MIEEC

Computer Networks

Lecture note 6

Medium access control

© R. MORLA 2011

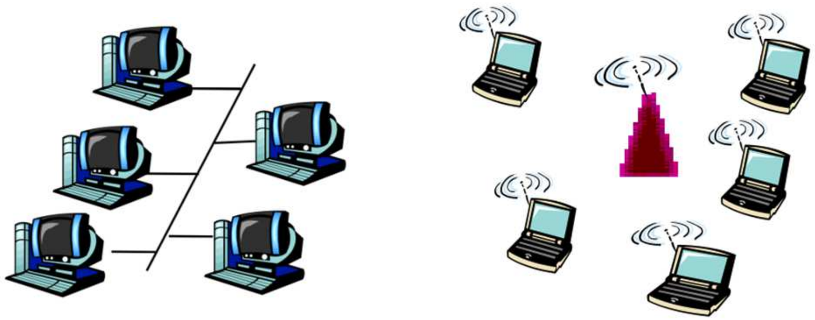
Medium Access Control

© R. MORLA 2011

Link access: single vs. multiple

- Point-to-point links
  - RS-232
  - Modem, dial-up link
  - Link between Ethernet switch and host

- Broadcast links
  - Initial Ethernet
  - 802.11 Wireless LAN



© R. MORLA 2011

TO THINK

- How do you coordinate stations to access a shared medium?

  - How does this relate to statistical multiplexing and queuing?

© R. MORLA 2011

Ideal multiple access protocol

- Goal
  - Coordinate stations to use R bit/s shared broadcast channel
  - One station wants to transmit => uses R bit/s
  - m stations want to transmit => use R/m bit/s on average
- Requirements
  - Decentralized
  - No coordination
  - No clock synchronization
  - Simple

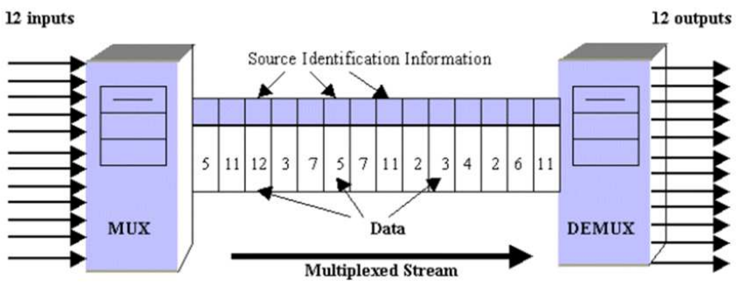
© R. MORLA 2011

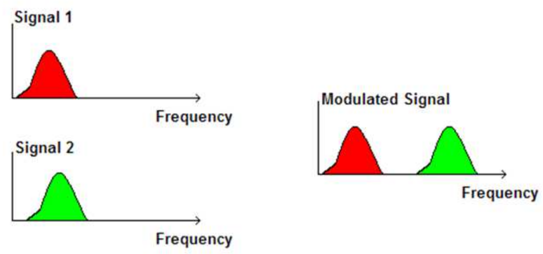
Classes of MAC protocols

- Channel partitioning
  - TDM - Time division multiplexing
  - FDM - Frequency division multiplexing
- Taking turns
  - Now it's my turn, now it's your turn
  - TDM?
- Random access
  - Collisions allowed

© R. MORLA 2011

TDM/FDM channel partitioning

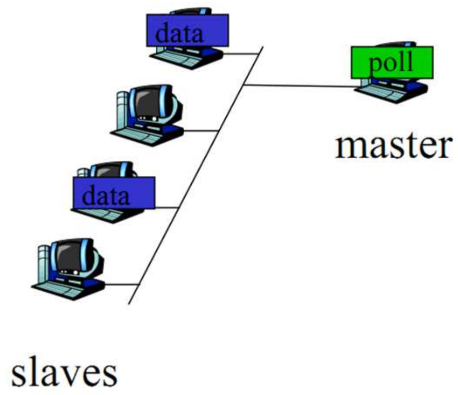




- From requirements
  - Decentralized?
  - Clock synchronization? TDM vs. FDM
  - Simple?
- Why don’t we use it?
  - Flexibility

© R. MORLA 2011

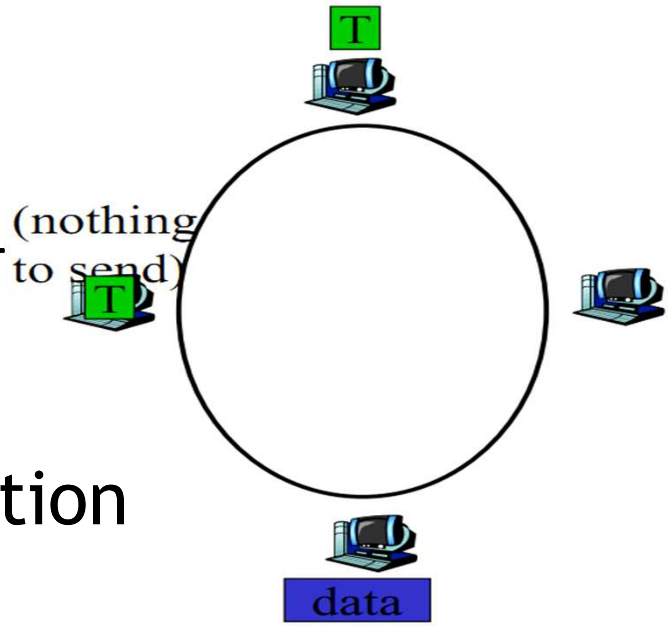
Taking turns 1: Polling



- Master station
  - Asks other stations to transmit in turns
  - One or more times every round, same/different bandwidth for different clients
- Concerns
  - Polling overhead
    - need to ask even if nothing to transmit
  - Latency
    - Need to wait for your turn
  - Master: single point of failure

© R. MORLA 2011

Taking turns 2: Token passing



- Control token
  - Its possession defines the station that can transmit
  - Token is passed sequentially from one station to the next
- Concerns
  - Token overhead
  - Latency
  - Token single point of failure

© R. MORLA 2011

Random Access

- No a priori coordination
  - Station transmits packet when it has a packet to send
  - At channel rate R
- Two or more stations transmit simultaneously
  - Collision
- Random access MAC defines:
  - When to send packets
  - How to detect collisions
  - How to recover from collisions
- Aloha, CSMA, CSMA/CD, CSMA/CA

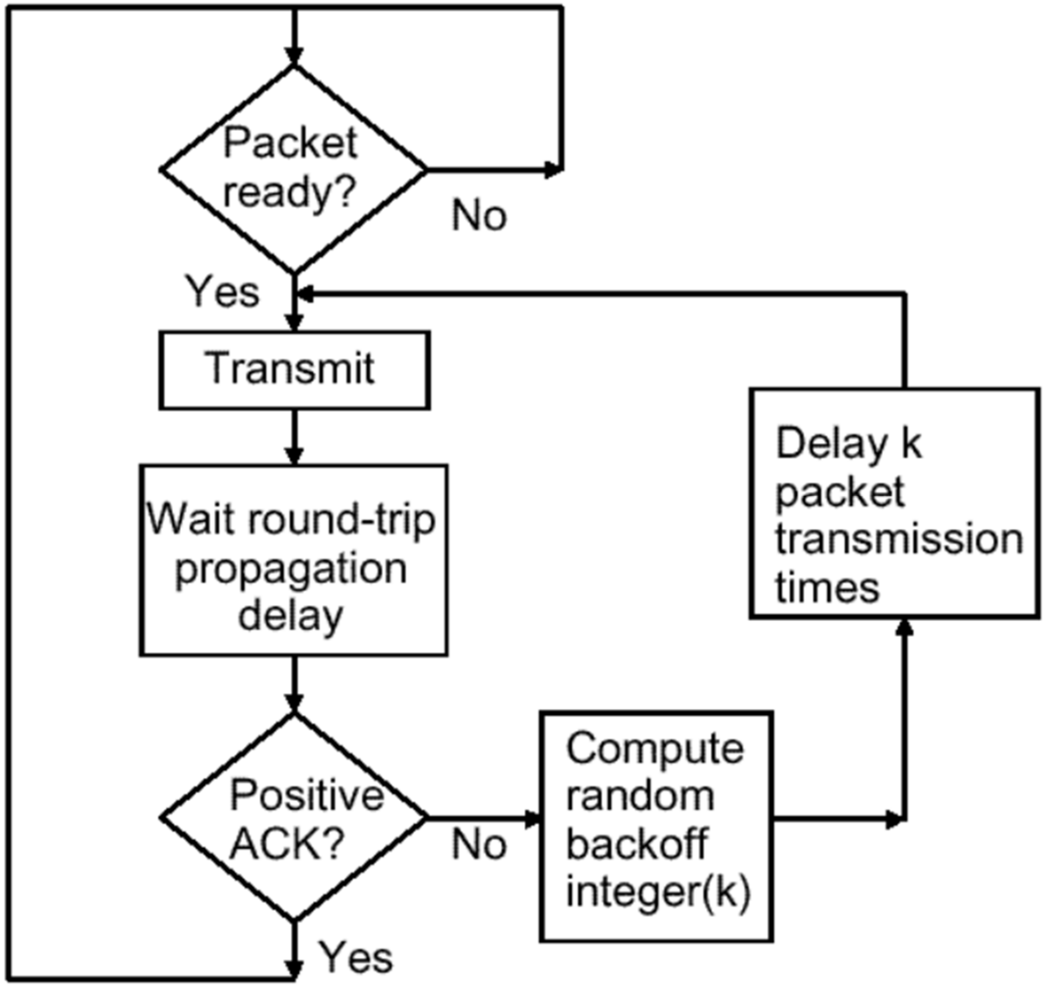
© R. MORLA 2011

MAC Concepts

- Traffic source
  - One frame transmitted at a time
  - Probability of 1 frame being transmitted in δ : $p_1(\delta) \sim \lambda\delta$
  - Poisson arrival
- Collision if two stations transmit at same time
  - Frame retransmission (how?)
- Continuous time vs. slotted time
  - Continuous: frame can be transmitted at any time
  - Slotted: frame must be transmitted at the beginning of slot
- Carrier sense vs. no carrier sense
  - Sensing: station can know if medium is busy before sending

