Computer Networks and Distributed Systems

Computer Networks – Data Link Layer

Course 527 – Spring Term 2014-2015

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- Overview of Data Link Layer
  - How do we divide data into chunks for the physical layer?
  - How do we control access to a physical channel?
- Data Framing
  - Gaps, counting, delimiters
  - Ethernet/IEEE 802.3 formats
- Medium Access Control
  - In wired networks
    - ALOHA, Ethernet (CSMA/CD), Token Ring
  - In wireless networks
    - IEEE 802.11 (CSMA/CA)

Data Link Layer

- Arranges data into bit stream for sending over physical link
  - Defines communication between two physically connected network nodes
  - Must cope with different physical layer technologies

- Two sub-layers:
- Logical Link Control (LLC)
  - Low-level flow and error control for single hop
  - ☛ *Not really covered in this course*
- Media Access Control (MAC)
  - Framing, addressing and channel access

Data Link Layer Services

- Unacknowledged connectionless service
  - Independent frames with no logical connection
  - No recovery from loss but fast
  - Common in LANs at data link layer
- Acknowledged connectionless service
  - Each frame in acknowledged
  - Out of order delivery possible
  - Good for unreliable channels such as wireless
- Acknowledged connection-oriented service
  - Connection established before data is sent
  - Each frame numbered and guaranteed to be delivered exactly once and in order
  - Provides reliable bit stream

LLC: Error Detection and Correction

Detection

- Serial connections use 8 data + 1 parity bit
  - Makes total number of 1s odd (or even)
  - Detects all single (and odd numbered) bit errors, misses even bit errors
- Cyclic Redundancy Check (CRC)
  - Hash-based checksum (often implemented in H/W)

Correction

- Forward Error Correction (FEC)
  - Add more redundancy → greater capacity to detect/correct bursts of errors
  - e.g. use 5 bit codewords to encode 2 data bits

Data Framing

- Need to group bits into separate messages
  - Large frames have less overhead, but:
    - Have greater chance of collision
    - Cost more to retransmit if error detected
- Need to add meta data to control protocol
  - Addressing, length, frame type, CRC, …
- Need to provide error detection/correction
  - Physical layer may introduce errors by adding, removing, or modifying bits

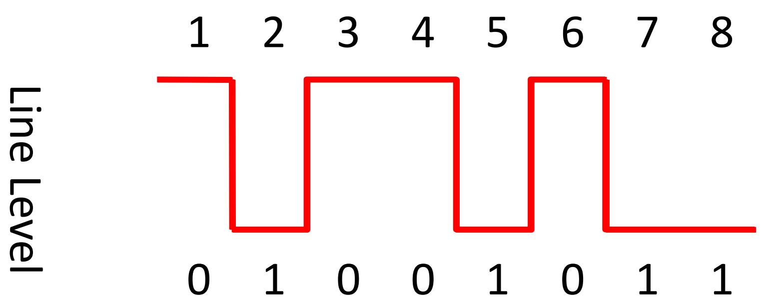
Framing: Gaps & Counting

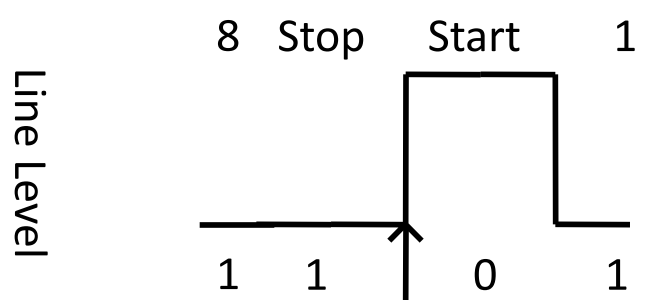
- Insert gaps
  - But timing hard to guarantee

- Count characters
  - Include length field to delimit data
  - Often used with another framing method

Count: 5	H	E	L	L	O	Count: 8	...

