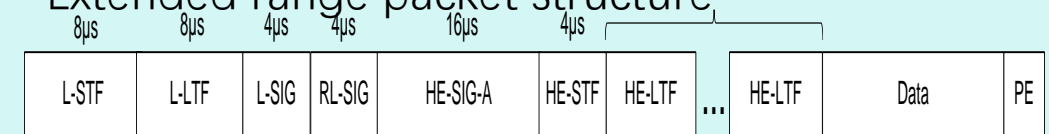


20 MHz-only clients



Outdoor / Longer range

Extended range packet structure



Enhanced delay
spread protection -
long guard interval

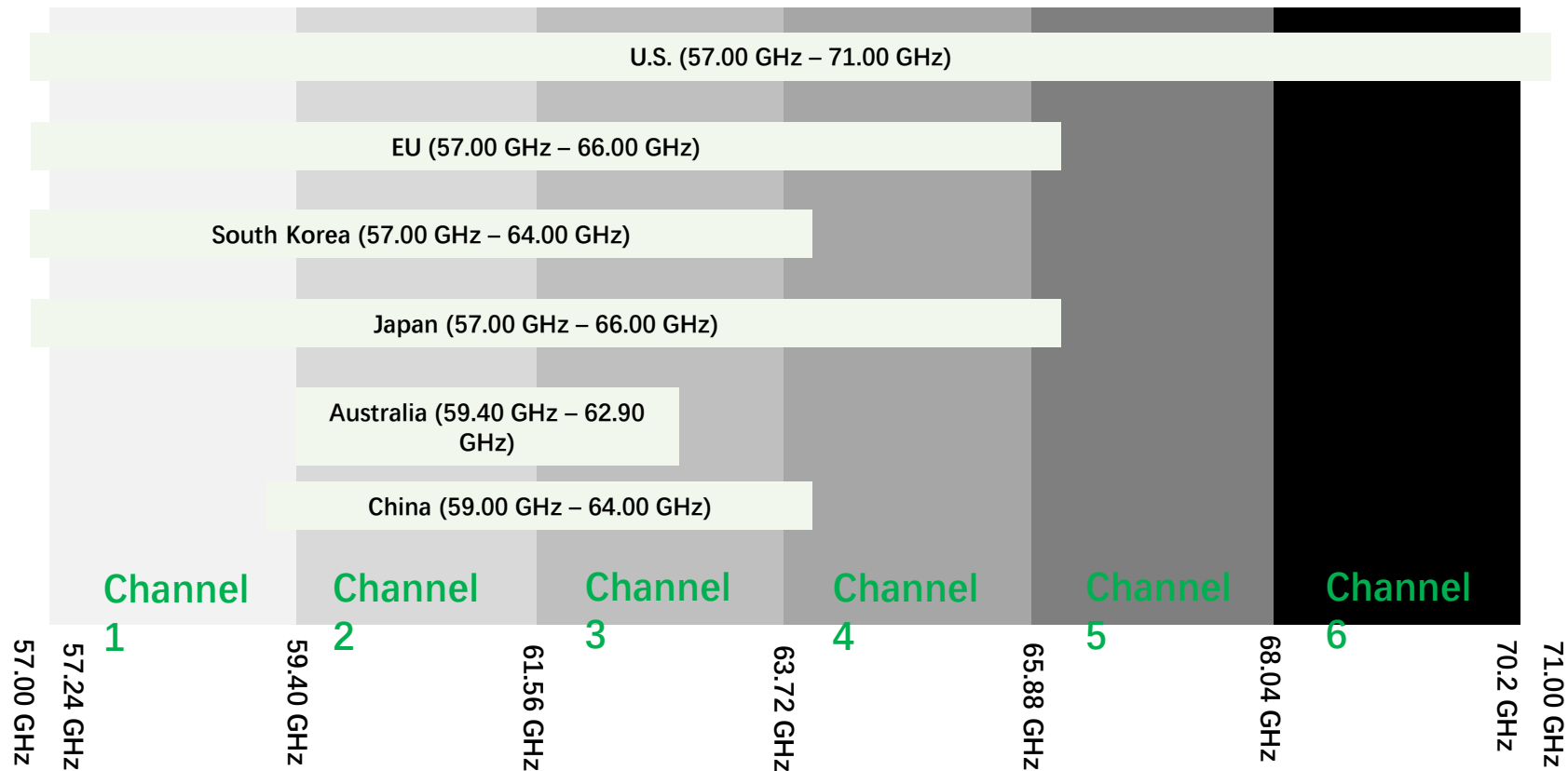
0.8µs
11ac

1.6µs 11ax

3.2µs 11ax

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

20Gbps+ rates are defined

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

What is Wi-Fi

- Different equipment producer may have different implementation of IEEE 802.11 standard
- How to make sure equipment from different companies can interoperate
- **Wi-Fi Alliance:** a non-profit organization with most 802.11 equipment producer.
- Wi-Fi is a trademark owned by Wi-Fi Alliance