© R. MORLA 2011

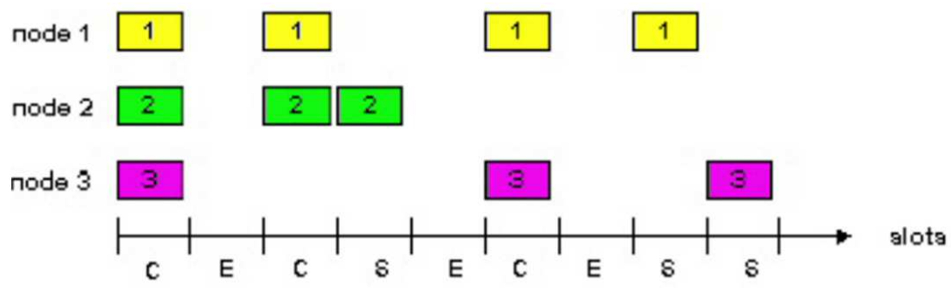
ALOHA



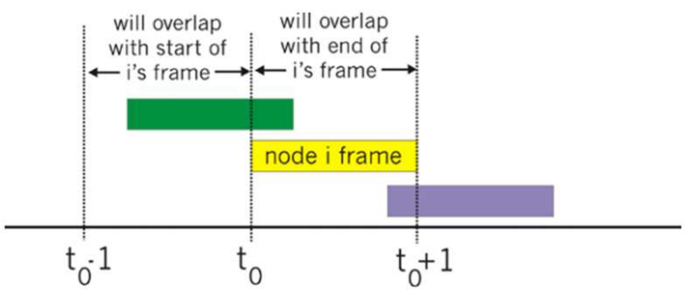
© R. MORLA 2011

Slotted vs. un-slotted ALOHA

- Slotted
  - $T_{slot} = T_{frame}$
  - Transmissions and retransmissions at beginning of slot



- Un-slotted
  - Stations transmit when they have frame to send



© R. MORLA 2011

Traffic model

- Poisson arrival, large number of stations N
- Constant frame length, $T_{frame} = 1$

- S: received traffic
  - λ_{rx} : rate of received frames, i.e. transmitted with success
  - $S = \lambda_{rx} * T_{frame} < 1$; S::efficiency

- G: generated traffic
  - λ: rate of transmitted frames
  - $G = \lambda * T_{frame} = Np$
  - p – probability of one station generating a frame in T_{frame} (new or retransmission)

© R. MORLA 2011

Slotted ALOHA: Efficiency

$p_0(t) = e^{-\lambda t}$
G: generated traffic
S:efficiency

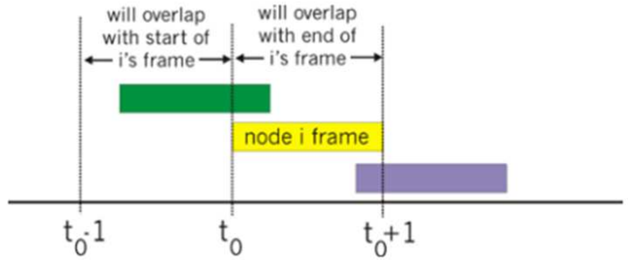
- $S = P(Success) = N(p(1-p)^{N-1})$
$$\sim Npe^{-p(N-1)} \sim Npe^{-pN} =$$
$$= Ge^{-G} = Gp_0(T_{frame})$$
- $S_{max} \Rightarrow \frac{\delta S}{\delta G} = 0 \Rightarrow G = 1; S_{max} = \frac{1}{e} \sim 36.8\%$

© R. MORLA 2011

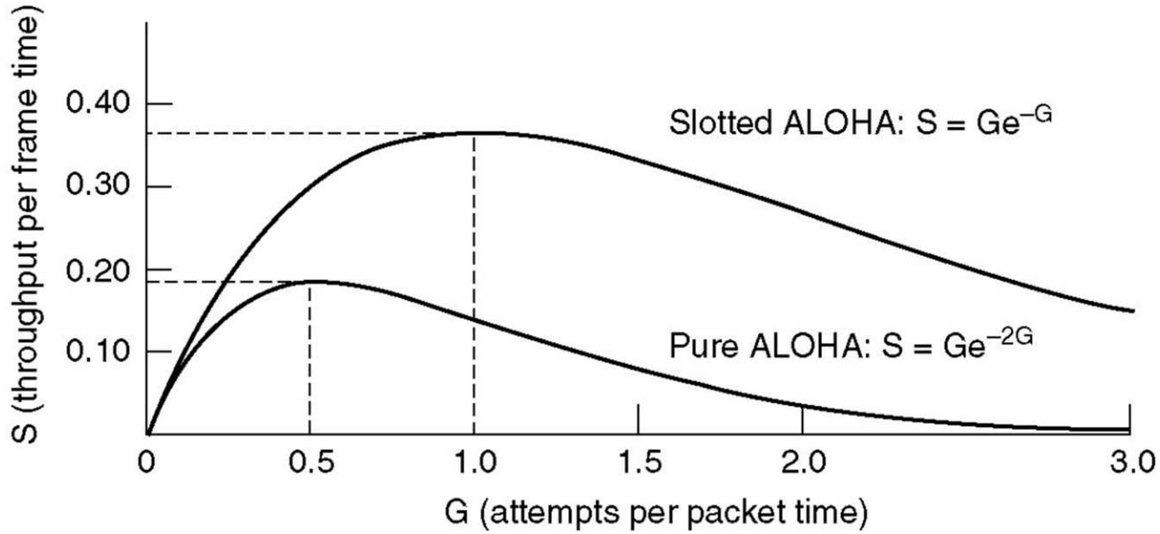
ALOHA: Efficiency

G: generated traffic
S:efficiency

- $S = Gp_0(2 * T_{frame}) = Ge^{-2G}$



- $S_{max} \Rightarrow \frac{\delta S}{\delta G} = 0 \Rightarrow G = \frac{1}{2}; S_{max} = \frac{1}{2e} \sim 18.4\%$



© R. MORLA 2011

ALOHA vs. TDM

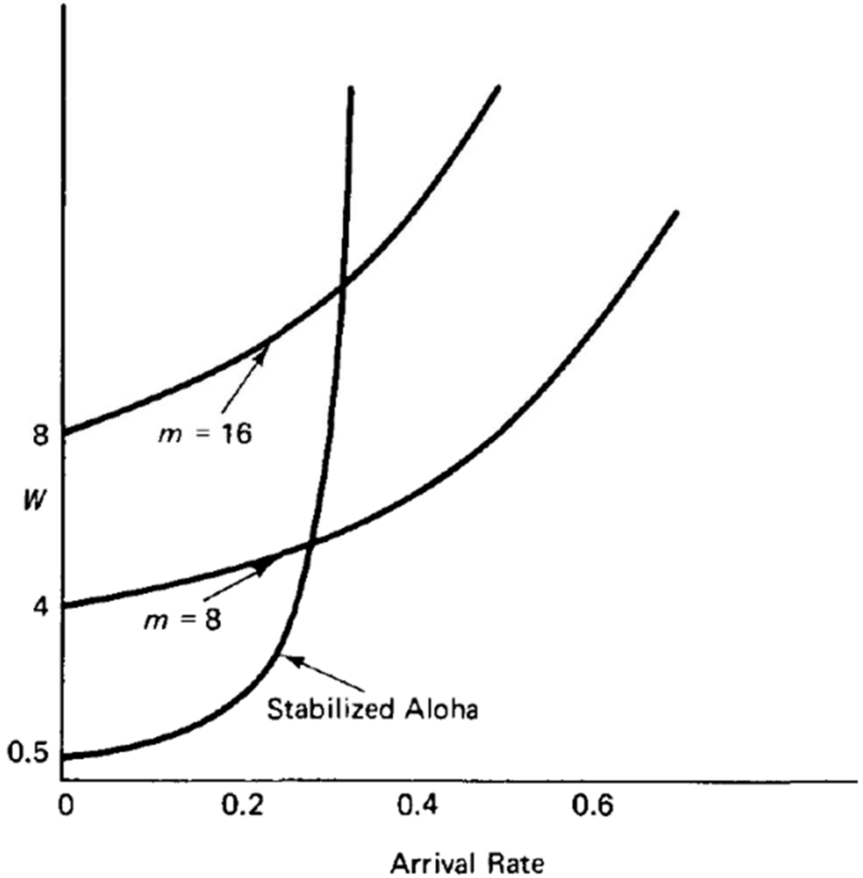


Figure 4.6 Comparison of expected waiting time W in slots, from arrival until beginning of successful transmission, for stabilized Aloha and for TDM with $m = 8$ and $m = 16$. For small arrival rates, the delay of stabilized Aloha is little more than waiting for the next slot, whereas as the arrival rate approaches $1/\epsilon$, the delay becomes unbounded.

© R. MORLA 2011

CSMA
Carrier Sense Multiple Access

- Logic: don't interrupt others

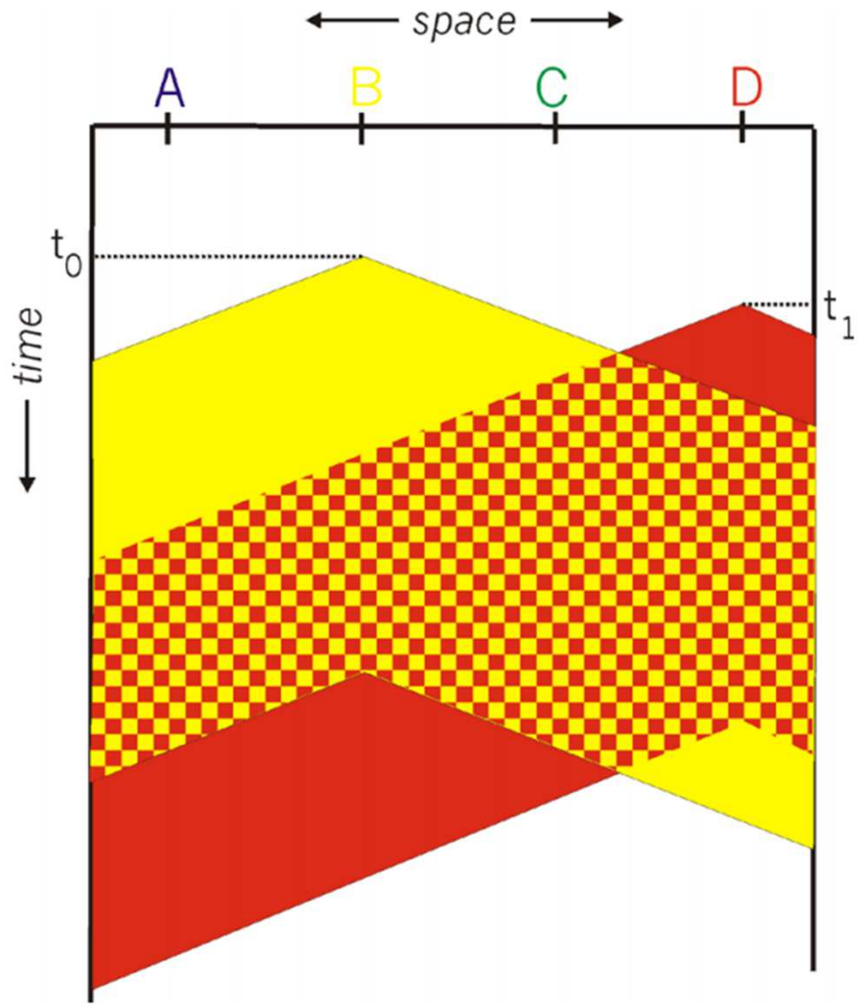
- Listen to the medium before transmitting
  - If free: transmit frame
  - If busy: defer transmission

- What if others start transmitting at the same time?

