Chapter 4: The Medium Access Layer

Computer Networks

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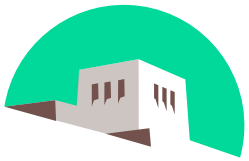

September 2002

Medium Access Layer

- Point-to-point versus broadcast networks
- Broadcast
  - multiaccess channels
  - random access channels
- Arbitrate contention
- General coverage of LANs

Topics

Arbitrating access to broadcast networks

- Channel Allocation
- Multiple Access Protocols
- Ethernet
- Wireless LANs
- Broadband Wireless
- Bluetooth
- Data Link Layer Switching

Channel Allocation
Static Allocation

- FDM and TDM are examples of static allocation
- Traffic is bursty, mean to peak ratio of 1:1000
- Mean delay:

$$T = \frac{1}{\mu C - \lambda}$$

where C is channel capacity in bps

λ is arrival rate in frames/sec

$1/\mu$ is the mean frame length in bits/frame

μC is the service rate

- Replace channel with N C/N bps channels

$$T_{\text{FDM}} = \frac{1}{\mu(C/N) - (\lambda/N)} = \frac{N}{\mu C - \lambda} = NT$$

Channel Allocation
Dynamic Allocation

- Station Model: N independent stations
  - probability of frame generation in interval Δt is $\lambda \Delta t$
  - station blocks until frame is transmitted
- Single Channel

  no external channels
- Collision

  simultaneous transmission results in garbled signal
- Time

  Continuous frame transmission can start at any time

  Slotted time is divided into discrete intervals
- Carrier

  No sense channels transmit then look for collisions

  Sense stations wait while channel is busy

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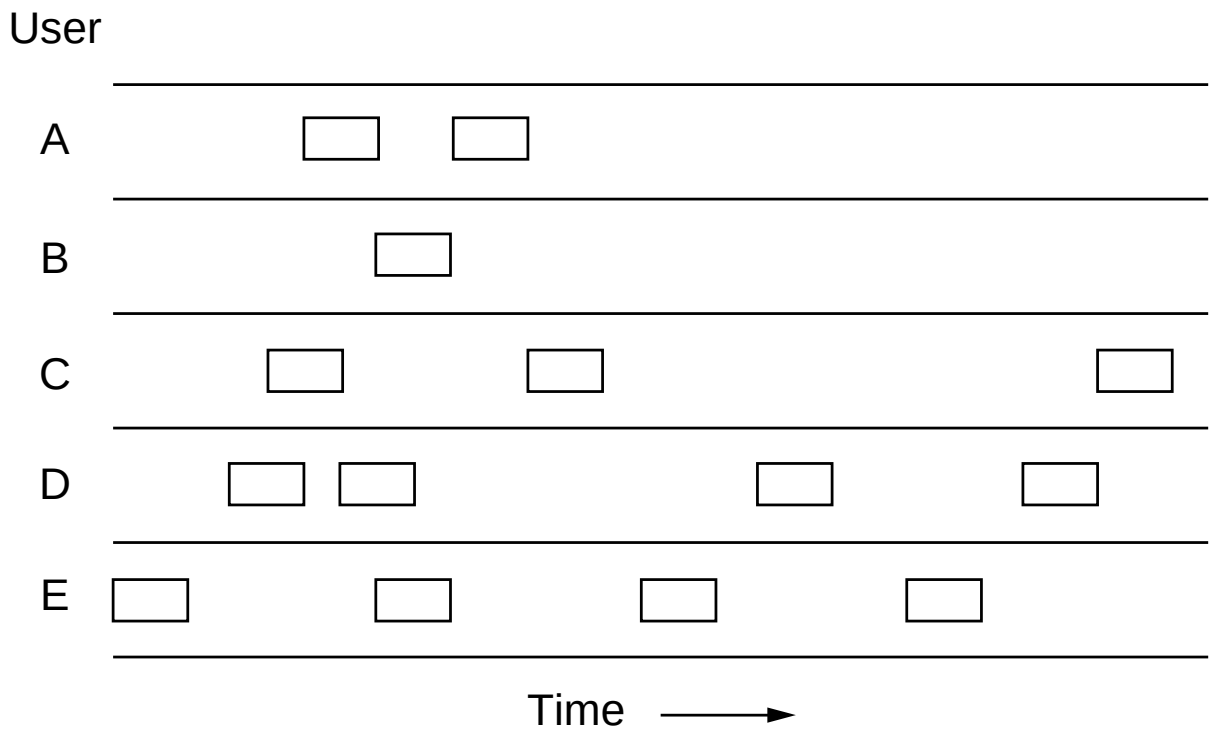
MAC Protocols

- ALOHA
- Carrier Sensed Multiple Access (CSMA)
- Collision-Free Protocols
- Limited-Contention Protocols (skip)
- Wavelength Division Multiple Access Protocols (skip)
- Wireless LAN Protocols

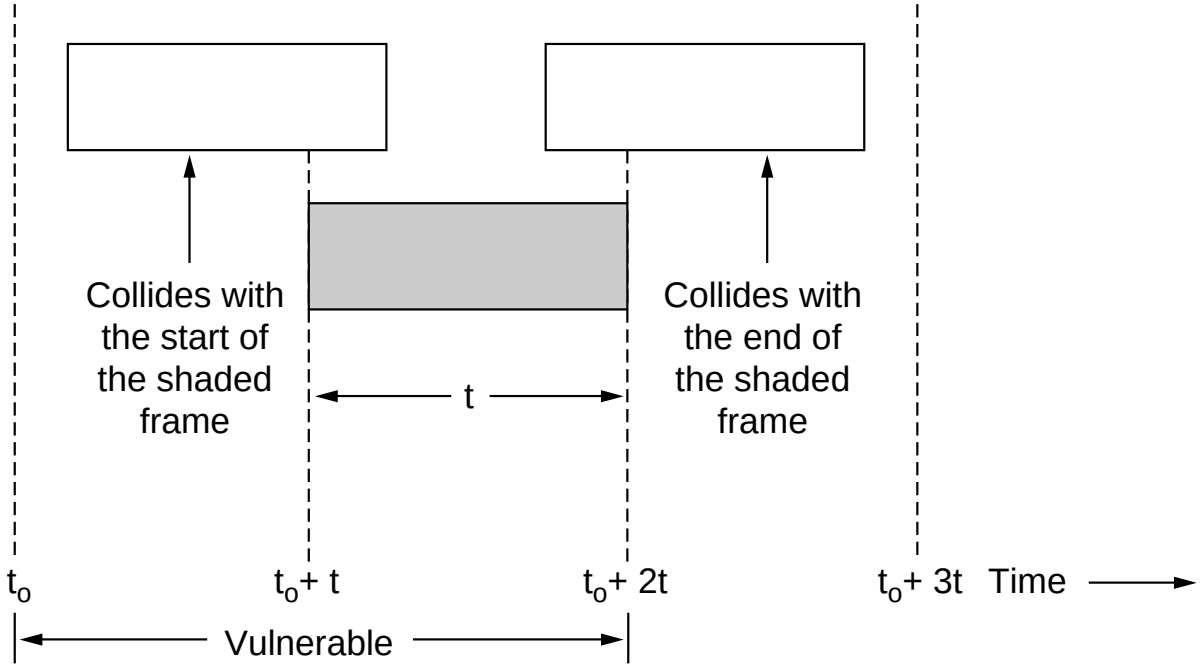
ALOHA
Pure ALOHA

- Stations transmit and look for collisions (could wait for ACKs if unable to listen while transmitting)
- Random time for backoff (avoids lockstep)



