IEEE 802

CSC 343·643

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IEEE 802 Standards

- Previously we discussed *abstract* channel allocation protocols
- IEEE has produced several LAN standards, known as IEEE 802
- IEEE 802 standards cover
  - Logical Link Control (LLC, IEEE 802.2)
  - CSMA/CD (IEEE 802.3)
  - Token bus (IEEE 802.4)
  - Token ring (IEEE 802.5)
  - Wireless (IEEE 802.11 and 802.16)
  - IEEE 802.1 serves as an introduction to IEEE 802

IEEE 802.3

- Standard describes a 1-persistent CSMA/CD LAN

  What are the transmission rules?

- 802.3 History
  - Pure ALOHA for communication between Hawaiian Islands
  - CSMA/CD developed at Xerox PARC, connected 100 stations, first demo November 11, 1973 by Robert Metcalfe
  - System called *Ethernet*

    Why the name Ethernet?

  - DEC and Intel later created standard for 10 Mbps Ethernet, the basis for IEEE 802.3
- Remember 802.3,4,5 will describe the *physical* and *MAC* layers

A Few IEEE 802.3 Standards...

Experimental Ethernet	1973[1]	2.94 Mbit/s (367 kB/s) over coaxial cable (coax) cable bus
Ethernet II (DIX v2.0)	1982	10 Mbit/s (1.25 MB/s) over thick coax. Frames have a Type field. This frame format is used on all forms of Ethernet by protocols in the Internet protocol suite.
IEEE 802.3	1983	10BASE5 10 Mbit/s (1.25 MB/s) over thick coax. Same as Ethernet II (above) except Type field is replaced by Length, and an 802.2 LLC header follows the 802.3 header
802.3a	1985	10BASE2 10 Mbit/s (1.25 MB/s) over thin Coax (a.k.a. thinnet or cheapernet)
802.3b	1985	10BROAD36
802.3c	1985	10 Mbit/s (1.25 MB/s) repeater specs
802.3d	1987	Fiber-optic inter-repeater link
802.3e	1987	1BASE5 or StarLAN
802.3i	1990	10BASE-T 10 Mbit/s (1.25 MB/s) over twisted pair
802.3j	1993	10BASE-F 10 Mbit/s (1.25 MB/s) over Fiber-Optic
802.3u	1995	100BASE-TX, 100BASE-T4, 100BASE-FX Fast Ethernet at 100 Mbit/s (12.5 MB/s) w/autonegotiation
802.3x	1997	Full Duplex and flow control; also incorporates DIX framing, so there's no longer a DIX/802.3 split
802.3y	1998	100BASE-T2 100 Mbit/s (12.5 MB/s) over low quality twisted pair
802.3z	1998	1000BASE-X Gbit/s Ethernet over Fiber-Optic at 1 Gbit/s (125 MB/s)
802.3-1998	1998	A revision of base standard incorporating the above amendments and errata
802.3ab	1999	1000BASE-T Gbit/s Ethernet over twisted pair at 1 Gbit/s (125 MB/s)
802.3ac	1998	Max frame size extended to 1522 bytes (to allow "Q-tag") The Q-tag includes 802.1Q VLAN information and 802.1p priority information.
802.3ad	2000	Link aggregation for parallel links, since moved to IEEE 802.1AX
802.3-2002	2002	A revision of base standard incorporating the three prior amendments and errata
802.3ae	2003	10 Gbit/s (1,250 MB/s) Ethernet over fiber; 10GBASE-SR, 10GBASE-LR, 10GBASE-ER, 10GBASE-SW, 10GBASE-LW, 10GBASE-EW
802.3af	2003	Power over Ethernet (12.95 W)
802.3ah	2004	Ethernet in the First Mile
802.3ak	2004	10GBASE-CX4 10 Gbit/s (1,250 MB/s) Ethernet over twin-axial cable
802.3-2005	2005	A revision of base standard incorporating the four prior amendments and errata.
802.3an	2006	10GBASE-T 10 Gbit/s (1,250 MB/s) Ethernet over unshielded twisted pair (UTP)
802.3ap	2007	Backplane Ethernet (1 and 10 Gbit/s (125 and 1,250 MB/s) over printed circuit boards)
802.3aq	2006	10GBASE-LRM 10 Gbit/s (1,250 MB/s) Ethernet over multimode fiber
P802.3ar	Cancelled	Congestion management (withdrawn)
802.3as	2006	Frame expansion
802.3at	2009	Power over Ethernet enhancements (25.5 W)
802.3au	2006	Isolation requirements for Power Over Ethernet (802.3-2005/Cor 1)
802.3av	2009	10 Gbit/s EPON
802.3aw	2007	Fixed an equation in the publication of 10GBASE-T (released as 802.3-2005/Cor 2)
802.3-2008	2008	A revision of base standard incorporating the 802.3an/ap/aq/as amendments, two corrigenda and errata. Link aggregation was moved to 802.1AX.
802.3az	2010	Energy Efficient Ethernet
802.3ba	2010	40 Gbit/s and 100 Gbit/s Ethernet. 40 Gbit/s over 1m backplane, 10m Cu cable assembly (4x25 Gbit or 10x10 Gbit lanes) and 100 m of MMF and 100 Gbit/s up to 10 m of Cu cable assembly, 100 m of MMF or 40 km of SMF respectively
802.3-2008/Cor 1	2009	Increase Pause Reaction Delay timings which are insufficient for 10G/sec (workgroup name was 802.3bb)
802.3bc	2009	Move and update Ethernet related TLVs (type, length, values), previously specified in Annex F of IEEE 802.1AB (LLDP) to 802.3.
802.3bd	2010	Priority-based Flow Control. A amendment by the IEEE 802.1 Data Center Bridging Task Group (802.1Qbb) to develop an amendment to IEEE Std 802.3 to add a MAC Control Frame to support IEEE 802.1Qbb Priority-based Flow Control.
802.3.1	2011	MIB definitions for Ethernet. It consolidates the Ethernet related MIBs present in Annex 30A & B, various IETF RFCs, and 802.1AB annex F into one master document with a machine readable extract. (workgroup name was P802.3be)
802.3bf	2011	Provide an accurate indication of the transmission and reception initiation times of certain packets as required to support IEEE P802.1AS.
802.3bg	2011	Provide a 40 Gbit/s PMD which is optically compatible with existing carrier SMF 40 Gbit/s client interfaces (OTU3/STM-256/OC-768/40G POS).
802.3bh	Mar 2012	A revision of base standard incorporating the 802.3at/av/az/ba/bc/bd/bf/bg amendments, a corrigenda and errata. (Expected to be published as 802.3-2012)
802.3bj	Mar 2014	Define a 4-lane 100 Gb/s backplane PHY for operation over links consistent with copper traces on improved FR-4 (as defined by IEEE P802.3ap or better materials to be defined by the Task Force) with lengths up to at least 1m and a 4-lane 100 Gb/s PHY for operation over links consistent with copper twin-axial cables with lengths up to at least 5m.

