This lecture is being recorded

18-452/18-750
Wireless Networks and Applications
Lecture 10: Wireless LAN
802.11 Standards

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Spring Semester 2022

http://www.cs.cmu.edu/~prs/wirelessS22/

Outline

- 802.11 power control
- 802.11 QoS
- 802.11b through g
- How do further increase bit rates?
- How about short data short transfers?
- 802.11n through ax

Early IEEE 802.11 Standards

- **IEEE 802.11a**
  - PHY Standard : 8 channels : up to 54 Mbps : some deployment
- **IEEE 802.11b**
  - PHY Standard : 3 channels : up to 11 Mbps : widely deployed.
- **IEEE 802.11d**
  - MAC Standard : support for multiple regulatory domains (countries)
- **IEEE 802.11e**
  - MAC Standard : QoS support : supported by many vendors
- **IEEE 802.11f**
  - Inter-Access Point Protocol : deployed
- **IEEE 802.11g**
  - PHY Standard: 3 channels : OFDM and PBCC : widely deployed (as b/g)
- **IEEE 802.11h**
  - Suppl. MAC Standard: spectrum managed 802.11a (TPC, DFS): standard
- **IEEE 802.11i**
  - Suppl. MAC Standard: Alternative WEP : standard
- **IEEE 802.11n, ac, ad, ay, ay**