ALOHA Efficiency

- Let t be the time to transmit a frame
- Vulnerable period for a frame is $2t$



ALOHA Efficiency

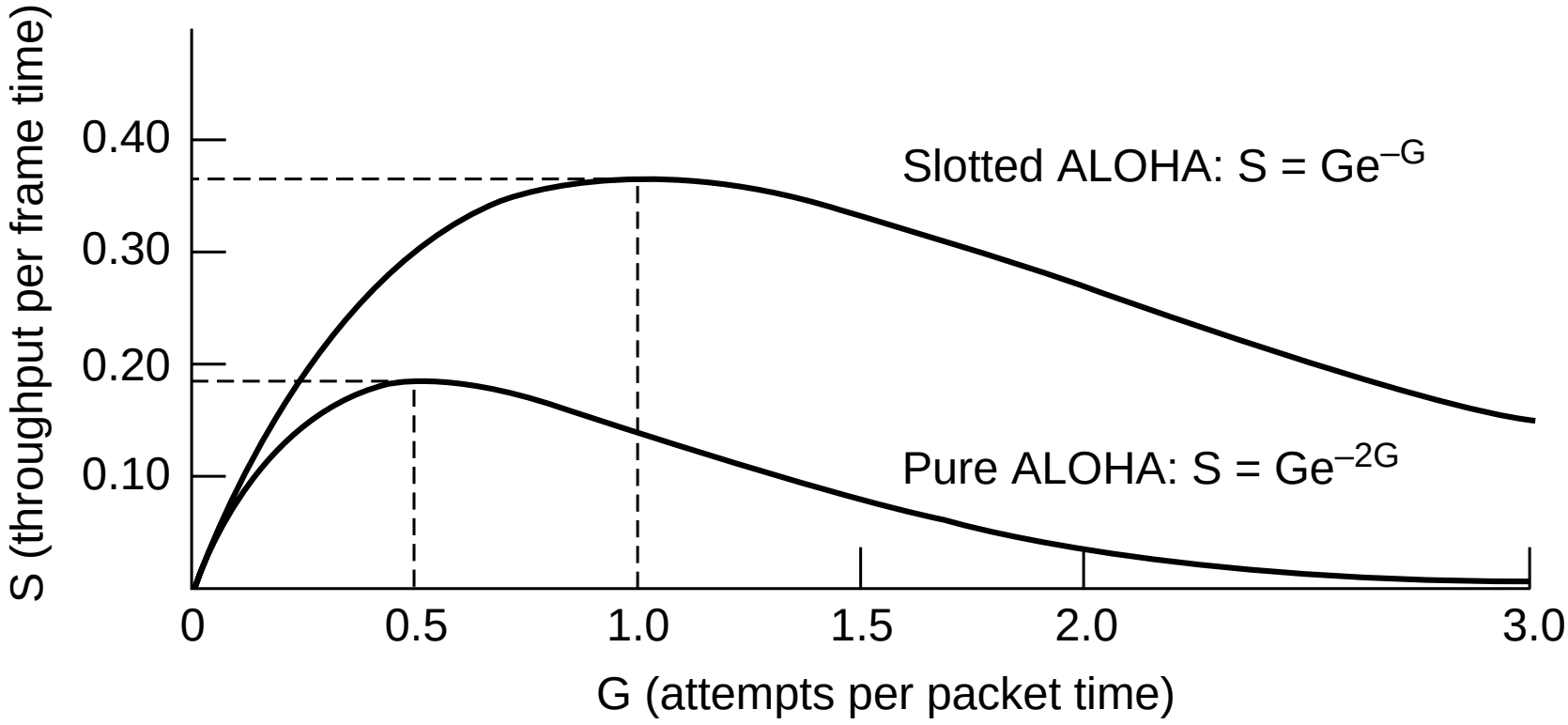
- Let G be the mean transmissions (old and new) per frame time
- Probability of k frames generated during a frame time is:

$$\Pr[k] = \frac{G^k e^{-G}}{k!}$$

- $2G$ frames in an interval of length $2t$
- Throughput is (offered load times probability of no collisions)