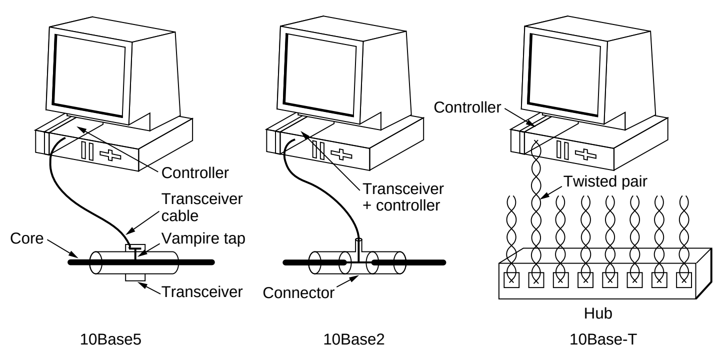
IEEE 802.3 Physical Layer

- Four types of cabling (original, or *classic*, 10 Mbps Ethernet)

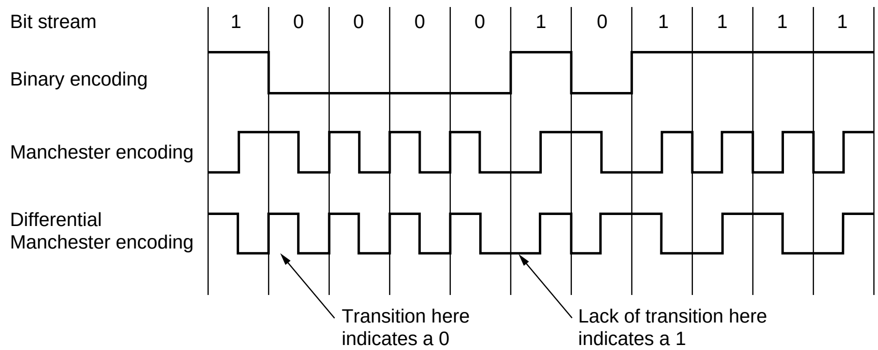
Name	Cable	Max segment	Nodes/seg	Advantages
10Base5	thick coax	500m	100	good for backbone
10Base2	thin coax	200m	30	cheap
10Base-T	twisted pair	100m	1024	easy setup
10Base-F	fiber optics	2000m	1024	long distance

  - Names have the form xBase$y$
- 10Base5 (thick Ethernet)
  - Requires thick (size of a garden hose) yellow coax
  - Connections via *vampire taps*
- 10Base2 (thin Ethernet)
  - Smaller diameter coax (cable TV size)
  - Connection via T-junctions

