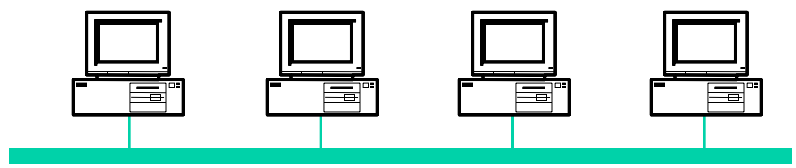
COMP/ELEC 429/556
Introduction to Computer Networks

Broadcast network access control

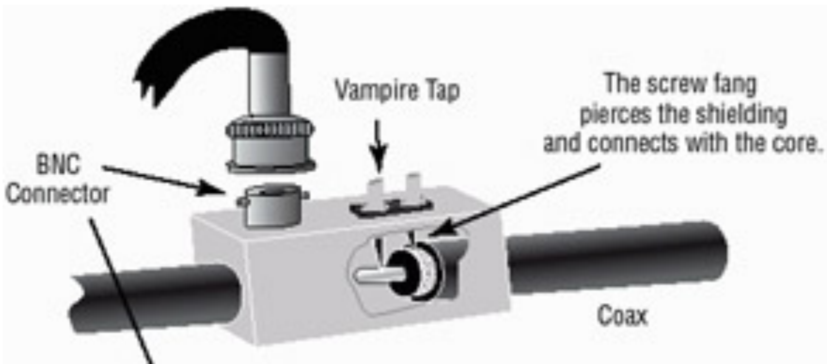
Some slides used with permissions from Edward W. Knightly, T. S. Eugene Ng, Ion Stoica, Hui Zhang

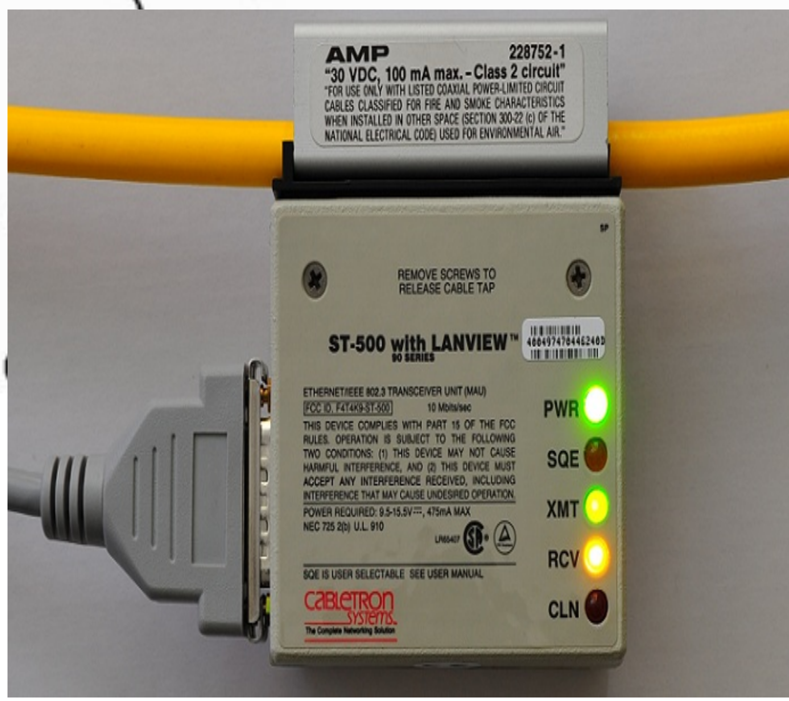
Let's Begin with the Most Primitive Network

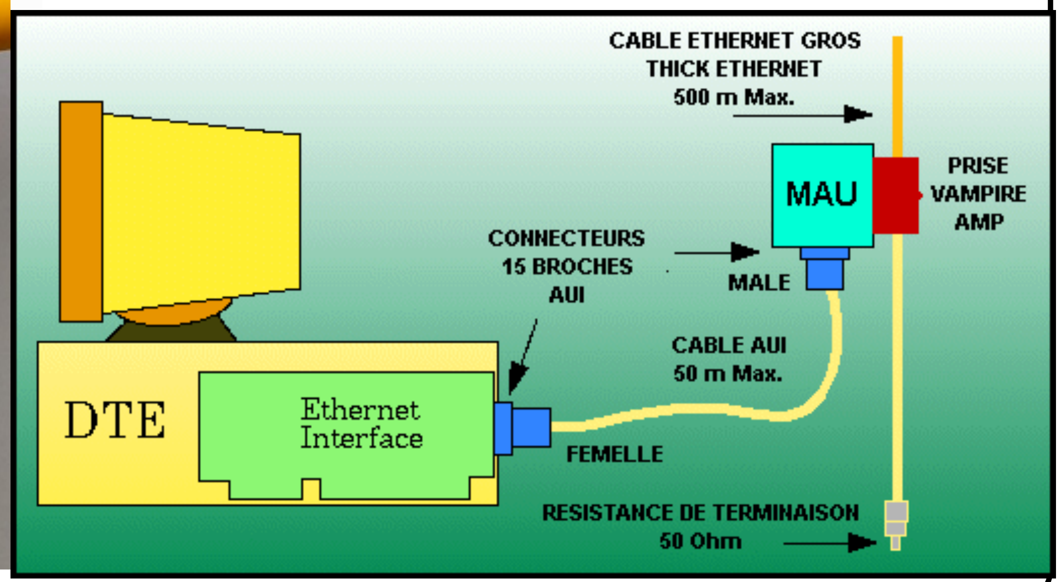


500 meters

Good Old 10BASE5 Ethernet (1976)

