Wireless LAN with focus on IEEE 802.11 and 802.11e

Slides contributed by

Thomas Nilsson
Dept. of computing Science
Umeå University
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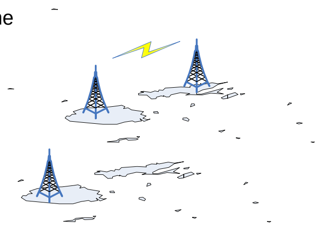
nilsson@cs.umu.se

Lecture outline

- A short history of the WLAN development
- IEEE 802.11 with focus on the MAC layer
- Some performance issues related to 802.11
- IEEE 802.11e
- A brief overview of HiperLAN Type 1
- Some facts about HiperLAN Type 2

A Short History…

- **Classical Aloha**
  - University of Hawaii (ALOHANET) in 1970, interconnect the islands
  - Packet radio com. cf. DARPANET
  - No central control, packets arrived randomly in time
  - Max channel utilization of *0.18* was achieved
  - Simultaneous transmission resulted in collisions
- **Slotted Aloha**
  - Senders synchronized and transmissions started at slot boundaries, random backoff Increased capacity to *0.37*
- **Carrier Sense Multiple Access (CSMA)**
  - "Listen before sending scheme", send if channel idle
  - ***non-persistent***: sends immediately and if busy waits a random time until retry
  - ***p-persistent***: transmits with prob p if medium idle and defers next slot with 1-p
  - ***CSMA/CA***: backoff, carrier sensing to achieve fairness



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A Short History…

- **HiperLAN Type 1**
  - Published in 1996 by ETSI, No commercial success.
  - ***EY-NPMA*** (Elimination Yield Non-Preemptive Multiple Access)
  - Nodes transmits bursts of different lengths (Geometric distribution)
  - Efficient protocol, small prob. of collisions, supports some QoS
- **IEEE 802.11**
  - Uses CSMA/CA, standard first published in 1997 by IEEE, no QoS
  - Commercial success, most widely deployed WLAN standard
  - Little competition from other technologies
- **HiperLAN Type 2**
  - Published in 2000 by ETSI, quite unlike HiperLAN Type 1
  - Complex standard, TDMA/TDD scheme, central control, supports QoS
  - No products available only prototypes, uncertain future

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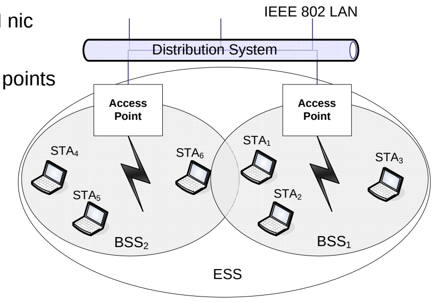
Components and Architecture of 802.11

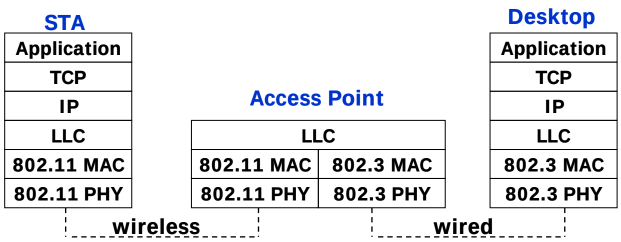
The 802.11 standard defines the following components

- **Station (STA)**
  - A mobile node, e.g. Laptop with WLAN nic
- **Access Point (AP)**
  - STAs connected/associated to access points
- **Basic Service Set (BSS)**
  - Access Point and mobile STAs
- **Basic Service Area (BSA)**
  - Geographical area covered by a BSS
- **Extended Service Set (ESS)**
  - A set of BSSs joined together
- **Distribution System (DS)**
  - Interconnects multiple BSS, backbone network, e.g. Ethernet IEEE 802.3



802.11 Protocol Architecture

- **802.11 Layers defined**
  - PHY Layer (Physical Layer) - Many different technologies
  - MAC Layer (Medium Access) - Only one MAC technology so far…
  - LLC (Logical Link Control) - a logical interface to higher layers



- **The AP only works as a bridge**

802.11 Physical Layer

- **3 PHY layers defined in original 802.11 (1997)**
  - **Frequency Hoping Spread Spectrum** (FHSS)
    - Operating in 2,4 GHz, ISM band, no license required
    - Frequency hopping, similar to Bluetooth, rates up to 2 Mbps
  - **Direct Sequence Spread Spectrum** (DSSS)
    - Operating in 2,4 GHz band, ISM band
    - The signal is spread over a wider spectrum, rates up to 2 Mbps
  - **Infrared**
    - limited use…Short range, typically 10 meters, rates up to 2 Mbps
- **Several new PHY layers have been standardized**
    - But the MAC layer remains the same as in the first standard

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802.11: Physical layer extensions

- **IEEE 802.11b**
  - Standardized in 1999, High Rate DSSS, CCK modulation
    - Spread Spectrum tech., chip rate 11 MHz, barker sequence, ISM band
  - Two different PHY header formats
    - Backward compatibility to previous DSSS
    - Less overhead (short preamble)
  - Supports rate: 5.5, 11 Mbps
    - Also supports the lower rates 1 and 2 Mbps (DBPSK, DQPSK)
    - Almost all products supports 802.11b
  - Subdivides the ISM band into
    - 13 overlapping channels or 3 non-overlapping channel

http://standards.ieee.org/getieee802/download/802.11b-1999.pdf

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802.11: Physical layer extensions

- **IEEE 802.11a**
  - Standardized in 1999, Multi carrier modulation
  - OFDM (Orthogonal Frequency Division Multiplexing)
    - Bit stream is split into several low bit streams
    - Each bit stream uses a different carrier, 52 sub-carriers
  - Supports rates: 6,9,12,18,24,36,48,54 Mbps
    - BPSK,QPSK,QAM: Different number of bits/symbol
  - Uses the 5GHz band
    - Regulatory issues (not license free band in many European countries)
    - DFS and TPS may be required
    - Only Indoor use in Sweden, max power 200mW EIRP (5150-5250 MHz)
    - Hard to find the exact regulations in the band, PTS only gives little info

http://standards.ieee.org/getieee802/download/802.11a-1999.pdf

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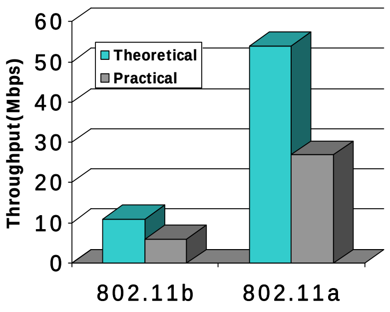
802.11a and b Throughput performance



