

COMS3200

COMS3200 – Week 6 Medium Access Sub-Layer

School of Information Technology and Electrical Engineering
The University of Queensland

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Outline

- Medium-Access Sub-layer
- Multiple-access protocols
 - Collision Based protocols
 - Collision Free Protocols
 - WDM and WLAN protocols
- IEEE 802 standards
 - 802.3 (Ethernet)
 - 802.11 (Wireless LAN)
 - 802.16 (WiMax)
 - 802.15 (Bluetooth)

} Next week

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Learning objectives

After this week, you should

- understand which networks require MAC protocols
- be able to describe different types of transmission channel allocation: **collision based**, **collision free** and methods used in **Wireless LANs**
- understand functionality of the ALOHA, Slotted ALOHA, CSMA, CSMA/CD protocols

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Learning objectives

- be able to analyse performance of ALOHA and Slotted ALOHA
- understand differences between 10base5, 10base2, 10baseT, 100baseT, 1000baseT

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Types of Network Channels

- Point-to-point links
 - Connects one sender to one receiver
 - Used for WANs, and hierarchical Ethernet (new Ethernet)
- Broadcast Channels
 - Also called
 - Multiple-access channel
 - Random-access channel
 - Signal sent by one station is received by all other stations
 - Only one station can send at a time
 - More than one sender → signal is garbled
 - Used for LANs
 - Need mechanism to control channel allocation

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Medium Access Sub-layer

- Who gets to use the channel and when?
 - Channel allocation problem
- Example: Telephone conference with 5 participants. Who can talk?
 - Rules?

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Medium-Access Sub-layer

- MAC Sub-Layer is part of Data-link layer
- LLC provides generic DLL services
 - Error control
 - Flow control
- LLC hides different MAC layers from Network layer
- MAC deals with channel allocation for different transmission media

| | |
|-----------------|---|
| Network Layer | |
| Data Link Layer | Logical Link Control (LLC) 802.2 |
| | MAC Sub-Layer 802.3 802.5 802.11, 802.15, 802.16 |
| Physical Layer | |

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Static Allocation

- Divide Channel into multiple sub-channels and allocate them statically to users
 - Synchronous TDM
 - FDM
- TDM Example
 - For telephone conference, each of the five participants get a 12 second time slot in each minute.
 - A gets seconds 1-12
 - B gets seconds 13 - 25
 - C gets seconds 26 - 38 ...
- Problems of this approach?

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Static Allocation

- Static allocation works fine if traffic is non-bursty
 - All users have something to say/send all the time
- Static allocation can be inefficient
 - Time slot (or FDM channel) is reserved even if user has nothing to say/send (bursty traffic)
 - A lot of wasted bandwidth
 - Can result in increased delay
 - In telephone conference example, assume only E has something to say. E needs to wait for a long time before she can talk
- Traffic in data networks is typically bursty
 - E.g Web Browsing, email etc.

→ Dynamic Allocation

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Dynamic Allocation

- Channel is allocated to users/stations dynamically, as needed

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Dynamic Channel Allocation Problem: Assumptions

1. *N* independent stations (computers, telephones etc.)
2. Single channel
 - All stations transmit/receive using it
 - No other channel to indicate frames to send
3. Collisions
 - Two frames may be transmitted simultaneously by different stations (i.e. overlapping in time), signal is garbled → collision
 - All stations can detect collisions
 - Collision → retransmit frame
 - Collision Detection (CD) → as soon as collision is detected, abort transmission

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Dynamic Channel Allocation Problem: Assumptions

4. Time
 - Continuous Time
 - Frame transmission can begin at any instant
 - Slotted Time
 - Time divided in discrete intervals (slots)
 - Transmission can start at beginning of each slot
 - Slot may contain
 - 0 frames = idle
 - 1 frame = successful transmission
 - 2 frames = collision
5. Carrier Sense
 - Station can detect if channel in use *before* transmission, only attempt to use when idle

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Classes of Multiple-Access Protocol

- Protocols for wired LANs
 - Contention (collisions allowed)
 - Collision free (arbiter decides who can transmit)
- Wavelength Division Multiple Access
 - Dynamic Allocation of WDMA channels
- Wireless LANs protocol
 - Contention-based protocol
 - Need to consider special characteristics of wireless medium

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Collision based protocols

- Various possibilities
 - Carrier sense (CS) / non carrier sense
 - Continuous time / slotted time
 - Collision detect (CD) / non collision detect
 - During transmission, continually check if there is a collision, if this is the case abort transmission immediately

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ALOHA

- Problem:
 - Hawaii: mountainous islands – land network difficult to install
 - Use ground-based packet radio transmission to connect various sites on different islands in Hawaii
 - ALOHA: Elegant solution for channel allocation problem (1970)
 - Completely distributed protocol
 - Inventors of Ethernet were inspired by ALOHA

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Pure ALOHA

- Model: No Carrier Sense, continuous time, no CD
 - Frames of constant size
- Whenever a sender is ready, it immediately sends the entire frame
- If the frame collides it retransmits the frame again (after completely transmitting the collided frame)
 - After collision, wait a random amount of time before attempting to retransmit (Why?)