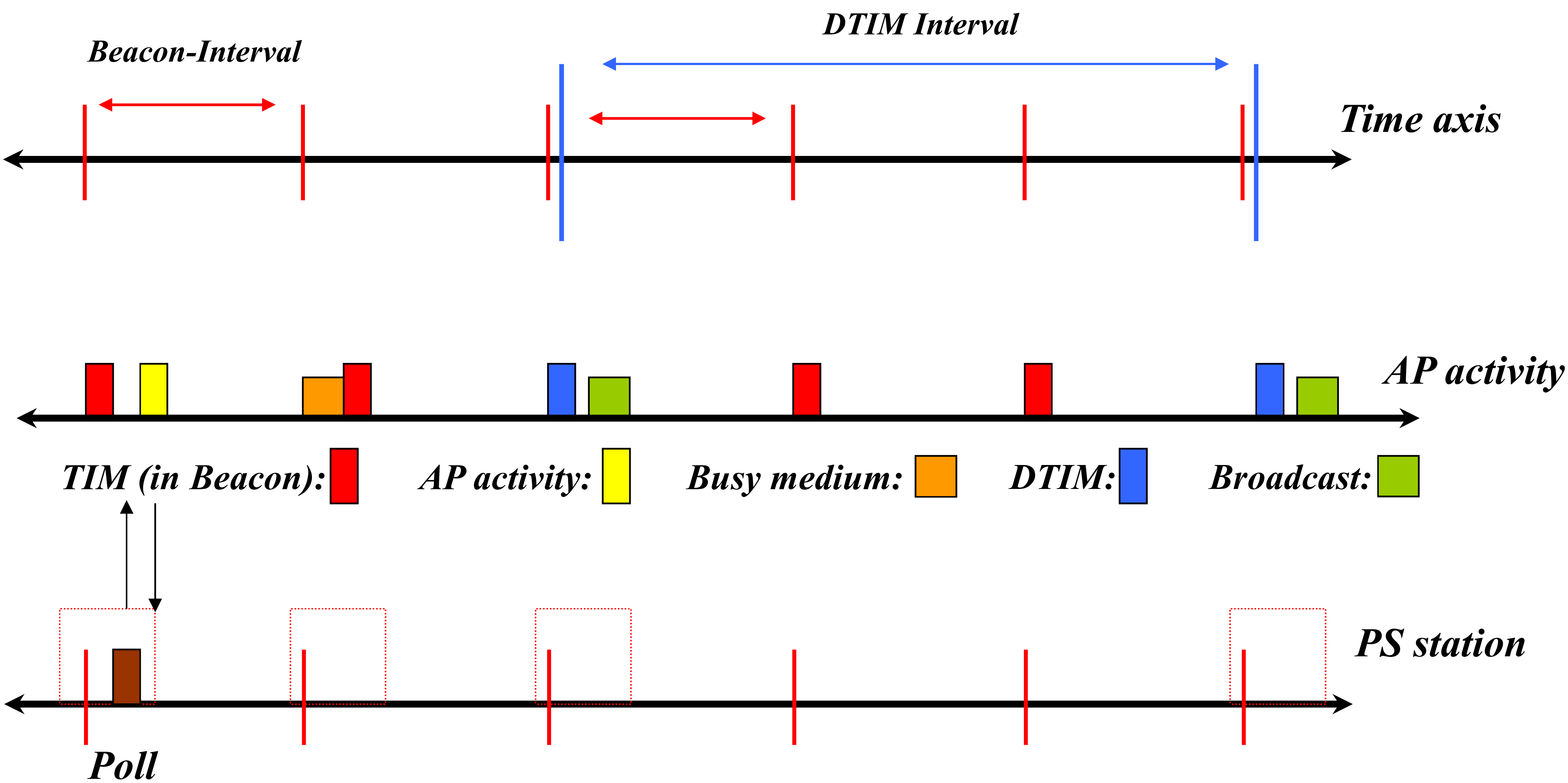
Power Management

- Goal is to enhance battery life of the stations
- Idle receive state dominates LAN adapter power consumption over time
- Allow stations to power off their NIC while still maintaining an active session
- Different protocols are used for infrastructure and independent BSS
  - » Our focus is on infrastructure mode

Power Management Approach

- Allow idle station to put radio in a low power mode
- AP keeps track of stations in Power Savings (PS) mode and buffers their packets
  - » Traffic Indication Map (TIM) is included in beacons to inform which power-save stations have packets waiting at the AP
- PS stations wake up periodically and listen for beacons
  - » If they have data waiting, they can send a PS-Poll to request that the AP sends their packets
  - » Poll is needed since stations can skip beacons with a TIM
- TSF assures AP and stations are synchronized
  - » Time Synchronization Function: Synchronizes clocks in a BSS
- Broadcast/multicast frames are also buffered at AP
  - » Sent after beacon with a Delivery Traffic Indication Map (DTIM)
  - » Stations must wake up for beacons with a DTIM
  - » AP controls DTIM interval

Infrastructure Power Management Operation



Spectrum and Transmit Power Management Extensions (802.11h)

- Support 802.11 operation in 5 GHz band in Europe: coexistence with primary users
  - Radar: cannot use bands if a radar is nearby
    - Allows opening up 11 more bands in 5 GHz band
  - Satellite: limit power to 3dB below regulatory limit
- Dynamic Frequency Selection (DFS)
  - Detect primary users and adapt
  - AP notifies stations to switch channel at some point in time
- Transmit Power Control (TPC)
  - Goal is to limit interference – also controlled by AP
- DFS and TPC have broader uses such as range and interference control, reduced energy consumption, automatic frequency planning, load balancing, ..