- **Large protocol overhead**
  - Inefficient design of the MAC
  - and PHY layers limits the throughput
- **Work is ongoing (11n)**
  - To overcome these limitations
  - Achieve at least 100 Mbps at MAC
- **If considering more STAs**
  - Contention for the medium will arise resulting in an additional overhead

Note: This result is for a single user

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802.11 Medium Access Control

- **MAC responsibilities**
  I. Controlling Access to Medium
  II. Reliable data delivery
  III. Fragmentation of frames
  IV. Roaming & authentication
  V. Power Save functionality

802.11 MAC Mechanisms

- **Access Mechanisms used by MAC**
  - **CSMA/CA**
    - The MAC algorithm used to access the medium
  - **Binary exponential backoff (BEB)**
    - Used to decrease the contention for the medium
  - **Carrier Sensing**
    - Used to determine if medium is idle or busy

802.11 Carrier Sensing

- **Physical carrier sense**
  - Senses the medium to determine if channel is idle
  - Based on CCA (Clear Channel Assessment)
  - Works be detecting a energy level of the channel
  - A interference strength above *the carrier sense threshold* -> busy
  - The implementation of CCA is PHY layer dependent
- **Virtual carrier sense**
  - Every STA keeps a Network Allocation Vector (NAV)
  - NAV tells the STA when medium is busy
  - NAV is updated by a field in the MAC frame of every packet heard
  - **NAV has precedence over physical carrier sense**

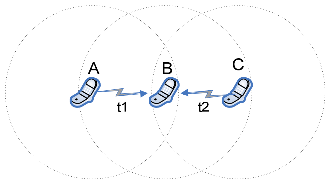
802.11 CSMA/CA

- CSMA/CA /(Collision Avoidance)
  - Carrier Sense Multiple Access with Collision Avoidance
  - For wireless communication
  - Collision avoidance before transmission
  - CS is used to determine if medium is idle before sending data
- CSMA/CD /(Collision Detection)
  - Carrier Sense Multiple Access with Collision Detection
  - Used in wired Ethernet, IEEE 802.3
  - A collision is detected while transmitting
  - Sender aborts the transmission if collision is detected

Why is collision avoidance used in wireless and not collision detection?

802.11 CSMA/CA

- **Collision detection not feasible in Wireless LANs**
  - The collision happens at the receiver side
    - Strong attenuation cf. wired networks



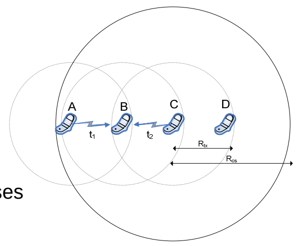
1. A and C out of range
2. A starts transmitting at t1
3. C senses medium idle and starts transmitting at t2
4. Collision happens at B
A and C do not know about the collision

A is called a "hidden terminal" with respect to C and vice versa

  - Radio architecture
    - Switching between receive and transmit (Half Duplex) , Only one antenna
  - Difference in energy/power for transmit and receive
    - Transmit power >> receive power (million times), difficult to detect difference

802.11: Physical Carrier Sense threshold

- **The Physical Carrier Sense Threshold**
  - Translates to a detection range (R_{cs})
  - Usually larger than the transmission range (R_{tx})
- **Size of the CS threshold**
  - **Increased Threshold**
    - The detection range increases.
    - HT problem decreases and ET problem increases
    - Spatial reuse of the channel decreases
  - **Decreased Threshold**
    - The detection range shrinks
    - ET problem decreases and HT problem increases
    - Spatial reuse of the channel increases



- **The CS threshold has a large effect**
  - The HT and ET problems and the spatial reuse of the channel
  - -> Capacity of the whole system

Binary Exponential Backoff (BEB)

- **802.11 Backoff has mainly two purposes**
  - Adjust the contention level under various traffic loads
  - Provide some degree of fairness among STAs
- **Backoff Counter**
  - Determines time to wait before a transmission attempt
  - Uniformly chosen within CW
  - Only decremented when medium is idle
  - Packet sent when counter reaches zero
- **Contention Window (CW)**
  - Upper and lower bound on the backoff counter
  - CW is doubled for every collision or lost frame

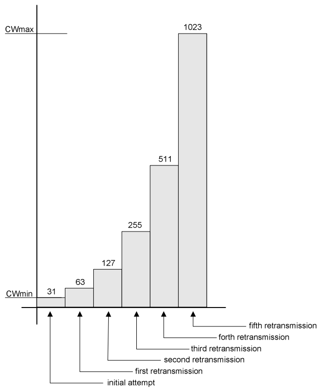
802.11 Binary Exponential Backoff

- **Binary Exponential Backoff definition**

$$BO \in U\{0, CW\}$$
$$CW \in [CW_{min}, CW_{max}]$$

- **Uniform distribution**
- **Backoff performed per packet basis**
- ***Pre* and *post* backoff**
- **CW parameters are PHY dependent**

802.11b: $Cw_{min} = 31$ $Cw_{max} = 1023$
802.11a: $Cw_{min} = 15$ $Cw_{max} = 1023$



802.11:Binary Exponential Backoff

- **Example of CW adjustment**

Attempt	Contention Window	Size	ACK
1	$CW = CW_{min}$	$2^5 - 1 = 31$	NO
2	$CW = (CW + 1)2 - 1$	$2^6 - 1 = 63$	NO
⋮	⋮	⋮	NO
n	$CW = min(CW_{max}, (CW + 1)2 - 1)$	$min(1023, 2^n - 1)$	YES
1	$CW = CW_{min}$	$2^5 - 1 = 31$	YES
1	$CW = CW_{min}$	$2^5 - 1 = 31$	YES

- **Two additional parameters affecting the CW**
  - Maximum number of transmission attempts for
    - Data packets is called ***Short Retry Limit***, default value is 4
    - Control packets is ***Long Retry Limit***, default value is 7
  - Interestingly, the SRL prevents CW from reaching CW_{max}

