IEEE 802.11 WLANS
- PHY Layers and MAC Protocols -

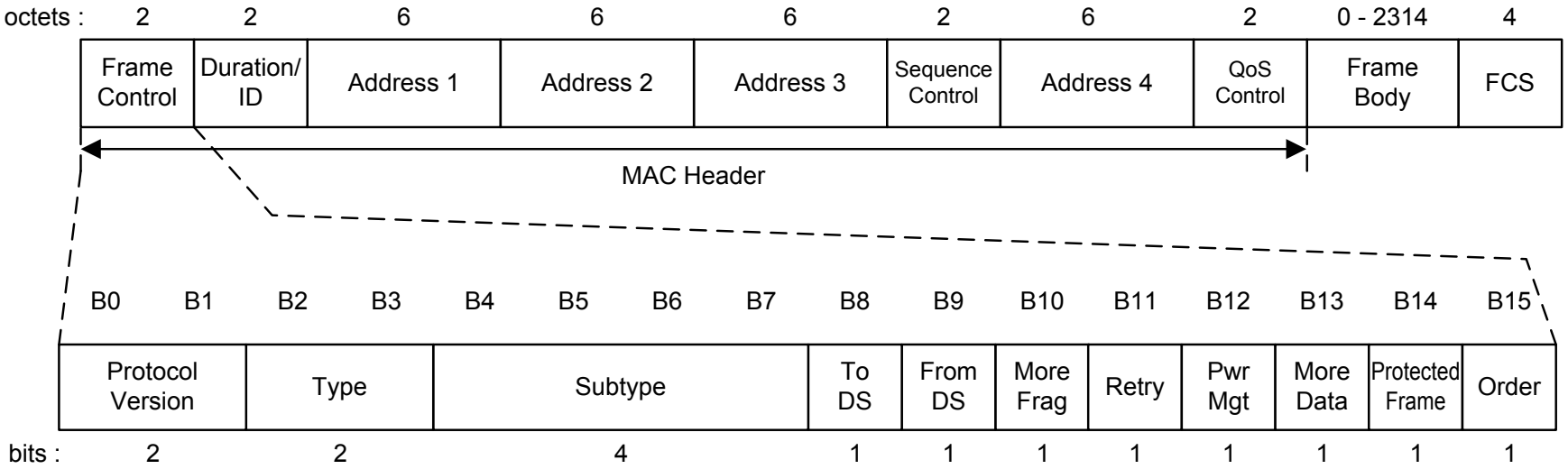
Kyunghan Lee
Networked Computing Lab (NXC Lab)
Department of Electrical and Computer Engineering
Seoul National University
https://nxc.snu.ac.kr
kyunghanlee@snu.ac.kr