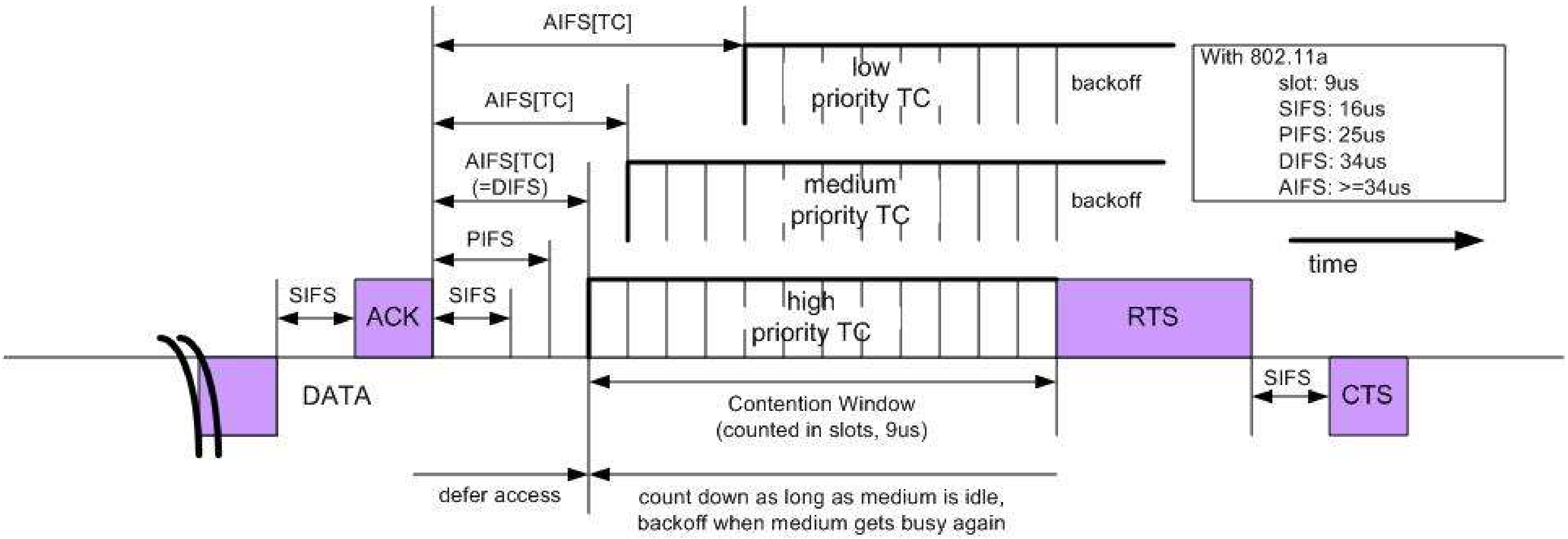
IEEE 802.11e

- Original intent was that 802.11 PCF could be used to provide QoS guarantees
  - Scheduler in the PCF priorities urgent traffic
  - But: overhead, "guarantees" are very soft
- 802.11e Enhanced Distributed Coordination Function (EDCF) is supposed to fix this.
  - Provides Hybrid Coordination Function (HCF) that combines aspects of PCF and DCF
- EDCF supports 4 Access Categories
  - *AC_BK (or AC0)* for Back-ground traffic
  - *AC_BE (or AC1)* for Best-Effort traffic
  - *AC_VI (or AC2)* for Video traffic
  - *AC_VO (or AC3)* for Voice traffic

