This lecture is being recorded

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

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http://www.cs.cmu.edu/~prs/wirelessS21/

Announcements

- **Project 2 team forming**
  - » You can use piazza to find a partner
    - – E.g., post topics of interest using project_2 tag
  - » You can also stick around after this lecture to meet other students looking for a partner
- **Homework 2 was posted yesterday**
  - » Note that homeworks include "problem solving" questions that require you to apply course material
- **Project 1 is due on Friday**
- **I have added a "Useful link" section to the course web page**
  - » It provides easy access to handouts (not assignments)

Outline

- Brief history
- 802 protocol overview
- Wireless LANs – 802.11 – overview
- 802.11 MAC, frame format, operations
- 802.11 management
- 802.11 security
- 802.11 power control
- 802.11*
- 802.11 QoS

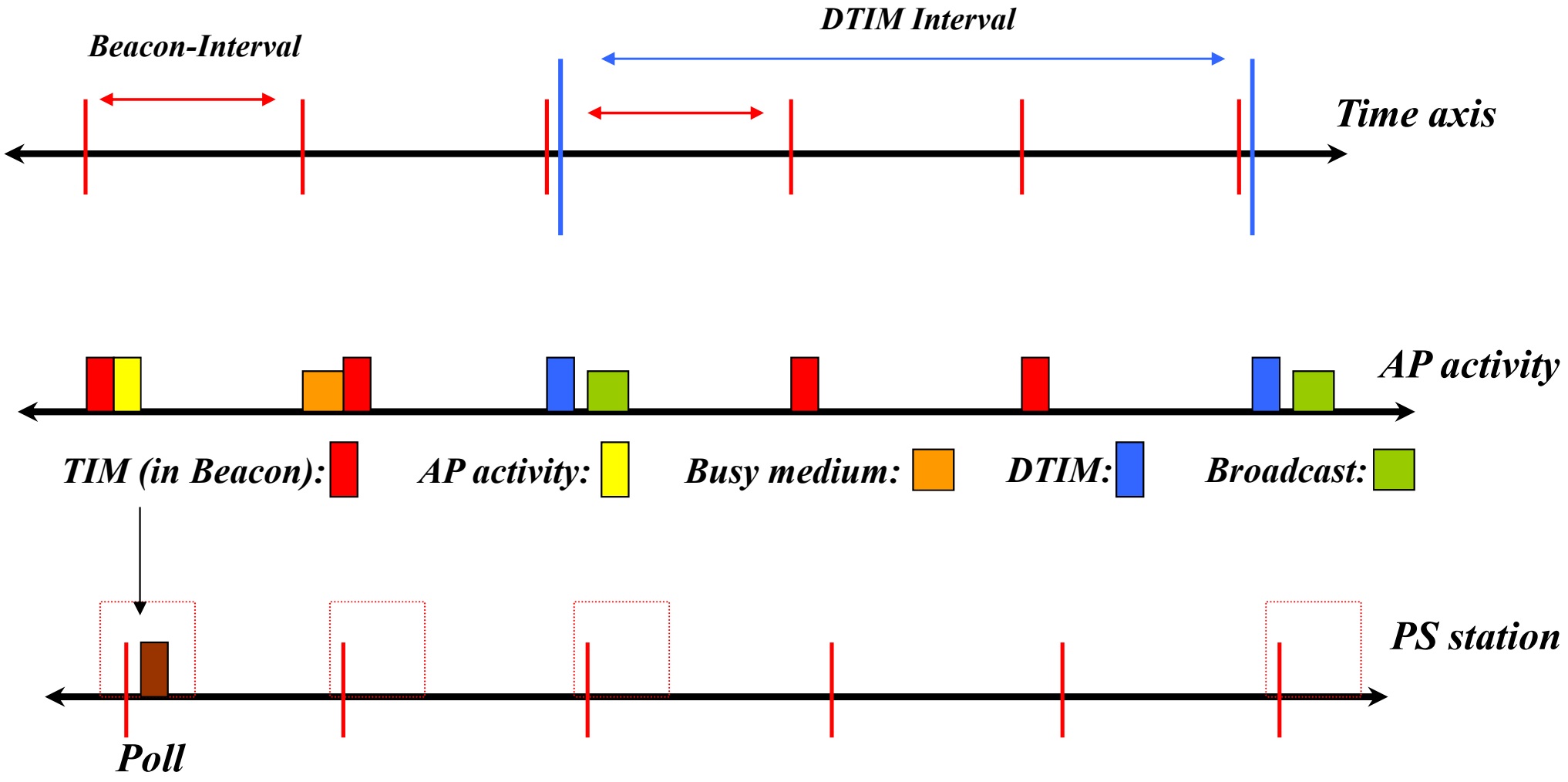
Power Management

- 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

- Idle station to go to sleep
- AP keeps track of stations in Power Savings 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