© R. MORLA 2011

CSMA collisions

- Propagation delay
  - Stations may hear others too late
- Vulnerability time
  - $2 * T_{prop}$
  - Entire packet is lost
- Collision probability
  - $a = \frac{T_{prop}}{T_{frame}} \ll 1$



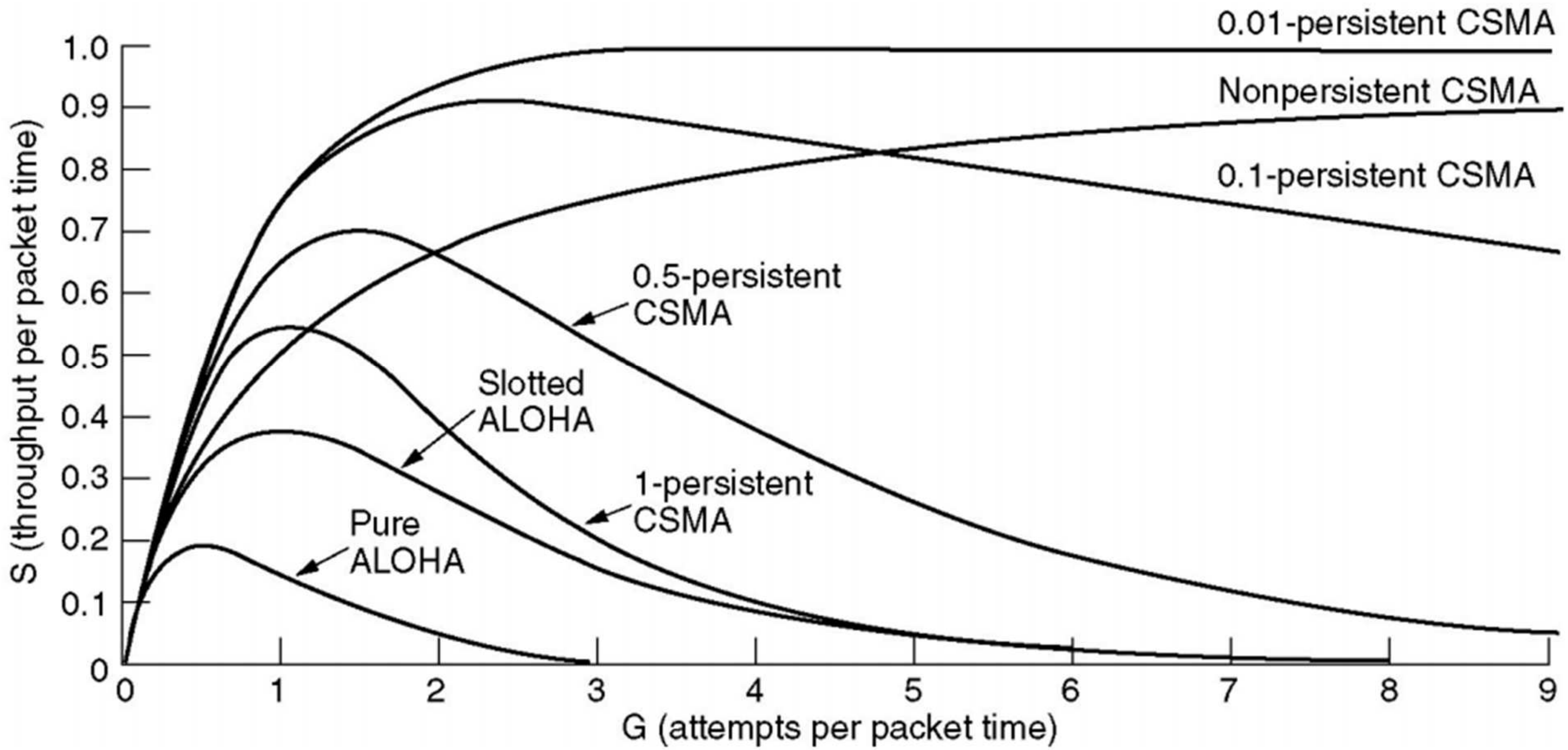
© R. MORLA 2011

Variations of CSMA

- Focus on what happens when the medium is busy
  - i.e. persistency
- Non-persistent
  - If busy: wait random time and retransmit
- Persistent
  - If busy: station waits until medium is free, then retransmits
- p-persistent
  - Slot time :: round trip time, $2 * T_{prop}$
  - If free: transmit with probability p, or defer to next slot (1-p)
  - If busy
    - 1) if deferred from previous slot => collision
    - 2) else station waits until medium is free and repeat algorithm

© R. MORLA 2011

Variations of CSMA: Efficiency

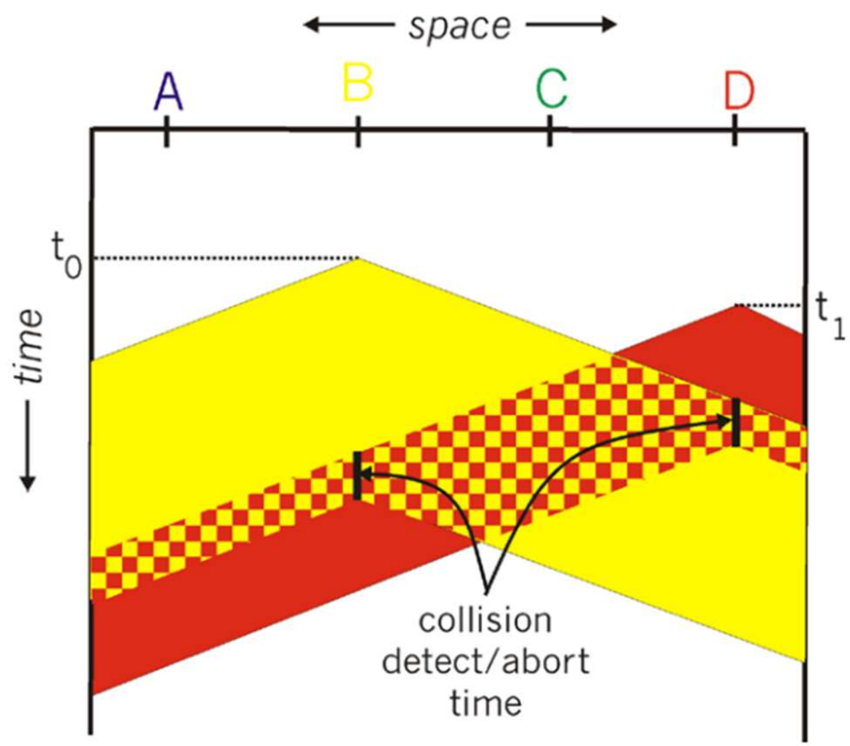


Non-persistent: better efficiency with G, longer delay

© R. MORLA 2011

CSMA/CD
CSMA/Collision Detection

- Carrier sense
  - Sense medium before transmitting
  - If free: start transmitting
  - If busy: wait until free and transmit (persistent)
- Collision detection
  - Listen to medium while transmitting
  - If collision detected
    - Stop transmission
    - Delay retransmission (binary exponential backoff algorithm)
  - No ACK



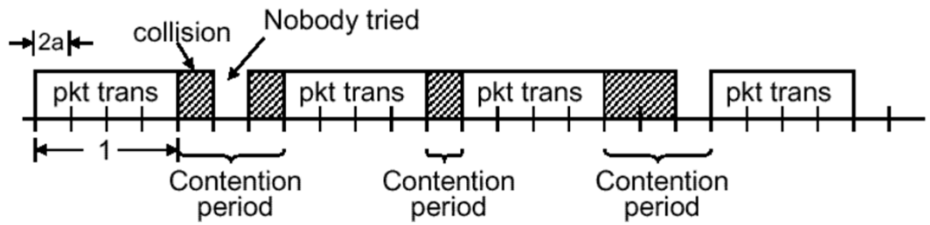
© R. MORLA 2011

CSMA/CD
Binary exponential backoff algorithm

- Time slots
  - $T_{slot} = 2 * T_{prop}$
- After the i^{th} consecutive collision
  - Attempt to transmit
  - After waiting
  - A random number of slots
  - Uniformly distributed 0 and $2^i - 1$