Serial Line Framing





Resynchronise
on this transition

- Counting for framing
  - Data transmitted at agreed rate
  - But clocks may not be accurate
- Use start/stop bits
  - At least 1 transition per byte
  - Bit asynchronous and byte synchronous

Framing: Flags

- Start and end flags
  - Special signal at start & end of frame: “FLAG”
  - Search for flag if receiver loses track

FLAG	Header	Payload data from network layer	Trailer	**FLAG**	**FLAG**	Header

- Uses byte stuffing
  - Identify data with same bit pattern as the flag
  - Use escape sequence to identify “next byte is data”

Stuffing	A	**ESC**	FLAG	B	C	**ESC**	**ESC**	D

IEEE 802.3 and Ethernet

- Originally developed by Xerox
  - Became open standard
  - These days it’s almost a marketing term…
- Uses Manchester encoding for line transitions
- Operates over various physical media
  - Data link layer is separate to physical layer
  - But physical layer affects parameters of Ethernet
- Two standards: IEEE 802.3 and Ethernet

IEEE 802.3: Frame Format

Bytes	7	1	2 or 6	2 or 6	2	0 to 1500	0 to 46	4
	Preamble	SD	DA	SA	Length	Data	Pad	FCS
	10101010	10101011						

46 to 1500 Bytes
Data and Pad

- Ethernet standard slightly different
  - Doesn’t have SD field
  - Replaces Length with Type field

IEEE 802.3: Frame Fields I

- Preamble
  - 7-byte alternating 0s and 1s to establish synchronisation
  - Framing then by timing, spaces between frames plus counting from length field
- SFD (start frame delimiter)
  - 10101011 indicates start of frame
  - Allows receiver to miss start of preamble and still synchronise
  - Compatibility with 802.4 and 802.5 (Token Ring)

IEEE 802.3: Frame Fields II

- Destination address
  - 16 or 48 bits (depending on implementation)
  - Host(s) intended to receive
    - Single host (unicast)
    - Group address (multicast)
    - Global address (broadcast)

- Source address
  - 16 or 48 bit address of sender

Ethernet Addresses

- Usually, Ethernet addresses are 48 bits:

Bit 47:	0 = ordinary addr 1 = group addr
Bit 46:	0 = global addr (fixed in hardware), 1 = local addr (assigned by admin)
Bits 23-45:	Vendor code (IEEE assigned)
Bits 0-23:	Unique code, set by vendor

- $2^{46} \Rightarrow 7 * 10^{13}$ possible global addresses

- Written as 6 pairs of hex digits
  – e.g. 00:11:85:7A:BC:E4

IEEE 802.3: Frame Fields III

- Type (Ethernet only)
  - Identifies higher level protocol
- Length (IEEE 802.3 only)
  - Bytes in this frame (optional)
- Data
  - Speaks for itself
  - Includes higher layer headers

IEEE 802.3: Frame Fields IV

- Pad
  - 0-46 bytes to ensure frame is long enough to enable collision detection (a few slides away)

- FCS (Frame Check Sequence)
  - CRC, based on all fields except preamble, SD and FCS
  - Enables error detection

Medium Access Control

- Physical channel supports multiplexing scheme
- But how do we allocate communications channels?
  - Contention
  - Fairness
  - Access latency
- Static allocation vs. dynamic allocation

Static Allocation

- Recall: TDM, FDM and CDMA
  – Static ways for stations to access fixed part of medium
- Properties
  – Connection-oriented service
  – Guaranteed, allocated bandwidth
  – Bounded latency to transmit

Dynamic Allocation

- But in many computer networks the following applies:
  - Most stations do not want to transmit at once
    - Don’t waste bandwidth on silent stations
  - Need to ensure fair access to medium
    - Would like bounded delay to transmit
  - Single transmitter on medium is simpler electronically
- Use dynamic allocation
  - Allocate time to use medium on demand
  - Connection-less service
- Use **statistical multiplexing** for TDM

Propagation Delay

- Finite time for signal to go from one node to another:

  delay = distance / speed (where speed = $2 * 10^8$ m/s)

- Finite time to send each signal:

  time = 1 / baud rate

- Nodes will receive signal at different times
  - Depends on distance from sender
  - Different nodes will perceive medium to be busy/quiet at different times

- Need to keep this in mind when managing who transmits when!