- Thick and thin Ethernet suffer from cable breaks, bad taps, and loose connectors real bus topology (no hub)
- 10Base-T
  - Twisted pair (telephone), all connect via hub
  - Limited distance (100m)
- 10Base-F
  - Fiber optics, long distances possible (low s/n ratio)

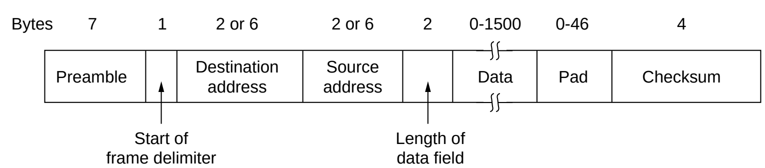


- Manchester encoding used by original 802.3 baseband systems
  - Manchester and Differential Manchester
    Advantages and disadvantages
  - High is +0.85 volts and low is -0.85 volts



802.3 MAC (Frame Structure)

- Frame structure is



- Frame starts with *preamble* 7 bytes of [10101010]
  - Results in a 10 MHz square wave for 5.6 μsec
  - Allows clock synchronization
- *Start delimiter* is next [10101011] indicates - *data is next*
- Source and destination addresses follow (**MAC address**)
  - First bit is 0 for *ordinary* address 1 for *group* address (all stations in the *group* receive, *multicasting*, which is weird at this layer)
  - If all bits are 1's then broadcast frame

- Ethernet cards (NICs) are typically assigned a *unique* address
  - IEEE assigns manufacturers a block of 2^{24} addresses
  - Manufacturer assigns a unique address from their block to each NIC
- Length field identifies number of bytes in data field
  - 64 to 1500 bytes possible *Why 64? Why 1500?*
  - As transmission speed increases, frame size must increase (or cable length decrease)...
- Checksum (CRC) of the data is added to the end

IEEE 802.3 MAC (Medium Access)

- CSMA/CD requires a random wait after collision
- *Binary exponential back off algorithm*
  - After collision time divided into discrete slots (equal to $2t_{prop}$)
  - After first collision each station waits 0 or 1 slots (random)
  - After second (consecutive) collision each station waits either 0, 1, 2, or 3 slots (randomly selected)
  - Therefore, after i collisions, wait 0 to $2^i - 1$ slots
- Exponential growth, reduces multiple collisions

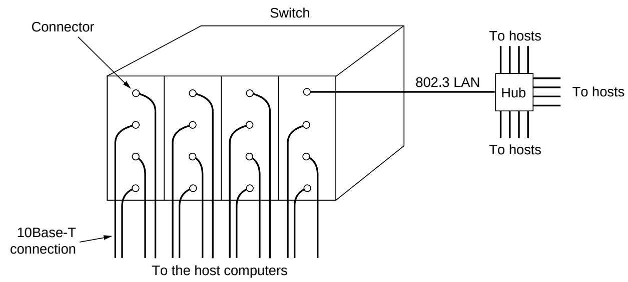
  Fairness is a growing concern, is the back-off procedure fair to everyone? How could we provide differentiated service?

Switched 802.3

- 802.3 performance decreases as the number of stations increases
  - Primarily because collisions are very *expensive*

    What does this mean? Any reasonable solutions?

- One solution is **switched 802.3**



- Consists of a switch containing a high-speed backplane
- When station wishes to transmit, it sends the standard frame

- Switch determines which card the frame is destined for
  - If destined for another card, sent (1Gbps) to that card

    What are the implications to network security?

- What is two stations on the same card send at the same time? Two possibilities (depends on manufacturer)
  1. Collision occurs on the card (*collision domain*) CSMA/CD
  2. Buffer every port, switch sends frames when medium idle (each port a collision domain)

  Most places have moved to switched Ethernet (including our department), so do collisions still exist?

Fast Ethernet 802.3u

- The previous slides described **classic Ethernet**
  - Bus and star topologies, and maximum data rate of 10 Mbps
- 802.3u describes **fast Ethernet**
  - Maximum data rate is 100Mbps (10 times faster)
  - Places limitations on the CSMA/CD protocol

    What are the limitations? How can it be resolved?

Name	Cable	Max segment	Notes
100BaseT4	twisted pair, cat3	100m	requires 4 twisted pairs
100BaseT	twisted pair, cat5	100m	requires 2 twisted pairs
100BaseFX	multimode fiber, two strands	2km	have you seen hostel?

- Cat5 cable uses a 4B/5B binary code instead of Manchester, it is balanced and only requires 25% overhead (Manchester is 100%)

Gigabit Ethernet

- 802.3z is the gigabit Ethernet standard, completed in 1998
  - Maximum rate is 1 Gbps, 10 times faster than *fast Ethernet*
  - Again, increasing speed places limitations on CSMA/CD

    What are the limitations?