- Power Saving 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
- 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 beacons that includes Delivery Traffic Indication Map (DTIM)
  - » AP controls DTIM interval

Infrastructure Power Management Operation



Some IEEE 802.11 Standards

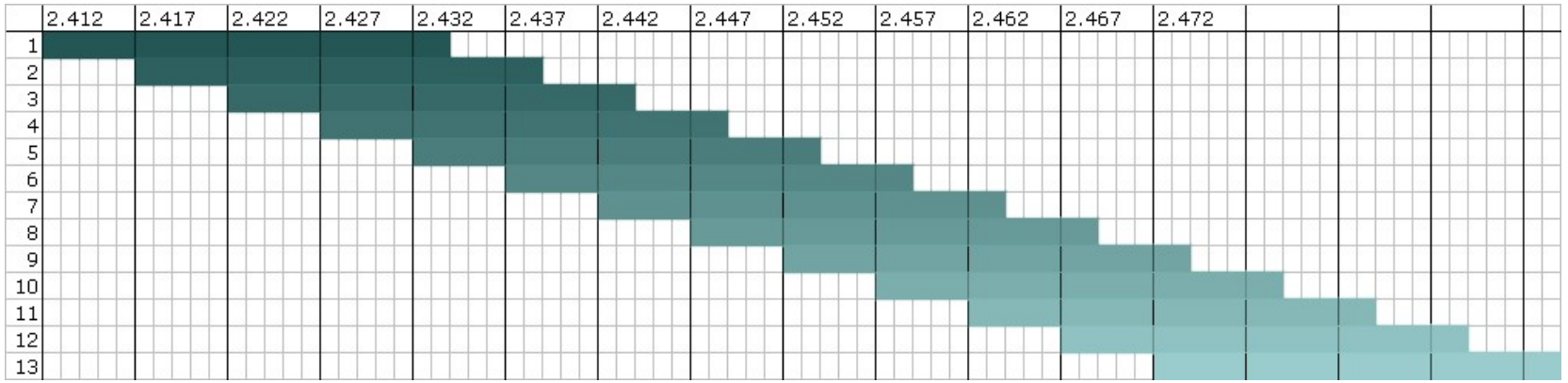
- IEEE 802.11a
  - PHY Standard : 8 channels : up to 54 Mbps : some deployment
- IEEE 802.11b
  - PHY Standard : 3 channels : up to 11 Mbps : widely deployed.
- IEEE 802.11d
  - MAC Standard : support for multiple regulatory domains (countries)
- IEEE 802.11e
  - MAC Standard : QoS support : supported 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
  - MAC Standard: MIMO : standardization expected late 2008

IEEE 802.11 Family

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

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

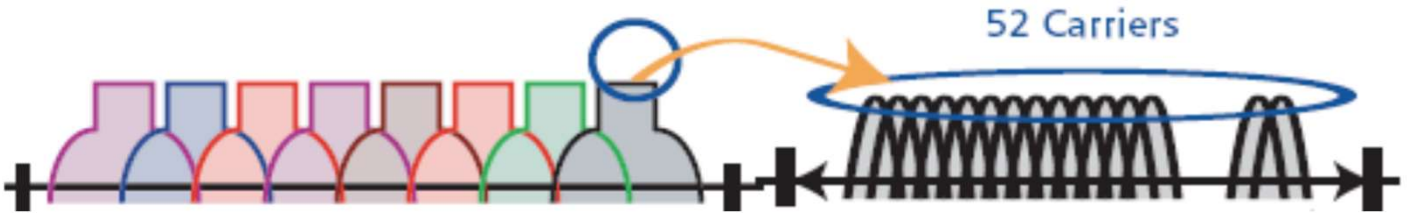


802.11b Physical Layer

- 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 (CKK) to generate spreading sequences that support the higher data rates
    - Spreading code is calculated based on the data bits