Collision Detection: ALOHA

- Original contention network
  - Developed at U. Hawaii
- Send whenever data ready to go
- Two stations whose signals overlap get garbled data
  - By listening can detect collision
  - Wait random time and try again
- Not very efficient
  - 18% theoretical maximum channel utilisation

Slotted ALOHA

- Divide time into slots
  - Start time of frames is synchronised
  - Probability of collisions is reduced
- Cannot assume synchronised clocks between stations
  - Master station sends short signal at start of each time frame
- Successful transmission 37% of the time

CSMA (or being polite)

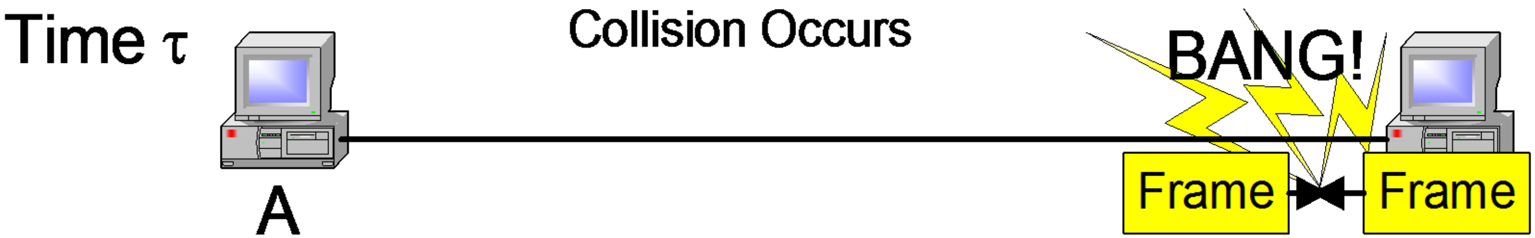
- ALOHA has simple problem:
  - No-one listens before they start to send
  - Leads to lots of collisions

- Carrier Sense Multiple Access (CSMA)
  - When ready to send, listen
  - If channel busy, wait until idle
  - When channel idle, send
  - If collision, wait random time and start listening again

CSMA with Collision Detection

- What if two hosts want to transmit?
  - Two overlapping signals interfere, needs to be spotted
- Collision Detection (CD)
  - Listen to channel while sending
  - When collision, abort signal with noise burst
  - Wait random time and try again
- Properties
  - Designed for fair access
  - Gives unbounded time to access network
  - Doesn’t waste channel sending broken frames

IEEE 802.3: Collision Detection



- Ensure sender still sending when collision noise arrives
  - Must send for twice the propagation delay

- 802.3 allows for 2.5 km max LAN (with repeaters)
  - Specifies minimum frame length that takes at-least 51.2 μs to transmit
  - Assuming 100 ns transitions for sending 1 bit, this means at least 512 bits, hence the pad

Data Frame Format

Bytes	7	1	2 or 6	2 or 6	2	0 to 1500	0 to 46	4
	Preamble	SD	DA	SA	Length	Data	Pad	FCS
	10101010	10101011						

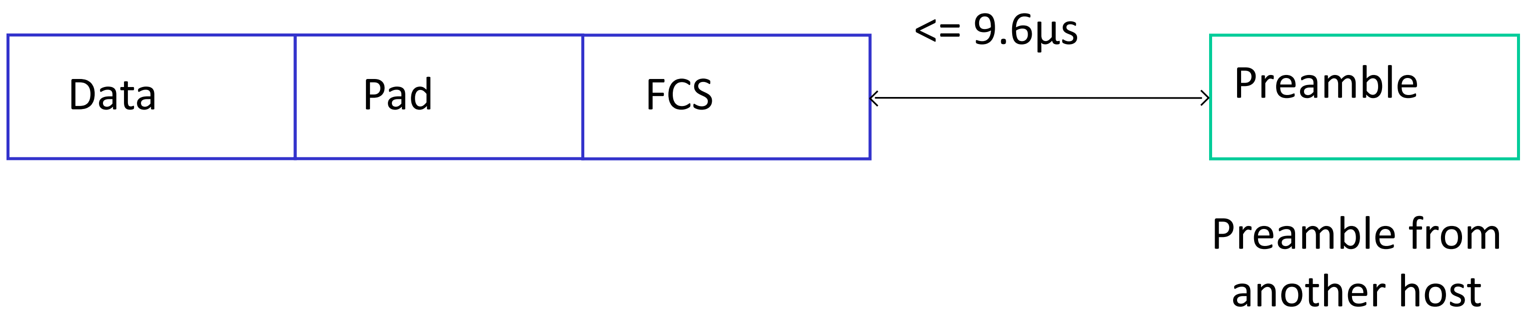
46 to 1500 Bytes
Data and Pad

- 7+1+2+2+2+46+4 bytes * 8 bits = 512 bits = 51.2 μs on a 10 Mbps link
  - Time to detect collision over longest network while still transmitting
  - When finished sending, cannot guarantee that still listening to hear collision