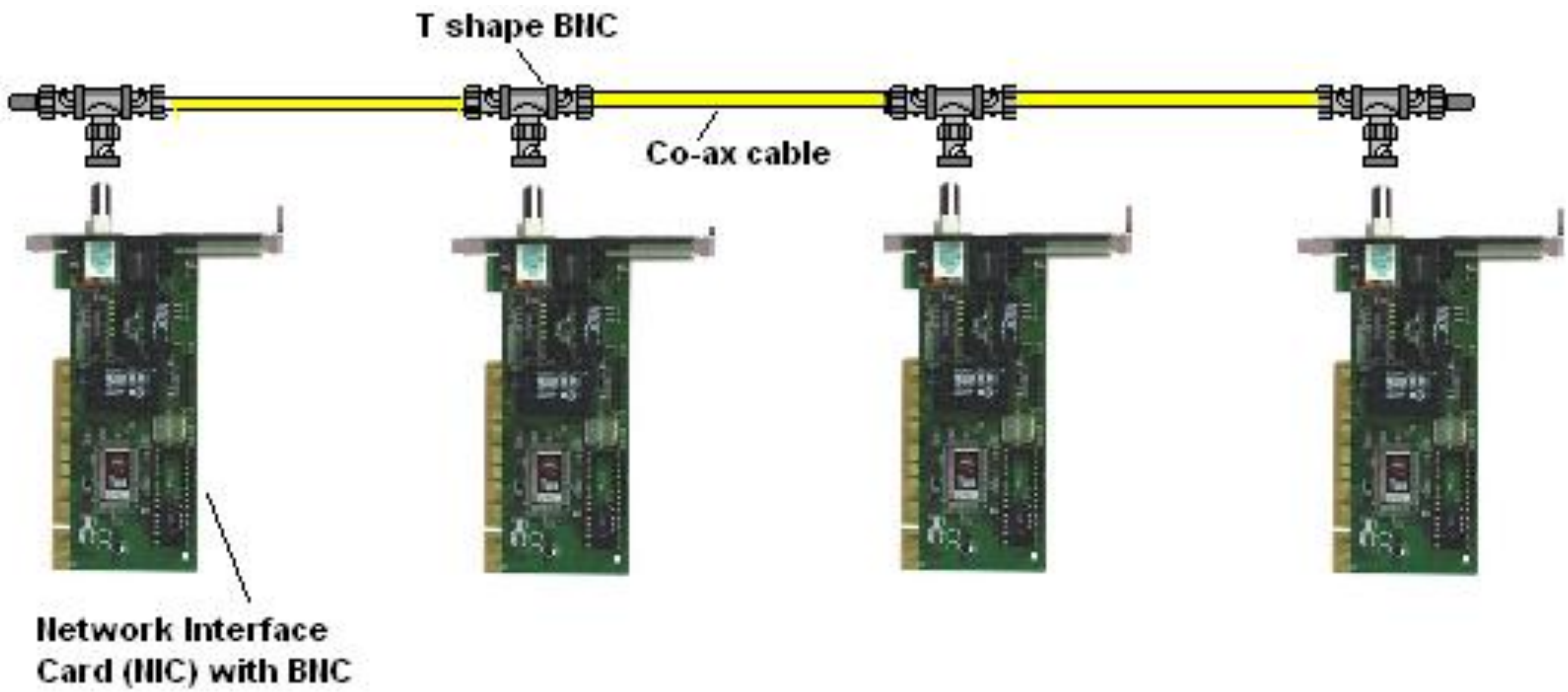






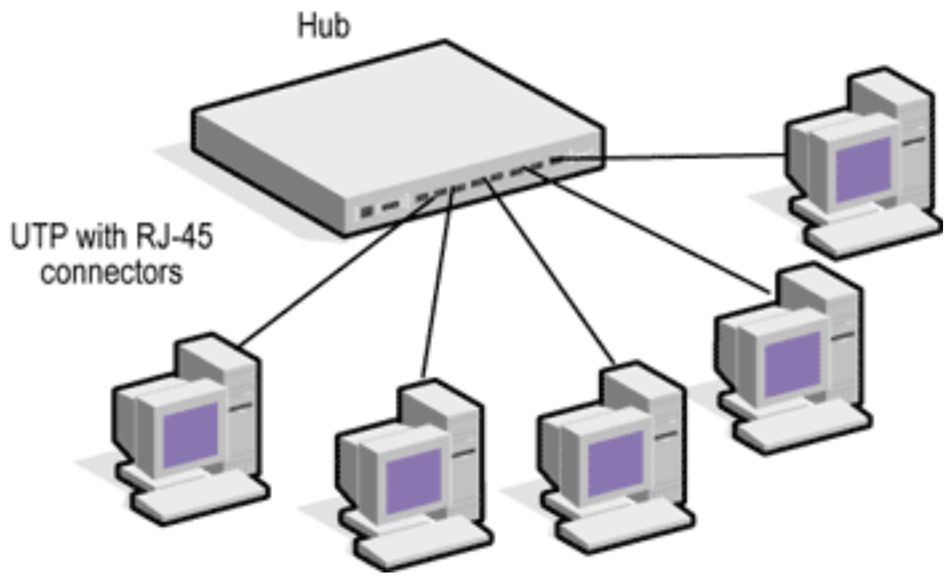
Then Came 10BASE2 Ethernet (1980s)

200 meters



Twisted pair, 100 meters

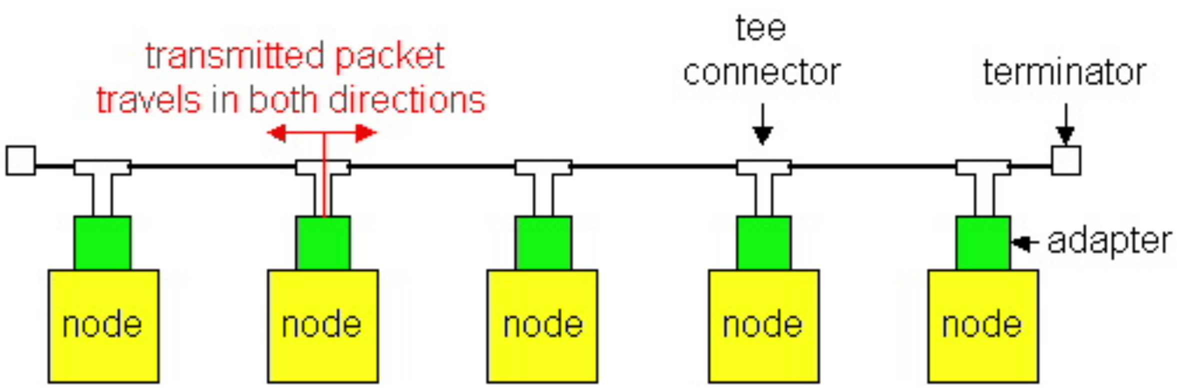
Then Came 10BASE-T Ethernet (1990)



More: 100BASE-TX, 1000BASE-T
At >= 10Gbit/s, broadcast no longer supported.