$$S = Ge^{-2G}$$

ALOHA Efficiency



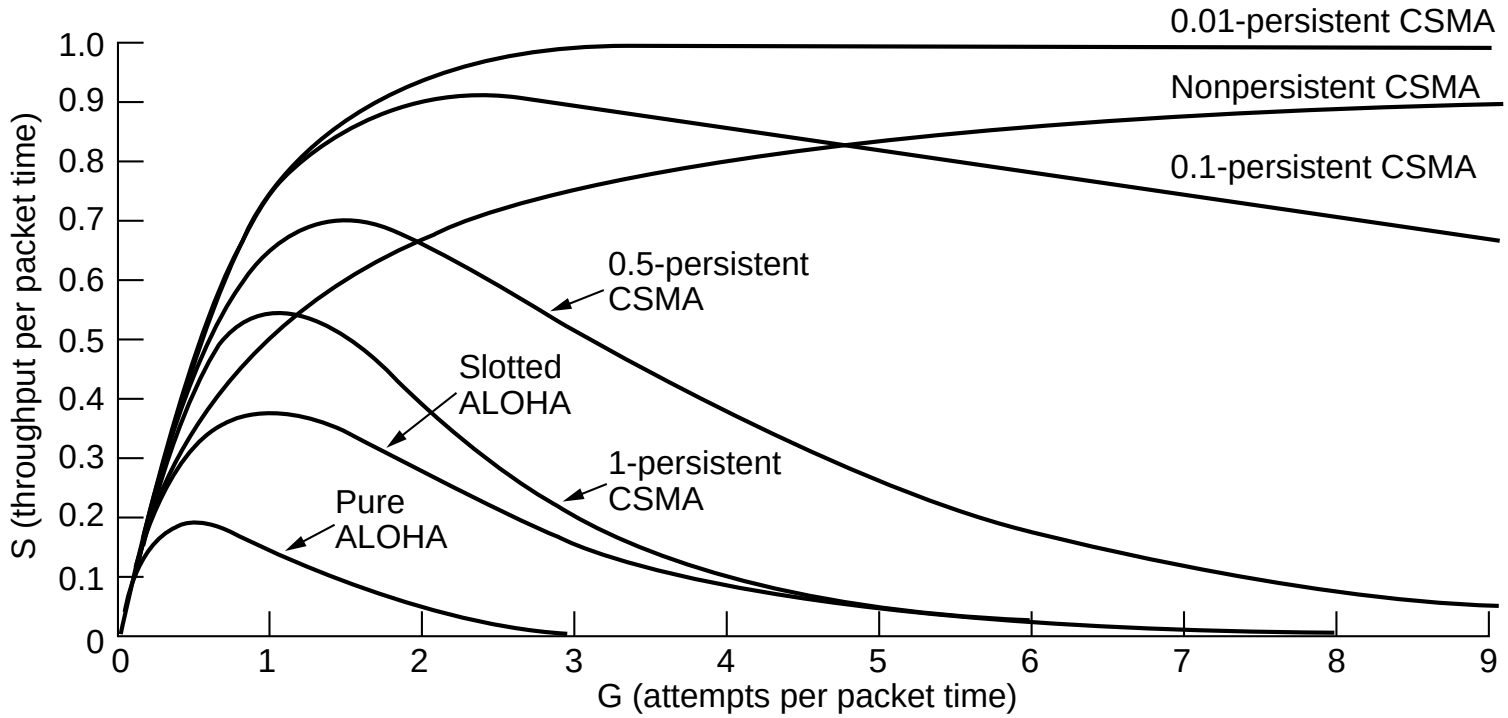
ALOHA Slotted

- Can only start at the beginning of a slot
- Reduces vulnerability by 1/2 $S = Ge^{-G}$
- Probability of a collision is $1 - e^{-G}$
- Probability of requiring k attempts $P_k = e^{-G}(1 - e^{-G})^{k-1}$
- Expected number of transmissions

$$E = \sum_{k=1}^{\infty} kP_k = \sum_{k=1}^{\infty} ke^{-G}(1 - e^{-G})^{k-1} = e^{G}$$

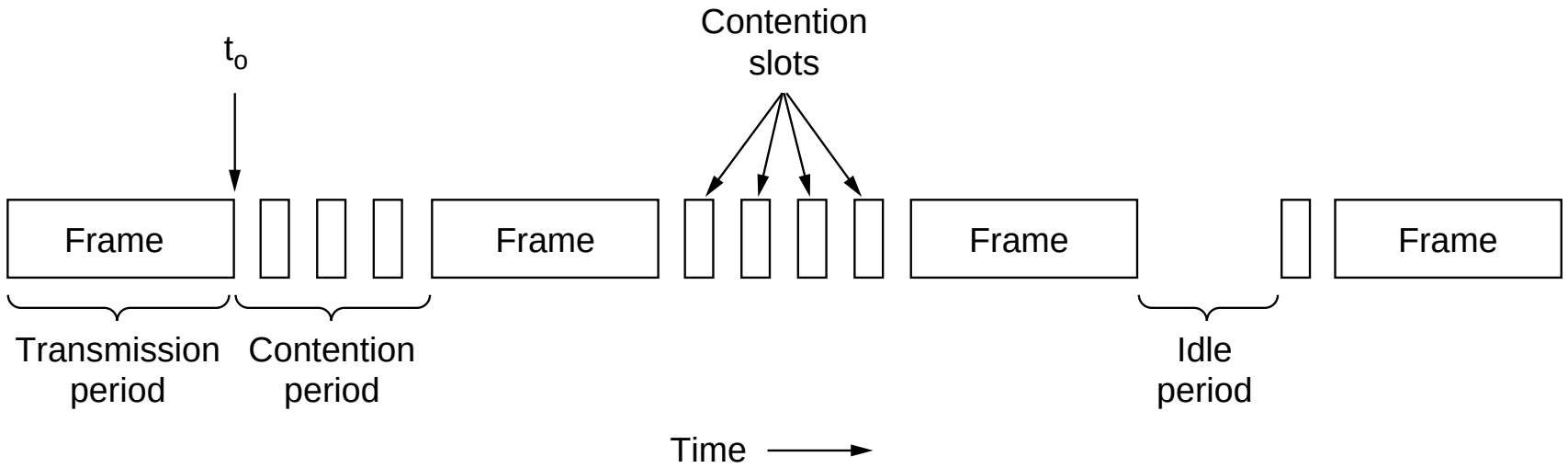
Carrier Sense Multiple Access

- 1-persistent: sense, when free transmit propagation delay
- nonpersistent: slotted, random delay when slot busy
- p-persistent: transmit with probability p when slot is idle



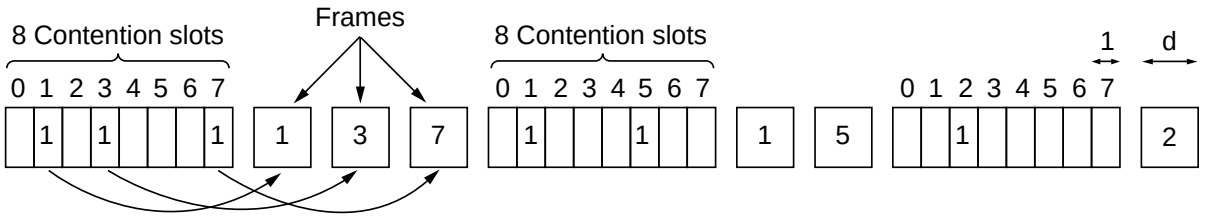
CSMA with Collision Detection (CSMA/CD)

- Early transmission abort
- Random backoff
- Bounding the contention interval (2τ, where τ is propagation delay)