Adapted from Prof. Sunghyun Choi's slides

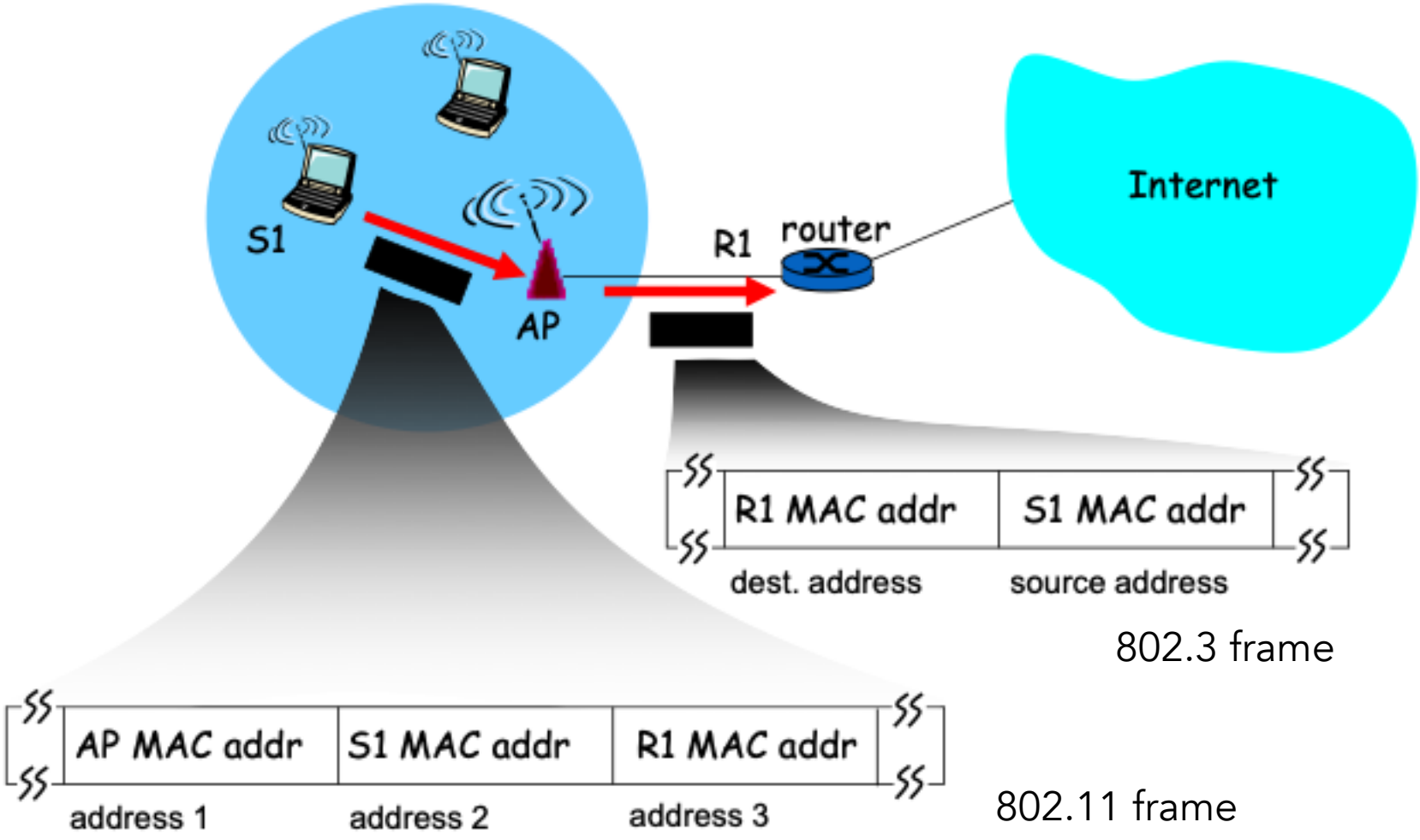
NXC LAB

802.11 MAC Frame (MPDU) Format

- 3 types: data, management, and control types
  - Management: no Addr 4, no QoS control
  - Control: various format, e.g., RTS 20 bytes, CTS/ACK 14 bytes
- Data type frame:
  - Addr 1 (Receiver), Addr 2 (Transmitter), Addr 3 (Source or Destination)
  - Addr 4 exists only for tx between APs (in Mesh Network)

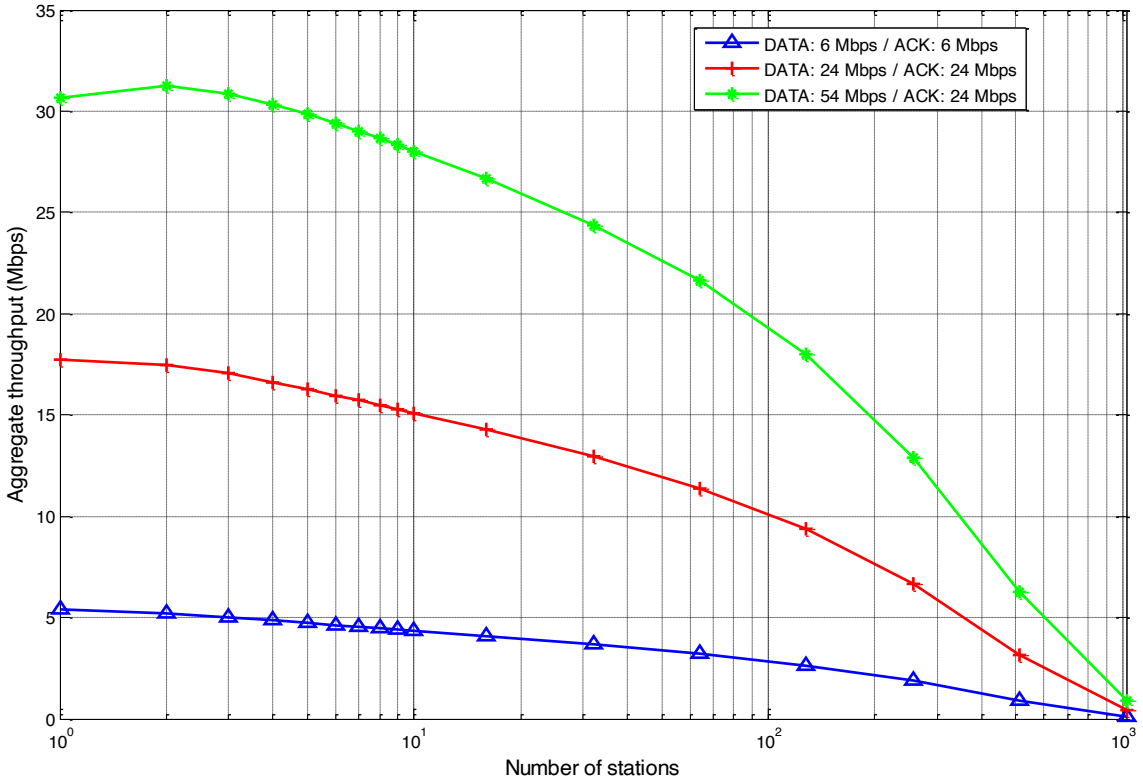


802.11 Frame: Addressing



Throughput Performance

- Varying number of stations w/ 802.11a PHY
- Performance can be improved by adapting random backoff!



Aggregate throughput vs. Number of stations

Rate Adaptation

- A transmitter can change its transmission rate with or without feedback from the receiver!
  - Open-loop rate adaptation
    - Automatic Rate Fallback (ARF)
    - More recent ones including CARA, Minstrel, RRAA
  - Closed-loop rate adaptation
    - Feedback is required
    - Signal-to-Interference/Noise Ratio (SINR) or the desired transmission rate determined by the receiver
    - Defined in IEEE 802.11n, but not practically used

Automatic Rate Fallback (ARF) & Collision Aware Rate Adaptation (CARA)

- Rate decrease
  - Decrease rate after 2 consecutive tx failures
  - 2 not 1 failures due to possible frame collisions
- Rate increase
  - Increase rate after N (e.g., 10) consecutive tx successes
- Thanks to its simplicity, ARF[1] was widely employed in "earlier" commercial 802.11 WLAN devices!
- CARA[2] uses RTS adaptively to determine whether failure is due to collision or channel error
  - RTS is used after 1st failure
  - Assumes RTS failure is due to collision

[1] Ad Kamerman and Leo Monteban, "WaveLAN-II: a high-performance Wireless LAN for the Unlicensed Band," Bell Labs Technical Journal, vol.2, no.3, pp.118-133, Aug. 1997.
[2] Jongseok Kim, Seongkwan Kim, Sunghyun Choi, and Daji Qiao, "CARA: Collision-Aware Rate Adaptation for IEEE 802.11 WLANs," in Proc. IEEE INFOCOM 2006, Barcelona, Spain, April 23-29, 2006.