Service Differentiation Mechanisms in EDCF

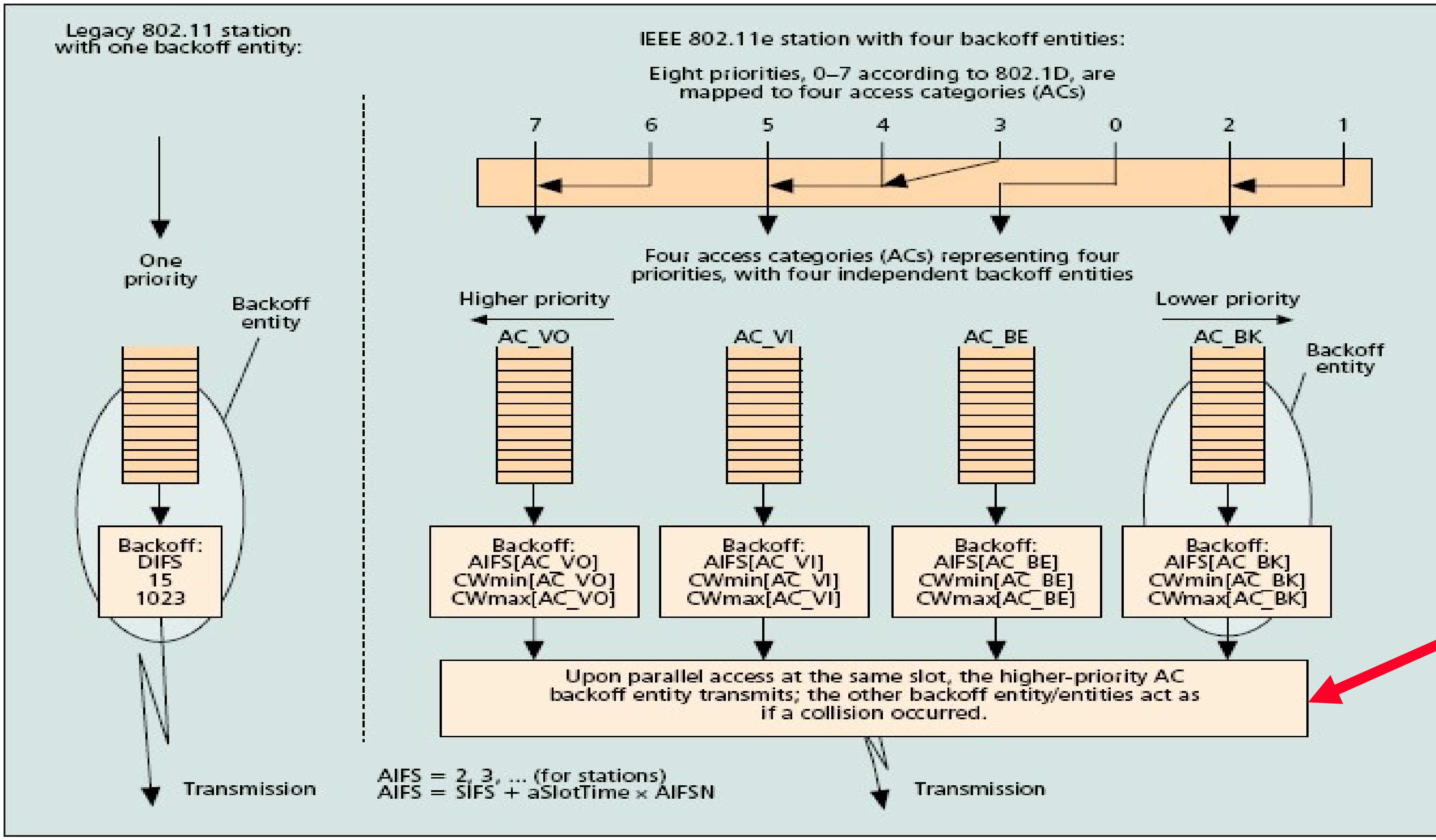
- **The two types of service differentiation mechanisms proposed in EDCF are:**
- ***Arbitrate Inter-frame Space (AIFS) Differentiation***
  - **Different AIFSs instead of the constant distributed IFS (DIFS) used in DCF.**
  - **Back-off counter is selected from [1, CW[AC]+1] instead of [0,CW] as in DCF.**
- **Contention Window (CWmin) Differentiation**
  - **Different values for the minimum/maximum CWs to be used for the back-off time extraction.**

IEEE 802.11e: Priorities



Mapping different priority frames to different AC

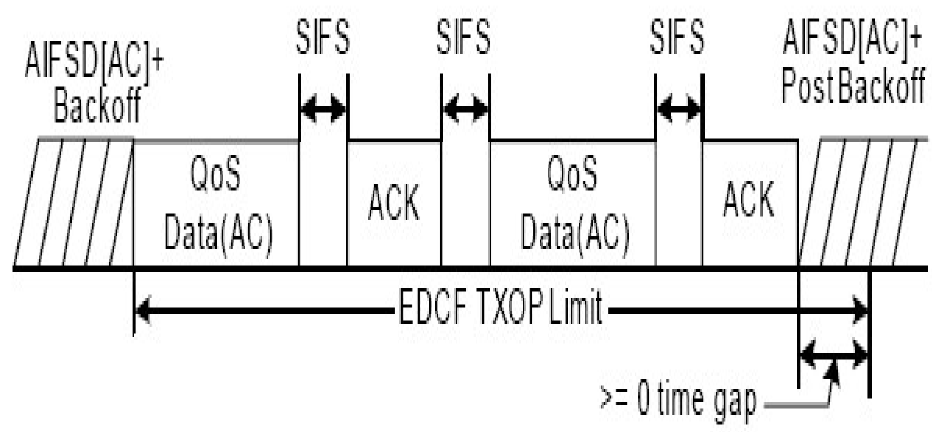
- **Each frame arriving at the MAC with a priority is mapped into an AC as shown in figure below.**