 - short for “Wireless Fidelity”
 - Certified to the products if they could interoperate based on IEEE 802.11 standards



Discussion

- Pros and cons between WLAN and cellular network (e.g. LTE)
 - Spectrum
 - Coverage/mobility support
 - Delay
 - Cost
 - Etc.

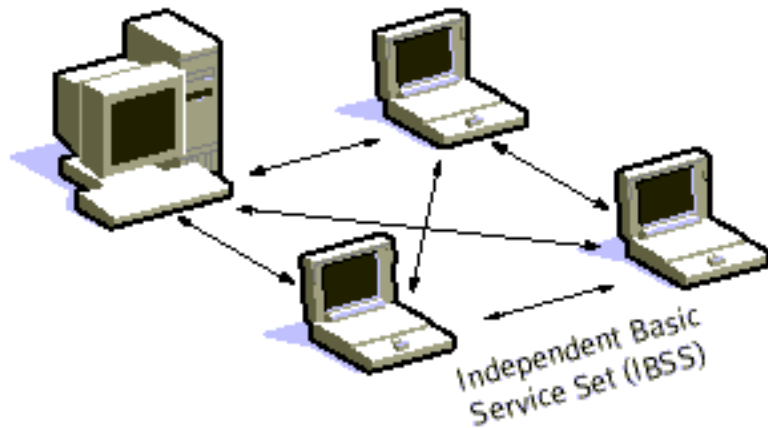


IEEE 802.11 Architecture

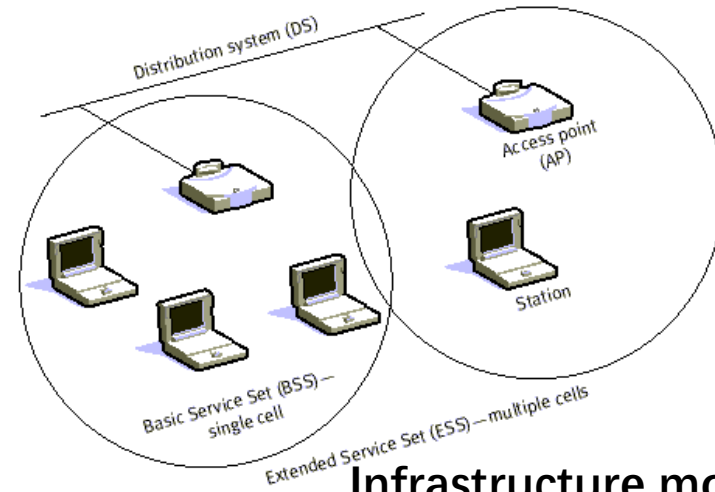


Ad hoc mode and infrastructure mode

- **Wireless station (STA)** : devices in 802.11
- **Basic service set (BSS)**: STAs communicate with each other
- **Access point (AP)** is also STA, it provides access outside BSS
- **Ad hoc mode or independent basic service set (IBSS)**: without AP
- **Infrastructure mode**: with AP