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Pure ALOHA (cont.)

- Psuedo-code


```

      WHILE connected DO
        generate a frame
      LOOP
        transmit a frame
        IF no collision THEN
          EXIT LOOP
        END
        wait random time
      END
      dispose of frame
      END
      
```

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Slotted ALOHA

- No CS, **Slotted time**, no CD
- As per ALOHA, but frame transmission aligned in time
- Slot width = frame-transmission time
- Halves likelihood of collision
 - Improves throughput

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Slotted ALOHA (cont.)

- Psuedo-code


```

      WHILE connected DO
        generate a frame
      LOOP
        transmit a frame in next slot
        IF no collision THEN
          EXIT LOOP
        END
        wait random time
      END
      dispose of frame
    END
      
```

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Performance Analysis But first ...

- Poisson process
 - Often used as a traffic model
 - telephone calls made per user per unit time
 - customers arriving at Coles checkout
 - frames generated per sender in a given period of time
 - Time between frames/phone calls/customer arrival has exponential distribution
 - Probability of k frames being generated in time interval t is given by **Poisson Distribution**

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Properties of a Poisson Process

- Inter-arrival time has exponential distribution →
 - Poisson Process has "no memory"
 - Probability of k customers/packets in interval T is independent of how many have arrived in any previous interval
- Combination of two Poisson Processes results in a Poisson Process

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Poisson Process

- Probability of k frame transmission attempts within time interval t is:

$$P(t, k) = \frac{e^{-\lambda t} (\lambda t)^k}{k!}$$

λ : "arrival rate", average number of frames arriving (being sent) per second

- To simplify things
 - t = expressed in multiple of frame times
 - Use same notation as in textbook $\lambda \rightarrow G$

$$P(k, t) = \frac{e^{-Gt} (Gt)^k}{k!} \quad (\text{Eq.1})$$

G : average number of transmission attempts per frame time

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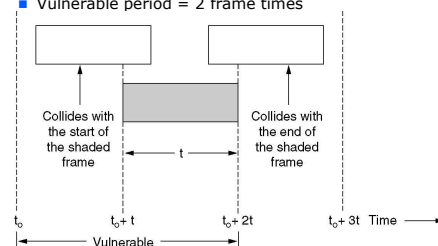
Performance Analysis of ALOHA

- We assume infinite number of stations that generate frames according to a Poisson process
- Aggregate of transmission attempts of all station is also a Poisson process with average # of transmission attempts per frame time G
 - G consists of new transmission attempts AND retransmission of collided frames
 - G : "offered load"
- The actual throughput S is the number of successful frame transmissions per frame time
 - $S = G * P_0$
 - P_0 : probability of success of a frame transmission

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Performance Analysis of ALOHA

- $S = G * P_0$
- P_0 : probability of success of a frame transmission
- P_0 : Probability that no other frame is sent in vulnerable period
- Vulnerable period = 2 frame times



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Performance Analysis of ALOHA

- $S = G * P_0$
- P_0 : Probability that no other frame is sent in time period $t = 2$ frame times
 - Eq.1, $k=0, t=2$ frame times

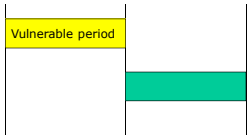
$$P(k=0, t=2) = \frac{e^{-Gt} (Gt)^k}{k!} = \frac{e^{-2G} (2G)^0}{0!} = e^{-2G}$$

- $S = G * P_0 = G * e^{-2G}$
- What's the maximum throughput (channel utilisation) S ?
 - $(G * e^{-2G})' = (1-2G) e^{-2G} = 0 \rightarrow G_{max} = 0.5$
 - $S_{max}(G=0.5) = 0.184$ (channel utilisation of $\sim 18\%$)