Minstrel

- Constructs multi-rate retry chains for each frame transmission
- Collect historical data on packets sent and use that information for rate selection
  - Every 100ms, evaluates every rate's performance
  - Pick out the best & 2nd best throughput and highest success rate
  - Results are used for constructing retry chain for next 100ms period

Retry Chain	Normal Transmission (90%)	Sampling Transmission (10%)	
		Random < Best	Random > Best
0	Best Rate	Best Rate	Random Rate
1	2nd Best Rate	Random Rate	Best Rate
2	Best Probability	Best Probability	Best Probability
3	Base Rate	Base Rate	Base Rate

•Best Rate - performing the highest throughput
•Random Rate - randomly selected
•Best Probability - performing the highest successful rate
•Base rate - lowest data rate

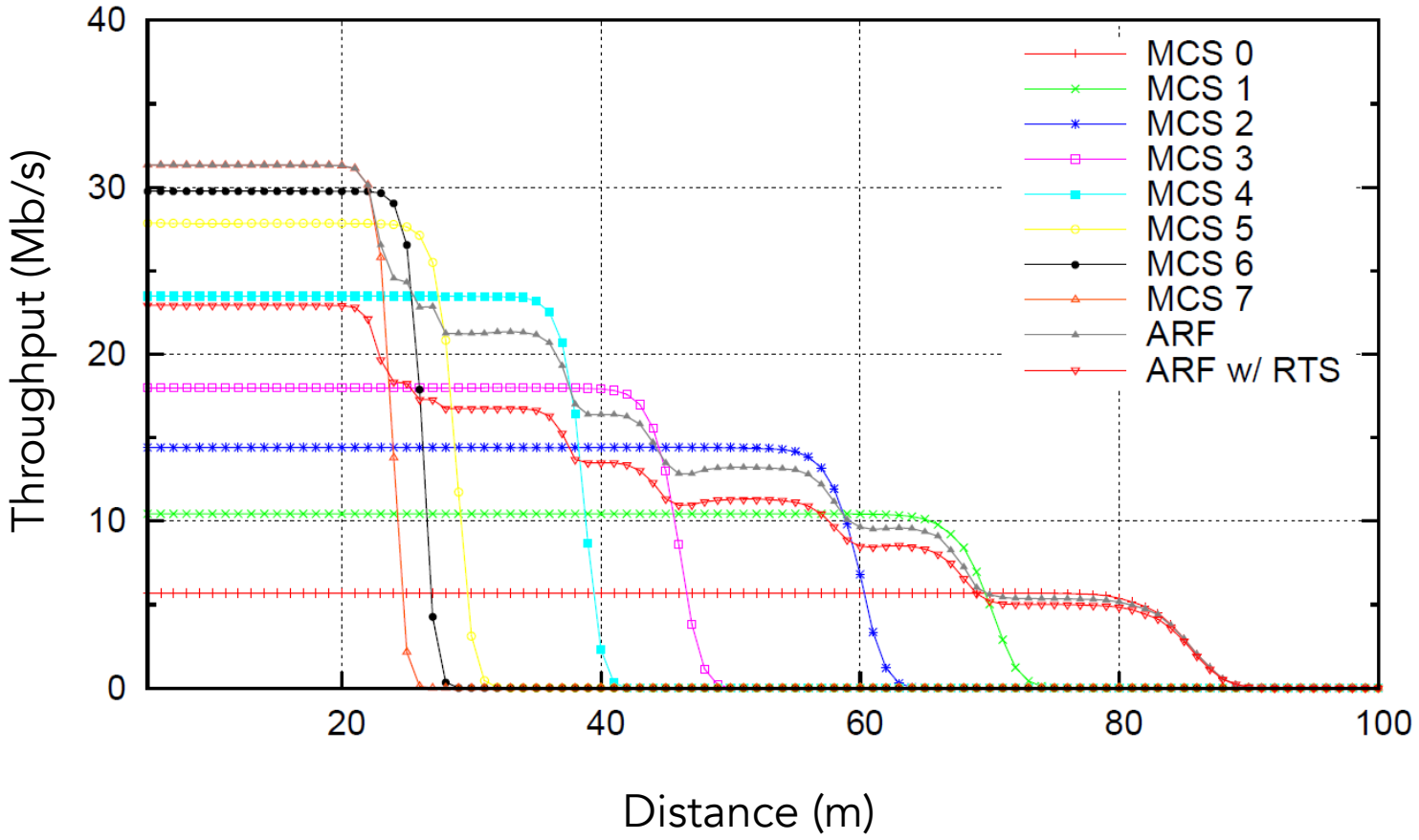
Linux Wireless Tool adopts Minstrel as the default embedded rate adaptation algorithm. (http://linuxwireless.org/.)

Performance Evaluation

- With 11n PHY
- Scenario 1
  - Topology : one (station) to one (AP) with varying distance
  - Saturated condition / 1500 bytes MSDU
- Scenario 2
  - Topology : multiple (stations) to one (AP)
  - All stations locate at the same distance very close from AP
  - Saturated condition / 1500 bytes MSDU