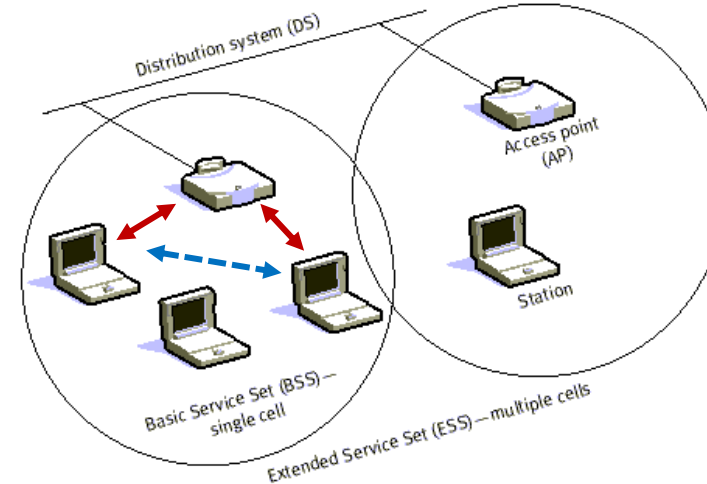
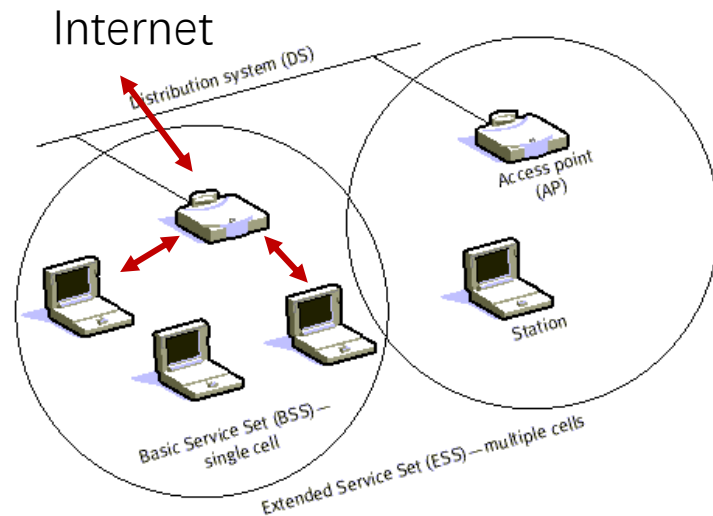
Ad hoc mode