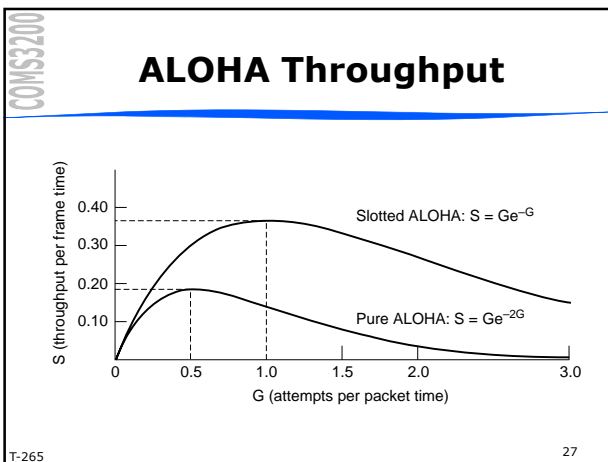
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Performance Analysis of Slotted ALOHA

- Same analysis as for ALOHA
- Only difference: vulnerable period is only 1 frame time instead of 2
- $S = G * P_0 = G * e^{-G}$
- $S(G)$, maximum is achieved for $G=1$
 - $S_{max} = 0.368$ (channel utilisation of $\sim 36\%$)



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ALOHA Performance

- Maximum channel utilisation of ALOHA is only 18%
- No surprise, since stations pay no attention to what other stations are doing
- How can we improve this?

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Carrier Sense Protocols (CSMA)

- CSMA – Carrier Sense Multiple Access
- Carrier Sense
 - Stations on wired local area networks can sense what other stations are doing
 - Can check if channel is being used before transmission
 - If channel in use -> wait
 - Telephone conference example
 - Listen if someone else is talking, if not participant can talk, otherwise wait

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1-Persistent CSMA

- **CS**, continuous time, no CD
- Station waits until channel quiet then immediately transmits *full frame*
- If collision (detected after full frame transmitted)
 - wait random time, repeat
- 1-persistent
 - Transmit with probability 1 when channel quiet
 - Persist with this behaviour, independent of collisions

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1 – Persistent CSMA

- Problem:
 - Assume that station A is transmitting a frame
 - During A's transmission, station B and C become ready to send a frame
 - After A stops sending, they both immediately start sending -> collision

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Non-persistent CSMA

- Also CS, continuous time, no CD
- Less greedy
- Doesn't constantly sense channel
- Senses channel at random intervals
 - Transmits on first quiet sample
- Improved throughput over 1-persistent (fewer collisions)
- Delay at light load is greater

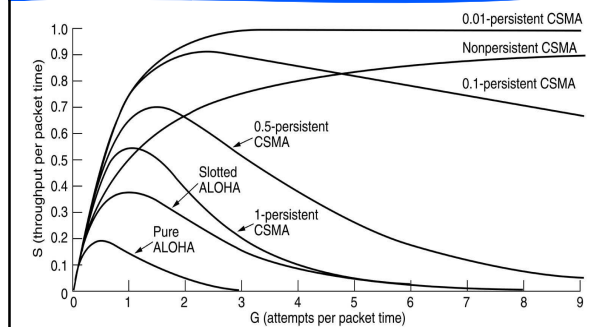
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p-Persistent CSMA

- CS, slotted time, no CD
- Channel sensed at *regular* intervals (not constantly or randomly as before)
- On first quiet sample
 - transmission is with probability p
 - defers to next slot with probability $1-p$
 - If next slot idle, transmits/defers again with probabilities $p, 1-p$
 - In case of a collision, wait a random time and try again

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Performance



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Performance – Discussion

- p-CSMA:
 - Channel utilisation increases with decreasing p
 - Problem: In case of low load, delay increases
- So far
 - If there is a collision, stations still transmit whole (corrupted) frame
 - More efficient to stop sending immediately when collision detected

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CSMA with CD

- During transmission
 - Constantly check if there is a collision
 - How can a collision be detected?
 - If a collision is detected, abort transmission immediately
 - Wait a random amount of time and try again

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COMS3200 CSMA/CD

- When has a station A "seized" the channel?
 - i.e. All other stations know that station A is transmitting a frame and will not interfere
- A starts transmitting at time $t_0=0$
- After transmitting for a time T and not seeing any collision, A can be assured that there was no collision.
 - T=?