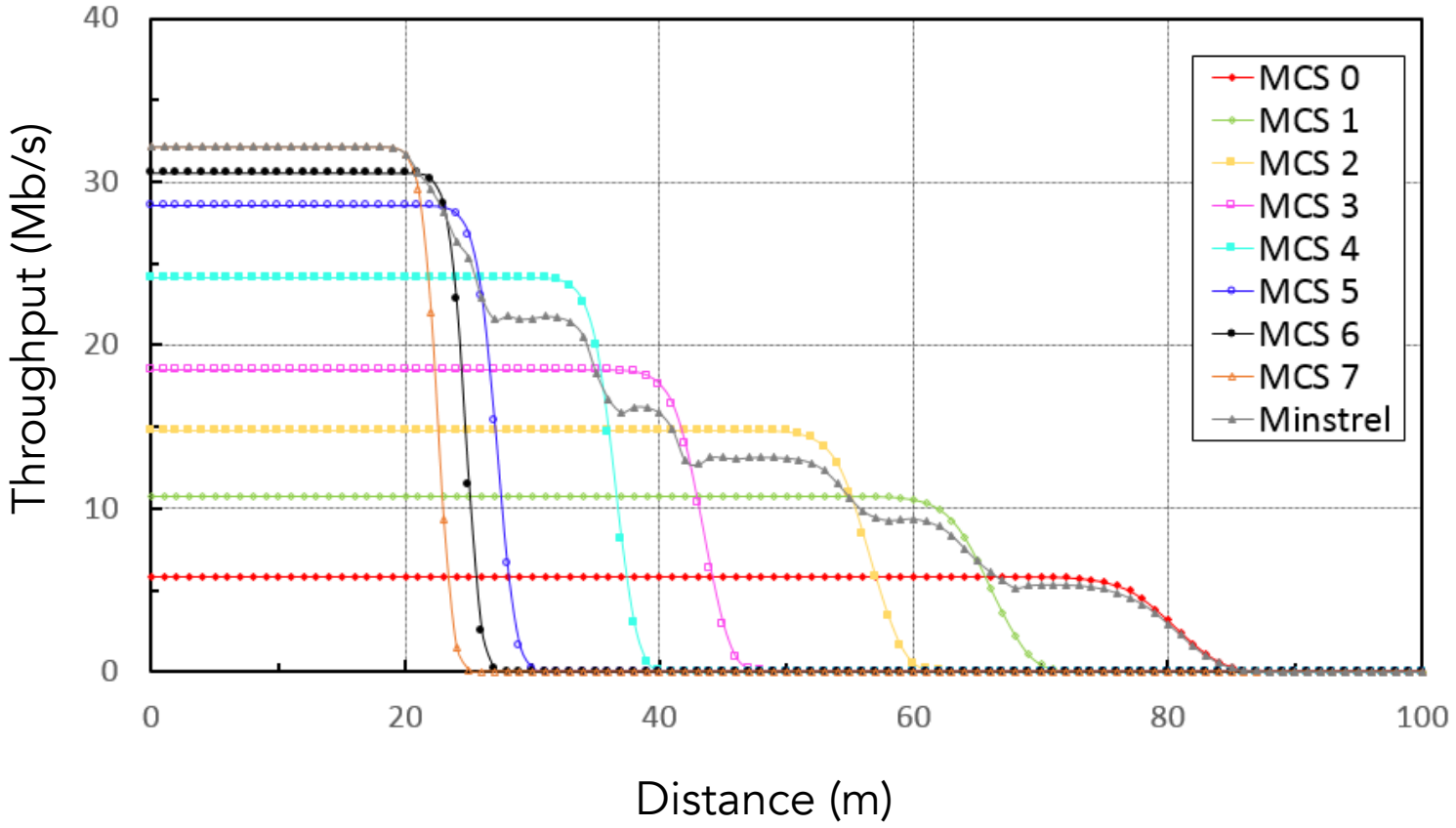
Scenario 1: ARF

- One Tx – One Rx with 802.11n PHY



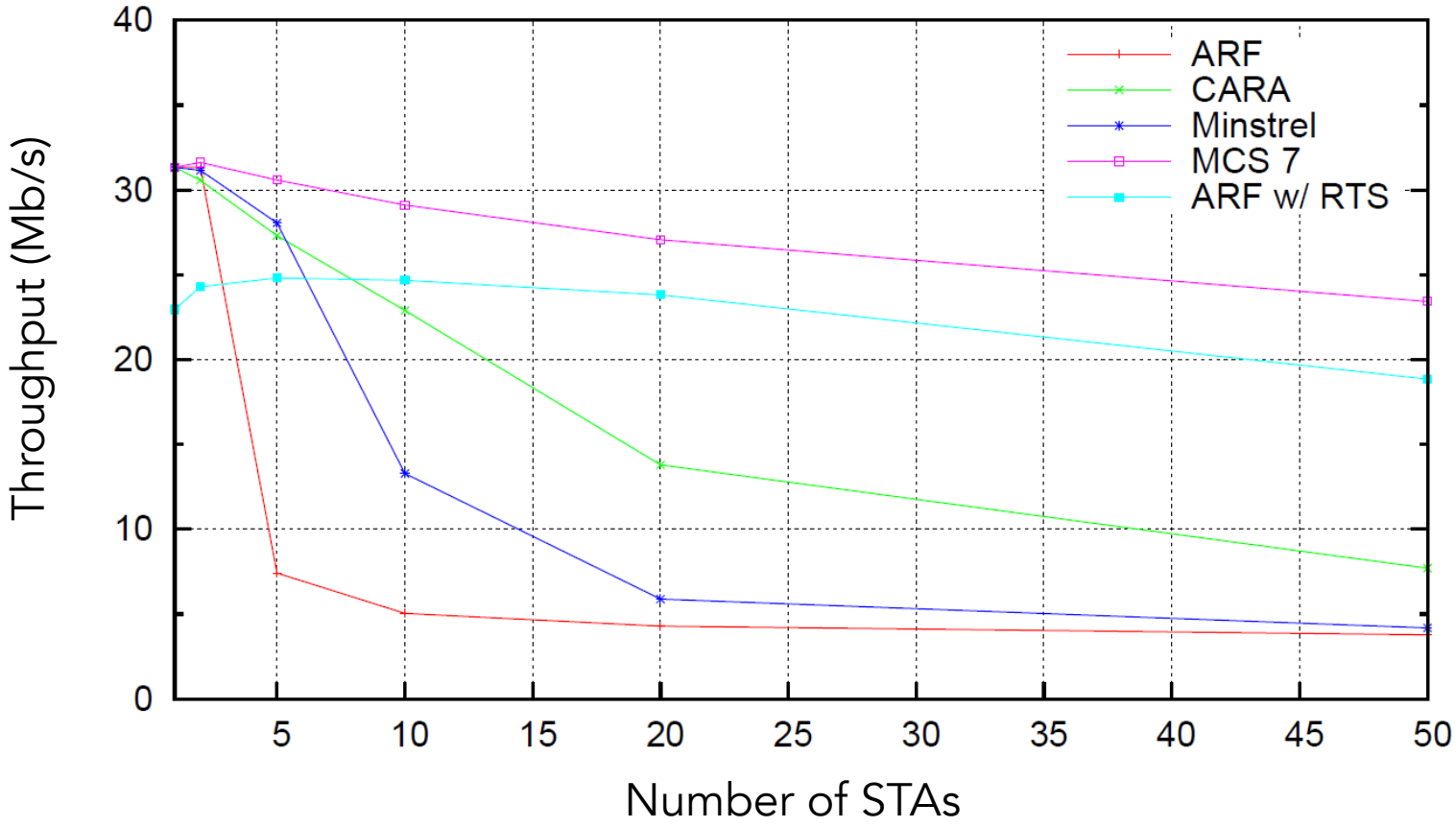
Scenario 1: Minstrel

- One Tx – One Rx with 802.11n PHY



Scenario 2

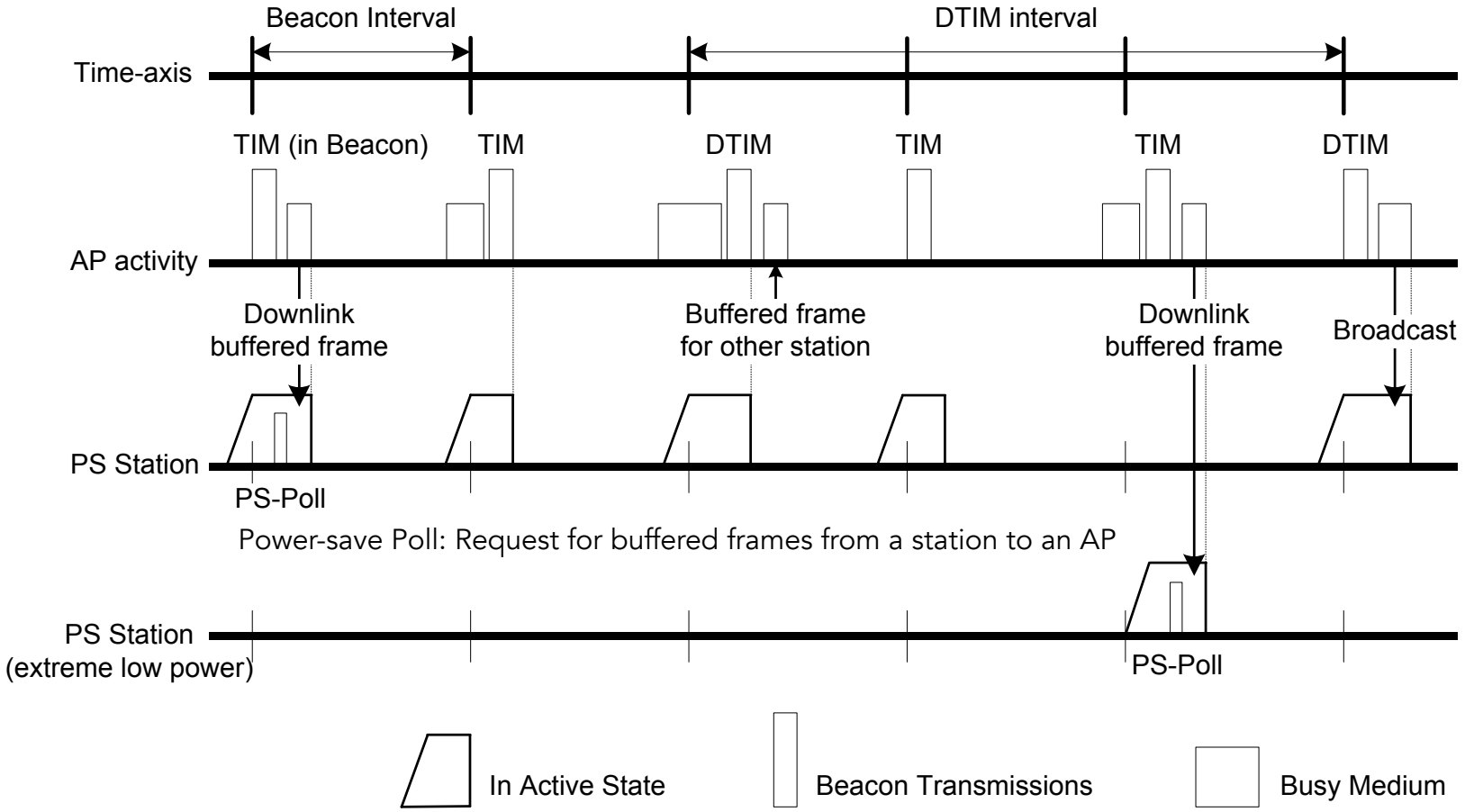
- Varying number of stations w/ 802.11n PHY



Power Management

- Without power management, a STA always senses medium
  - Lots of power consumption for channel sensing/receiving
  - e.g., 1.3 W for Tx, 0.6 W for both sensing and Rx
- Two states of a STA
  - Awake vs. doze states
- Power management allows STAs to go to doze state as much as possible without losing incoming data
  - Active mode (AM) – always awake state
  - Power Save mode (PSM) – switch between awake and doze states