Infrastructure mode

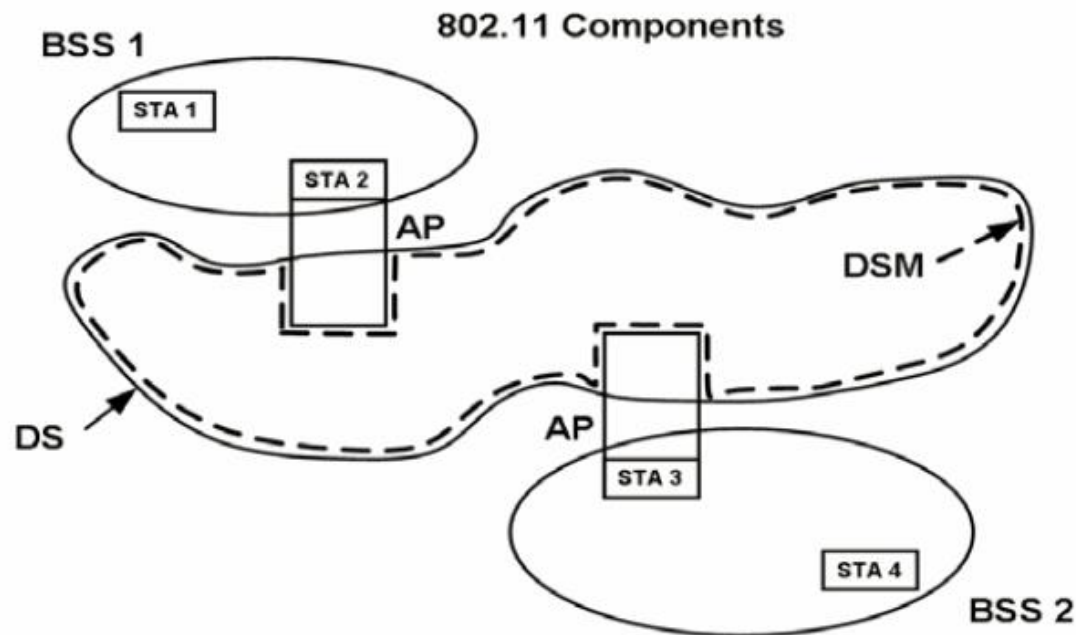
Infrastructure mode: pros and cons

- Infrastructure mode works well if STAs want to access Internet
- However, its efficiency is low if STAs want to talk with each other
- IBSS mode or WiFi Direct (Wi-Fi CERTIFIED Wi-Fi Direct®) can help
 - WiFi Direct is not a specification of IEEE802.11



Distribution System

- APs of multiple BSS can be connected via **distribution system (DS)**, such that their STAs can communicate as if they were in the same “big BSS”. Thus MAC service data unit (MSDU) can be delivered among their MAC-layers.
- **Distribution system media (DSM)**: media with which information is delivered in DS.



How to improve the coverage of AP in your house?

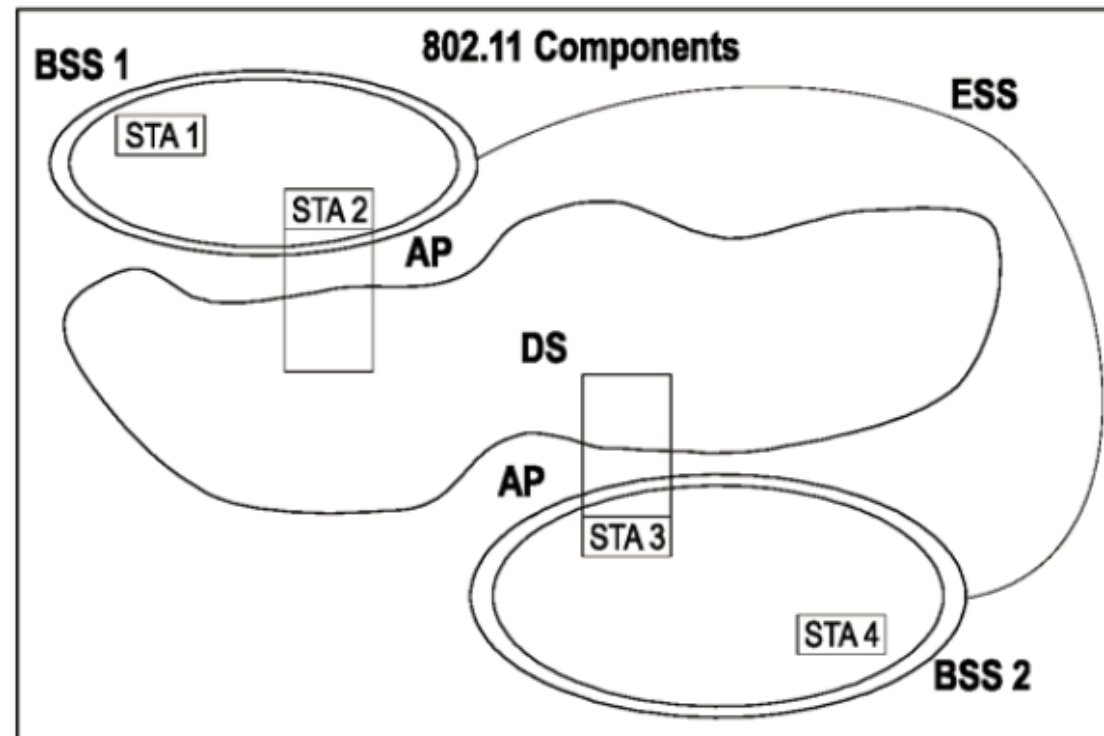
- WDS (Wireless Distribution System)
- Wi-Fi range extender via powerline --- DSM is powerline
- Etc.