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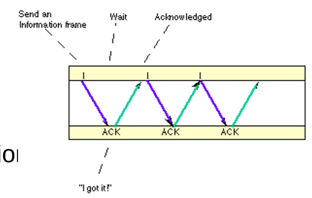
802.11: Stop and Wait ARQ

- **Automatic Repeat Request (ARQ)**
  - Error control
  - and flow control mechanism
- **Stop and Wait ARQ protocol**
  - Each packet reception confirmed with an ACK frame
  - Serves 2 purposes: detect lost packets and adjust the CW
- **Large overhead in ARQ**
  - Sliding window protocols
    - ***Go-back-N***
    - ***Selective Repeat***
  - More suitable for continues transmissio
  - 802.11e option for Selective Repeat



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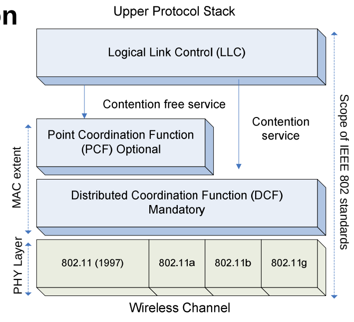
802.11 Medium Access Methods

Two methods to access the wireless medium exist

- **Distributed Coordination Function**
  - (DCF), Distributed algorithm
  - STAs contend for access
  - *Mandatory* in standard
- **Point Coordination Function**
  - (PCF), Centralized algorithm
  - AP is controlling access
  - Builds upon the mandatory DCF
  - *Optional* in standard

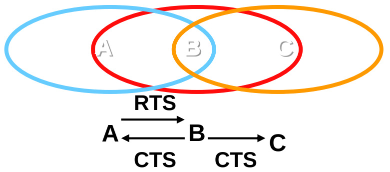


Medium Access Methods

- **Distributed Coordination Function (DCF)**
  - **Physical** and **Virtual** carrier sense (NAV) is used
  - **CSMA/CA**, STAs contend for access to the channel
  - **ARQ**: ACK required for each successful transmission
    - ACK Timeout -> lost packet
  - **Backoff** is used if medium is busy or frame is lost
  - Medium Reservation with **RTS/CTS**
    - Avoid collisions (hidden terminal problem)

RTS/CTS handshake

- **Request to Send/Clear to Send (RTS/CTS)**
  1. The source issues a Request to Send (RTS) packet
  2. The destination responds with a Clear to Send (RTS) packet
  3. Source starts transmitting the data
  4. Destination responds with an ACK
- **All STA hearing this "handshake" will know about the coming transmission and defer access**



- **A and C want to send to B**
- **A sends RTS to B**
- **B sends CTS to A**
- **C "overhears" CTS from B**
- **C waits for duration of A's transmission**

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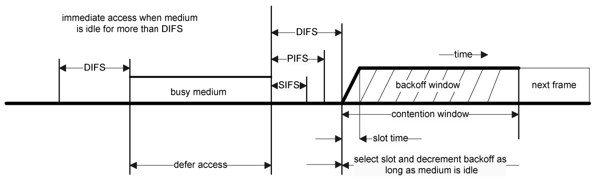
Inter Frame Spaces (IFS)

- **Transmissions are separated by short Inter Frame Spaces**
  - Used for priority access to the medium
  - Short IFS (***SIFS***) , Point Coordination Function IFS (***PIFS***) and
  - Distributed Coordination Function IFS (***DIFS***)



- **Extended Inter Frame Space (EIFS)**
  - STAs receiving a corrupted frame (and is not the receiver) should defer access when medium becomes idle again for a EIFS (approx the time to transmit an ACK)
  - Purpose is to provide enough time for the receiver (if correctly received the frame) to respond with an ACK frame

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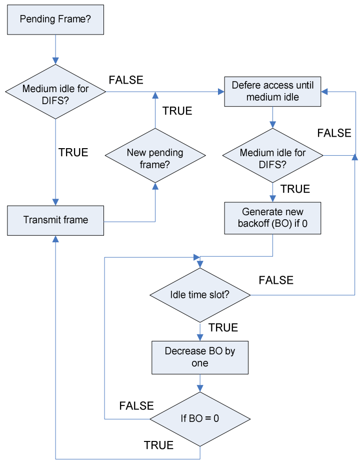
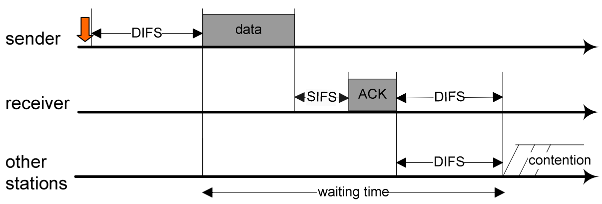
DCF Basic Access Method



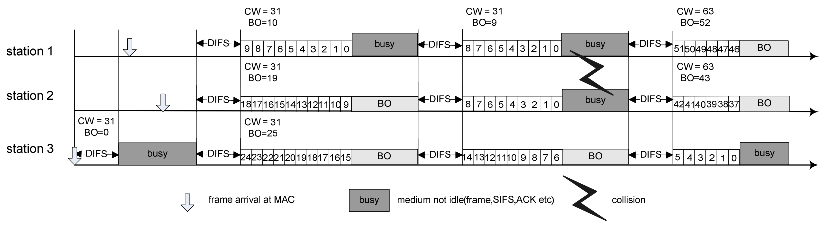
DCF Basic Access Method



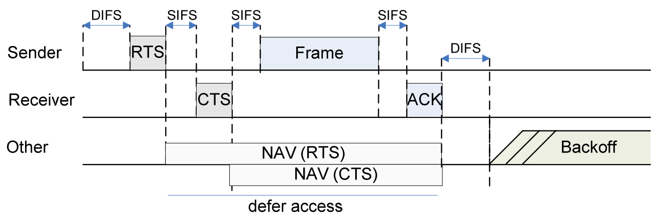
Backoff counter is decremented by one for every slot time medium is detected idle (after first waiting a DIFS)