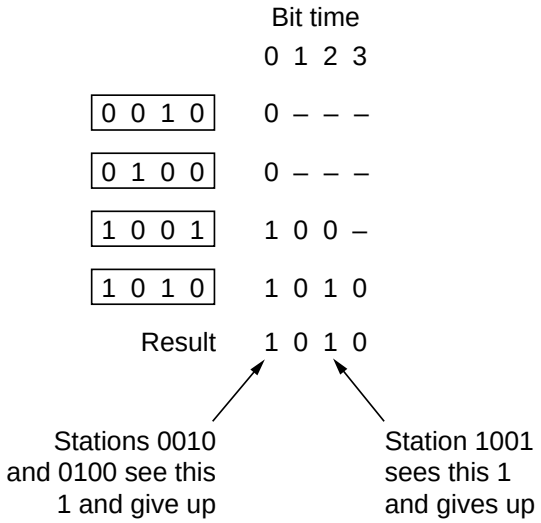


Collision-Free

- 1-bit reservation



  issue: 1 bit per station
- Making the overhead logarithmic

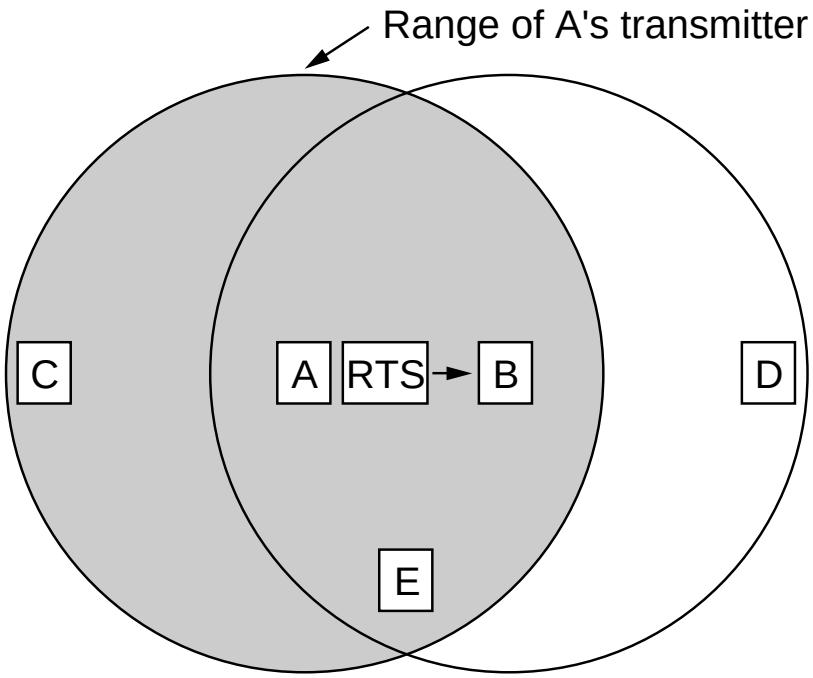


Wireless LAN CSMA

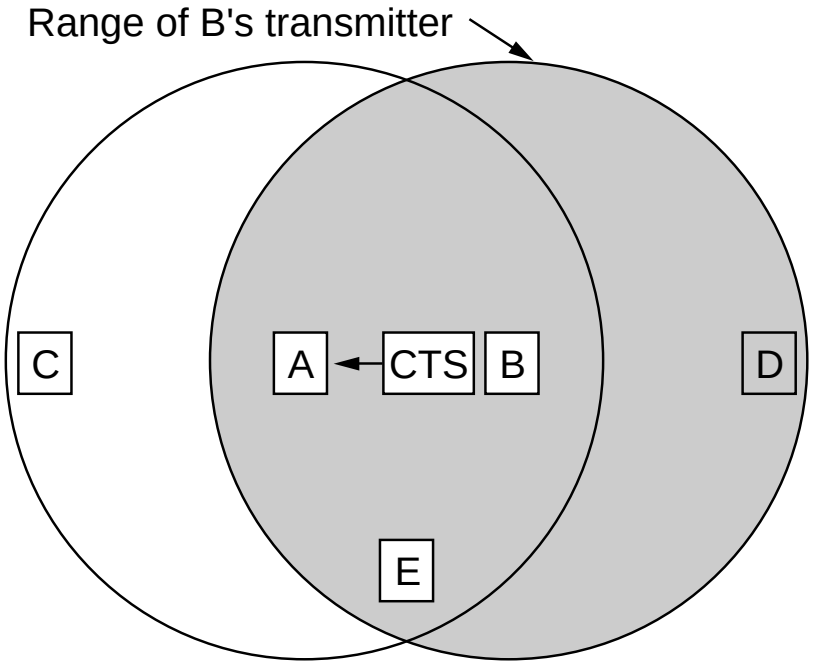
- Hidden station (a – C better not send to B)
- Exposed station (b – C could send to D)

Wireless LAN Avoidance

- RTS / CTS



(a)



(b)

Topics

Arbitrating access to broadcast networks

- Channel Allocation
- Multiple Access Protocols
- Ethernet
- Wireless LANs
- Broadband Wireless
- Bluetooth
- Data Link Layer Switching

Ethernet

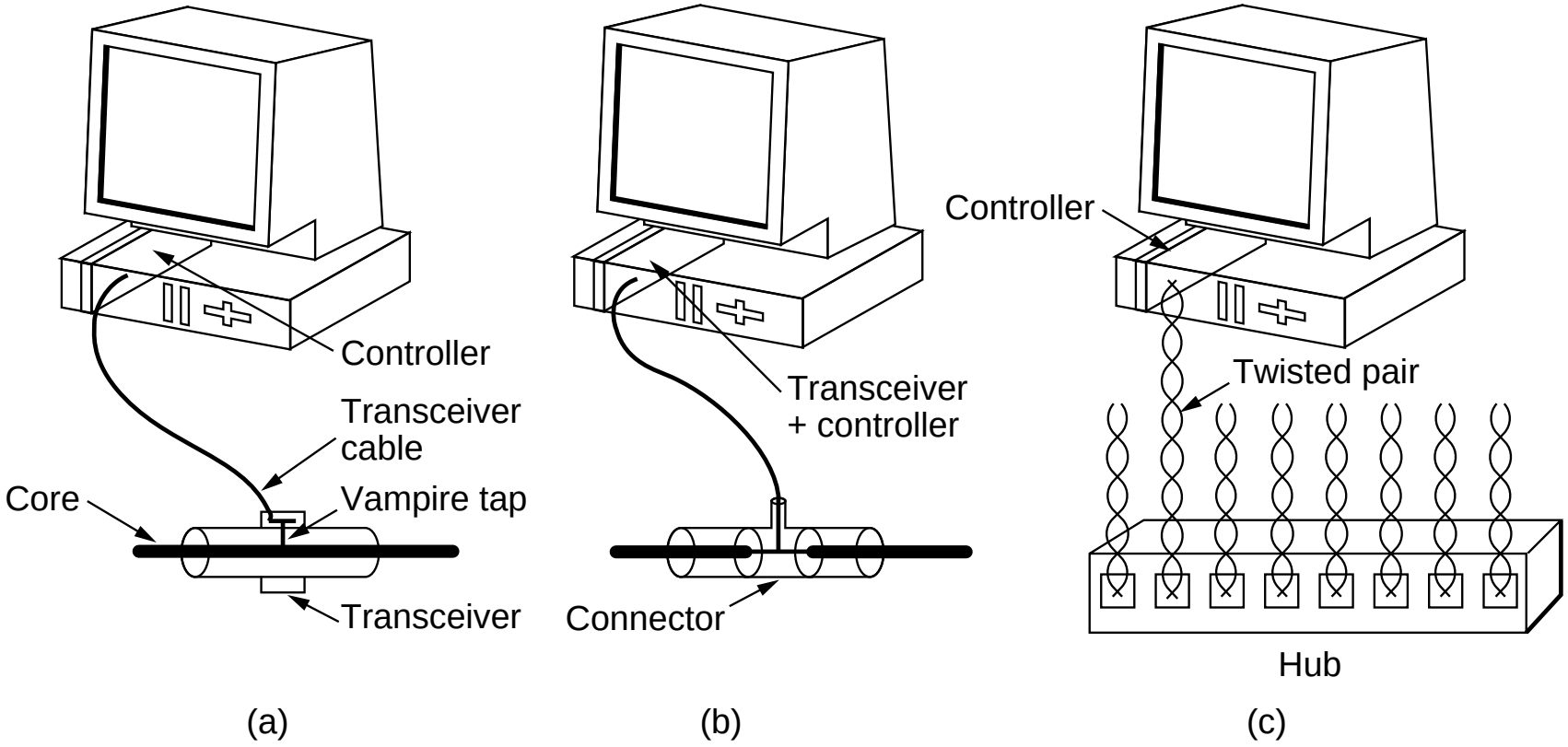
- Cabling
- Manchester Encoding
- MAC Sublayer Protocol
- Binary Exponential Backoff
- Performance
- Switched Ethernet
- Fast Ethernet
- Gigabit Ethernet
- Logical Link Control
- Retrospective