Hence DS is not defined in 802.11 standard.



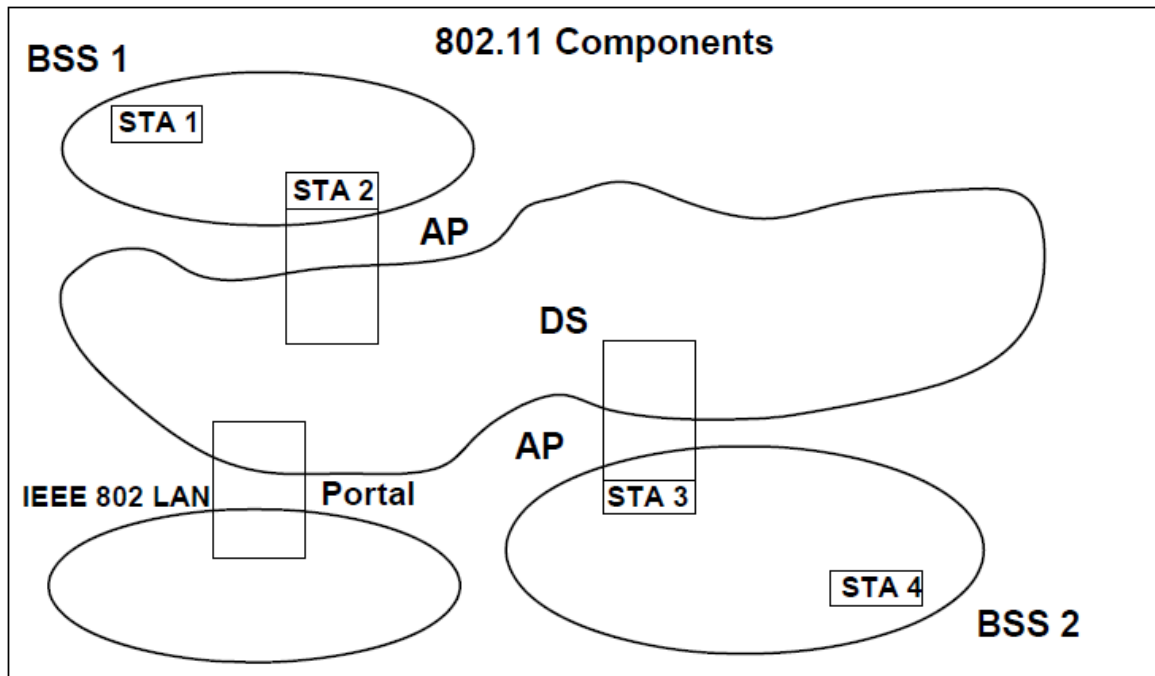
Extended service set

- **Extended service set (ESS):** with DS, STAs at multiple BSS can communicate with each other as if they were in the same BSS.
- ESS does not include DS