Packet arrives at MAC layer

DCF Contention with collision



DCF Access using RTS/CTS



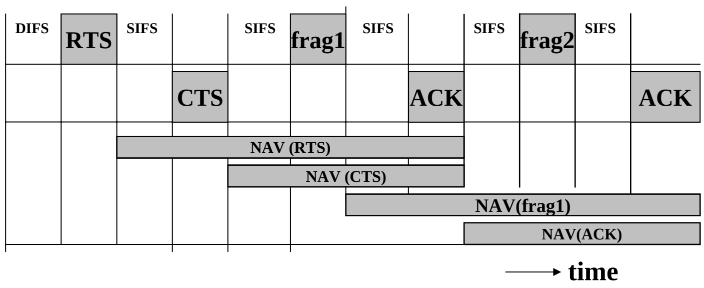
- **The RTS/CTS packet contains the duration of the transmission**
- **STAs hearing the RTS/CTS packet updates its NAV accordingly**
  - This is virtual carrier sensing
- **RTS/CTS imposes an additional overhead**
  - Overhead is larger for small packets, a RTS/CTS threshold is used

Fragmentation

- **Wireless LANs experience high bit error rates**
  - Error rates in WLANs >> LANs, Medium experience error bursts
- **Smaller probability of error with shorter frames**
  - Smaller frames have better chance of escaping error burst
  - Fragmentation may be a way to increase throughput
  - Increased overhead, more header information/per data unit
- **Fragmentation threshold**
  - Only packets above a threshold is fragmented, Manually configured

> The probability that a frame arrives without error P_1 assuming the bit errors P_b are indepedent and constant is
> $P_1 = (1 - P_b)^N$,
> where N is the number of bits per frame

Fragmentation burst



- If one fragment is lost backoff procedure is invoked
- Fragmentation may also be used without RTS/CTS

802.11 MAC Frame

Bytes:

2	2	6	6	6	2	6	0-2312	4
Frame Control	Duration ID	Addr 1	Addr 2	Addr 3	Sequence Control	Addr 4	Frame Body	CRC

◁ **802.11 MAC Header** ▷ (Frame Control through Addr 4)

Bits:

2	2	4	1	1	1	1	1	1	1	1
Protocol Version	Type	SubType	To DS	From DS	More Frag	Retry	Pwr Mgt	More Data	WEP	Rsvd

Frame Control Field

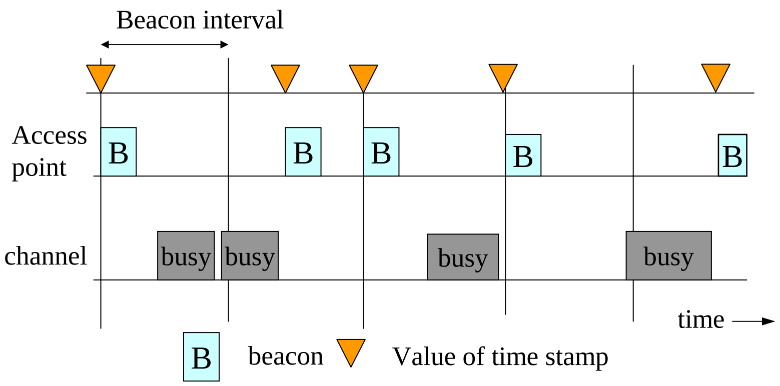
802.11 MAC Management

- **Synchronization**
  - STAs need to be synchronized with the WLAN (on the MAC layer)
  - In Infrastructured mode, STA synchronized with AP
  - Necessary for Power management and PCF operation
- **Power Management**
  - STAs may have limited battery capacity
  - Power Save features necessary, sleep mode
- **Roaming**
  - Terminals may enter a new BSS
  - Terminal must change AP
  - Like Handover in GSM (but not as smooth)
- **Authentication & encryption**
  - Authentication before access to the network
  - Encryption of data to prevent eavesdrop

Synchronization

- **All STA timers in a BSS are synchronized**
  - Needed for Power management and
  - PCF coordination
- **The access point maintains a clock**
  - The AP transmits periodic frames called *Beacons*
  - The Beacon contains the clock value
  - Time between two beacons are called the *beacon interval*
- **STAs hearing the beacon updates their clock**
  - This prevents clock drifting
- **The beacon is transmitted using normal CSMA/CA**
  - Beacon may be delayed significantly

Synchronization (cont.)



Power Management

- **Purpose is to save battery capacity**
  - Limited battery capacity and 802.11 drains batteries fast!
  - Cicso Aironet: Tx 530-560 mA, Rx 280-330 mA, Standby 200 mA
- **A STA may enter sleeping mode and turn of the radios**
  - This is notified to the AP (a bit in the MAC header is flipped)
  - The AP maintains a list of STAs in Power saving mode
  - Packets for a sleeping STAs are buffered in the AP
  - Buffered packets are sent to the STAs at designated times
- **STA must wake up periodically to receive beacons**
  - Beacon contains a *traffic indication map,* info on buffered frames
- **STAs are required to stay a wake to receive the buffered data**
  - STA sends a PS-poll frame to the AP and waits to receive the buffered data
  - In power save mode: the consumption can be reduced to 30 mA

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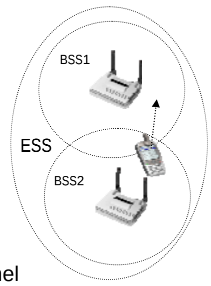
Roaming between access points

- If a Mobile STA moves beyond the coverage **of the AP**
  - but within range of another AP than (within the ESS only)
- Packet losses and incapability problems exists
  - IEEE 802.11f (Inter Access Point Protocol)
- STA decides that link to its current AP is poor
  - Radio link quality, e.g. SNR and BER, missed beacons etc
- STA uses scanning function to find another AP
  - ***Active* scanning**, STA sends a probe request on each channel
  - ***Passive* scanning**, STA listens for beacons on each channel
  - Station sends Re-association Request to new AP
- If Re-association Response is successful
  - STA has roamed to a new AP else STA scans for another AP



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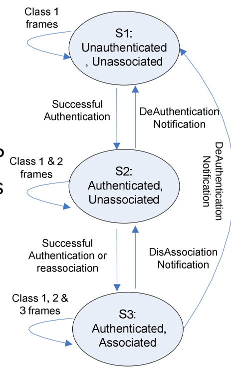
Association & Authentication