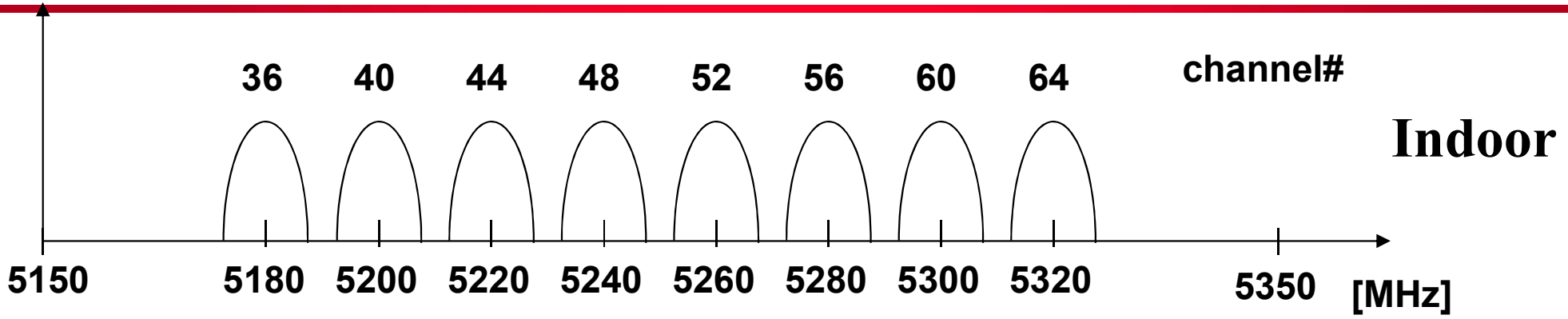
802.11a Overview

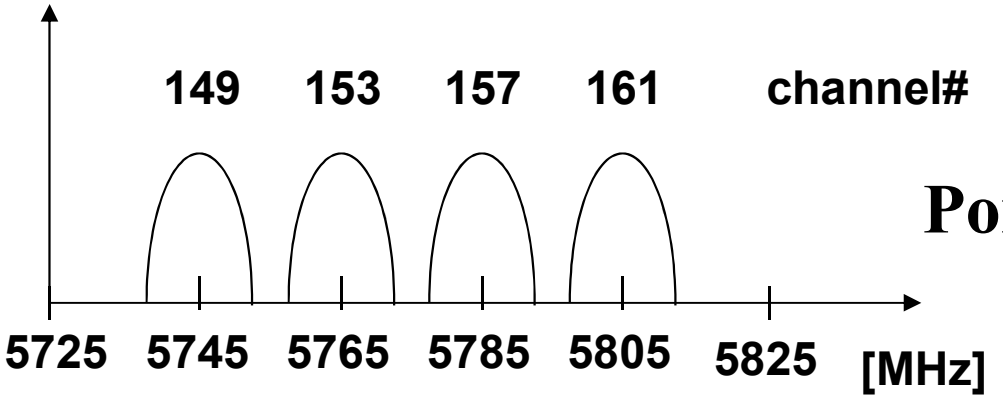
- First WiFi version in the 5 GHz band
- Use OFDM to divide each physical channel (20 MHz) into 52 subcarriers (20M/64=312.5 KHz each)
  - » 48 data, 4 pilot