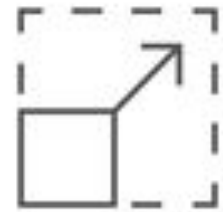
Overview

- Ethernet (< 10Gbps) and Wi-Fi are both "multi-access" technologies
  - Broadcast medium, shared by many nodes/hosts
- Simultaneous transmissions will result in collisions
- Media Access Control (MAC) protocol required
  - Rules on how to share medium



Media Access Control Strategies

- Channel partitioning
  - Divide channel into smaller "pieces" (e.g., time slots, frequencies)
  - Allocate a piece to each host for exclusive use
  - E.g. Time-Division-Multi-Access (TDMA) cellular network



- Taking-turns
  - Tightly coordinate shared access to avoid collisions
  - E.g. Token ring network

- Contention
  - Allow collisions
  - "Recover" from collisions
  - E.g. Ethernet, Wi-Fi

Contention Media Access Control Goals

- To share medium
  - If two hosts send at the same time, collision results in no packet being received
  - Thus, want to have only one host to send at a time
- Want high network utilization
- Want simple distributed algorithm

- Take a walk through history
  - ALOHAnet 1971
  - Ethernet 1973
  - Wi-Fi 1997

ALOHAnet (Necessity is the mother of invention)

- **Topology:** Broadcast medium with multiple hosts
- **Aloha Protocol:**
  - Whenever a host has a packet to send, it transmits the packet immediately
  - The receiver acknowledges the packet immediately
  - No ACK = collision. Wait a random time and retransmit

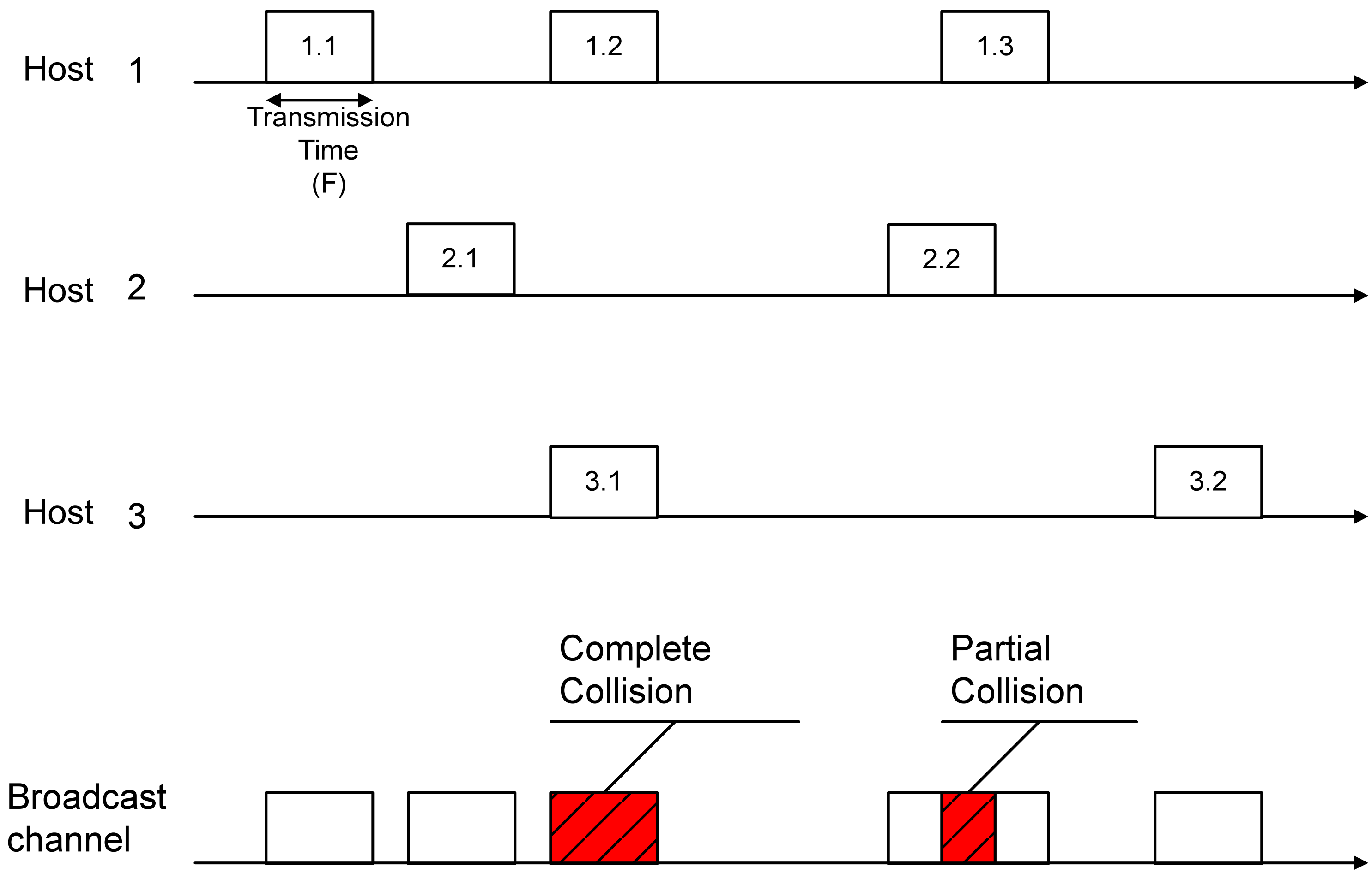
Simple, but radical at the time

- Previous attempts all partitioned channel
  - TDMA, FDMA, etc.
- Aloha optimized for the common case (few senders) and dealt with collisions through retries

Trade-off Compared to TDMA

- In TDMA, you always have to wait your turn
  - delay proportional to number of hosts
- In Aloha, a host can send immediately
- Aloha gives much lower send delay, at the price of lower maximum utilization (as we will see)

Collisions in ALOHA



Performance of ALOHA

- **Performance questions:**
  - What is the collision probability?
  - What is the maximum throughput?
- **Notation:**