- **Authentication**
  - Shared key authentication, AP sends a challenge *k* STA encrypts *k* with the pre-shared key in the reply.
  - The WEP encryption is not secure…802.11i improves
- **Association**
  - STA needs to get synchronization information from AP
  - Exchange capability information, e.g. Supported rates
- **Disassociation**
  - May be performed by either STA or AP
  - Data cannot be sent to a disassociated STA

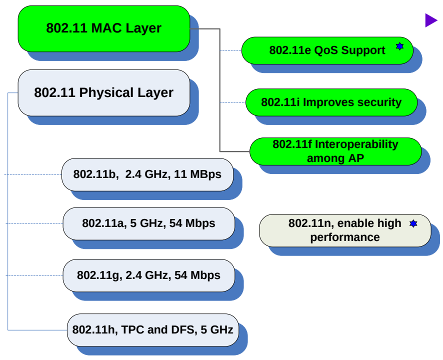


Class 1: Control frames, e.g. ACK, RTS, (de) Authentication
Class 2: Management frames, e.g. (re) (dis) Association
Class 3: Data frames

802.11 Link Adaptation (LA)

- **Adjust the modulation scheme based on the link quality**
  - Improve the performance by minimizing packet loss
  - Uses SNR/BER/ACK statistics to adjust the data rate
  - Not defined in IEEE 802.11 but manufacturer dependant
- **11b four rates (1-11Mbps) and 11a eight (6-54Mbps)**
  - Every rate has a limited operating range
  - Generally lower rates have larger operating ranges
- **When a STA moves beyond the optimal range of a rate**
  - the device will fall back to a lower rate
  - The result is better performance, less packet errors
- **However, LA may cause lower total system capacity!**
  - There is a performance anomaly using LA in a shared broadcast channel

The 802.11 Alphabet Soup



- **IEEE 802.11 task groups**
  - Updates and improves various parts of the standard
  - From a to z (20 in total)
  - Focus areas like
    - PHY layers, MAC layers
    - Spectrum regulations
    - Interoperability
  - Many groups have completed
  - Almost no letters left to be used
    - ?

Task group info and timeline: http://www.ieee802.org/11/802.11_Timelines.htm

802.11: Contention window performance

- When considering a ***fixed backoff scheme***. i.e. $CW_{min} = CW_{max}$
- The optimal CW under saturation is approximately

$$W^{opt} \approx n\sqrt{(2T)}^{*},$$

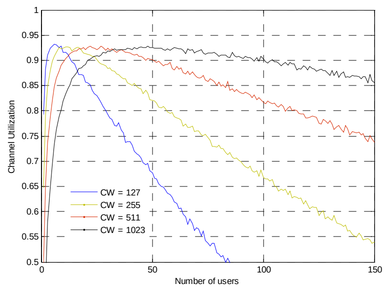
where T is the transmission time in $slotTimes$

- More complex relationship when considering a CW doubling scheme
  - But the dependency still remains to the number of users
- The biggest problem is how to approximate the optimal CW
  - The binary exponential backoff (BEB) scheme in 802.11 does a bad job
  - The BEB is discrete with little precision
- The CW is reset to CW_{min} after each successful transmission
  - This may be non optimal under saturation

* G. Bianchi, Performance Analysis of the IEEE 802.11 DCF, IEEE Journal on Selected Areas in Communications, 18:3,2000

Contention window performance

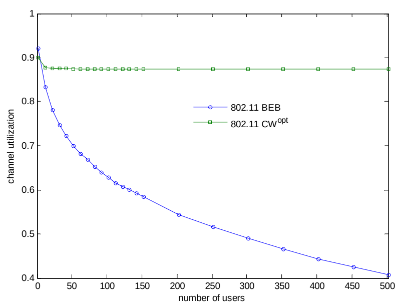
- **A simple simulation of DCF**
  - 802.11a and fixed CW for an increasing number of STAs,
  - Under saturation
  - For a given number of STAs,
    too small CW yields many collisions
    too large CW yields many idle slots
  - Cost for a collision is high since the whole packet is transmitted
  - ARQ is needed to detect the collisions
  - Capacity is wasted



Number of users	Optimal CW
10	$CW^{opt} \approx 213$
20	$CW^{opt} \approx 426$
50	$CW^{opt} \approx 1065$
100	$CW^{opt} \approx 2132$
150	$CW^{opt} \approx 3204$

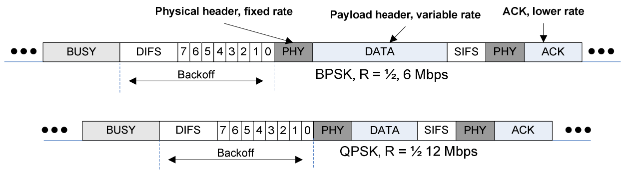
Contention window performance

- **A comparison between**
  - 802.11 BEB (normal)
  - 802.11 CW^{opt}, uses the optimal CW
  - BEB used in 802.11 is far from optimal,
  - especially for large number of users
  - for few stations the result is satisfactory



802.11: Theoretical throughput limit

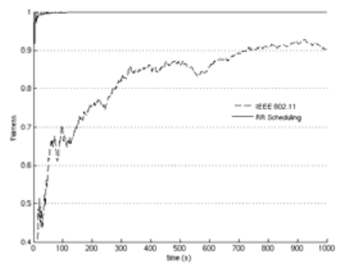
- **Physical layer and MAC layer overhead**
  - A Theoretical throughput limit exists even if the data rate goes to infinity[1]
  - Simply by increasing the rate without reducing the overhead is not an option
- **To achieve higher throughput, changes need to be done**
  - Task group **n** is working on both MAC and PHY enhancements to
  - achieve throughput figures above 100 Mbps
  - Frame aggregation: aggregate frames and thus reduce some overhead

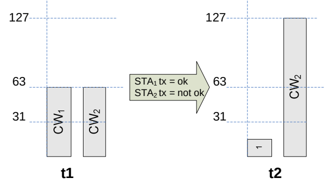


[1] Y. Xiao and R. Rosedahl, Throughput and Delay Limits of IEEE 802.11, IEEE Communications Letters, 6:8, 2002