  - Slot time extended to 512 bytes, frames must be $\geq$ 64 bytes

    How can this work? Frame must be greater than slot.

  - 802.3z medium alternatives

Name	Cable	Max segment
1000BaseSX	multimode fiber, two strands	550m
1000BaseLX	single mode fiber, two strands	5m
1000BaseT	twisted pair, cat5	100m

- 802.3ab is the gigabit Ethernet standard for copper wire
  - Uses unshielded twisted pair category 5, 5e, or 6
  - Can use four wires to transmit simultaneously in both directions
  - Encoding is 4D-PAM-5

10 Gbps Gigabit Ethernet

- 802.3ae is the 10Gbps Ethernet standard, ratified in 2002
  - Only operates in full-duplex, mode point-to-point connections
  - CSMA/CD protocol is disabled

    How can Ethernet operate without CSMA/CD?

  - 802.3ae medium alternatives

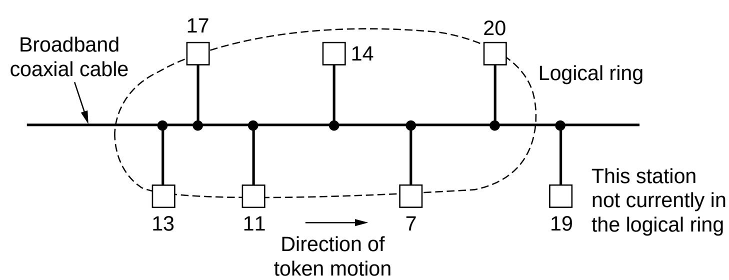
Name	Cable	Max segment
10GBaseSR	multimode fiber, two strands	300m
10GBaseLR	single mode fiber, two strands	10km
10GBaseEW	single mode fiber, two strands	40km

When would 802.3ae be useful?

IEEE 802.4

- The IEEE 802.4 standard describes a **token bus**
- While 802.3 was widely accepted, GM had reservations
  - 802.3 is probabilistic, no guarantees of delivery
  - Not appropriate for real-time data (assembly line)
- GM liked the idea of a token ring, but...
  - An actual ring topology is not robust
  - Ring topology does not fit an assembly line
- 802.4 was developed to combine
  - Robustness of linear medium 802.3
  - Predictability of token passing

- Solution is to logically organize stations as ring
  - Stations must know *left* and *right* neighbors
- Use token passing for MAC
  - After sending station passes token to neighbor (addressed)



- In general, MAC is very complex over 200 pages describing 10 different timers

IEEE 802.5

- The IEEE 802.5 standard describes token ring
- 802.5 Attributes
  - Rings are *fair* and have *bounded* channel access
  - IBM developed the ring as its LAN technology
- Major design issue is *physical length of a bit*
  - Each station can only store a single bit at a time
  - Therefore, stations do **not** store and forward an entire frame
  - If the propagation speed is 200×10^6 m/sec, the ring is 1000 m, and bit rate is 1 Mbps, then only ______ bits are on the ring (at once)

    The token will not even fit on the ring...

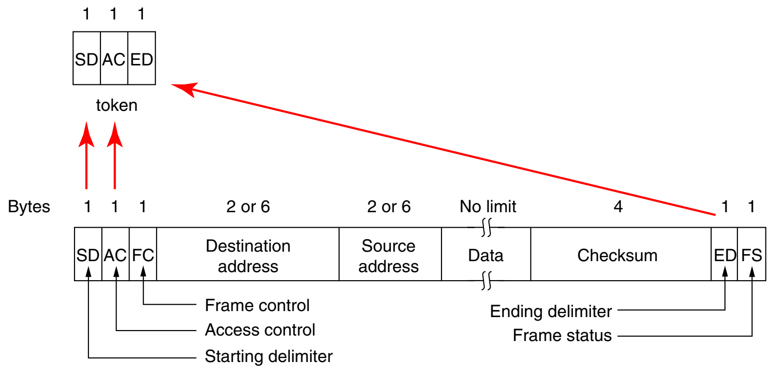
- A *token* is circulated while the stations are idle
- If a station wishes to transmit, then it seizes the token
  - This is done by inverting a bit in the 3 byte token
  - This converts it into a normal data frame

    What?!
- Station is free to transmit
  - Data frame(s) transmitted (around ring) and returned to sender

    An extremely efficient ACK from receiver is possible
- Due to the limitations of the ring topology, IBM implemented token ring as a star

IEEE 802.5 MAC

- Token is a 3 byte frame
  - To seize the token, a single bit is set to 1 which converts it to a *start of frame sequence*



token ring frame

- Station may hold the token (10 msec) and transmit

- Data frame
  - Starting delimiter and ending delimiter mark frame boundaries
  - Access Control (AC) contains token bit
  - Frame Control (FC) distinguishes data from control frames
- Generally, ring can not hold entire data frame (once bits return to sender, they are removed)
- 802.5 also supports priorities
  - To send frame of priority n, must seize token with same (or lower) priority
- Separate station is the *monitor*
  - Monitors the ring and ensures correct operation
  - Checks for lost token, multiple tokens, ...