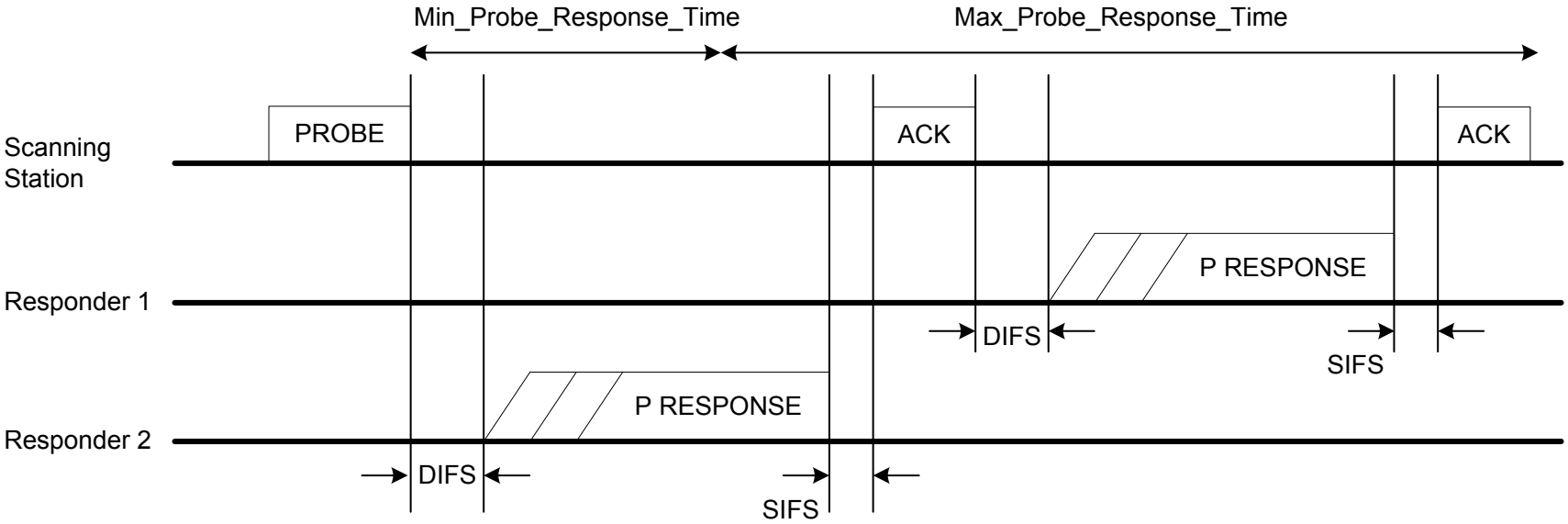
TIM & Dedicated TIM (DTIM) Beacons



- TIM (Traffic Indication Map) indicates buffered frames toward PS station
- DTIM is for buffered broadcast/multicast frames

Scanning

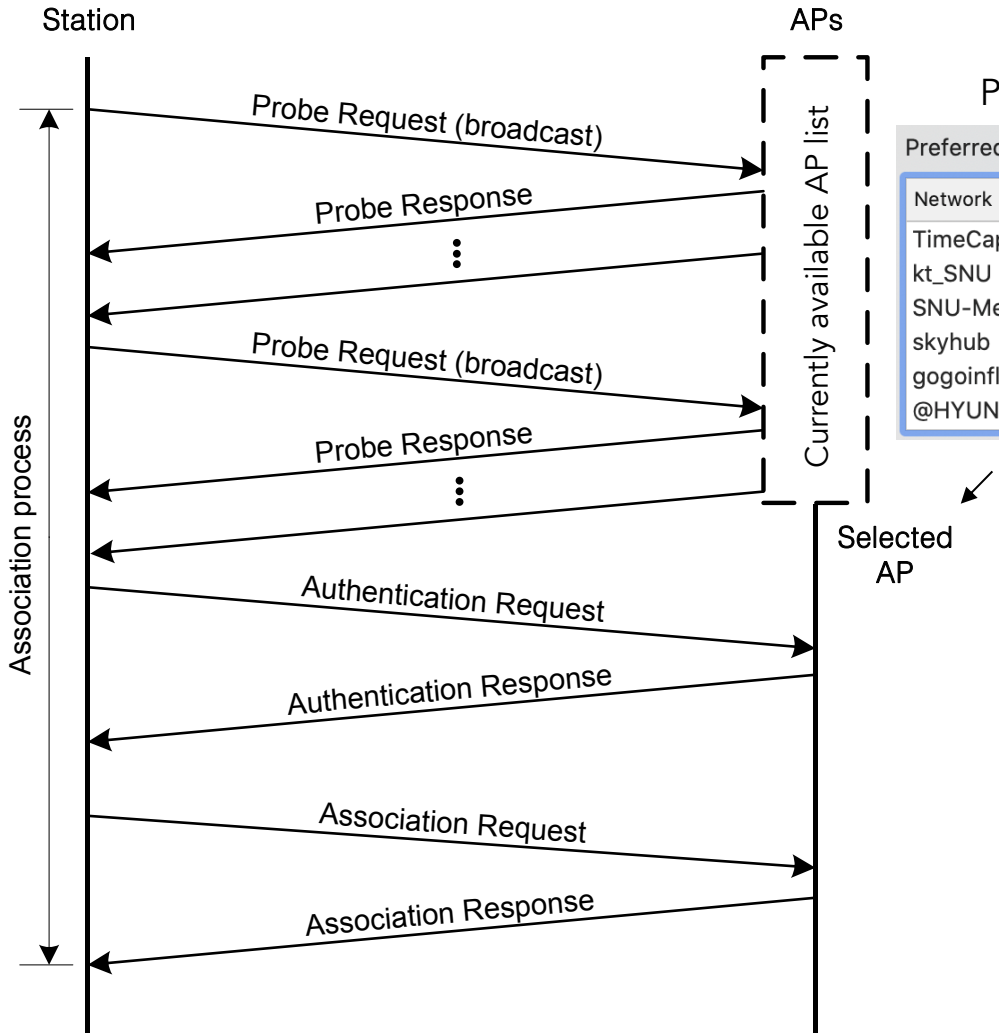
- Passive scanning vs. active scanning
  - Passive relies on the beacon reception only
  - Active uses probe request/response frames



(Re)association

- Associate with an AP before data transfer
- Re-associate with an AP if the STA is currently associated with another AP
  - Hand-off situation
  - New AP notifies the re-association to the old AP through the infrastructure
- Passive scanning vs. active scanning
  - Passive relies on the beacon reception only
  - Active uses probe request/response frames