802.11 Fairness among Stations

- **Fairness has many definitions**
  - Generally how the capacity is shared
  - Fairness on different time scales
    - *Short* and *long* term fairness
  - 802.11 is not considered to be fair in the shorter time context
  - Fairness between STAs, EBB favors STAs that exceeded last and vice versa.
  - EIFS may also be a factor influencing Fairness

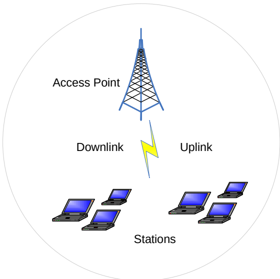


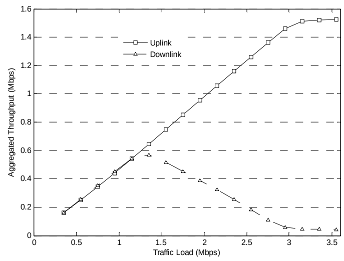


Min-max Fairness Index:
$I_{min-max} = \frac{min\{x_i\}}{max\{x_j\}}$,
where x is the rate or throughput.

802.11 Uplink/downlink starvation

- **AP has no precedence in medium access over STAs**
- **AP is responsible for all transmissions in the downlink**





- **The AP is easily starved by the uplink**
- **This problem has a large impact on TCP performance**
- **A fairness problem**

Definition of Quality of Service

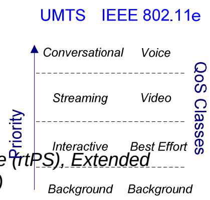
- **Applications have different QoS requirements**
  - Real time Vs. non-real time applications
  - Streaming, Web browsing, email
- **Elastic vs. Inelastic applications**
  - Tolerance of variations in throughput
- **Typical QoS parameters**
  - Throughput, Delay, Jitter. Packet loss, Bit error rate
- **Networks capable of satisfying requirements**
  - Supports quality of service
  - Not all wireless networks implement QoS support
  - IEEE 802.11 DCF has not support

Motivation: QoS in wireless networks

- **QoS is not very prioritized in wired networks**
  - Implementing QoS is difficult! Adding more hardware is easy!
  - Capacity shortage is easily solved
- **Adding more hardware in wireless**
  - Is often not an option
  - Shannon's law, one ether shared by many, limited spectrum
- **Supporting QoS in wireless is important**
  - Limited resources, maximizing resource utilization important
  - Commercial interests, user satisfaction important
  - Operators want to maximize their revenue, support new services
- **QoS guarantees in wireless is difficult**
  - Too many uncertainty factors: interference, traffic load, handover
  - May be easier to provide QoS guarantees in wired networks

Quality of Service Classes

- **Supporting arbitrary requirements is difficult**
  - One solution to this is *QoS classes*
  - Network optimizes performance according classes
  - An application belongs to a QoS class
- **Some networks utilizing QoS classes**
  - UMTS: *conversational, streaming, interactive, background*
  - IEEE 802.11e: *voice, video, Best effort, background*
  - WiMAX: *Unsolicited Grant Service (UGS), real-time Polling Service (rtPS), Extended rtPS (ertPS), Non-real-time polling service (nrtPS), Best effort (BE)*



- **Some service requirements**
  - Voice/speech: tolerates some losses sensitive to
  - delay/jitter, delay in voice < 200ms
  - Streaming: tolerates some losses, less sensitive to delay/jitter
  - Data applications: generally more sensitive to losses than delay/jitter

IEEE 802.11e (QoS support)

- **Defines the new Hybrid Coordination Function (HCF)**
  - Enhanced Distributed Channel Access (EDCA),
  - decentralized access
  - HCF Controlled Channel Access (HCCA),
  - centralized access
- **Some new mechanisms in 802.11e**
  - **User Priorities**, ranging from 0 to 7
  - **Access Categories** (AC), four per STA
  - **Arbitration Inter Frame Space** (AIFS)
  - **Transmission opportunity** (TXOP)
  - **Block Acknowledgement**, more efficient ARQ scheme
  - **Admission Control,** increases control by AP

802.11e: Priority mapping between UPs ACs.

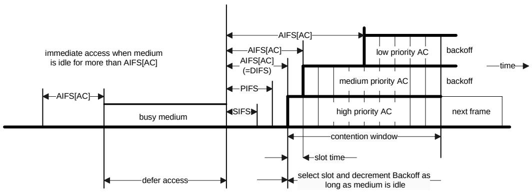
Priority	User Priorities (UP)	Access Category (AC)	Designation
lowest	1	AC_BK	Background
	2	AC_BK	Background
	0	AC_BE	Best Effort
⋮	3	AC_BE	Best Effort
	4	AC_VI	Video
	5	AC_VI	Video
	6	AC_VO	Voice
highest	7	AC_VO	Voice

802.11e: Arbitration Inter Frame Space

- **EDCA Parameters: AIFS (Arbitration Inter Frame Space)**
  - Time medium is sensed idle before an AC starts Tx or BO
  - Not fixed as in DCF instead variable value, specific to the AC

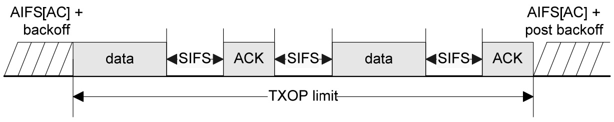
$$AIFS = AIFSN \times SlotTime + SIFS$$

  - Higher priotrity AC use smaller AIFSN
  - Minimum allowed AIFSN is 2, which makes AIFS = DIFS



802.11e: contention free bursting

- **EDCA Parameters: Transmission Oppurtunity**
  - Each AC contends for a TXOP
  - The *TXOP Limit* parameter defines its maximum length
  - If length allows, multiple frames may be transmitted
  - Consecutive transmissions are separated by SIFS
  - This is called **Contention Free Bursting**