© R. MORLA 2011

CSMA/CD Efficiency

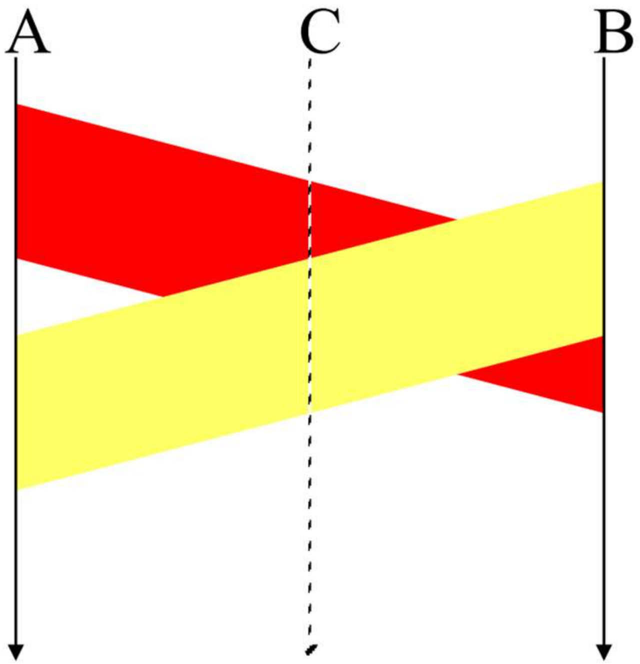


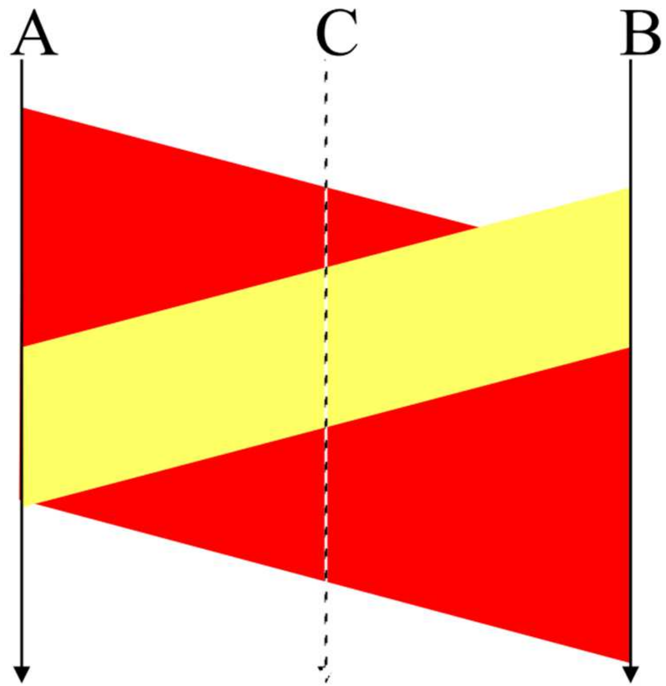
- Efficiency $S = \frac{n_{tx}}{n_{tx}+E[n_{contention}]}$
  - $n_{tx} = \frac{T_{frame}}{T_{slot}} = \frac{T_{frame}}{2*T_{prop}} = \frac{1}{2a}, a = \frac{T_{prop}}{T_{frame}}$
- P: probability that one station transmits in one slot
- A: probability that exactly one station transmits in a slot and gets the medium
- $A = \binom{N}{1} p^1(1-p)^{N-1} = Np(1-p)^{N-1}$
- $E[n_{contention}] = \sum_{i=1}^{+\infty} i(1-A)^i A = \frac{1-A}{A}$
- $S = \frac{\frac{1}{2a}}{\frac{1}{2a}+\frac{(1-A)}{A}} = \frac{1}{1+2a\frac{1-A}{A}}$
- $p = \frac{1}{N} \Rightarrow A_{max} = \left(1-\frac{1}{N}\right)^{N-1}; \lim_{N\to\infty} A_{max} = \frac{1}{e} \Rightarrow \lim_{N\to\infty} S = \frac{1}{1+3.44a}$

© R. MORLA 2011

CSMA/CD
Minimum frame size required

- Frame too short
  - Collision not visible at A
  - Visible at C
- Frame long enough
  - Collision visible in A





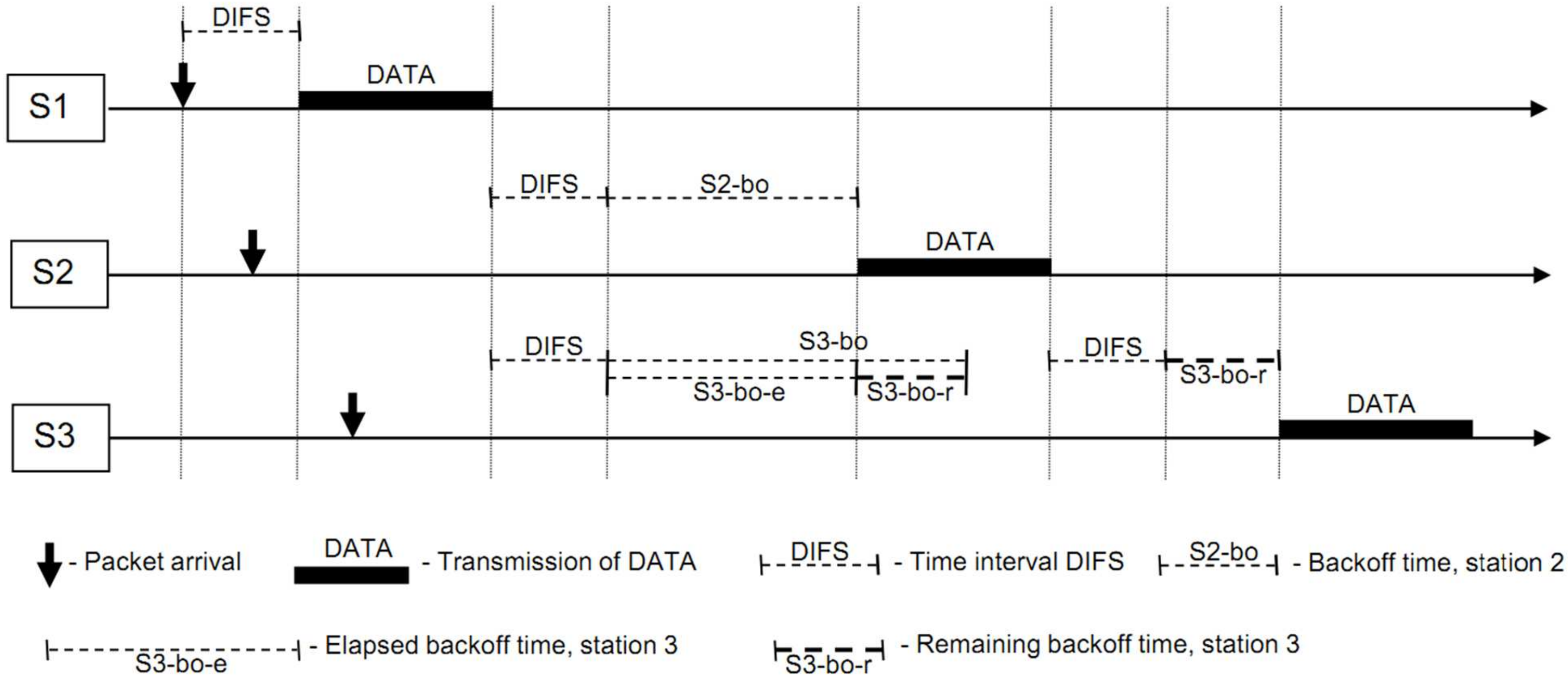
© R. MORLA 2011

TO THINK

- Why don’t we need ACK packets in CSMA/CD ?
- Can we use CSMA/CD in a wireless medium?

© R. MORLA 2011

CSMA/CA
Collision Avoidance



© R. MORLA 2011

CSMA/CA
Collision Avoidance

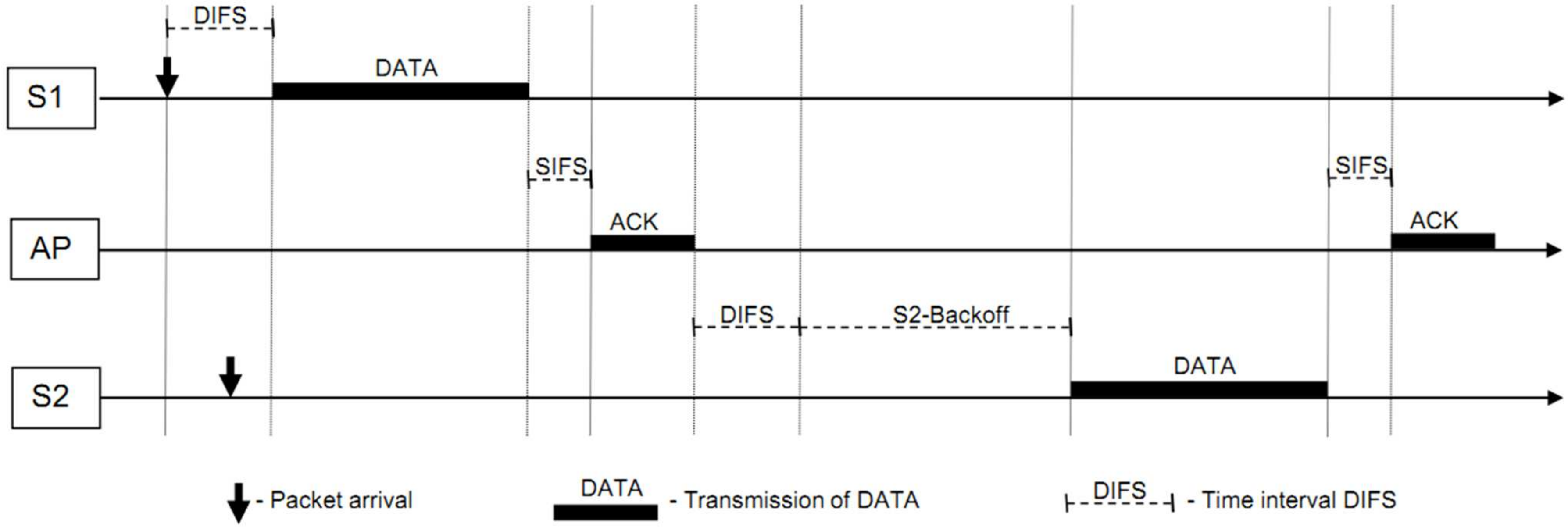
- Station has a packet to transmit:
  - Monitors channel activity
  - Waits after DIFS idle period
  - Transmits if medium is free

- If medium is busy
  - Selects random backoff interval
  - Decrements backoff timer when channel idle > DIFS
  - Stops timer when channel busy
  - Transmits when backoff timer reaches zero

- Consecutive packet transmission
  - Wait for random backoff interval, even if free after DIFS
  - Avoids channel capture

© R. MORLA 2011

CSMA/CA
ACK packet required



© R. MORLA 2011

CSMA/CA
ACK packet required

- CSMA/CD, vulnerability time
  - CSMA/CA does not rely on CD
  - no vulnerability time
  - no guarantee that collisions are visible

- Acknowledgment packet
  - Sent by receiving station to indicate transmission success
  - Immediate response after SIFS < DIFS interval, priority over other transmissions
- No ACK after timeout or different packet
  - Retransmission scheduled, backoff rules
- CSMA/CA efficiency depends strongly on # competing stations
  - 60% efficiency is a common value