802.3, 802.4, 802.5 Comparison

Issue	802.3	802.4	802.5
simple engineering	yes	no	yes
analog components	yes	yes	no
deterministic	no	yes	yes
priorities	no	yes	yes
high load performance	poor	good	good
reliability	good	good	*good*
current deployment	everywhere	small	large

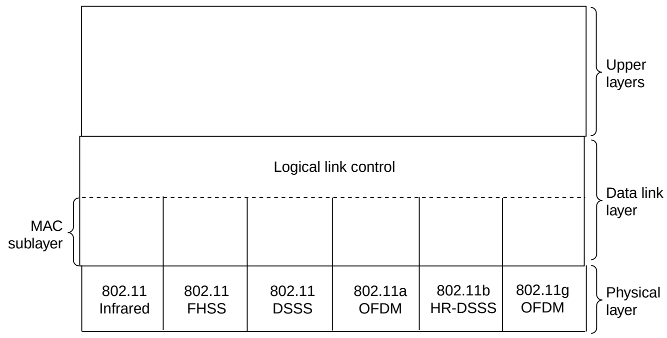
Resilient Packet Ring 802.17

- 802.17 is Resilient Packet Ring (RPR), completed June 2004
  - Dual ring technology (opposite directions)
  - Can handle mutliple gigabit transmission speeds
  - For MAN and WAN
- Designed to transport packets (layer 3)
  - Can provide different forms of *fairness*, different types of traffic can be transported

    What is important about different types of traffic?

802.11

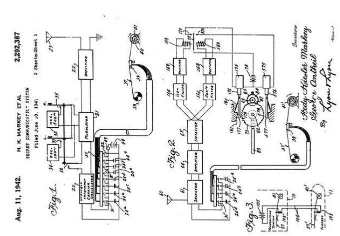
- The IEEE 802.11 standards are for wireless networks (LAN)
  - The standard describes the physical layer and MAC



- Only one MAC, but 5 different physical layers...
  - Infrared, FHSS, DSSS, OFDM, HR-DSSS, and OFDM
  - Therefore, 802.11a, b, and g only differ in the physical layer

Spread Spectrum

- Most 802.11 wireless physical layers rely on **spread spectrum**
  - Invented and patented (in part) by Austrian-born Hedy Lamarr



- The idea of spread frequency was developed before WWII
  - Lamarr and her husband (an arms merchant) lived in Europe
  - Radio controlled torpedoes was sought by governments
  - But, *narrow-band* (one frequency) wireless is easily jammed

- Lamarr developed the idea of *hopping* from frequency to frequency during transmission sending short bursts
- Even if a frequency was jammed, the entire signal was not
- Of course there is a secret predetermined hopping pattern

• Hedy Lamarr fled to the US before the war started
- She married George Antheil and patented spread frequency
- US patent number 2,292,387 dated 1942
- Unfortunately the US government did not believe in the system
- It was never used and the patent expired in 1959

• This work was rediscovered in the 1990's for wireless networks

So what else was Hedy Lamarr famous for?

802.11 Physical Layer

802.11 Infrared	802.11 FHSS	802.11 DSSS	802.11a OFDM	802.11b HR-DSSS	802.11g OFDM	} Physical layer

• Frequency Hopping Spread Spectrum (FHSS) used by 802.11
- Uses 79 channels each 1 MHz wide
- *Randomly* hops from channel to channel
- Transmits a short burst per hop, maximum rate is 2 Mbps
- All stations must be synchronized

  How is this accomplished?

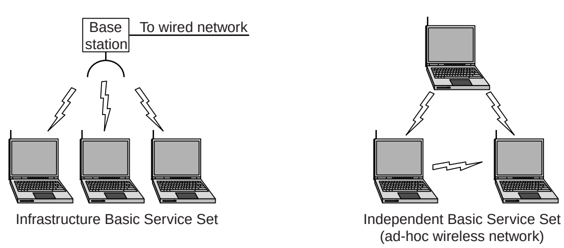
• Direct Sequence Spread Spectrum (DSSS) used by 802.11
- Spreads the power over a larger spectrum
- See CDMA for details, maximum rate is 2 Mbps

- Orthoganal Frequency Division Multiplexing (ODFM), 802.11a
  - Divides channel into smaller sub-channels
  - Transmits on different sub-channels in parallel
  - Very similar to DSL modems, maximum rate is 54 Mbps
  - 802.11g uses a variation of OFDM, maximum rate is 54 MBps
- High Rate Direct Sequence Spread Spectrum (HR-DSSS), 802.11b
  - Improved encoding with a maximum rate of 11 Mbps
  - 802.11b is slower than 802.11a, its range is 7 times greater
- All methods use Industrial, Scientific, and Medical (ISM) bands
  - Unlicensed frequencies used by microwaves, cordless phones, ...
  - *So consider what the error rate is...*

Now, let us move from EE back to the comfort of CS...