Ethernet Cabling
Common Kinds of Cable

- 10Base5
  - vampire taps
  - 10 Mbps, Baseband signaling, 500 meters
- 10Base2: BNC connectors

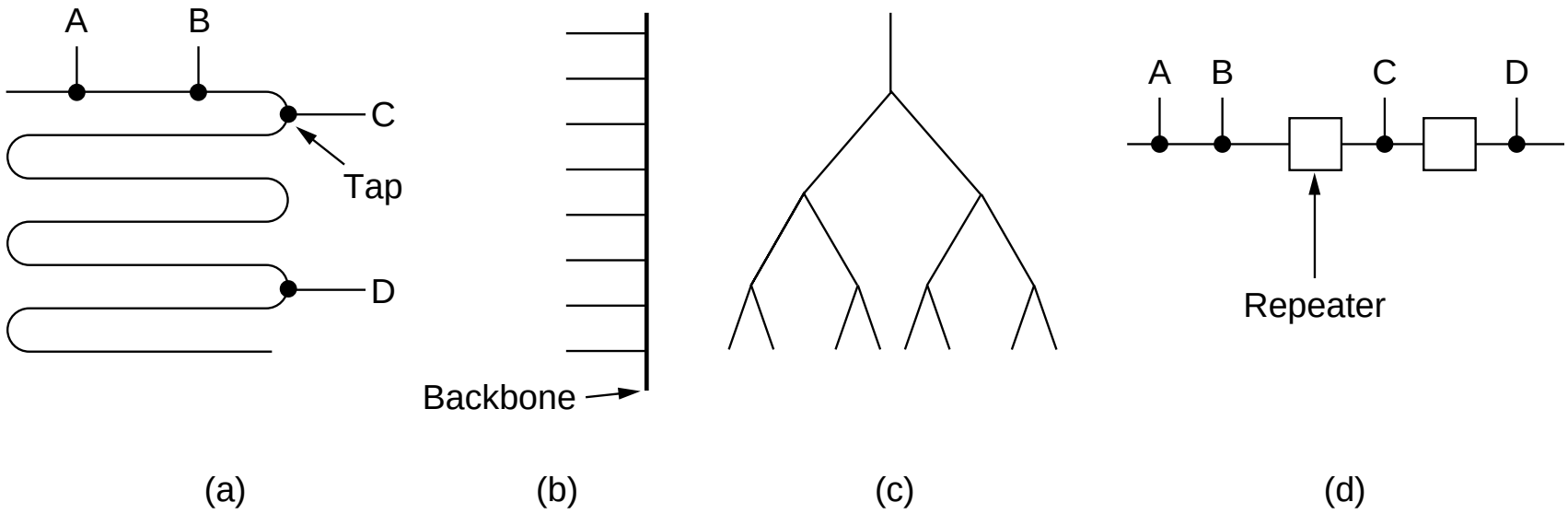
Name	Cable	Max seg	N/seg	Advantages
10Base5	Thick coax	500 m	100	Original; now obsolete
10Base2	Thin coax	185 m	30	No hub
10Base-T	Twisted pair	100 m	1024	Cheapest
10Base-F	Fiber optics	2000 m	1024	Best between buildings