© R. MORLA 2011

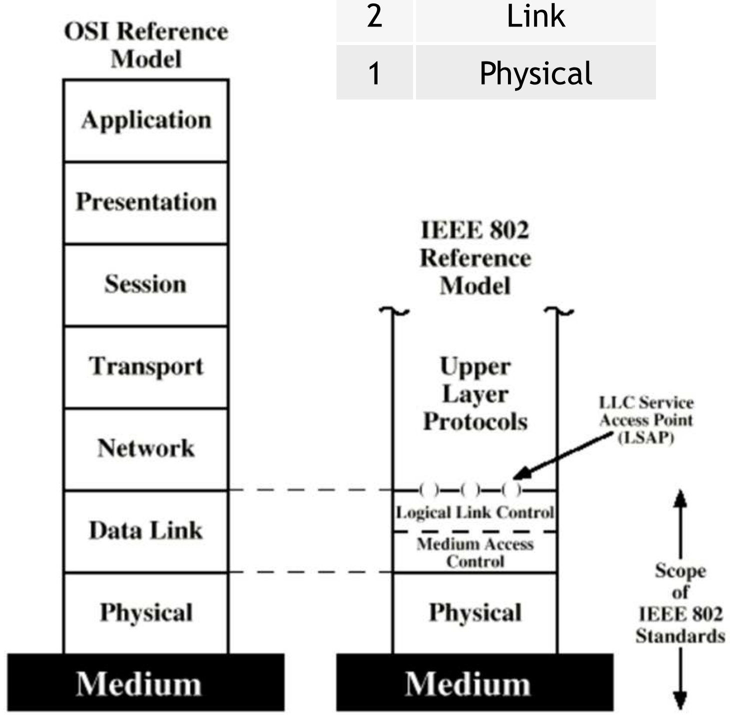
Standards and Technology

© R. MORLA 2011

IEEE 802 Reference Model

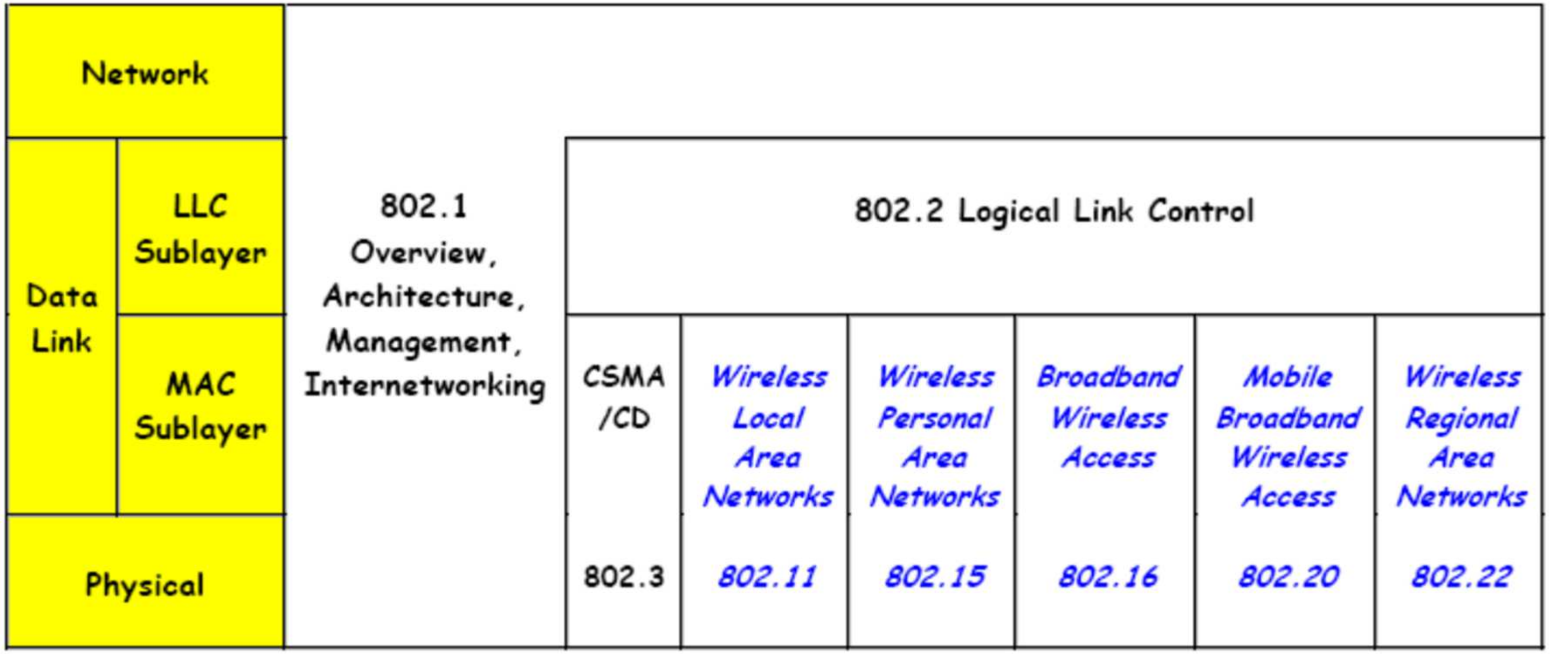
- Data Link Layer has 2 sub-layers
- LLC logic link control
  - Interface to network layer
  - Error detection, ARQ, flow control
- MAC medium access control
  - Access control
  - Frame retransmission/reception
  - Addressing
  - Error control

5	Application
4	Transport
3	Network
2	Link
1	Physical



© R. MORLA 2011

IEEE Standards



- 802.1 Higher layer LAN protocols
- 802.2 Logical Link Control
- 802.3 Ethernet, CSMA/CD
- 802.11 Wireless LAN
- 802.15 PAN (Personal, Bluetooth, ZigBee)
- 802.16 Broadband Wireless Access (WMAN, WiMax)
- 802.20 Mobile Broadband (MBWA, Mobile WiMax)
- 802.22, Wireless Regional (Cognitive radio, free TV spectrum)

© R. MORLA 2011

Ethernet MAC Sublayer

- Frame formats
  a) DIX (DEC, Intel, Xerox) Ethernet
     - No LLC sublayer, IP over Ethernet

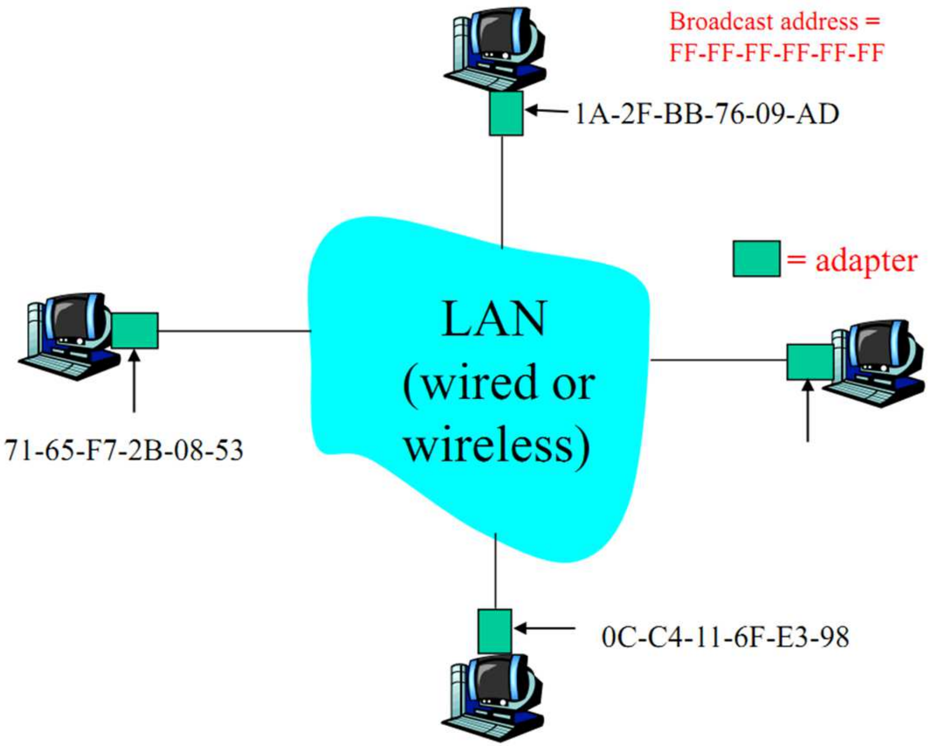
  b) IEEE 802.3

Bytes	8	6	6	2	0-1500	0-46	4
(a)	Preamble	Destination address	Source address	Type	Data	Pad	Check-sum
(b)	Preamble SOF	Destination address	Source address	Length	Data	Pad	Check-sum

© R. MORLA 2011

MAC Addresses

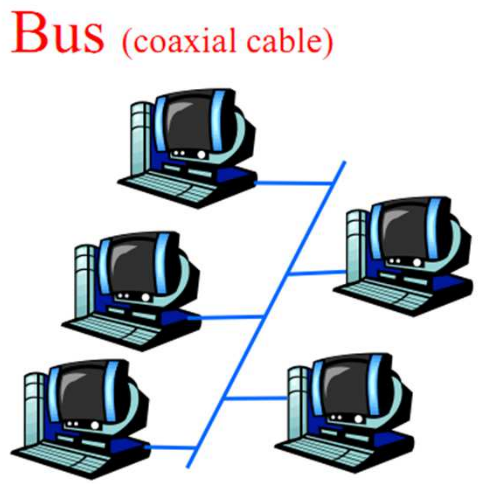
- Why do you need an address?
- 48 bit MAC addresses
- Each adapter has a unique MAC address

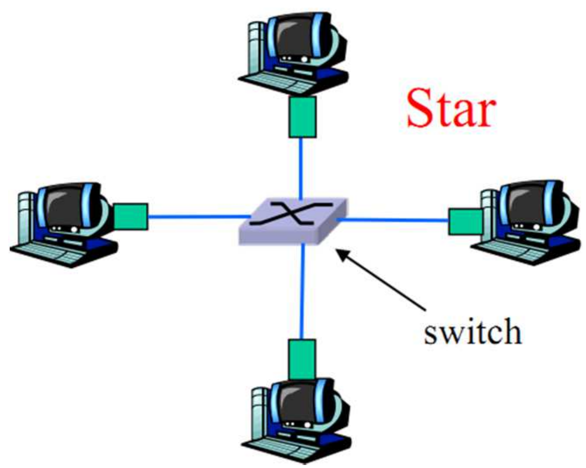


© R. MORLA 2011

Ethernet Topology

- CSMA/CD MAC
- Bus topology
  - Popular in the 90's
  - Stations in same collision domain
- Star topology
  - Today's topology
  - Active switch in the center
  - Stations don't collide with each others
    - Each station runs its own Ethernet protocol with the switch