Portal

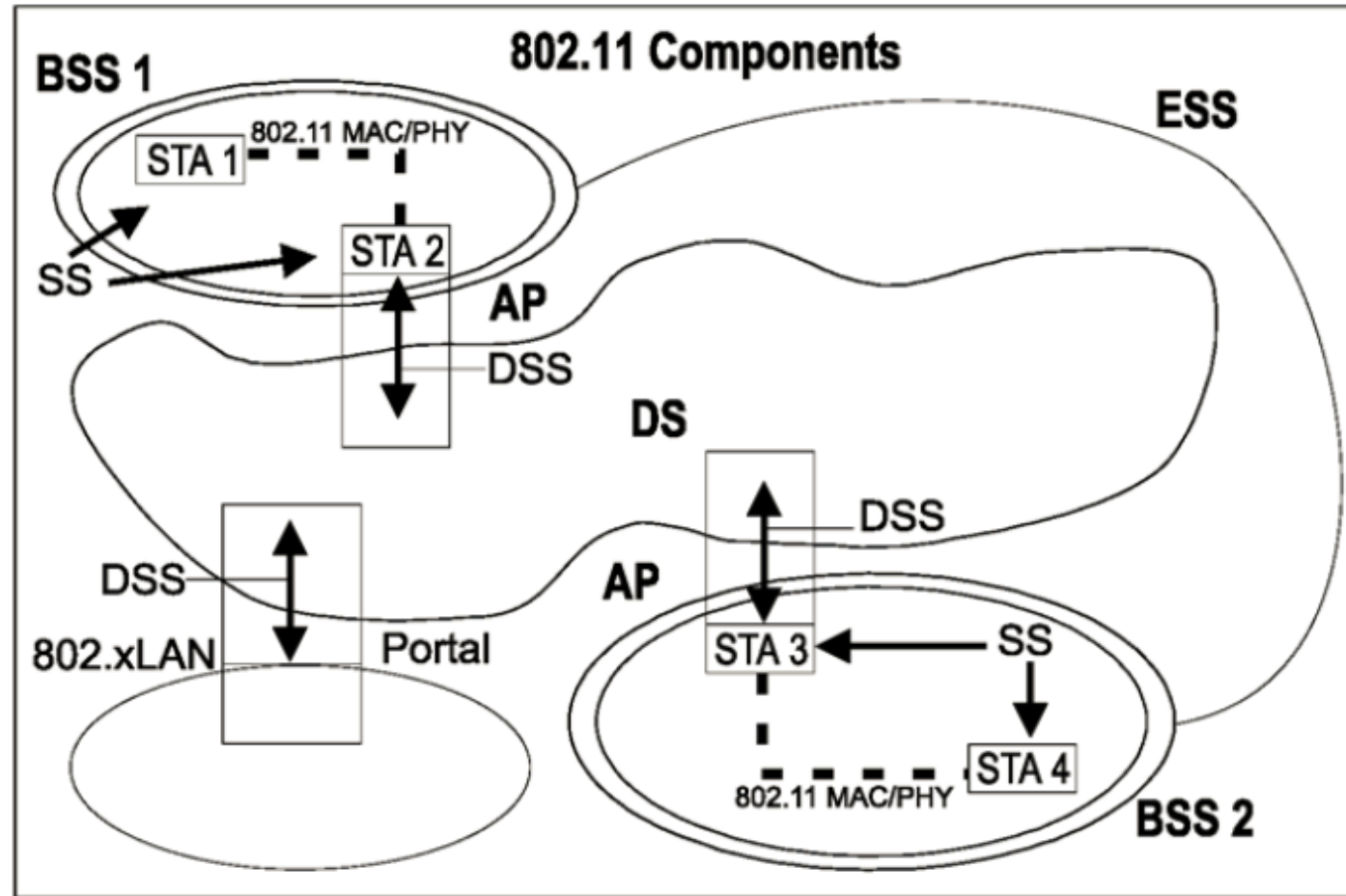
- A **portal** is the logical point at which MSDUs from an integrated non-IEEE-802.11 LAN enter the IEEE 802.11 DS.



A gate between non-IEEE-802.11 LAN and IEEE-802.11 LAN



Complete Architecture



Service

- The basic service provided by WLAN is to deliver MSDU. However, in order to make sure the MSDUs are delivered correctly and safely, more services are defined in WLAN
- **Station service (SS):** service provided by STA
 - i.e., authentication, deauthentication, Privacy, MSDU delivery and etc.
- **Distribution system service (DSS):** service provided by DS
 - i.e., association, reassociation, disassociation, distribution, integration and etc.



Mobility Support

- There are three types of mobility in 802.11
 - **No-transition:** service within a BSS
 - **BSS-transition:** “a STA movement from one BSS in one ESS to another BSS within the same ESS”
 - **ESS-transition:** “STA movement from a BSS in one ESS to a BSS in a different ESS”



Reading Assignment

IEEE Std 802.11™-2020

- Section 1
- Section 4