Ethernet Cabling
Illustrating Kinds of Cable



(a) 10Base5, (b) 10Base2, (c) 10Base-T

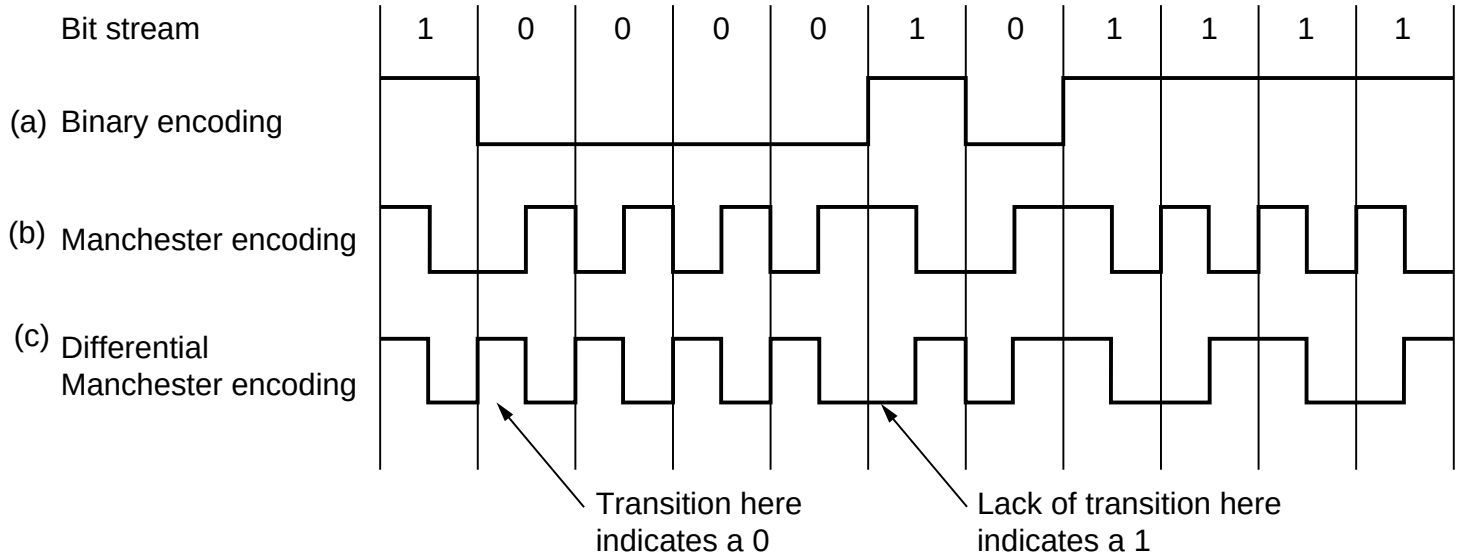
Ethernet Cabling
Cable Topologies



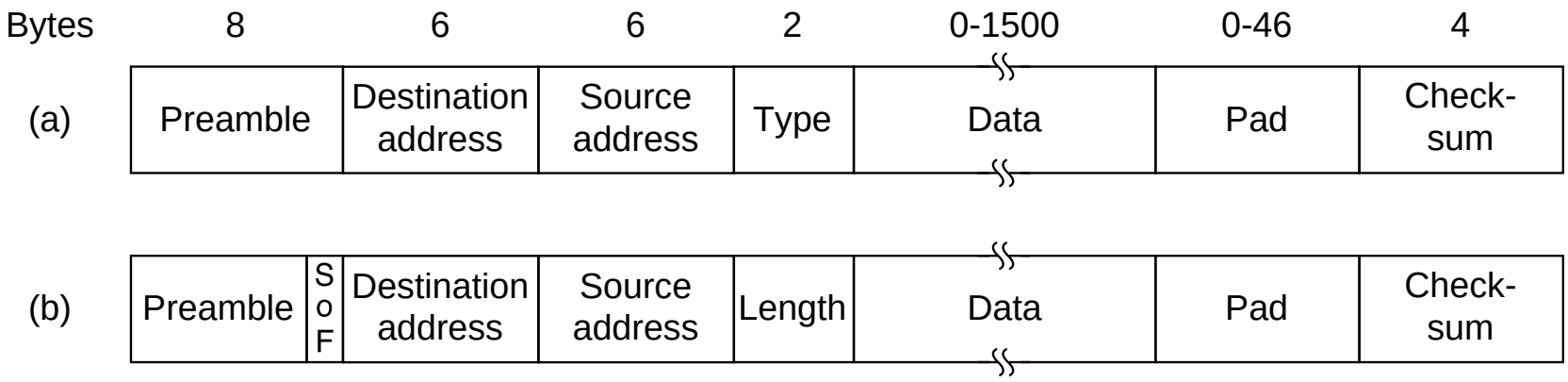
(a) Linear, (b) Spine, (c) Tree, (d) Segmented

Ethernet Manchester Encoding

- Transition on every bit, clock recovery
- Basic: 1 is high to low; 0 is low to high
- Differential: 0 has a transition at the start
- Requires 2x bandwidth
- +.85V, -.85V



Ethernet MAC Sublayer Protocol Frame Formats

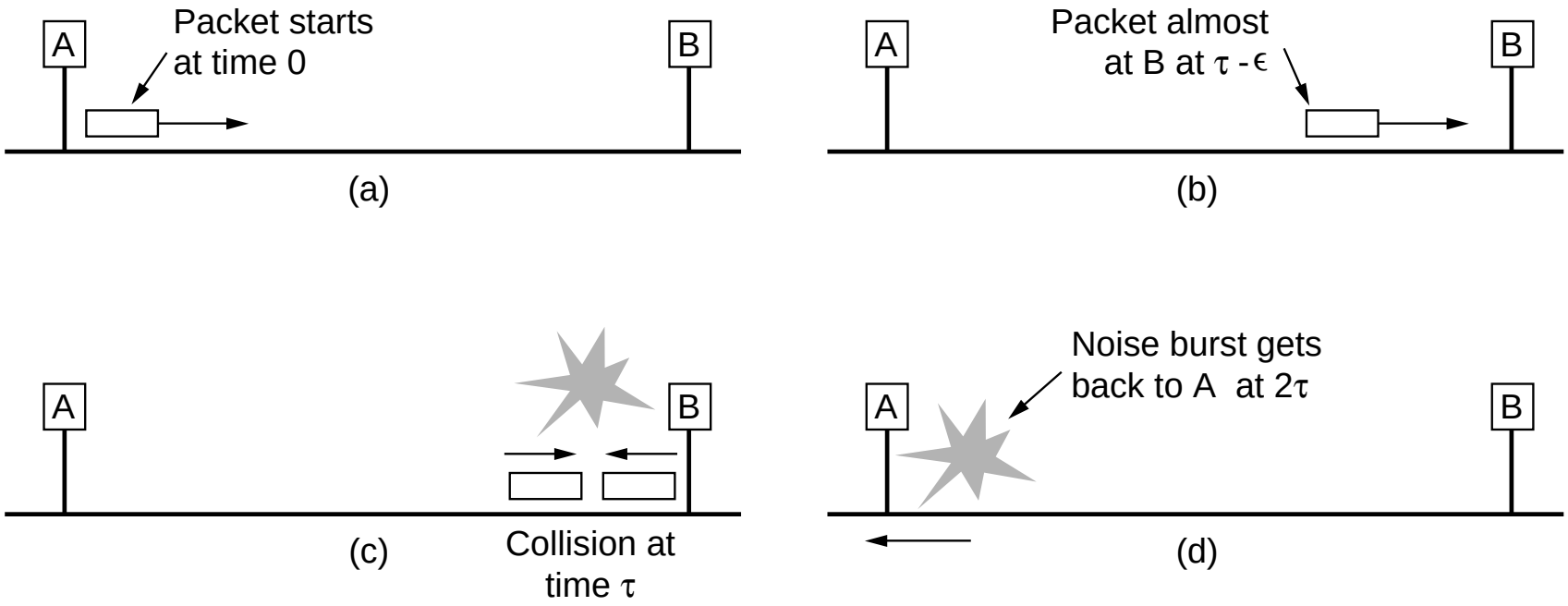


(a) DIX (Digital, Intel, Xerox) Ethernet, (b) IEEE 802.3

Ethernet Frame DIX

- Preamble: 10101010 (* 8) – 10-MHz square wave for 6.4 μsec
- Destination and Source addresses: 2 or 6 bytes (only 6 is used)
  - Group addresses – msb is 1
  - Broadcast – all 1's
  - Bit 46 is used for local versus global address
  - $48 - 2$ bits for global addresses
- Types field specifies the upper level protocol
- Data – 1500 byte maximum die to memory costs
- Pad: to ensure minimum length
- Checksum: CRC-32