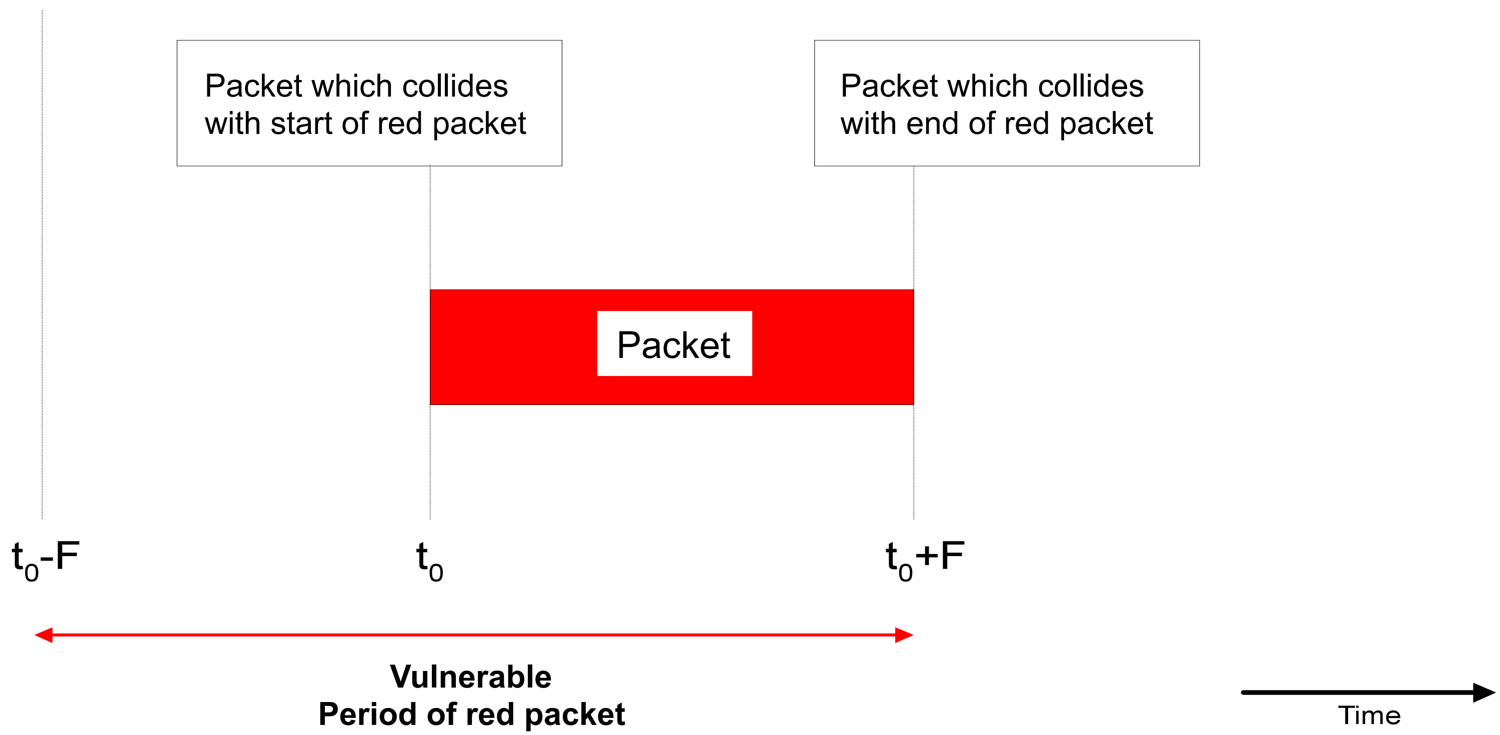
  C: link bandwidth (bits/sec)

  s: packet size (bits)

  F: packet transmission time (sec)

$$F = \frac{s}{C}$$

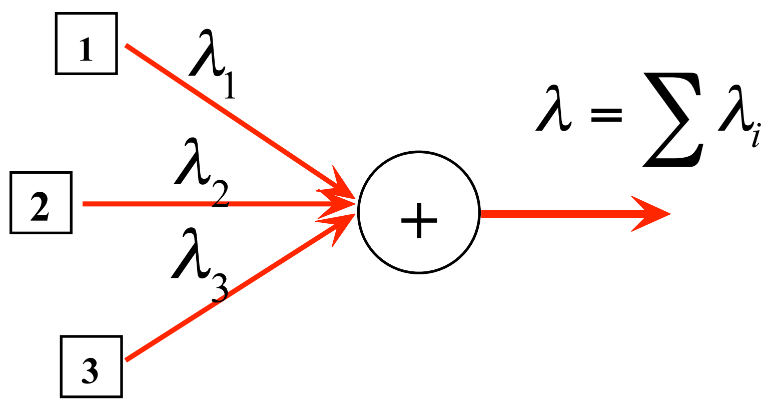
Collisions and Vulnerable Period



- A packet will be in a collision if and only if another transmission begins in the vulnerable period of the packet
- Vulnerable period has the length of 2 packet transmission times

Traffic Model

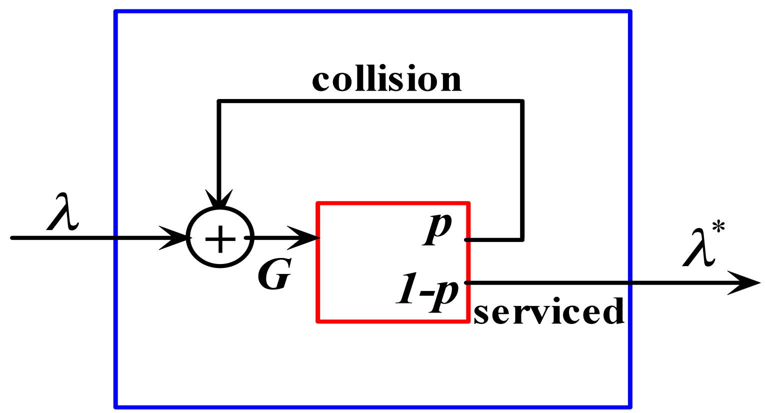
Assume each host sends packets according to a Poisson process at average rate λ_i packets per second



$\lambda \equiv$ Aggregate average packet rate from all hosts (Poisson processes are additive)