IEEE 802.3: Retry Timing

- Must avoid repeated collisions
  - At n^{th} retry, wait between 0 and 2^{n-1} slot times (51.2 μs)
  - Do this up to a maximum of 1023 slot times
  - Give up on 16^{th} collision
- Properties
  - Low delay for two hosts' frames colliding
  - Reasonable delay for many hosts' frames colliding

IEEE 802.3: Inter-frame Gap



- 9.6 μs interval between successive frames from host
  - Allows other hosts to use medium
  - Initial frame can be transmitted immediately

CSMA/CD Summary

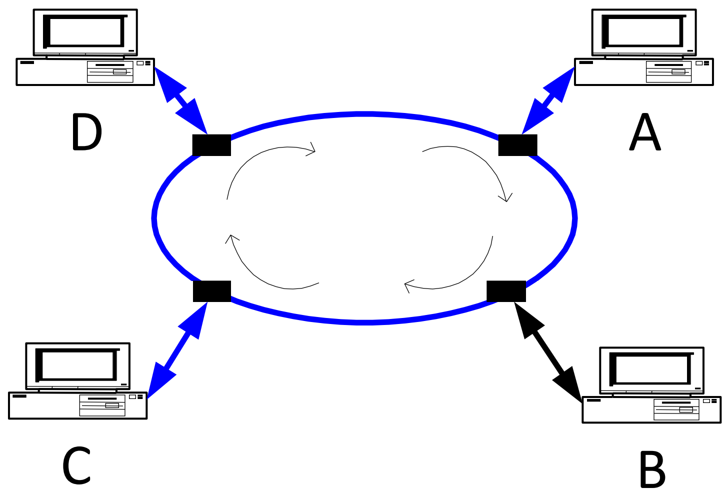
- Fairness
  - Equal access to all stations
  - No priorities
- Probabilistic
  - Unbounded access time
  - Bad at heavy loads due to exponential back-off
- IEEE 802.3/Ethernet use this

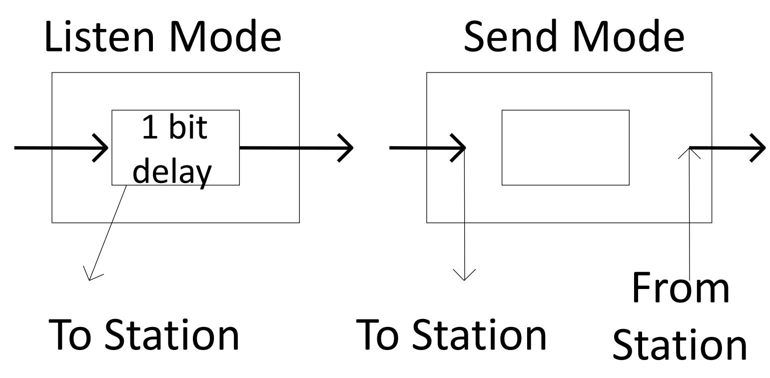
Token Passing

- Arrange more orderly sharing of medium
  - Uses permission **token**
  - Access to medium signalled by passing token around
- Avoids collisions through strict control
  - But need to handle token control
  - Differentiate between tokens and data

IEEE 802.5 Token Ring

- Developed by IBM
  - Token Ring and Bus
- Token frame inserted by Active Ring Monitor (ARM)
  1. Any station takes token and sends data frame
  2. Destination copies passing data
  3. Sender removes frame on return





Token Passing

- Bounded access delay for fair use
  - Control passes round all nodes
  - But no instant on demand access
- Supports giving some stations priority over others
  - Not just equal/fair access of contention like CSMA
  - Good for real-time control systems
- Nice idea but complex in practice → rarely used
  - All stations must cooperate
  - Must handle token loss
- IEEE 802.4/802.5 Token Bus/Ring and FDDI use this