Resolves Virtual Collisions

Other 802.11 MAC Improvements

- *TXOP- **Transmission opportunity*** **(TXOP) is an interval of time during which a back-off entity has the right to deliver multiple MSDUs.**
  - » **A TXOP is defined by its starting time and duration**
  - » **Announced using a traffic specification (length, period)**
  - » **Can give more transmission opportunities to a station**
  - » **Can also limit transmission time (e.g. for low rate stations)**
- *CFB-* **In a single TXOP, multiple MSDUs can be transmitted.**
  - » ***Contention Free Burst (CFB)***
  - » ***Can also use a block acknowledgement – reduces overhead***



IEEE 802.11 Family High Level

Protocol	Release Data	Freq.	Rate (typical)	Rate (max)	Range (indoor)
Legacy	1997	2.4 GHz	1 Mbps	2Mbps	?
802.11a	1999	5 GHz	25 Mbps	54 Mbps	~30 m
802.11b	1999	2.4 GHz	6.5 Mbps	11 Mbps	~30 m
802.11g	2003	2.4 GHz	25 Mbps	54 Mbps	~30 m
802.11n	2009	2.4/5 GHz	200 Mbps	600 Mbps	~50 m
802.11ac	2013	5 GHz	100s Mbps	3.5 Gbps	~50 m
802.11ad	2012	60 GHz	~1 Gbps	6.7 Gbps	~10 m
802.11ax	2021 est	5 GHz	~1 Gbps	9.6 Gbps	~50 m
802.11ay	2021 est	60 GHz	1< Gbps	20 Gbps	~10 m

IEEE 802.11 Family Technology

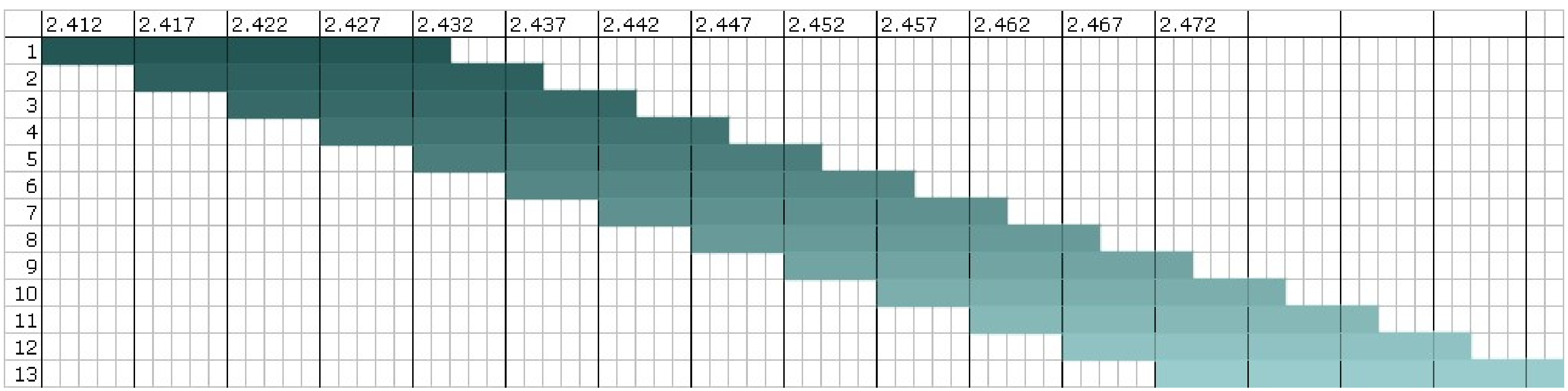
Protocol	Release Data	Bands GHz	PHY Features	Max Rate	Channel Width
802.11a	1999	5	OFDM	54 Mbps	20 MHz
802.11b	1999	2.4	DSSC/CCK	11 Mbps	20 MHz
802.11g	2003	2.4	OFDM	54 Mbps	20 Mhz
802.11n	2009	2.4. 5	OFDM, BF, MIMO-d	600Mbps	20, 40 MHz
802.11ac	2013	5	OFDM, BF MU-MIMO-d	3.5 Gbps	20, 40, 80, 160 Mhz
802.11ad	2016	60	BF	6.7 Gbps	2.16 GHz
802.11ax	2021	2.4, 5, 6	MU-MIMO, OFDMA, BF	9.6 Gbps	20, 40, 80, 160 Mhz
802.11ay	2021	60	MU-MIMO	20 Gbps	2.16, 4.32, 8.64 Ghz