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COMS3200 CSMA/CD

- Time for the signal to propagate between the two furthest stations A and B be Δt
- Station A starts transmitting at $t=0$
- Worst case:
 - At time $\Delta t - \epsilon$ station B senses the channel and since it can't sense any signal, starts sending
 - The collision which happens only during interval ϵ takes Δt to travel back to A
- A station needs to wait at least $2 * \Delta t$ to be sure it has the channel
 - station needs to transmit for at least $2 * \Delta t$ to be able to detect collision before station has finished sending the frame → minimum frame size (Ethernet 64 bytes)
- Efficiency of CSMA/CD depends on Δt being small

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COMS3200 States of CSMA/CD

- CSMA/CD can be in one of three states
 - contention
 - transmission
 - idle

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COMS3200 CSMA/CD

- Forms the basis of Ethernet
- Remember – no MAC sub-layer guarantees reliable transmission (even if there are no collisions)
- If reliability is implemented by DLL, it is done by the LLC-layer

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COMS3200 Collision Free Protocols

- Look at CSMA/CD:
 - Collisions avoided once station has unambiguously seized channel, but
 - Contention slots waste time
 - Problem is worse when cable is long → Δt large
- Collision free protocols

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COMS3200 Collision Free Protocols: Basic Bit-map method

- Resolving contention without collision
- Assume N stations (0 ... N-1)
- N slot contention period
 - Station j sends 1 during j 'th slot if it has something to transmit

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Basic Bit-map method (cont.)

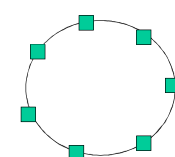
- This is a **reservation protocol**
 - Station broadcasts desire to transmit before actual transmission
- Delay
 - On average, need to wait N slots before can start sending (See Tanenbaum p.260)
- Efficiency
 - Low load (e.g. one transmitter)
 - waste N bits per single frame
 - High load (e.g. all transmitting)
 - waste N bits per N frames
- Does not scale well for large N

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Collision Free Protocols

- Token passing protocols
 - Two collision free protocols standardised
 - IEEE 802.4, IEEE802.5
- Token Ring (IEEE802.5) created by IBM
 - three byte token is passed between stations (ring topology)
 - station which has token may transmit, then passes token on



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Wireless LAN Protocols

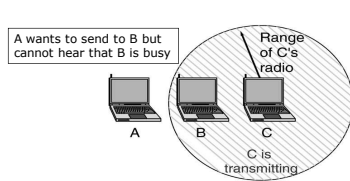
- Use Collision Avoidance (CA) instead of CD
- Once a station starts transmitting a frame, it transmits it completely, even if there is a collision
- Why not use CD like for Ethernet?
 - It's expensive to build wireless hardware that can send and receive on the same frequency at the same time, which is required for CD
 - Hidden station problem

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Hidden Station Problem

- C is transmitting to B, which is within its radio range
- If A senses the medium, it does not hear C (out of range) and assumes the channel is free
- A starts sending to B and the signals from A and C collide at B
 - → Neither A nor C can detect collision
- Collision needs to be detected at receiver, not sender!!
- CS is of limited use. Channel sensing works only for stations within radio range

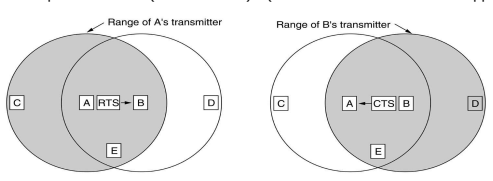


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MACA (Multiple Access with Collision Avoidance)

- Early protocol, no CS, no CD
- Adds mechanism that solves hidden station problem. Idea:
 - Sender makes receiver send a short frame to announce upcoming transmission
 - Nearby stations detect this and will be quiet for the duration for the upcoming transmission
- A wants to send a frame to B
 - A sends RTS (Request to send)
 - B replies with CTS (Clear to send). (Now even D knows what's happening)

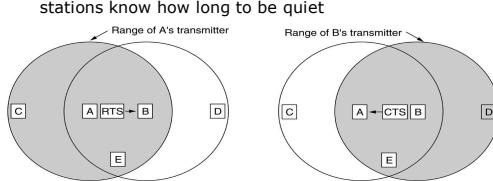


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MACA (Multiple Access with Collision Avoidance)

- Stations that can hear RTS are close to A and must remain silent long enough for CTS to be sent back to A without conflict
- Stations that can hear CTS are close to B and will have to remain silent during upcoming transmission of frame
 - Solves hidden station problem
 - RTS and CTS include length of frame to be sent, so nearby stations know how long to be quiet



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Virtual Channel Sensing (RTS/CTS)

- A wants to send a frame to B. It sends a RTS. B replies with CTS.
- RTS and CTS contain information about length of frame to be sent.
- C sees RTS and calculates Network Allocation Vector (NAV). NAV indicates time for upcoming frame transmission including ACK. C generates virtual channel busy signal. (not transmitted)
- D is out of range of A but sees CTS. It also calculates NAV

The diagram shows a timeline for four nodes: A, B, C, and D. Node A sends an RTS frame. Node B receives it and immediately sends a CTS frame back to A. Node A then sends a Data frame. Node C receives the RTS and calculates a Network Allocation Vector (NAV), represented by a shaded bar. Node D receives the CTS and also calculates a NAV, represented by another shaded bar. The Data frame and ACK frame are shown between A and B. A time axis at the bottom indicates the sequence of events.