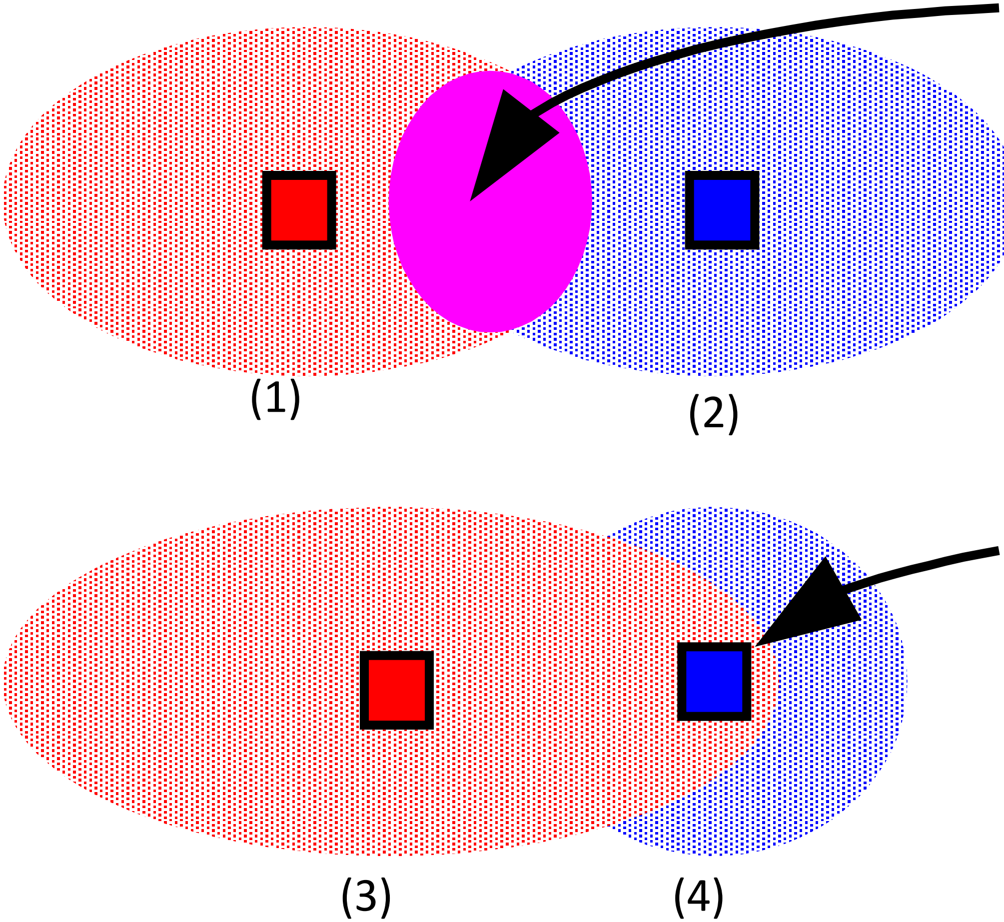
Summary: MAC in Wired LANs

- ALOHA
  - Contention based service
  - Low performance but simple, equal access
- CSMA/CD
  - Tries to avoid collisions, will detect collisions
  - Probabilistic/unbounded access time, equal access
- Token Passing
  - Avoids collisions
  - Bounded access time, access hierarchy but complex

MAC in Wireless LANs

- Centralised Medium Access Control
  - Good where data is time-sensitive or high priority
  - Suffers limits of centralisation
- Distributed Medium Access Control
  - Good for ad-hoc peers with bursty traffic
- No guarantee that all nodes can hear each other
  - Makes collision detection harder