802.11 Network Types

There are two basic types of 802.11 wireless networks



- Infrastructure Basic Service Set (Infrastructure BSS)
  - Have a wireless Access Point (AP) present
  - AP are used for **all** communications

    If one station needs to communicate with another station, how many hops are required?

- Independent Basic Service Set (ad-hoc network, MANET)
  - Stations communicate directly with one another

    Must all the stations be within range of each other?

  - Designed to be dynamic and self-organizing, hence *ad-hoc*

  It appears that an ad-hoc wireless network can do as much as a infrastructure BSS and more, what are two advantages of using an infrastructure BSS?

- Each network type will have a different MAC
  - Distributed Coordination Function (DSF)
  - Point Coordination Function (PCF)

Distributed Coordination Function

Distributed Coordination Function (DCF) is for ad-hoc networks

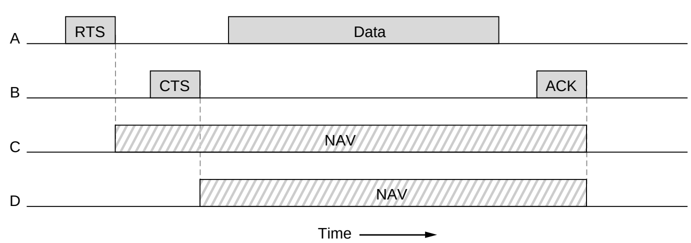
- Uses CSMA/CA (Collision Avoidance) and **no** central control
  - *Physical* and *virtual* channel sensing
- Physical sensing
  - Station listens, if idle (*physically* and *virtually*) then transmit
  - Does **not** sense channel while transmitting
  - If the channel is busy, it waits until idle
  - If a collision occurs, then binary back-off is used

  Do stations send whenever the channel is idle? What about the hidden and exposed station problems?

DCF and MACAW

The preceding physical sensing, but virtual sensing is also used

- Virtual sensing is done using MACAW (enhancement of MACA)
  - Sender and receiver are required to send RTS and CTS
- Assume station A sends to B, a complete transaction would be
  1. Station A sends RTS message to station B
  2. Station B replies with a CTS message
  3. Station A sends frame and sets an ACK timer
  4. Station B receives the frame and sends ACK
- RTS and CTS include a Network Allocation Vector (NAV) field
  - NAV indicates the time for the **complete transaction**
  - Allows for *virtual sensing*



- Assume stations C and D are present (C within A, D within B)
  - Station C hears the RTS and is idle for NAV
  - Station D hears the CTS and is idle for the NAV
- After transaction is complete, other stations may send
  - Channel is idle physically and virtually

Therefore, what occurs after a successful transaction?

Point Coordination Function

Point Coordination Function (PCF) is used for infrastructure BSS

- PCF provides **contention free** access using the access point
  - Access is coordinated by the access point (AP)
  - As a result PCF can provide fair and predictable service

  Is DCF fair or predictable? Why is predictability important?

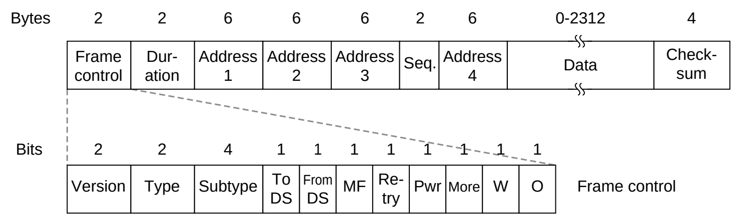
- PCF operation is based on polling
  - The AP transmits a beacon frame, asking for new stations
  - Once a station is added, it is systematically polled
  - A station can send one frame per poll

  If I use a AP with my wireless network, I am using PCF, right?