$$P[no\_frame\_sent\_in\_t] = e^{-\lambda t}$$

System Model

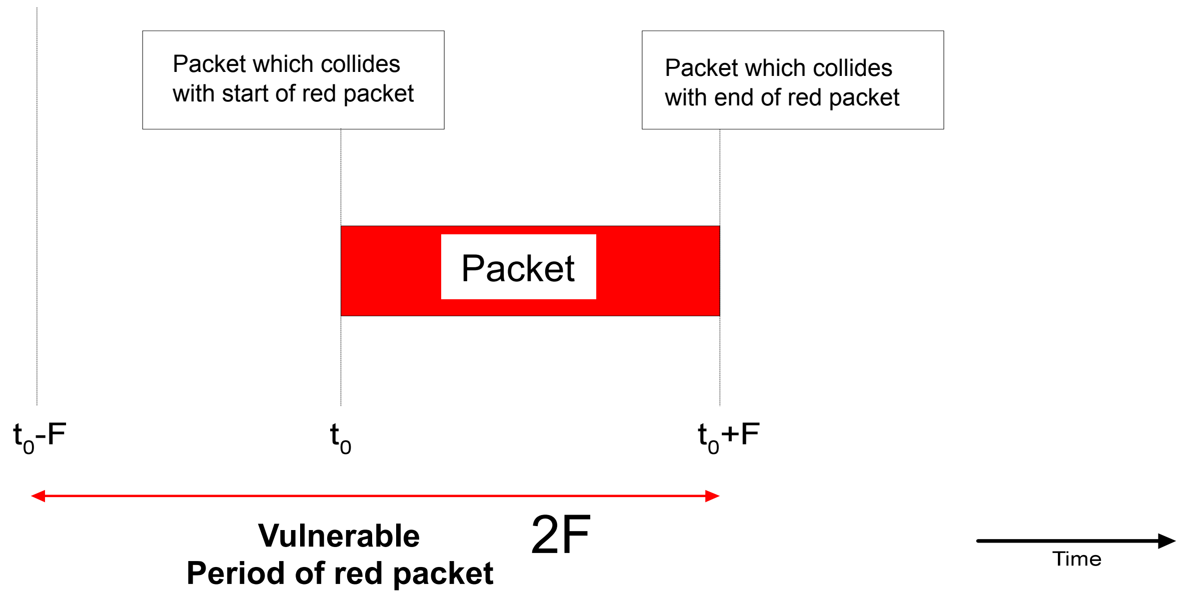


$p \equiv$ Probability of collision

$G \equiv$ Actual average packet rate carried including retransmissions

$$\Rightarrow G = \lambda + pG$$

Probability of Collision



Recall that if Poisson events occur at rate λ,

$$P(\text{no event in T seconds}) = e^{-\lambda T}$$

$$p = P(some\_frame\_sent\_in < 2F) = 1 - e^{-G2F}$$

Throughput and Total Carried Load

$$p = 1 - e^{-2FG}$$

$$G = \lambda + pG \quad \Rightarrow \quad \lambda = Ge^{-2FG}$$

$$F\lambda = FGe^{-2FG}$$

$$R(\text{normalized total carried load}) = \frac{G}{C/s} = FG$$

$$\rho\ (\text{normalized offered load}) = \frac{\lambda}{C/s} = F\lambda$$

$$\Rightarrow \qquad \rho = \mathrm{Re}^{-2R}$$

If stable, all offered traffic is serviced, and ρ is also the throughput.

Maximum Throughput

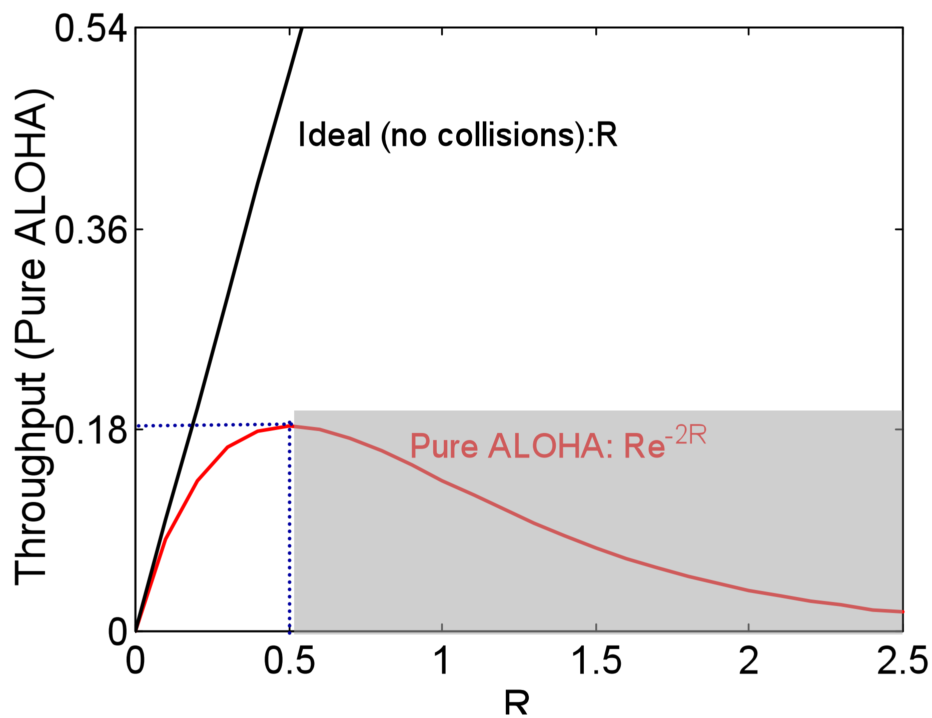
Maximum achievable throughput:

$$\frac{d\rho}{dR} = 0 \Rightarrow R(-2e^{-2R}) + e^{-2R} = 0 \Rightarrow R = \frac{1}{2}$$

$$\rho_{\max} = \frac{1}{2}e^{-1} \approx 0.18$$

Observe: if offered load > .18*C, unstable

Performance of ALOHA (assume Poisson arrival)

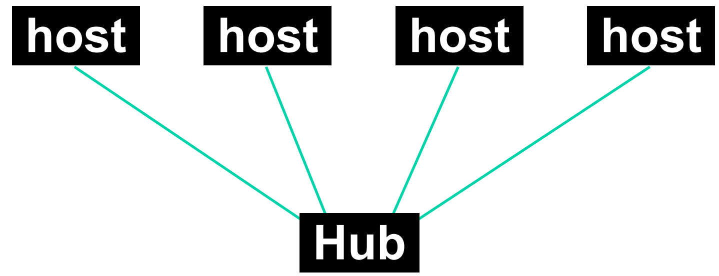


- Maximum throughput approximately 18% of the capacity
- However, ALOHA is still used for its simplicity
  - 3G phone call establishment

Wireline Network: 802.3 Ethernet

Bob Metcalfe named it after the disproven luminiferous ether as an "omnipresent, completely-passive medium for the propagation of electromagnetic waves"

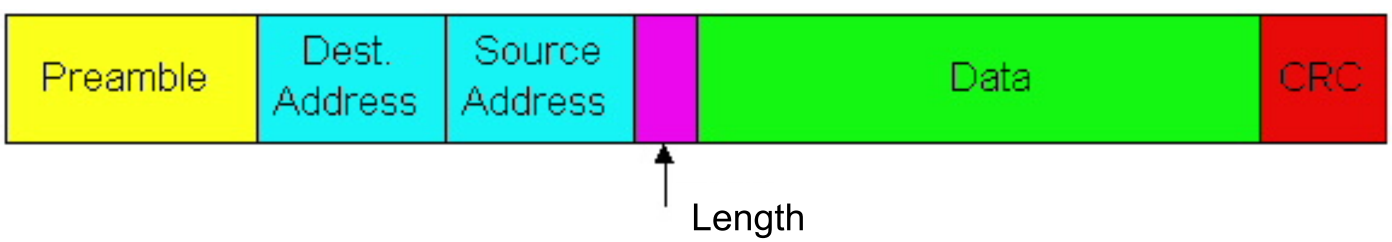
Broadcast technology



- Carrier-sense multiple access with collision detection (CSMA/CD).
  - MA = multiple access
  - CS = carrier sense
  - CD = collision detection