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MACAW (MACA for Wireless)

- Fine-tuned version of MACA
 - Uses RTS/CTS (optional in 802.11)
- Adds Carrier sense (CSMA/CA)
 - (Not as effective as in Ethernet because of hidden station problem)
- If channel is busy, wait random amount of time before sensing the channel again → reduces collision (CA)
- Adds Acknowledgements for successfully received frames → increased efficiency

The diagram shows a network topology. A laptop is connected to a cloud labeled 'Internet'. The cloud is connected to a 'Wireless Access Point'. The Access Point is connected to a 'Wireless link' which leads to another laptop.

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Wireless LANs

- We will come back to this later...

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IEEE 802 LAN Standards

- Several standards for LANs/MANs
 - Ethernet (802.3)
 - WLAN (802.11)
 - Bluetooth (802.15)
 - WiMAX (Broadband wireless) (802.16)
 - check Fig. 1-38 for other standards
- IEEE 802 standards cover
 - Data-link layer
 - link-control
 - medium access
 - Physical layer
- Some adopted by ANSI, ISO, NIST, ...

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IEEE 802 Standards

Several documents

- 802.1 - Introduction
- 802.2 - LLC (Logical Link Control) layer
- 802.3 - CSMA/CD
- 802.11 - WLAN
- 802.15 - Bluetooth

| | | | | | |
|------------------|--------------|--------|--------|----------------------------|-----------------------------|
| | 802.2 | | | | |
| OSI Data Link | 802.3 | 802.11 | 802.15 | Logical Link Control (LLC) | Medium Access Control (MAC) |
| OSI Physical | | | | Physical | |

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802.3 - History

- Early 70's - Xerox PARC, Metcalfe and Boggs built a 2.94Mbps CSMA/CD network
 - 100 workstations
 - 1km cable
 - called "Ethernet"
 - published 1976
- 1979-1982 - DEC, Intel, Xerox standardised 10Mbps "thick-wire" Ethernet
 - later known as 10base5
 - "base" refers to baseband transmission
- 1983 - IEEE defined a standard for a CSMA/CD protocol
 - very similar to Ethernet

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802.3 – Standards

- 802.3 (1983) – **10Base-5** – original (thick) Ethernet
 - Thick coaxial cable
- 802.3a (1985) – **10Base-2** – thin Ethernet
 - "Cheapernet" – thinner cheaper coax.
- 802.3i (1990) – **10Base-T** – 10Mbps over Cat 3 UTP or Cat 5 UTP
- 802.3u (1995) – **100Base-T**
 - "Fast Ethernet"
 - several media supported (Cat-5 UTP, Optical Fibre)
- 802.3z (1998) – **1000Base-T**
 - "Gigabit Ethernet"
 - several media supported
- 802.3ae (2002) – **10-Gigabit Ethernet**
- 802.3ba (2010) **40 and 100-Gigabit Ethernet**

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10base5 topology

- "Yellownet"
- Cable is a broadcast medium
- max segment length - 500m
- max 5 segments connected by 4 repeaters
 - Why limit?

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10base2 topology

- max segment length - 185 m (~200m)
- max 5 segments connected by 4 repeaters
- max 30 stations per segment
- Problem of bus topology?

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10base-T topology (hierarchical Ethernet)

- Stations connected to repeaters (hubs)
- Topology: Star (hierarchy)
- Hubs create one collision domain
- max hub-station distance is 100 m
- max 4 hubs between any two stations

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Ethernet Cabling

(a) 10Base5, (b) 10Base2, (c) 10Base-T (Hubs and Switches).

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Ethernet Switching

- Today, 10Base5, 10Base2 and 10Base-T with Hubs is replaced almost entirely by Ethernet Switching
 - Mainly historical relevance
- Breaks one collision domain into several isolated domains
 - if hubs still present in the network
 - No collisions if networks has switches only

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