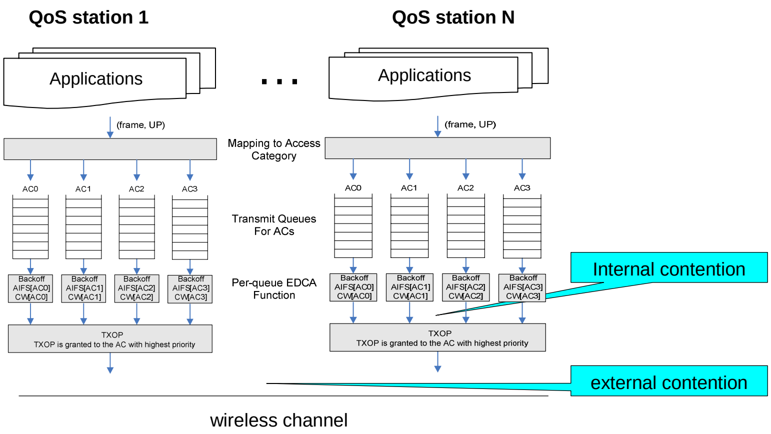
802.11e: default contention parameters

- AC Specific default contention parameters

AC	AIFSN	CW_{min}	CW_{max}
AC_VO	2	7	15
AC_VI	2	15	31
AC_BE	3	31	1023
AC_BK	7	31	1023

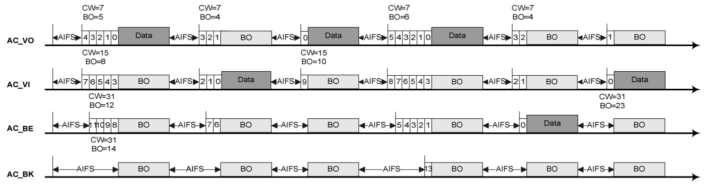
  - These values are not fixed, can be dynamically adjusted by the AP
  - No algorithm for doing so is given in the standard
  - up to manufacturers

802.11e EDCA: Basic concept



802.11e: Internal contention

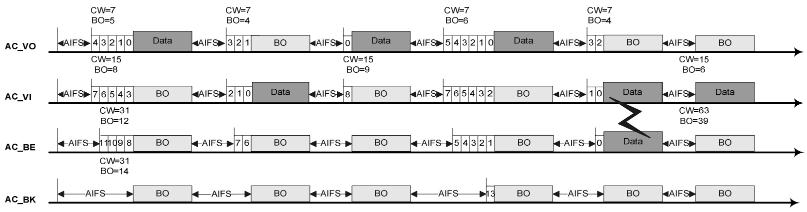
- **EDCA Access Mechanism**
  - Example: four EDCAFs contending *inside a single station*
  - Each AC acts as a virtual station inside the station



  - Each AC contends independantly from other ACs
  - Each AC uses the specific CW values: CW[AC], AIFS[AC]

802.11e: Internal contention

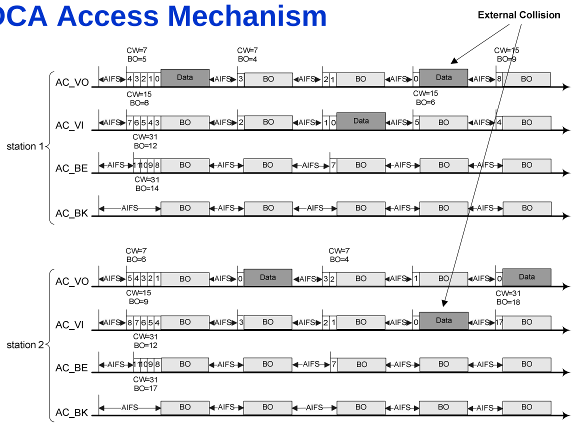
- **EDCA Access Mechanism**
  - Collisions among AC within a single STA, called Virtual Collisions



  - **Virtual collisions**: solved by grating the highest AC access
  - Other colliding ACs act as external collisions: doubling CW and backoff

802.11e: external contention

- **EDCA Access Mechanism**



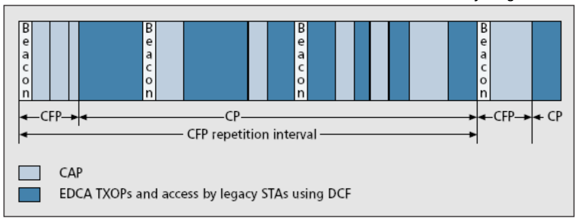
- Collisions among AC within a two STA may arise, real collisions

802.11e: HCF controlled channel access

- Similar to the legacy PCF, HCCA provides polled access to the wireless medium. In particular, HCCA uses a QoS-aware hybrid coordinator (HC), which is typically located at the QoS access point (QAP) in infrastructure WLANs.
- HC uses PIFS to gain control of the channel and then allocates TXOPs to QSTAs, which are referred as HCCA TXOPs or polled TXOPs.
- Unlike PCF, HCCA can poll the QSTAs during contention periods (CPs), and HCCA takes into account QSTAs' specific flow requirements in packet scheduling.
- Controlled access phase (CAP) is defined as the time period when HC maintains control of the medium.
- After grabbing the channel, the HC polls QSTAs in turn according to its polling list.
- In order to be included in the polling list of the HC, a QSTA must send a QoS reservation request using the special QoS management frame, and each individual flow needs one particular reservation request.

802.11e: HCF controlled channel access

D. Gao *et. Al.* “Admission Control in IEEE802.11e Wireless LAN”, IEEE Network, July/August, 2005



- **CAP** **Controlled Access Phase**
- **CP** **Contention Period**
- **CFP** **Contention Free Period**

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802.11e: Admission Control mechanism

- **Gives the AP better controll over the resource**
  - Contention based Admission Control
  - Goal is to protect sensitive flows from ACs AC_VO and AC_VI
  - not to violate servie commitments made earlier to granted flows
  - AP signals in the Beacon if adm. control is mandatory for ACs
    - New ACs/STAs must make explicit requests to the AP and
    - provide the AP with: packet size, mean data rate, min PHY rate etc
  - Based on this info a new AC is granted access with a response
    - How to make this decission is non trivial and not defined in the standard
    - The response contains the *medium time* allowed for the spcific AC
    - The actual admission control algorithm is not specified in the standard

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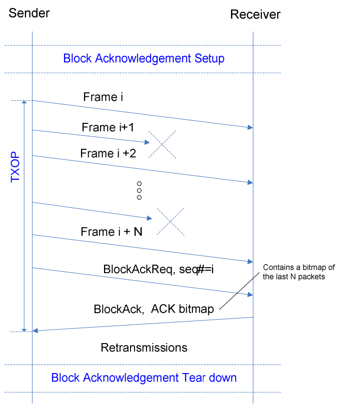
802.11e: Block Acknowledgement Mode

- **802.11 has inefficient ARQ**
  - Stop and wait, imediate ACK scheme
  - Purpose is two-fold: detect lost packets, adjust CW
  - Overhead is large, a significat share of the capacity is waisted
- **Two new config. for ARQ**
  - No ARQ, Block Acknowledgement mode
  - Block Acknowledgement mode is a type of selective repeat
  - May be used in contention free busrsting
  - A new problem.. How to adjust CW when immediate feedback is lost?