Ethernet Packet Structure

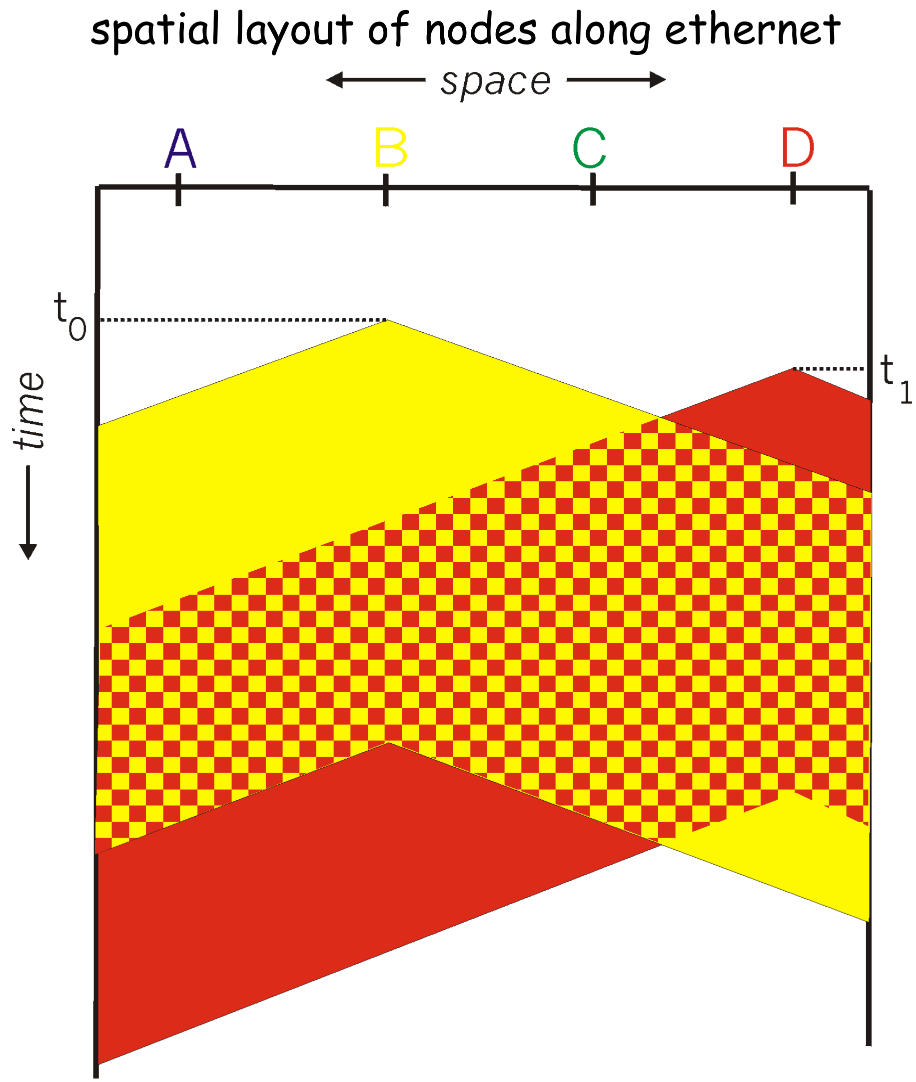
- Preamble:
  - 7 bytes with pattern 10101010 followed by one byte with pattern 10101011
  - Used to synchronize receiver, sender clock rates
- Addresses: 6 bytes, a packet is received by all adapters on a shared Ethernet and dropped if address does not match
- Length: 2 bytes, length of actual data
- CRC: 4 bytes, checked at receiver, if error is detected, the packet is simply dropped
- Data payload: maximum 1500 bytes, minimum 46 bytes
  - If data is less than 46 bytes, pad with zeros to 46 bytes



CSMA/CD Algorithm

- Sense for carrier
  - i.e. an on-going transmission
- If carrier present, wait until carrier ends
  - Sending now would force a collision and waste time
- Send packet and sense for collision
- If no collision detected, consider packet delivered
- Otherwise, abort immediately, perform “exponential back off” and send packet again
  - Start to send at a random time picked from an interval
  - Length of the interval increases with every retransmission

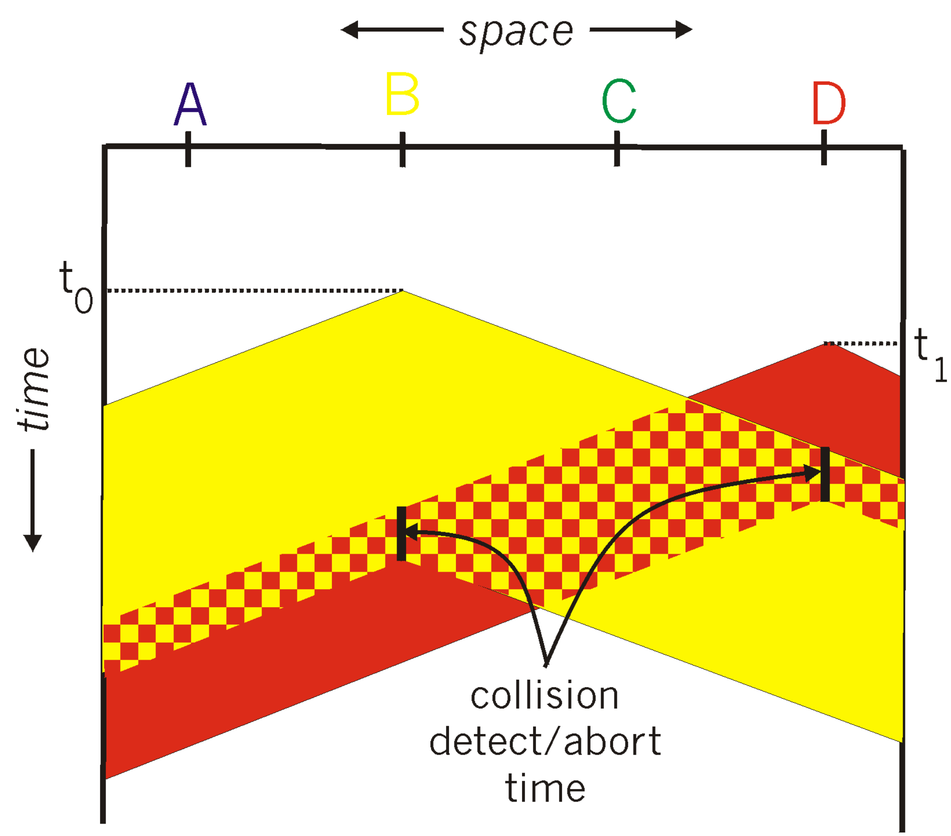
Collision Example



CSMA/CD (Collision Detection)