- 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





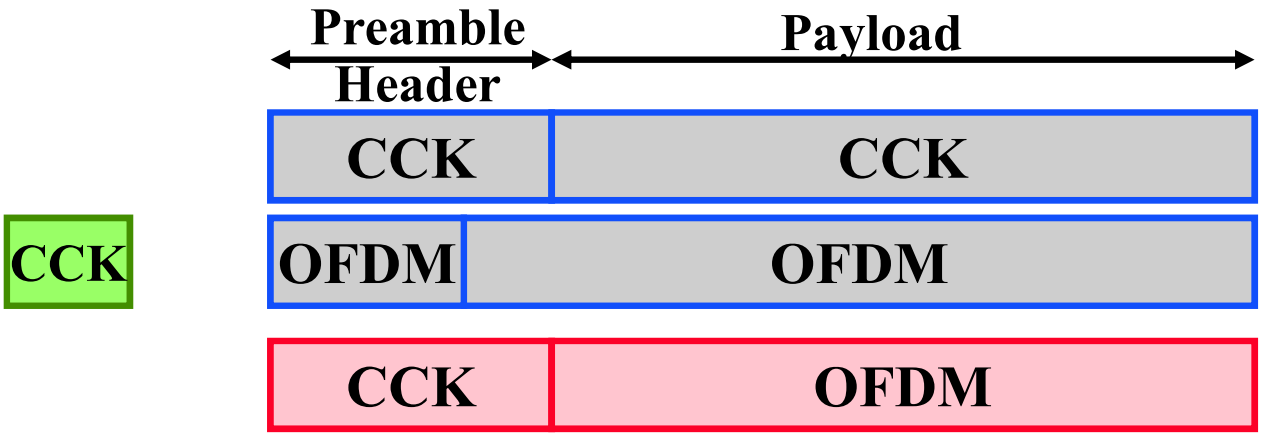
center frequency =
5000 + 5*channel number [MHz]