Ethernet MAC Sublayer Protocol Minimum Frame Size



Ethernet MAC Sublayer Protocol Minimum Frame Size

- 802.3
  - longest segment 500 m
  - at most 4 repeaters
  - maximum LAN length is 2500 m
- Maximum round-trip time is 50μsec
- 10 Mbps implies 100 nsec / bit, 500 bits takes 50 μsec
- 802.3 uses 512 bits (64 bytes) as minimum frame size

Ethernet
Binary Exponential Backoff

- Slots are defined to be 51.2μsec during contention period
- After i collisions, backoff random number of intervals between 0 and $2^i - 1$
  - i is bounded at 10
  - after 16 attempts, the sender quits
- Intuition
  - Assume that number of contending stations is small until proven otherwise
  - if i were fi xed at 1023, lots of unnecessary waiting
  - if i were fi xed at 1, potential for unbounded waiting

Ethernet Performance Model

- Metcalfe and Boggs – ignore binary exponential backoff and assume constant probability, p, of retransmission in each slot
- Probability that one station acquires a slot, A, is

$$A = kp(1-p)^{k-1}$$

where

k	number of stations ready to transmit
p	probability that a station will retransmit

- A is maximized when p is $1/k$
- When p is $1/k$, $A \rightarrow 1/e$ as $k \rightarrow \infty$

Ethernet Performance
Size of Contention Window, w

- $A(A-1)^{j-1}$ is the probability that the contention window is j slots
- Mean number of slots per contention is:

$$\sum_{j=0}^{\infty} jA(1-A)^{j-1} = \frac{1}{A}$$

- Each slot is bounded by 2τ, so the mean window size is bounded by $2\tau/A$
- Assuming optimal p ($p = 1/k$), $A = 1/e$ and