- Collision detection easy in wired Ethernet:
  - compare transmitted and received signals
- Colliding transmissions aborted, reducing channel wastage

Collision detection



Minimum Packet Size

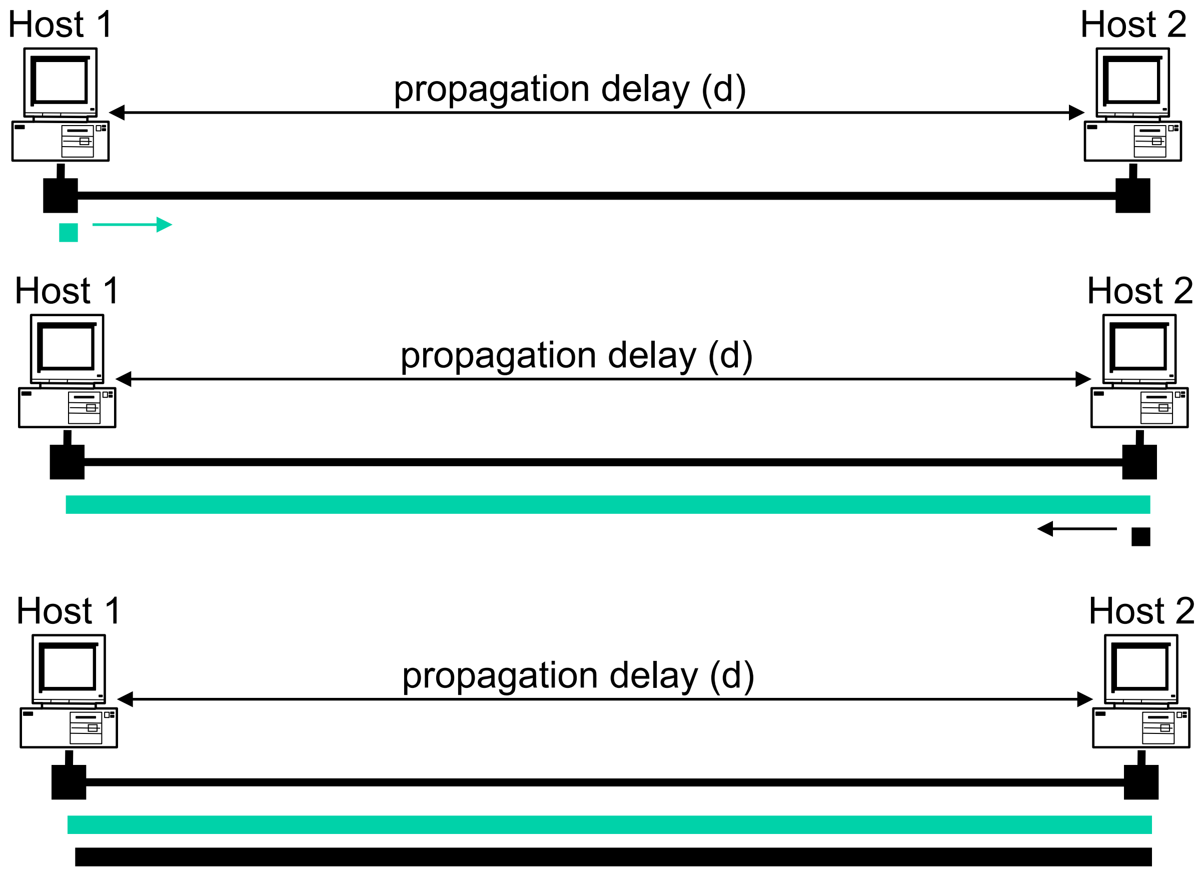
- Why require a minimum packet size?
- To give a host enough time to detect collisions
- In Ethernet, minimum packet size = 64 bytes (two 6-byte addresses, 2-byte type/length, 4-byte CRC, and 46 bytes of data)
- If host has less than 46 bytes to send, the adaptor pads (adds) bytes to make it 46 bytes
- What is the relationship between minimum packet size and the length of the Ethernet?

Minimum Packet Size & Network Length

a) Time = t; Host 1 starts to send packet

b) Time = t + d; Host 2 starts to send a packet just before it hears Host 1's packet

c) Time = t + 2*d; Host 1 hears Host 2's packet → detects collision



Network length <= (min_packet_size)*(propagation_speed)/(2*bandwidth) = = $(8*64b)*(2.5*10^8 mps)/(2*10^7\ bps)$ = 6400m approx

Exponential Backoff Algorithm

- Ethernet uses the exponential backoff algorithms to determine when a station can retransmit after a collision

Algorithm:

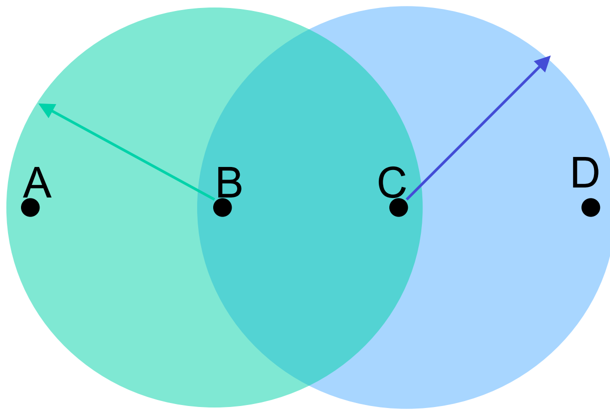
- Set “slot time” equal to 512bit time
- After first collision wait 0 or 1 slot times
- After i-th collision, wait a random number between 0 and 2^i-1 time slots
- Do not increase random number range, if i=10
- Give up after 16 collisions

802.3 Ethernet vs 802.11 Wi-Fi

- Ethernet: one shared “collision” domain
- 802.11: radios have small range compared to overall system: collisions are local
  - collisions are at receiver, not sender
  - carrier-sense plays different role
- CSMA/CA not CSMA/CD
  - collision avoidance, not collision detection