What is Actually Used

- You won't find a PCF option on your average AP
  - Most vendors do not include PCF
  - Even when chipsets have PCF, AP vendors don't activate it
- PCF has been part of the 802.11 standard since 1997
  - The problem is 802.11 is fairly vague when defining PCF
  - As a result, you would need to use the same vendor for the access points and radio cards to make it work properly
  - The *Wi-Fi Alliance* does not include PCF functionality in their interoperability standard
- Therefore if you have an AP, the wireless network will use DCF and the AP behaves like any other station

802.11 Frame Structure

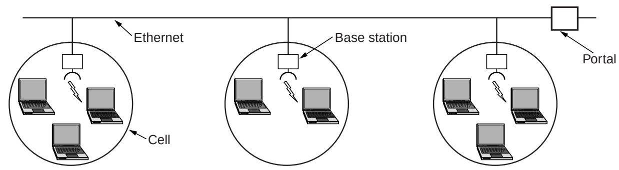


- The first field is the *frame control* that has 11 sub-fields
  - *Protocol version* indicates the protocol used (DCF or PCF, both can be used simultaneously)
  - The *type* field indicates control, data, or management
  - *To DS* and *FromDS* indicates if the frame is going to or coming from and intercell distribution system

    What is an intercell distribution system?

  - *MF* indicates more fragments will follow
  - *Retry* indicates the frame is a retransmission
  - *Power management* is used to put the receiver to sleep or to wake the receiver
  - The *More* bit tells the receiver more frames follow
  - *W* bit indicates the frame is encrypted using the Wired Equivalent Privacy (WEP)
  - The O bit indicates the frames must be processed in order
- The second field of the data frame is the *Duration*
  - Tells how long the transaction will take (NAV)
- Four addresses follow, interpretation depends To DS and From DS

802.11 Frame Address Fields



toDS	fromDS	Address 1	2	3	4	Use
0	0	destination	source	BSS ID		from station to station is same BSS
0	1	destination	BSS ID	source		frame exiting the distribution system
1	0	BSS ID	source	destination		frame destined for the distribution system
1	1	receiver	transmitter	destination	source	frame distributed from AP to AP

Why is this necessary? Is this routing?

802.11 Frame Structure Continued

- The *sequence* field is between the third and fourth addresses
  - Allows fragments to be numbered
  - 12 bits for the frame and 4 bits identify the fragment
- The *Data* field stores the frame data
  - Payload may contain up to 2313 bytes
- The *Checksum* field follows

802.11 Protocols

Prot.	Release	Freq. (GHz)	BW (MHz)	Data Rate per stream (Mbps)	MIMO streams	Modulation
	Jun 1997	2.4	20	1, 2	1	DSSS, FHSS
a	Sep 1999	5, 3.7	20	6, 9, 12, 18, 24, 36, 48, 54	1	OFDM
b	Sep 1999	2.4	20	1, 2, 5.5, 11	1	DSSS
g	Jun 2003	2.4	20	6, 9, 12, 18, 24, 36, 48, 54	1	OFDM, DSSS
n	Oct 2009	2.4/5	40	15, 30, 45, 60, 90, 120, 135, 150	4	OFDM
ac	Dec 2012	5	160	up to 866.7	8	OFDM
ad (WiGig)	Feb 2014	2.4/5/60		up to 6912		

Other 802.11 Groups

- 802.11c - Bridge operation procedures; included in the 802.1d standard (2001)
- 802.11d - International (country-to-country) roaming extensions (2001)
- 802.11e - Enhancements: QoS, including packet bursting (2005)
- 802.11f - Inter-Access Point Protocol (2003) Withdrawn 2005
- 802.11h - Spectrum Managed 802.11a (5 GHz) for European compat. (2004)
- 802.11i - Enhanced security (2004)
- 802.11j - Extensions for Japan (2004)
- 802.11k - Radio resource measurement enhancements
- 802.11l - *just not good...*
- 802.11m - Maintenance of the standard; odds and ends.
- 802.11o - *just not good...*
- 802.11p - WAVE - Wireless Access for the Vehicular Environment
- 802.11q - *just not good...*
- 802.11r - Fast roaming

- 802.11s - ESS Mesh Networking
- 802.11t - Wireless Performance Prediction (WPP) - test methods and metrics
- 802.11u - Interworking with non-802 networks (e.g., cellular)
- 802.11v - Wireless network management
- 802.11w - Protected Management Frames
- 802.11x - I made this up

Broadband Wireless

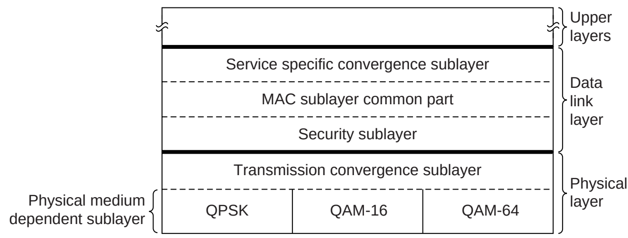
- Increasingly networks are encountering the *last mile problem*
  - The backbone (or core) networks are high-speed
  - However, the last mile connection is low speed

    What is the problem with this?