Undetectable Collisions



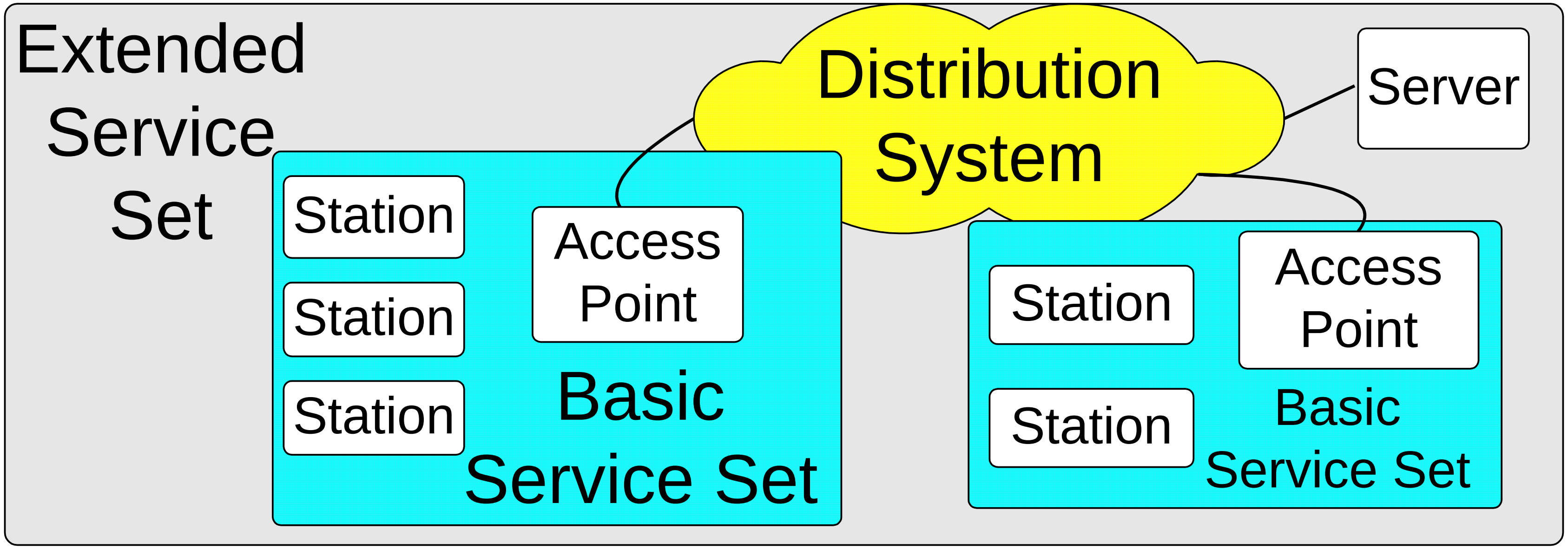
Signals from (1) and (2) collide

– But (1) cannot hear (2), and vice versa

Hidden receiver problem

– (4) can hear (3)
– But (3) cannot hear (4)

IEEE 802.11 - WLAN



- Basic Service Set (BSS)
  - Smallest building block with stations sharing medium using the same MAC protocol, aka **cell**
  - BSSes can overlap
- Extended Service Set (ESS)
  - Two or more BSSes, connected by distribution system
  - Appears as single logical LAN to higher levels