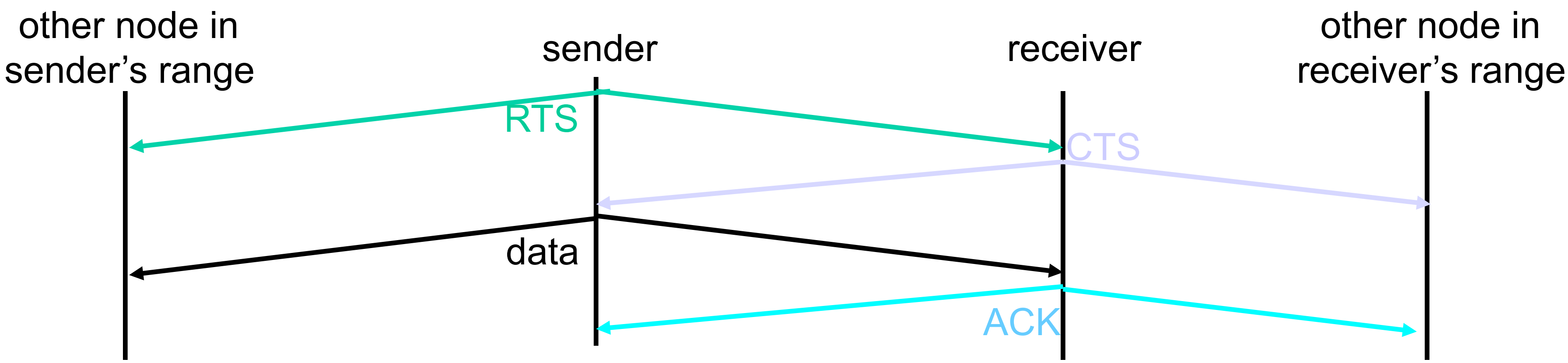
Collision Avoidance: The Problems

- Reachability is not transitive: if B can reach C, and C can reach D, it doesn't necessary mean that B can reach D



- Hidden node: A and C send packets to B; neither A nor C will detect the collision!
- Exposed node: B sends a packet to A; C hears this and decides not to send a packet to D, despite the fact that sending it will not cause interference at A or D!

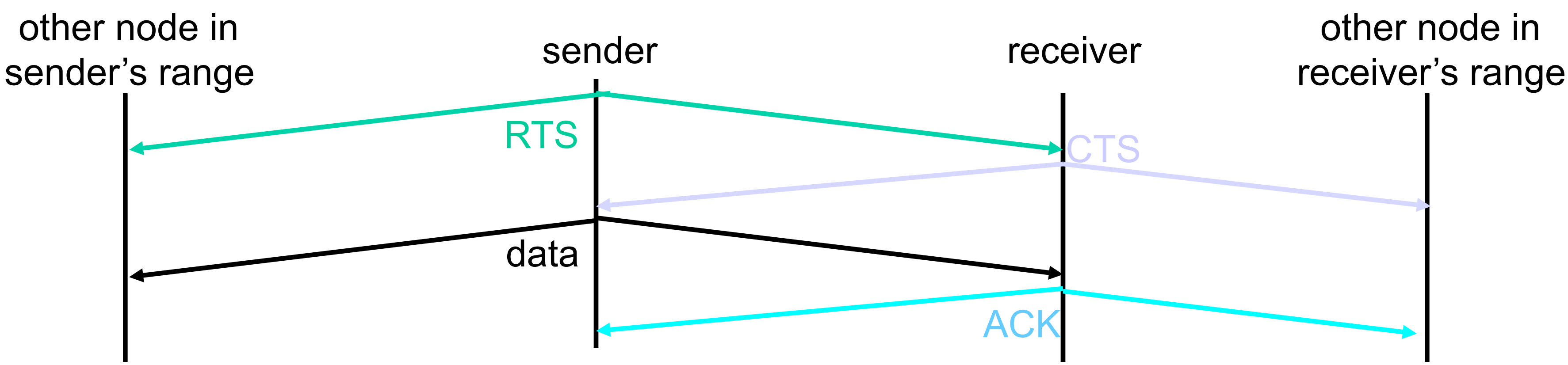
Multiple Access with Collision Avoidance (MACA)



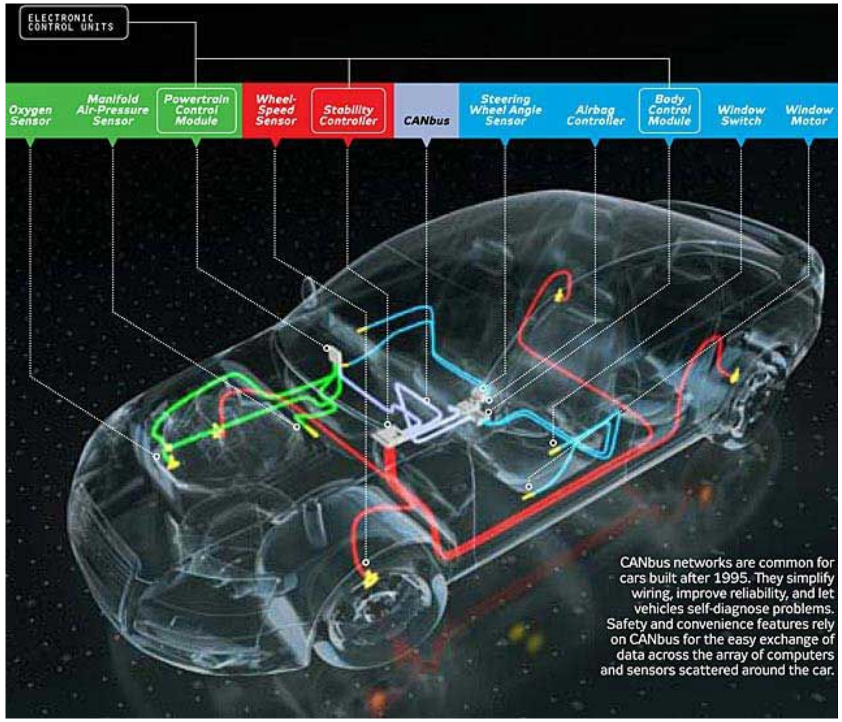
- Before every data transmission
  - Sender sends a Request to Send (RTS) packet containing the length of the transmission
  - Receiver respond with a Clear to Send (CTS) packet
  - Sender sends data
  - Receiver sends an ACK; now another sender can send data
- When sender doesn't get a CTS/ACK back, it assumes collision

Other Nodes

- When you hear a CTS, you keep quiet until scheduled transmission is over, that is you hear the ACK
- If you hear a RTS, but not the CTS, you can send
  - interfering at source but not at receiver



What about the Tesla?



	Start Bit	ID Bits											The Rest of the Frame
		10	9	8	7	6	5	4	3	2	1	0	
Node 15	0	0	0	0	0	0	0	0	1	1	1	1	
Node 16	0	0	0	0	0	0	0	1	Stopped Transmitting				
CAN Data	0	0	0	0	0	0	0	0	1	1	1	1	

Wrap up

- A glimpse of the many challenges and ideas in broadcast network access control
- Wireless network access control is still an area for active research
  - Many requirements such as power efficiency, low delay, high transmission success rate, etc.