Legend

- DSSS: Direct Sequence Spread Spectrum
- CCK: Complementary Code Keying
- OFDM: Orthogonal Frequency Division Multiplexing
- MIMO: Multiple In Multiple Out
  - » MIMO-d: MIMO downstream only
- BF: Beam Forming
- MU-MIMO: Multi-User MIMO
  - » MU-MIMO-d: MU-MIMO downstream only
- OFDMA: Orthogonal Frequency Division Multiple Access
  - » Implies OFDM

802.11b Channels

- In the UK and most of EU: 13 channels, 5MHz apart, 2.412 – 2.472 GHz
- In the US: only 11 channels
- Each channel is 22MHz
- Significant overlap
- Non-overlapping channels are 1, 6 and 11

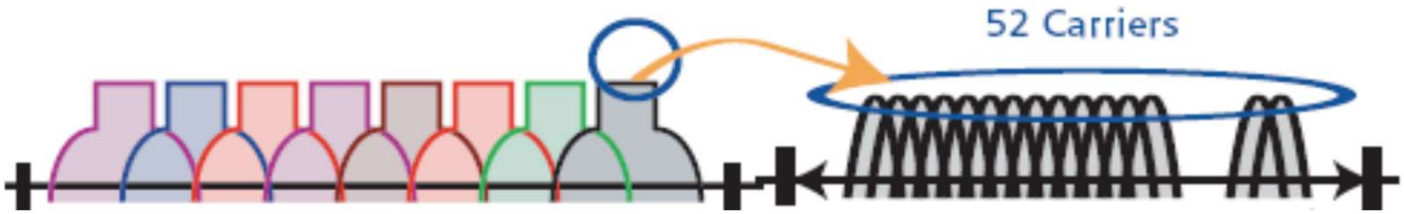


802.11b Physical Layer

- FHSS (legacy)
  - » 2 & 4 GFSK
  - » Using one of 78 hop sequences, hop to a new 1MHz channel (out of the total of 79 channels) at least every 400milliseconds
- DSSS (802.11b)
  - » DBPSK & DQPSK
  - » Uses one of 11 overlapping channels (22 MHz)
  - » 1 and 2 Mbps: multiply the data by an 11-chip spreading code (Barker sequence)
  - » 5.5 and 11 Mbps: uses Complementary Code Keying (CCK) to generate spreading sequences that support the higher data rates
    - – Spreading code is calculated based on the data bits