(Re)association Procedure



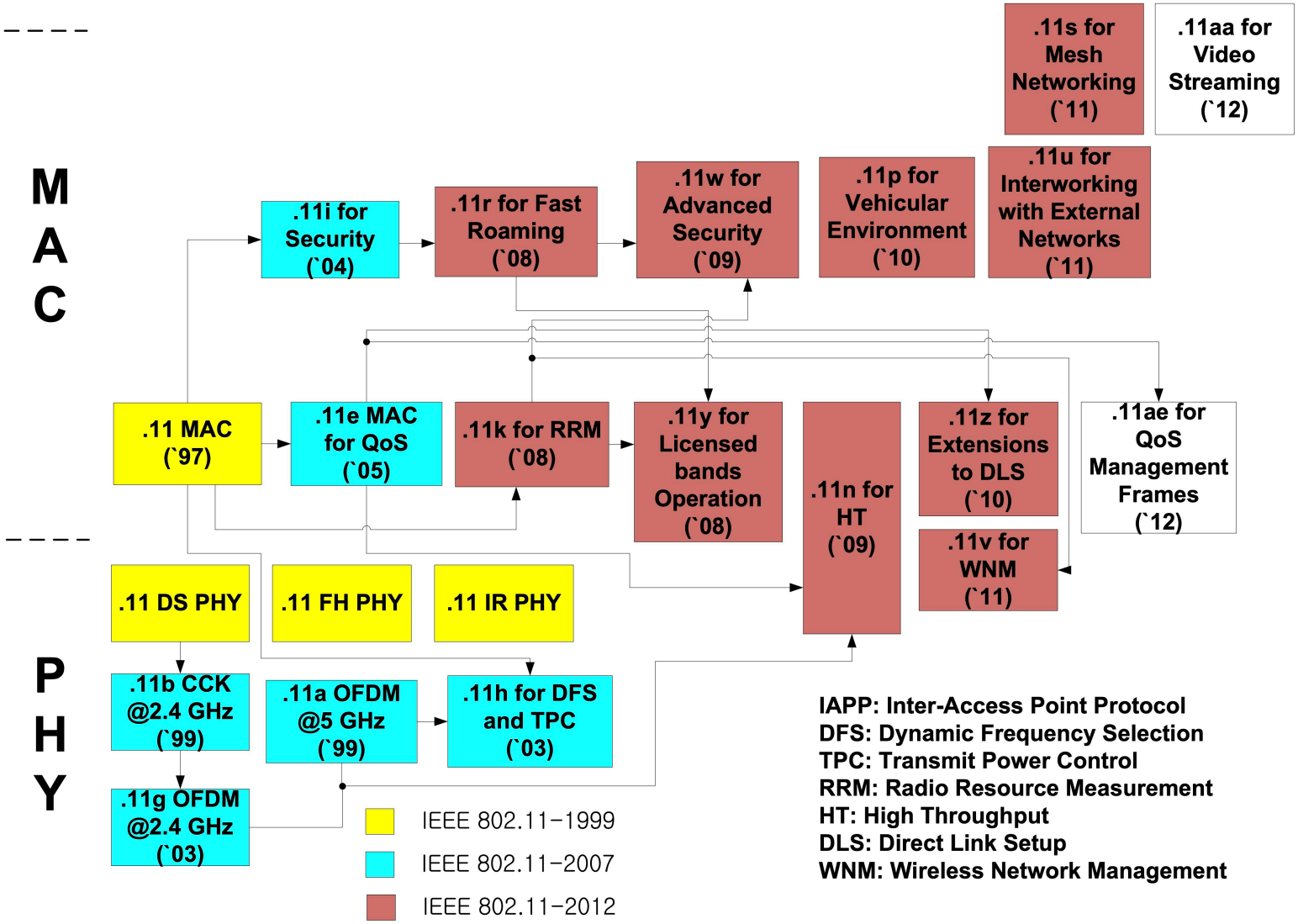
Preferred AP list (sorted by the preference)

Preferred Networks:

Network Name	Security	Auto-Join
TimeCapsule 5GHz	WPA2/WPA3 Personal	☑
kt_SNU	None	☑
SNU-Member	WPA2 Enterprise	☑
skyhub	WPA2/WPA3 Personal	☑
gogoinflight	None	☑
@HYUNDAI-WiFi	None	☑

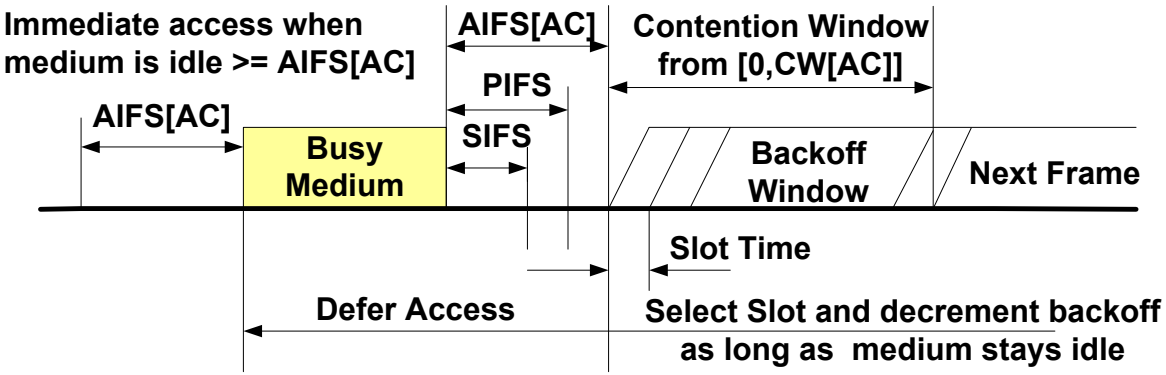
Matching APs will be tried one by one.