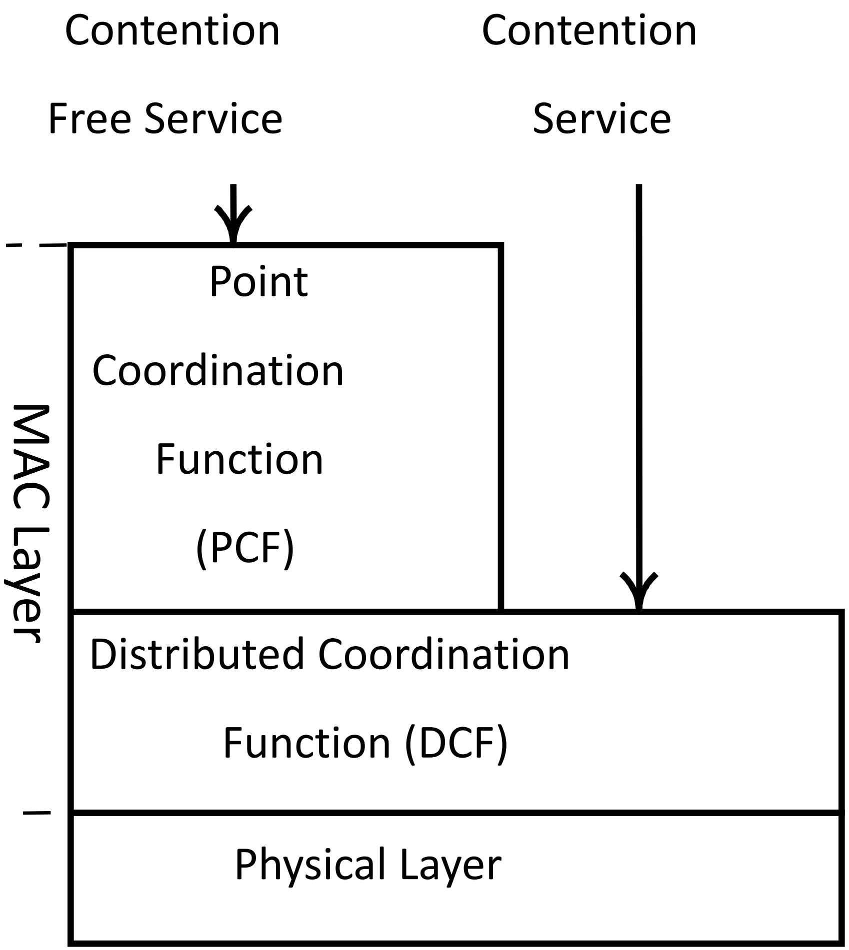
IEEE 802.11 Station Types

- Station types based on mobility
- No Transition
  - Stationary/only moves within range of one BSS
- BSS Transition
  - Moves between BSSes in one ESS
  - Addressing must recognise new location and deliver via appropriate BSS
- ESS Transition
  - Moves between BSSes in different ESSes
  - Does not guarantee connection to upper layers

IEEE 802.11 Media Types

- Frequency-hopping spread spectrum
  - 2.4GHz ISM band with 20 x 1MHz hopping channels
  - 1 or 2Mb/s with different FSK encodings
  - Low bandwidth but good interference resistance
- Direct-sequence spread spectrum (similar to CDMA)
  - 2.4GHz ISM band at up to 11Mb/s (802.11b)
  - Very good range and variable speed
- Orthogonal FDM (similar to ADSL)
  - 5Ghz ISM band with 52 narrow bands (802.11a)
  - 2.4Ghz ISM band (802.11g)
  - Up to 54Mb/s but lower range

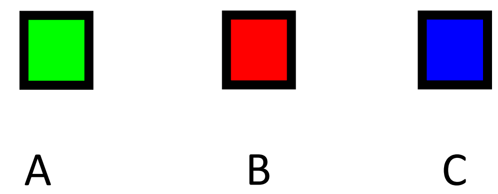
Distributed Foundation Wireless MAC



- Distributed access control
  - With optional centralised control by base station
- DCF uses CSMA/CA
  - Collision Avoidance but no detection (not practical)
  - Inter Frame Spaces (IFS) give fair access with priorities