- Telephone and cable companies can provide high-speed service
  - Provides high speed last-mile (local loop) connections
  - However, requires upgrading the infratructure
- High-speed wireless service is a *better* option for a community
  - Cheaper alternative to installing cables
  - IEEE 802.16 is *outdoor* broadband wireless

802.16

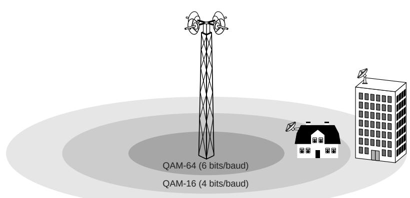
- IEEE 802.11 standard describes wireless broadband [2002]



- The bottom sublayer provides narrow-band radio modulation
- The data-link layer consists of 3 sublayers
  - Security (more important here than 802.11) *Why?*
  - MAC provides channel management
  - Convergence sublayer interfaces with the network layer

802.16 Physical Layer

- Physical layer uses the 10 to 66 GHz frequency range
  - Waves in this range travel in a straight line (line of sight)



  - As a result, multiple antennas can be used
- 802.16 employs three different modulation methods
  - Which is used depends on the distance from the antenna
  - QAM-64, QAM-16, or QSPK

    The father away from the station, the...

- More recent versions of WiMAX allows mobility

Long-Term Evolution

- Long-Term Evolution (LTE) is an alternative to 802.16
  - Defined by 3rd Generation Partnership Project (3GPP)
  - Consortium of telecommunication groups (and companies)
- Several similarities in the technical specifications

	LTE	LTE-Advanced	WiMAX 802.16e	WiMAX 802.16m
Physical Layer	Dl:OFDMA UL:SC-FDMA	DL: OFDMA UL: SC-FDMA	DL: OFDMA UL: OFDMA	DL: OFDMA UL: OFDMA
User Mobility (mph)	217	217	37 to 74	217
Channel Bandwidth (MHz)	1.4, 3, 5, 10, 15, 20	Aggregate of release 8	3.5, 5, 7, 8.75, 10	5, 10, 20, 40
Peak Data Rates (Mbps)	DL: 302 UL: 75	DL: 1000 UL: 300	DL: 46 UL: 4	DL: $>$ 350 UL: $>$ 200
Latency (msec)	link layer $<$ 5 Handoff $<$ 50	link layer $<$ 5 Handoff $<$ 50 ms	link layer $\approx$ 20 Handoff $\approx$ 35 to 50	link layer $<$ 10 Handoff $<$ 30
VoIP Capacity	80 users per sector/MHz (FDM)	$>$ 80 users per sector/MHz (FDM)	20 users per sector/MHz (TDM)	$>$ 30 users per sector/MHz (TDM)

- Physical layer, both LTE and WiMAX use OFDMA for download
  - OFDMA is power inefficient, suitable since base station has power
  - Not suitable for battery-based devices, so LTE does not use OFDMA for upload (*mobile device to base station*)
- Both WiMAX and LTE have the ability to provide Quality of Service (QoS) and some provisions for security

IEEE 802.2

- We have not addressed *reliable* communication
  - 802.3,4,5,11,16 just provides best-effort datagram service

    What was the primary service provided?
  - Perhaps this is adequate...
- IEEE 802.2 describes the Logical Link Control (LLC)
- Provides flow and error control
- Three service types
  1. Unreliable datagram
  2. Acknowledged datagram
  3. Reliable connection-oriented

802 Status

Number	Status	Topic
802.1		Overview and architecture of LANs
802.2	⇃	Logical link control
802.3	⋆	Ethernet
802.4	†	Token bus (briefly used in manufacturing plants)
802.5	⇃	Token ring (IBM's version of a LAN, good but too expensive)
802.6	⇃	Dual Queue Distributed Bus (early MAN, used in Europe)
802.7	⇃	Technical advisory group for broadband
802.8	†	Technical advisory group for fiber optics
802.9	⇃	Isochronous LANs (real-time LANs)
802.10	⇃	Virtual LANs and security
802.11	⋆	Wireless LANs
802.12	⇃	Demand priority (HP's AnyLAN)
802.13		Unlucky number
802.14	⇃	Cable modems (industry developed it first)
802.15	⋆	Personal area networks (Bluetooth)
802.16		Broadband wireless
802.17		Resilient packet ring
802.18		Radio Regulatory TAG
802.19		Coexistence TAG
802.20		Mobile Broadband Wireless Access (*vehicular speeds of 250 km/h*)
802.21		Media Independent Handoff
802.22		Wireless Regional Area Network
802.23		Emergency Services Working Group
802.24	⋆	Smart Grid TAG New (*November, 2012*)
802.25		Omni-Range Area Network
TAG = Technical Advisory Group, Legend: ⋆ = important, ⇃ hibernating, and † = dead		

Want more 802 information, then go to `http://standards.ieee.org/getieee802/`