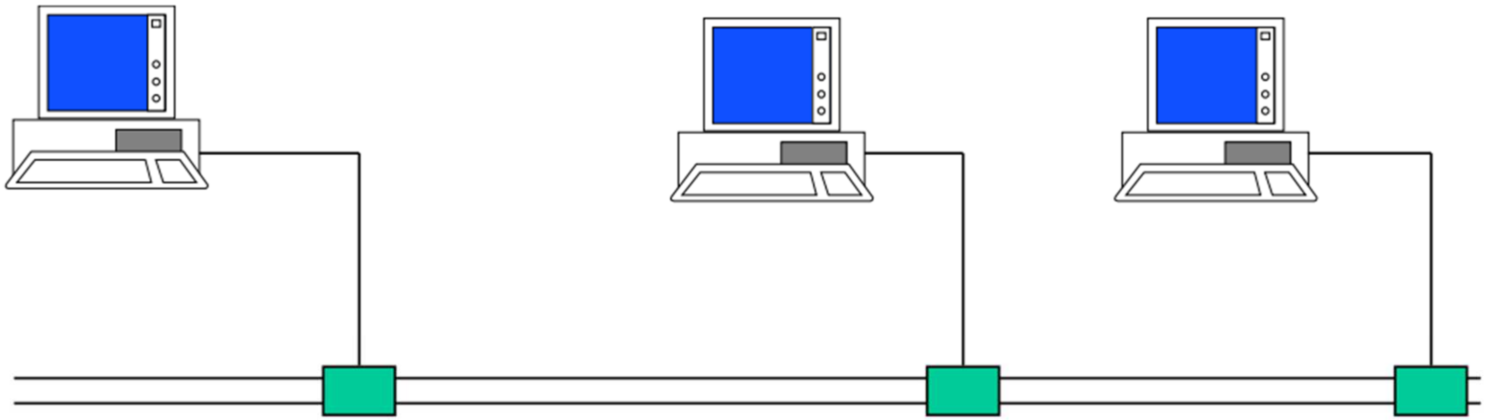


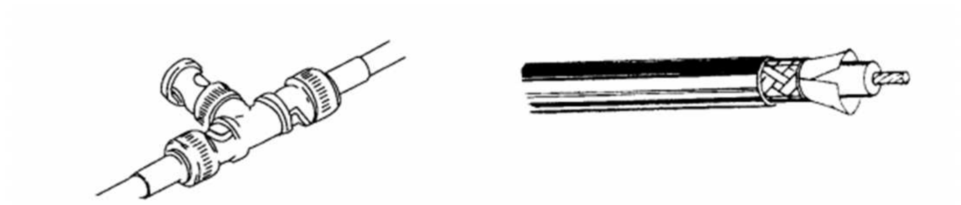


© R. MORLA 2011

Ethernet evolution: Coaxial cable

- First Ethernet was on coaxial cable
  - Multiple transmitters and receivers



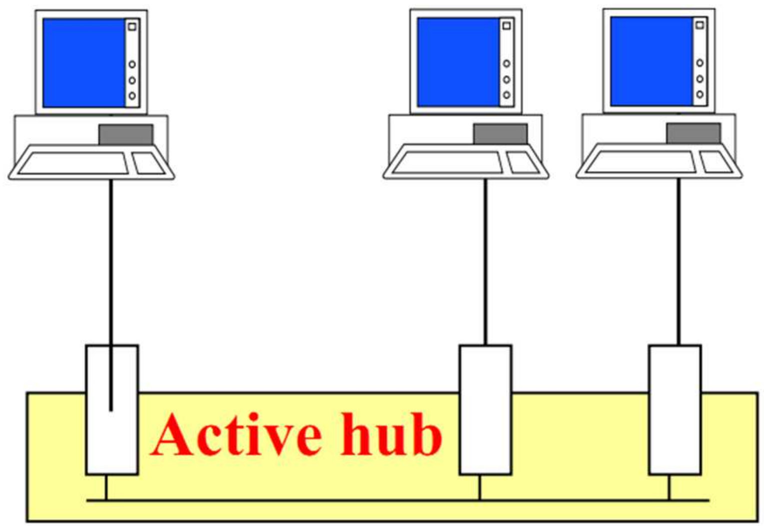


© R. MORLA 2011

Ethernet evolution: Active Hub

- Original Ethernet difficult to manage
  - Cable faults hard to detect
  - Single fault can bring entire network down

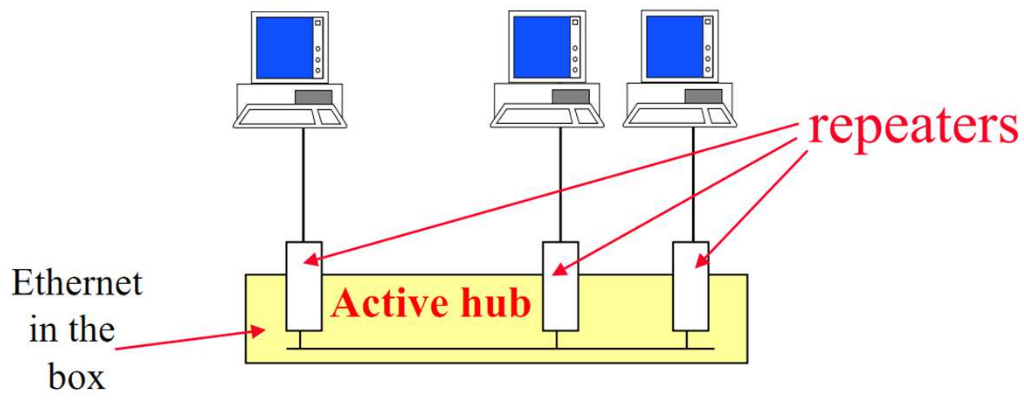
- Solution: active hub
  - Point-to-point cables only



© R. MORLA 2011

Active hubs as repeaters

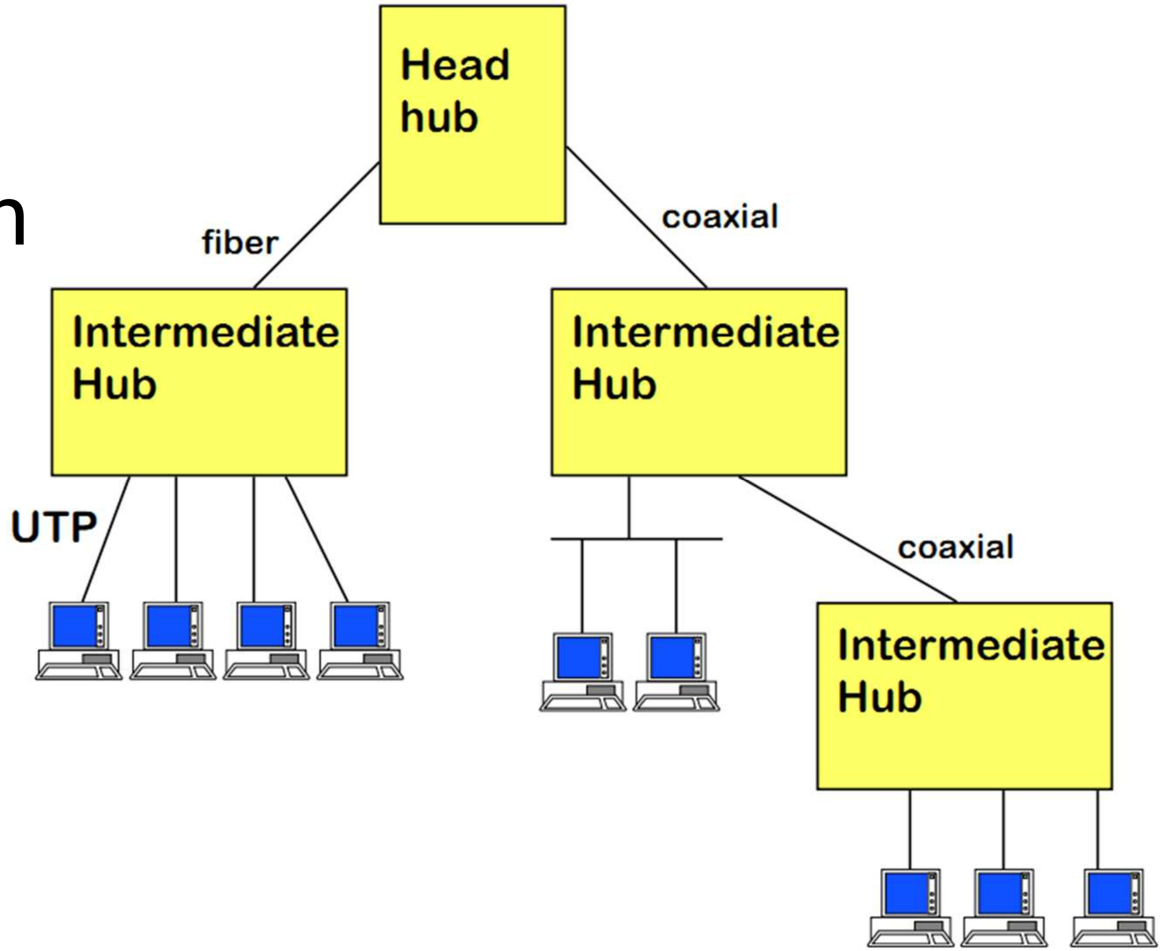
- Repeats bits on one port to all other ports
- Physical layer functions only
- Collision in one port => repeated to all ports
- One network with repeaters
  - one collision domain



© R. MORLA 2011

Networks of hubs

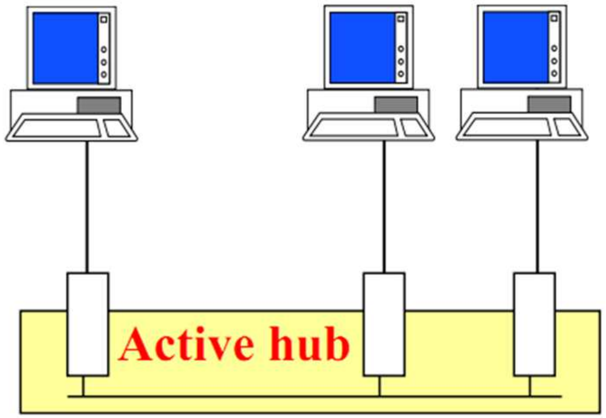
- Tree topology
- Single collision domain



© R. MORLA 2011

TO THINK

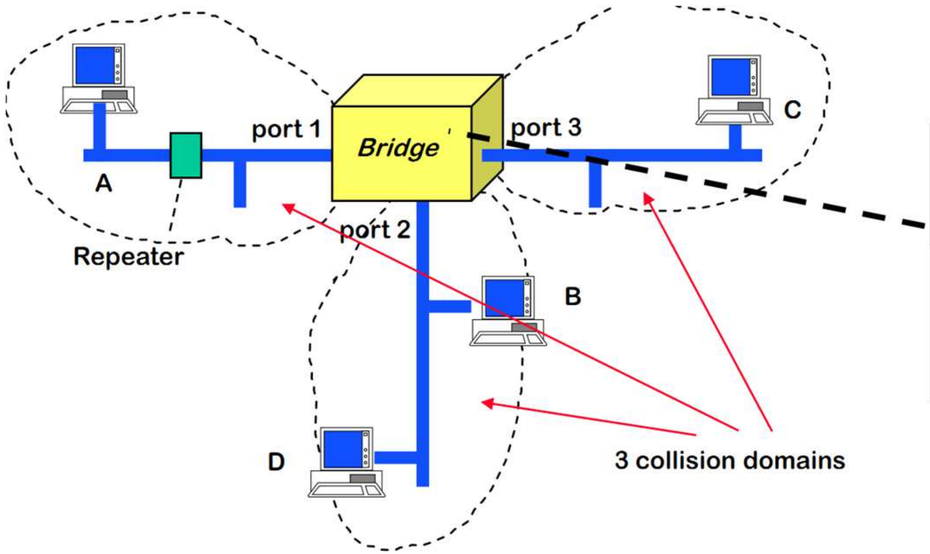
- How to improve the efficiency of a hub?
  – Collision domain