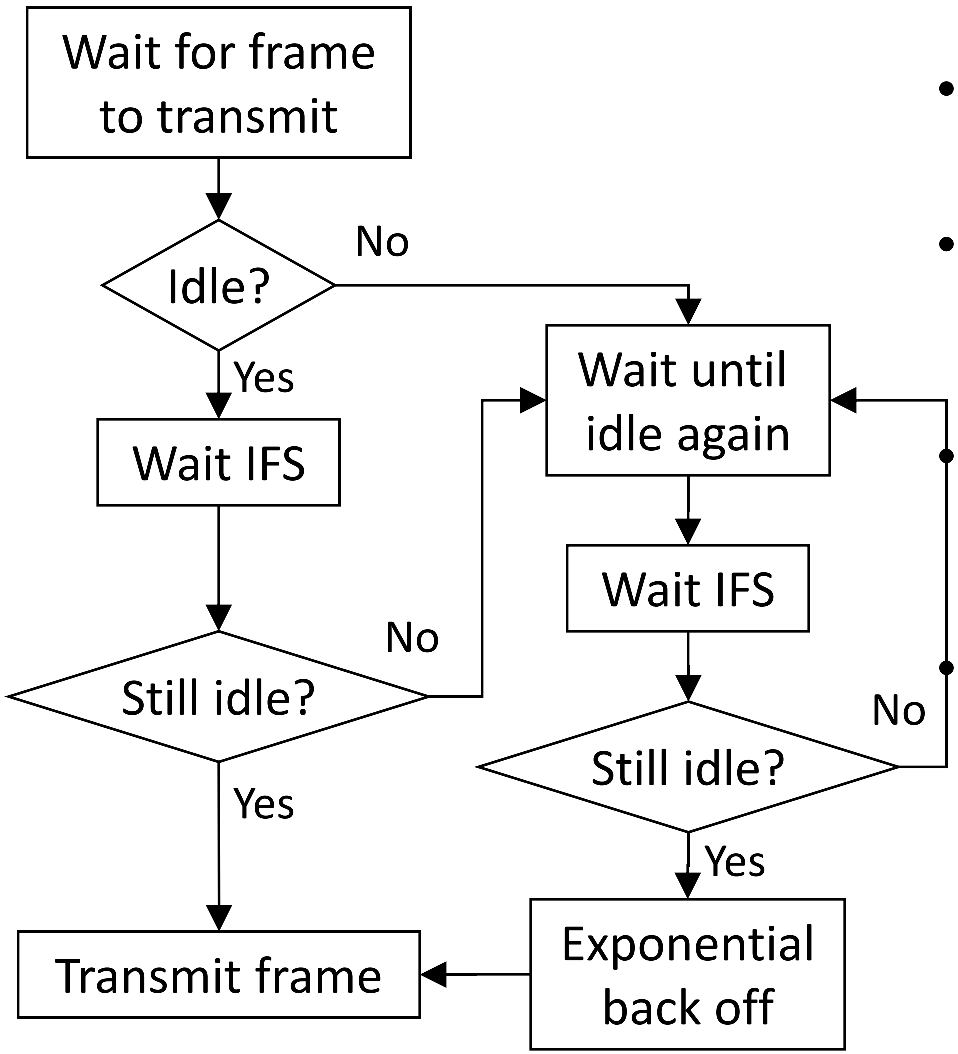
Collision Avoidance

- **RTS** (Ready to Send) – request the channel
- **CTS** (Clear To Send) – response to RTS frame
- **ACK** (Acknowledgement) – sent on receipt of frame
  - MAC-level ACK provides efficient collision recovery



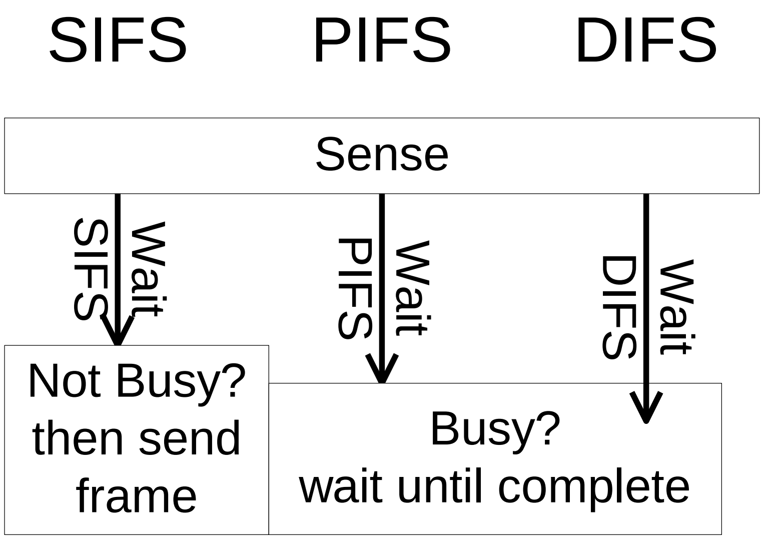
- Other stations hear exchange and “sense” channel
  - Stations infer how long the channel will be busy
  - Repeated failures to transmit → greater back-off time

CSMA with Collision Avoidance



- Station with frame to transmit senses medium
- If idle and remains idle for IFS period ➔ transmit immediately
- If busy ➔ wait until transmission ends + another IFS
- If still idle ➔ back off random amount of time (exponential algorithm) + then transmit, otherwise wait until idle again

Priority and Timing



Contention example

- <u>Short IFS (SIFS)</u>
  - Immediate response actions (e.g. ACK, CTS)
  - Short IFS gets medium first
- <u>PCF IFS (PIFS)</u>
  - Medium length
  - Polls from central controller
- <u>DCF IFS (DIFS)</u>
  - Ordinary & management data
  - 1st MAC Protocol Data Units (MPDU) of series

Multi-Frame Transmissions

- Data unit broken into multiple frames
  - Individual ACKs good for noisy channels
- Once medium acquired sent data without interruption
  - Following frames sent on receipt of ACK

- Use DCF IFS to initiate connection (1st MPDU)
- Use Short IFS for later frames of MPDU

IEEE 802.11 Summary

- Wireless LAN network
- Distributed communication
  - Not always via centralised controller
- CSMA/CA but no CD
- Inter-frame spacing
  - Provide priority system using CSMA