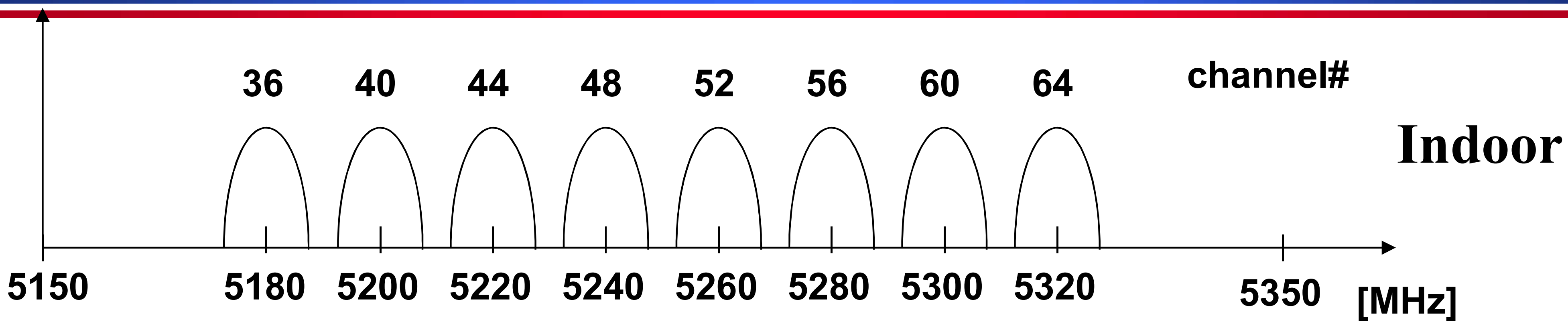
802.11a Overview

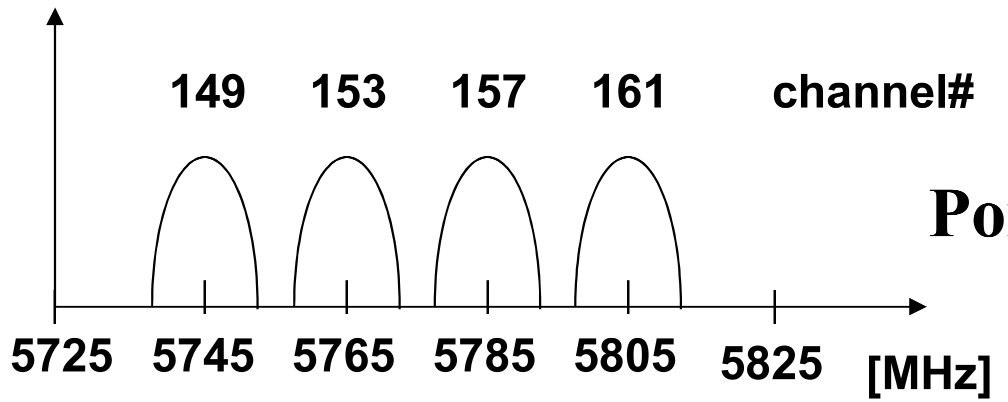
- First WiFi version in the 5 GHz band
- Use OFDM to divide each physical channel (20 MHz) into 52 subcarriers (20M/64=312.5 KHz each)
  - » 48 data, 4 pilot



- Adaptive modulation
  - » BPSK: 6, 9 Mbps
  - » QPSK: 12, 18 Mbps
  - » 16-QAM: 24, 36 Mbps
  - » 64-QAM: 48, 54 Mbps
- Also used in the 2.4 GHz as 802.11g
  - » Same PHY layer as 802.11a
  - » But has the benefits and drawbacks of the 2.4 GHz band compared to 5 GHz

802.11a Physical Channels





center frequency =
5000 + 5*channel number [MHz]

802.11a Discussion

- Uses OFDM in the 5 GHz band
  - » Also used by 802.11g in 2.4 GHz (next slides)
- What are the benefits of 802.11a compared with 802.11b/g?
  - » Greater bandwidth (up to 54Mb)
    - – 54, 48, 36, 24, 18, 12, 9 and 6 Mbs
    - – 802.11g (next slide) offers same benefit
  - » Less potential interference (5GHz)
  - » More non-overlapping channels
- But it does not provide interoperability with 802.11b, as 802.11g does
  - » Cannot fall back to lower rates (not an issue in practice)
  - » Cards typically support a and g

Interoperability 802.11b and 802.11g

- 802.11g is the same as 802.11a, but in 2.4GHz band
  - » Falls back to 802.11b for the lower rates (1,2, 5.5, 11 MHz)
  - » Uses 802.11a OFDM technology for new rates (6 Mbs and up)
- Creates an interoperability problem since 802.11b cards cannot interpret OFDM signals
  - » Interoperability mode: protection mechanism in hybrid environment: Send CCK CTS before OFDM packets or use (optional) hybrid packet
  - » Can also run an 802.11n only network – reduces overhead