© R. MORLA 2011

Ethernet evolution: Bridge

- Bridge (i.e. switch)
  - Forwards frames based on MAC addresses
  - Receive packet => analyze packet => resend on other port
- Bridge separates collision domains
  - Bridge LAN may be larger than LAN with repeaters
  - Several frames can be transmitted simultaneously

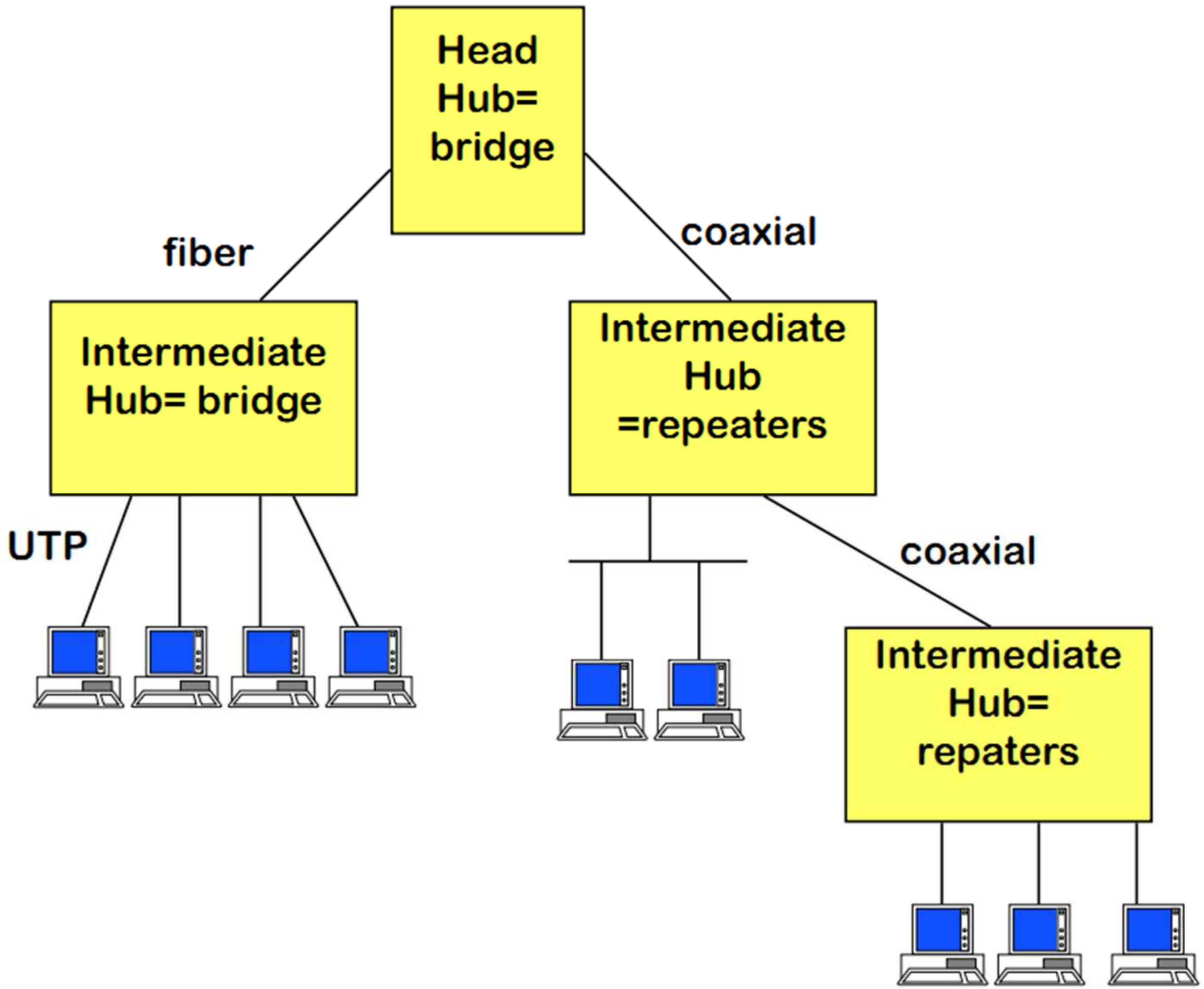


Forwarding Table

Dest MAC addr	Port Nb
A	1
B	2
C	3
D	2

© R. MORLA 2011

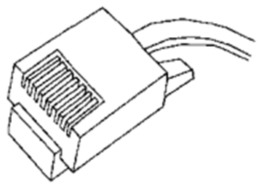
Ethernet evolution: Bridges and repeaters together



© R. MORLA 2011

Ethernet evolution: Point-to-point only cable

- Unshielded Twisted Pair (UTP)
  - Cheaper, easier to install (can be bent)
  - Does not support multiple transmitters/receivers as well as coaxial
- Ethernet is now Point-to-point
  - No multiple transmitters/receivers
  - UTP can be used




© R. MORLA 2011

Ethernet evolution: Full duplex Ethernet

- UTP cables have two pairs of cables
  - Can be used simultaneously in both directions

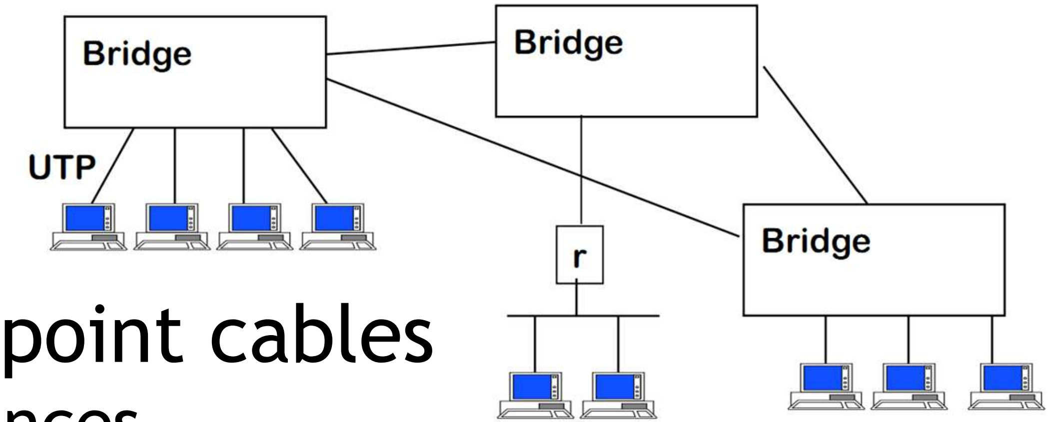
- This is called “Full Duplex Ethernet”
  - No CSMA/CD
  - From the original Ethernet we now retain only

    The frame format and the MAC addresses

© R. MORLA 2011

Current Ethernet

- Used mostly for local interconnection
  - of a limited number of stations
  - up to a few hundreds

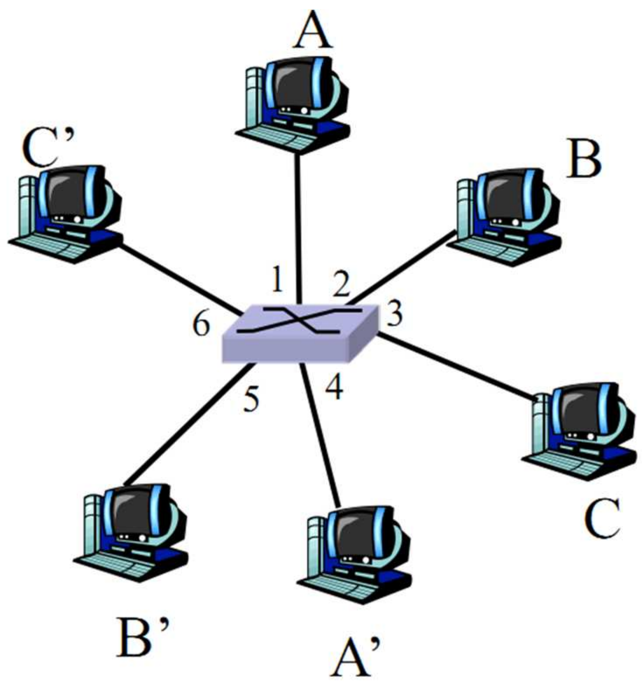


- Primarily point-to-point cables
  - UTP for short distances
  - Fiber for long distances
  - Active hubs are primarily bridges

© R. MORLA 2011

Switch

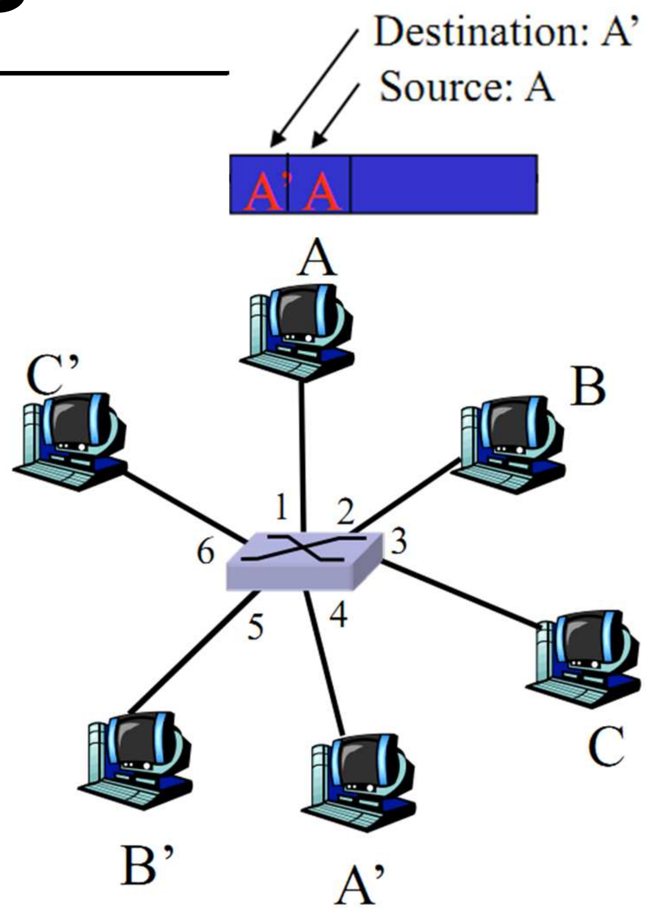
- Link-layer device
- Forwards Ethernet frames
- Transparent to hosts
  - Unaware of its presence
- Plug-and-play, self-learning
  - Does not need configuration
- Has forwarding table