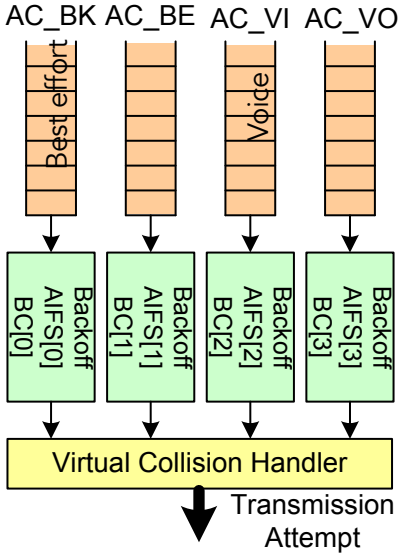
Wi-Fi Evolution



802.11e-2005 for Quality of Service (QoS)

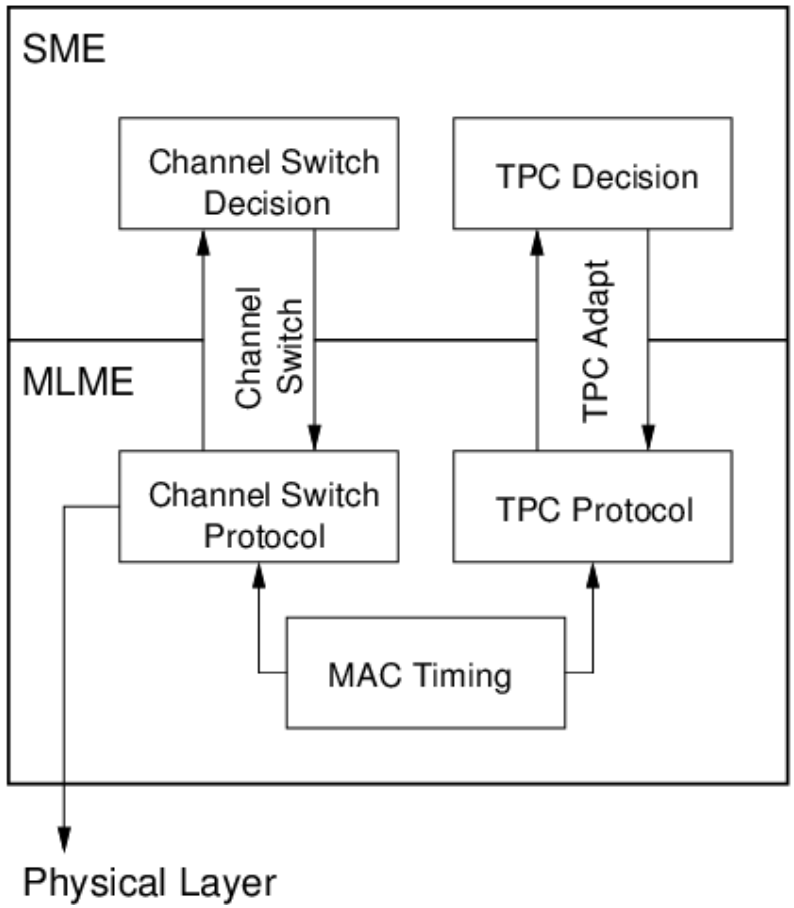
- Frames of different priorities are transmitted with different access delays
  - Higher priority frames are transmitted with shorter backoff
    - By differentiating the backoff window selection range (e.g., controlling CW)
    - And even has shorter IFS (Arbitration-IFS) depending on AC (app category)
  - Often used for Voice over Wi-Fi applications
    - e.g., Wi-Fi-based 070 VoIP phones





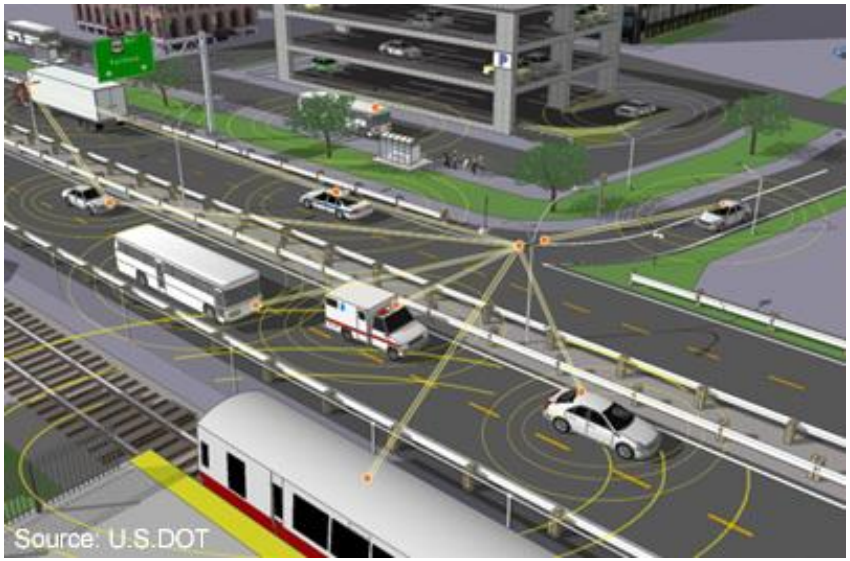
802.11h-2003 for DFS and TPC

- Needed for certain 5 GHz sub-bands to co-exist with primary users, e.g., radar and satellites
  - Dynamic Frequency Selection (DFS)
  - Transmit Power Control (TPC)
- Kind of Cognitive Radio (CR) mechanism



802.11p-2010 for V2X

- Wireless access for vehicular environments (WAVE)
  - Inter-car (V2V) and car-to-road (V2I) communications
  - Extension of 802.11a for 5.9 GHz (5.850-5.925GHz) Dedicated Short-Range Communication (DSRC) band
  - Multi-channel (of 10 MHz each) operation using IEEE 1609.4 MAC extension
  - Over line-of-sight distances within 1 km



802.11s-2011 for Mesh Networks

- Multi-hop wireless backhaul
  - APs are connected via 802.11s wireless links
  - Supports auto-configuring wireless paths among mesh APs