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



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, ..**

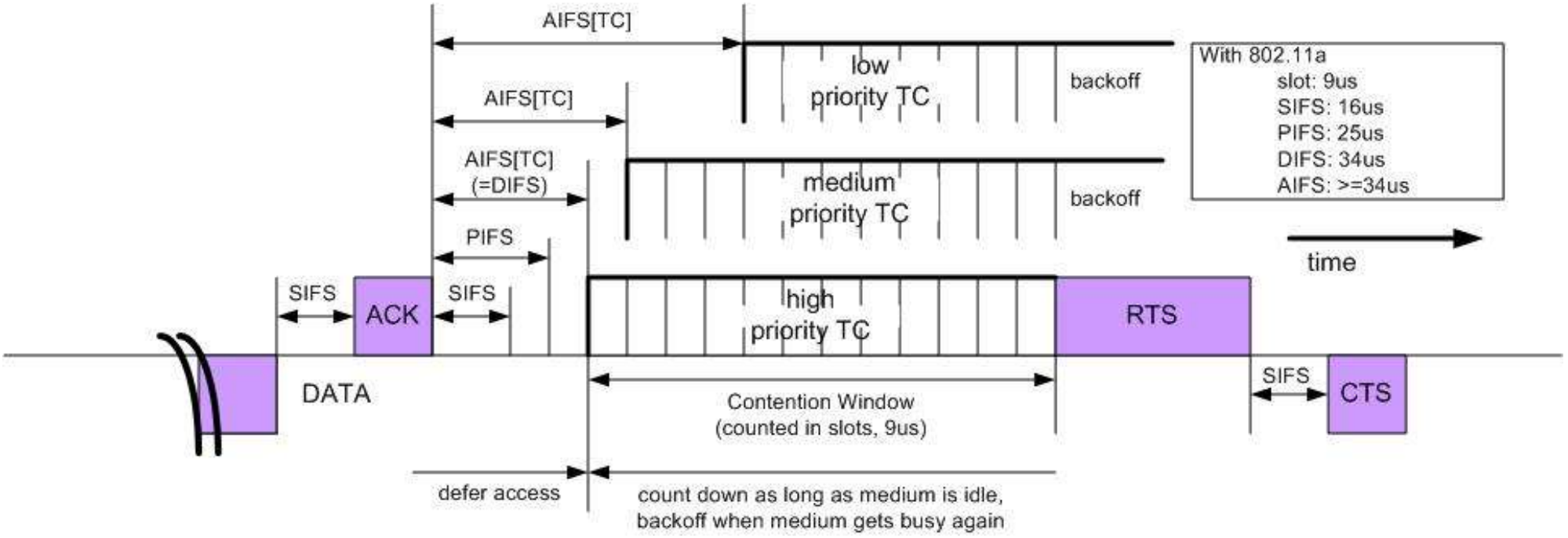
IEEE 802.11e

- **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

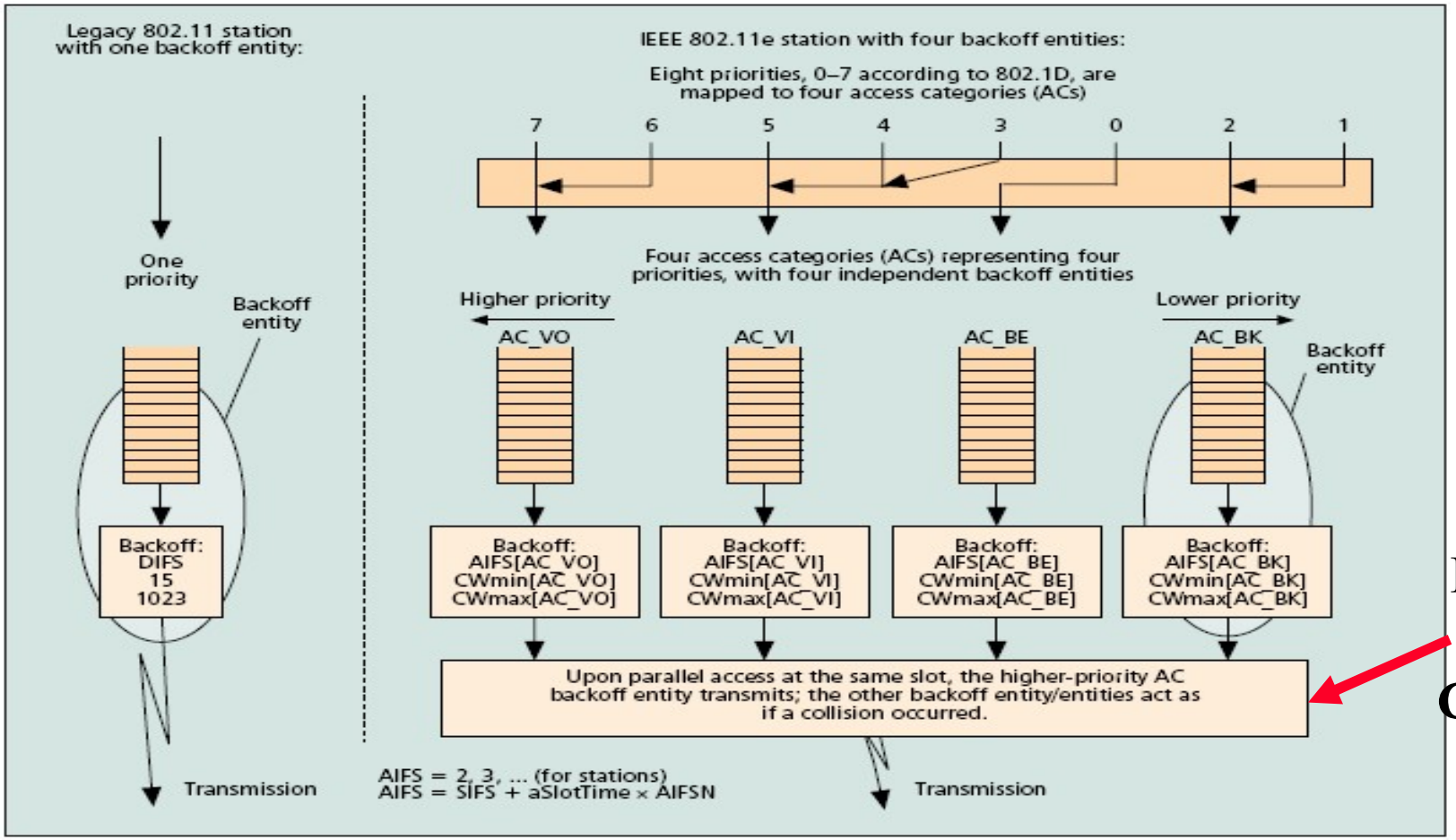
- **The two types of service differentiation mechanisms proposed in EDCF are:**
- ***Arbitrate Inter-frame Space (AIFS) Differentiation***
  - **Different AIFSs instead of the constant distributed IFS (DIFS) used in DCF.**
  - **Back-off counter is selected from [1, CW[AC]+1] instead of [0,CW] as in 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 use a block acknowledgement***