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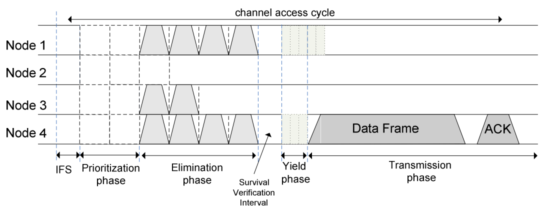
EY-NPMA (MAC for HiperLAN 1)

- **Elimination Yield Non-preemptive Priority Multiple Access**
  - MAC for HiperLAN Type 1, p2p ad-hoc mode, some QoS support, 23 Mbps



  - ***Prioritization phase***: nodes listen for a number of slots according to their priorities.
  - ***Elimination phase***: length is sampled from a *truncated geometric distribution* (max length = *m),* The probability of selecting a burst of length *k* is:

$$P(k) \overset{p=0.5}{=} \begin{cases} p^k(1-p) & \text{if } 0 \leq k < m \\ p^m & \text{if } k = m, \end{cases}$$

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EY-NPMA (MAC for HiperLAN 1)

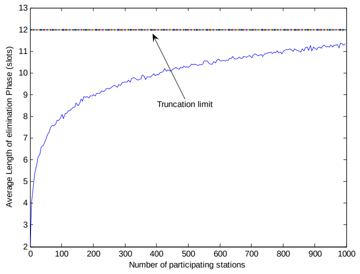
- ***The Yield phase:***
  - The remaining nodes will sense the channel for a uniformly chosen number of slots
  - *The winner:* selects the fewest number of mini slots and starts the transmission
- **Two channel access modes**
  - Access in ***channel free condition***:
    - listen to the channel for a random number of slots (*0, k*)
    - if idle transmit, Intended for lower channel loads
  - Access in ***synchronized channel condition***
    - Immediately following the previous channel access cycle
    - For higher loads

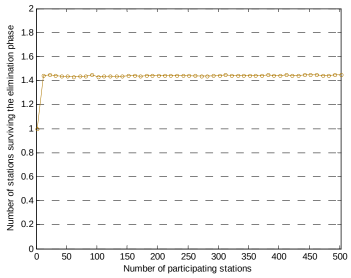
EY-NPMA (MAC for HiperLAN 1)

- **Prioritization phase**
  - Each node has a so-called channel access priority, P_i
  - Defines *h* priorities, with 0 denoting the highest priority
  - Priorities are ***non preemptive*** only nodes with highest P_i contends
  - Under high loads only the highest priorities will access the channel
- **IEEE 802.11e priorities vs. HiperLAN priorities**
  - Priorities in H1 are *non-preemptive* while *preemptive* in 802.11e
  - In 802.11e backoff performed after AIFS (additional idle time)
  - In HiperLAN a burst follows immediately after AIFS (Prio phase)

EY-NPMA performance

- **Elimination phase length**
  - The number of nodes have only an effect of the length of the elimination phase (right figure)





- **Elimination phase survivors**
  - the number surviving this phase is almost independent on the number of participating nodes (left figure)

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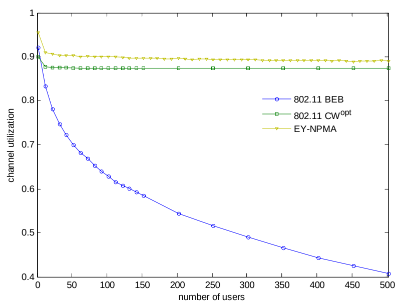
EY-NPMA vs. 802.11 comparison

- **Simulation study**
  - Simple model of the MAC layers
  - Under saturation conditions
  - Same PHY layer as 802.11a is assumed, i.e. slot times etc.
  - All nodes have the same priorities
  - No propagation effects are modeled
- **Results from Ad hoc study**
  - EY-NPMA is a 'noise protocol'
  - Under high loads much background noise will be generated due to the elimination phase
- **802.11 vs. HiperLAN Type 1**



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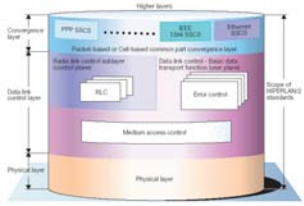
ETSI HiperLAN Type 2

- **Centralized mode with AP**
  - A complex standard published in 2000 by ETSI
  - Resemblance with a telecommunication std.
  - An ad hoc mode but requires central control
- **H2 Features**
  - High speed transmission, up to 54 Mbps
  - Connection oriented cf. IEEE 802.11
  - QoS, DFS, TPC, convergence layers
  - Mobility support, Interworking with e.g. UMTS, ATM, etc.



- **Medium Access Control (MAC)**
  - The air interface is based on TDMA: MAC frames have a fixed size and are repeated every 2ms (time slots)
  - Time Division Duplex (TDD): Uplink and downlink are multiplexed onto the same MAC frame
  - Many control channels are mapped onto the MAC frame

ETSI HiperLAN Type 2

- **Physical layer**
  - OFDM, 52 sub carriers, 54 Mbps, 5 GHz
  - Similar to 802.11a, a harmonization between the two
- **Transport Channels**
  - **Broadcast Channel (BCH)**
    Control info, reaches all MTs, for RRC functions, e.g. power levels, AP ID
  - **Frame Channel (FCH)**
    describes structure of current MAC frame, e.g. size of DL phase.
  - **Random Access Channel (RCH)**
    For MTs to request transmission resources in future frames
  - **Access Feedback Channel (ACH)**
    information on previous access attempts made in the RCH
- **Resource Control (MAC)**
  - MTs make requests in RCH using slotted Aloha, exponential backoff
  - centralized controller schedules the resource, polling