© R. MORLA 2011

Switch: self-learning

- Look at frame source address
- Add entry to forwarding table



MAC addr	interface	TTL
A	1	60

Forwarding table (initially empty)

© R. MORLA 2011

Switch: Frame forwarding/flooding

- When switch receives frame:

1. record link of sending host
2. lookup destination MAC
3. if entry found

    if destination on sender segment => drop frame

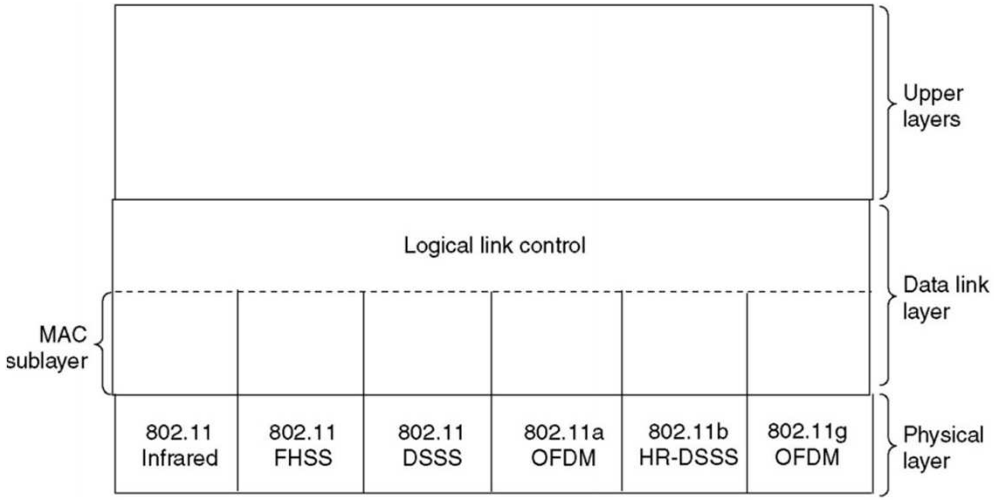
    else forward frame to destination

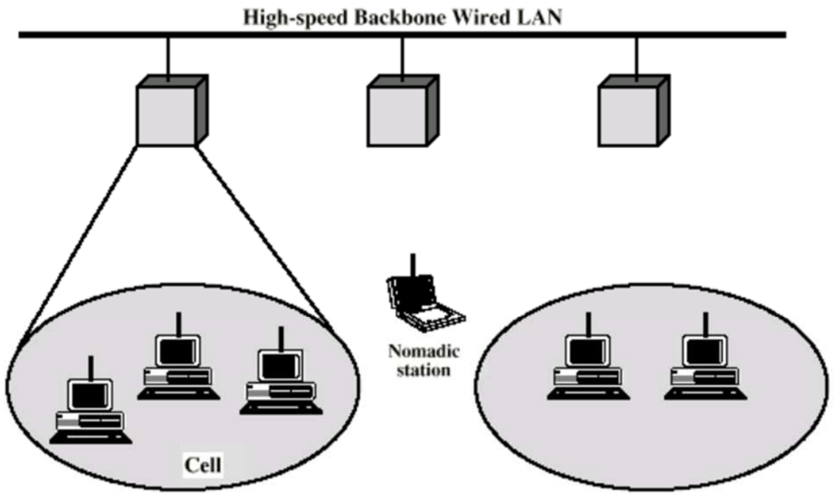
  else flood (i.e. forward on all interfaces except sender)

© R. MORLA 2011

Wireless LAN

- Infrastructure or ad-hoc topology
- CSMA/CA MAC
- 802.11 protocol stack





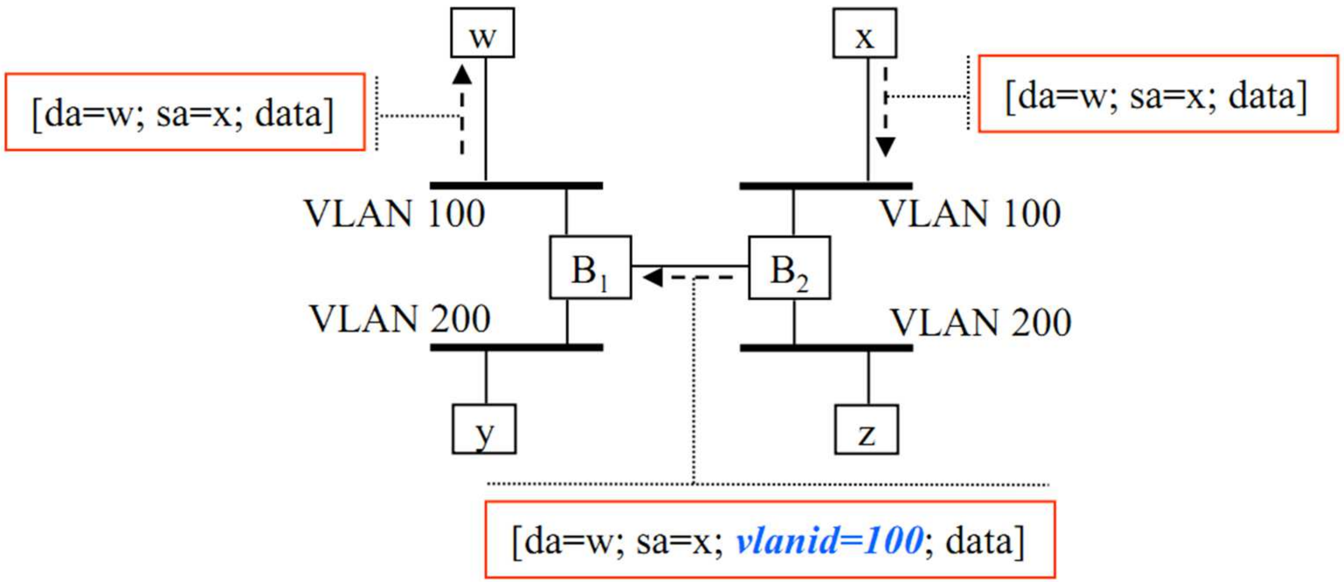
(a) Infrastructure Wireless LAN

(b) Ad hoc LAN

© R. MORLA 2011

Virtual LANs

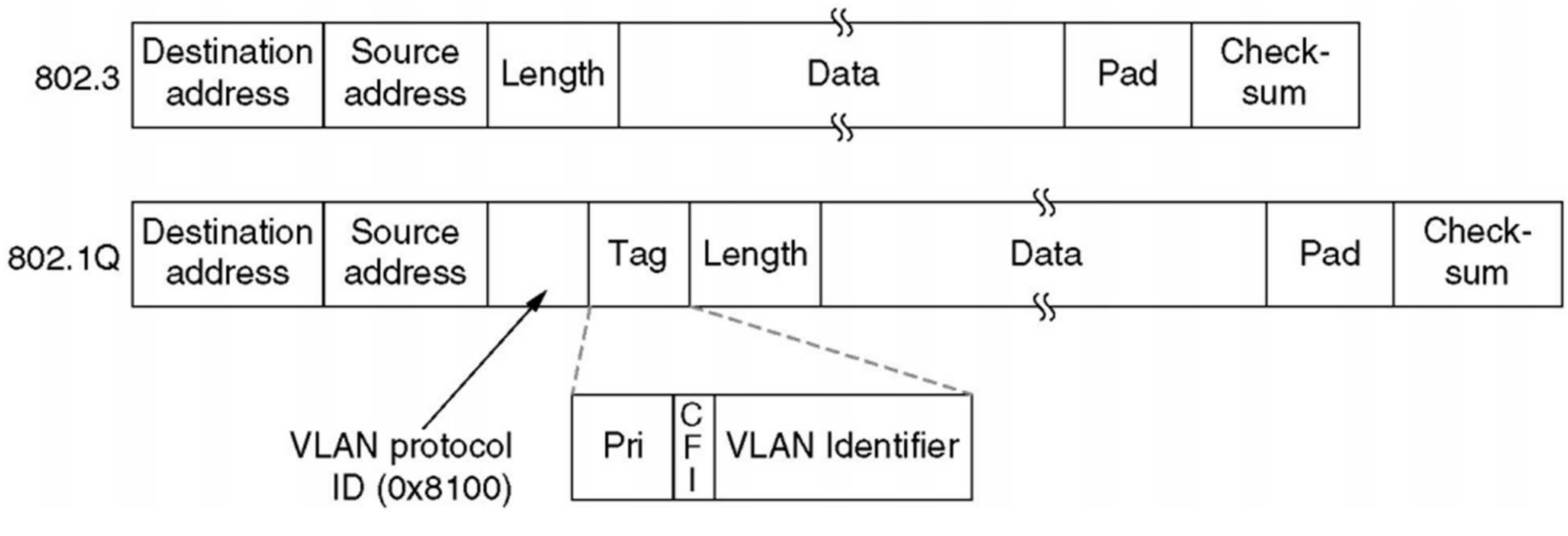
- One bridge emulates multiple LANs / broadcast domains
- VLANs can be extended to other bridges



© R. MORLA 2011

VLANs: IEEE 802.1Q Standard

- 802.3 (legacy) and 802.1Q frame formats



© R. MORLA 2011

- How does the ideal MAC work?
- Name the differences:
  - Aloha, Slotted Aloha, CSMA, CSMA/CD, CSMA/CA
- Delay and offered traffic: how do they relate in a random MAC?
- Why doesn't CSMA/CD require ACK packets?
- What is the format of a MAC address?
- What's left from the original coaxial Ethernet in today's switched, full-duplex Ethernet?
- How do hubs and switches retransmit frames?
- How does a switch learn MAC addresses of stations?
- What's a virtual LAN?

© R. MORLA 2011

HOMEWORK

- Review slides
- Read:
  - Tanenbaum – 4.1, 4.2, 4.3, 4.4, 4.7, 4.8
  - Bertsekas – 4.2, 4.4
- Do your Moodle homework

© R. MORLA 2011