$$w = 2\tau e \approx 5.4\tau$$

Ethernet Performance Efficiency

- Let P be the mean transmission time / frame

$$\text{Channel effi ciency} = \frac{P}{P + 2\tau/A}$$

- Let

  F frame length

  B bandwidth

  L cable length

  c speed of light

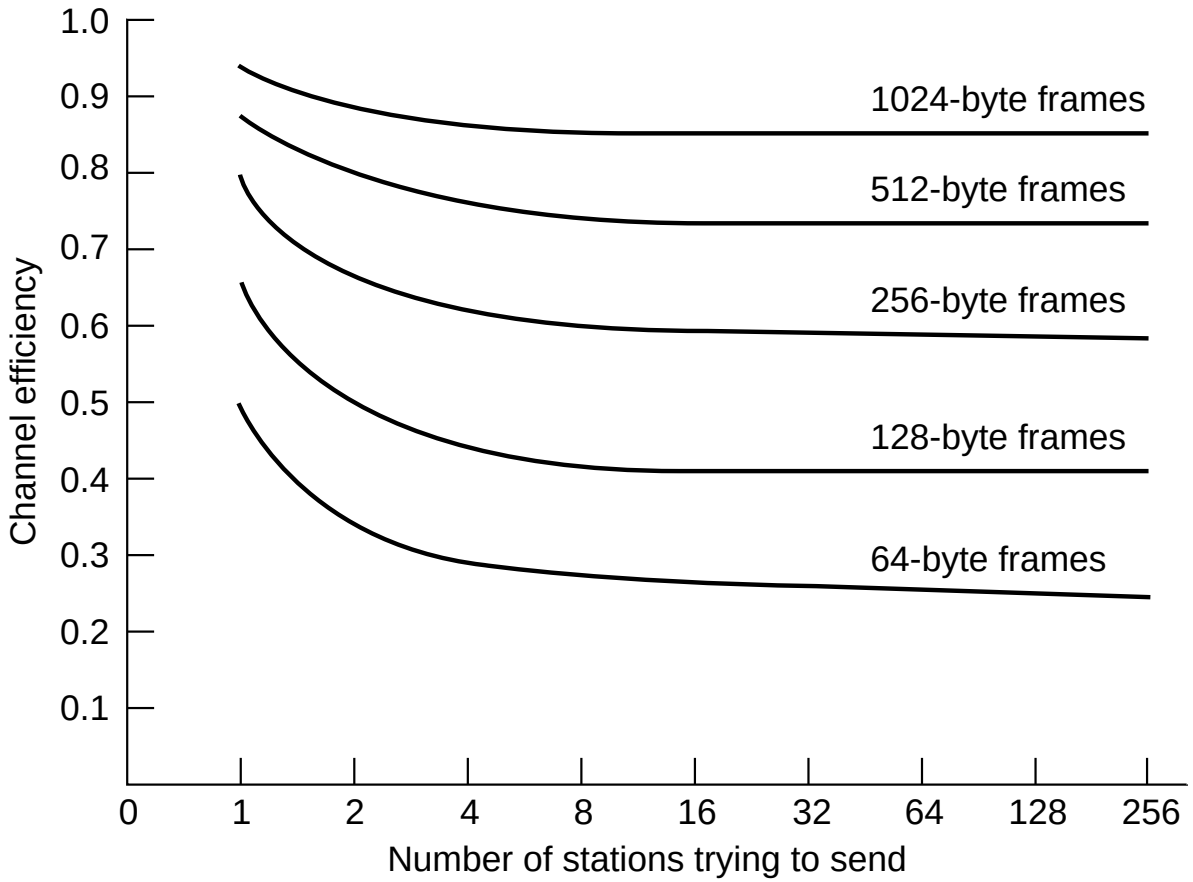
$$P = F/B$$

and

$$\text{Channel effi ciency} = \frac{1}{1 + 2BLe/cF}$$

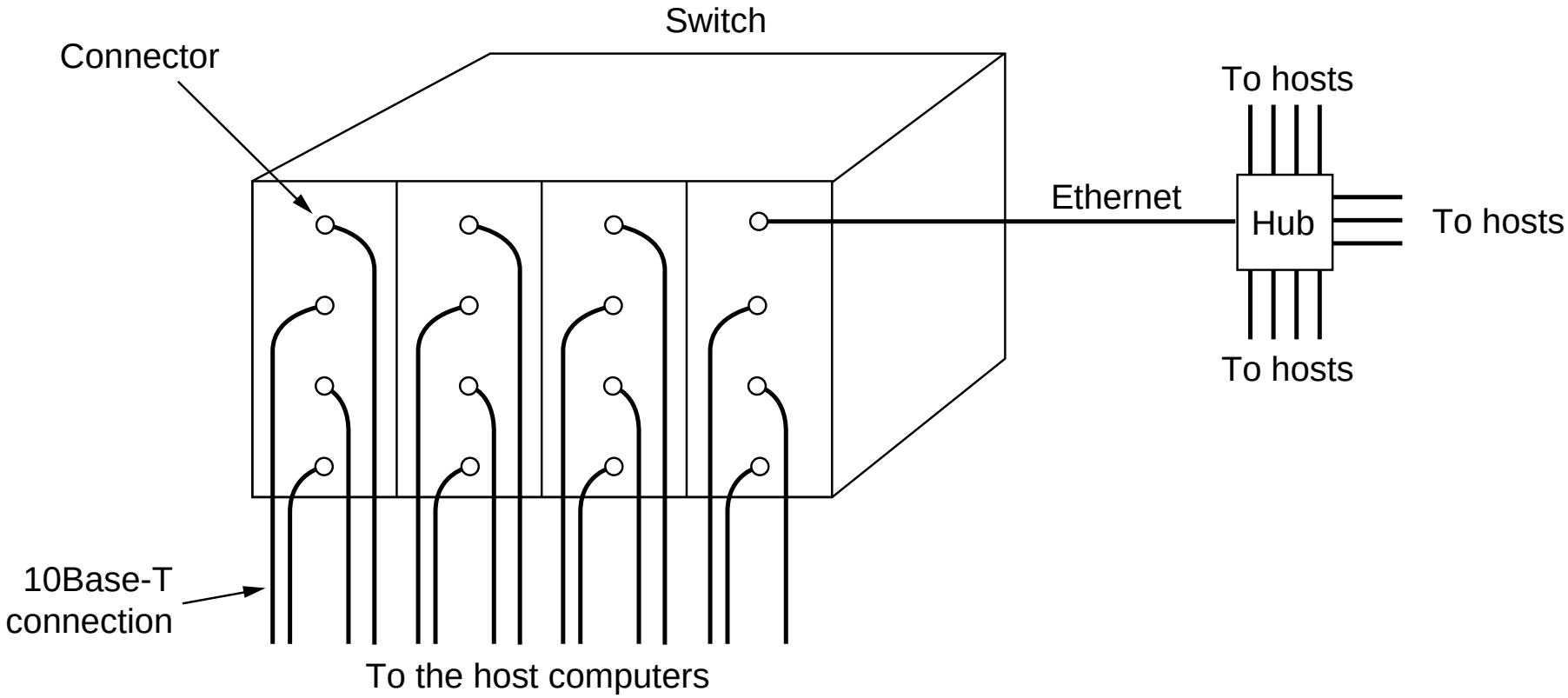
- As BL increases, effi ciency decreases

Ethernet Performance Efficiency



$2\tau = 51.2\mu$sec, 10 Mbps

Switched Ethernet

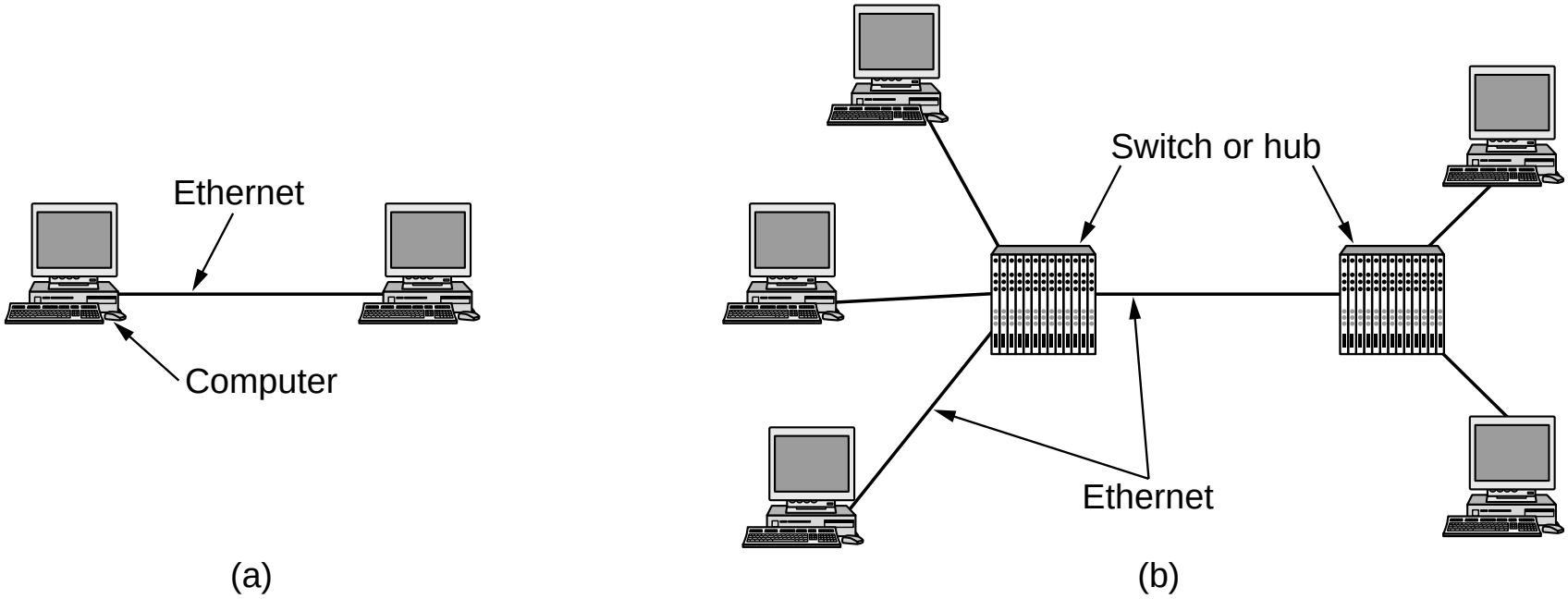


collision domains

Fast Ethernet Cabling

Name	Cable	Max seg	Advantages
100Base-T4	Twisted pair	100 m	Category 3 UTP
100Base-TX	Twisted pair	100 m	full duplex 100 Mbps category 5
100Base-TF	Fiber optics	2000 m	full duplex 100 Mpbs long runs

Gigabit Ethernet



(a) two-station Ethernet, (b) multistation Ethernet

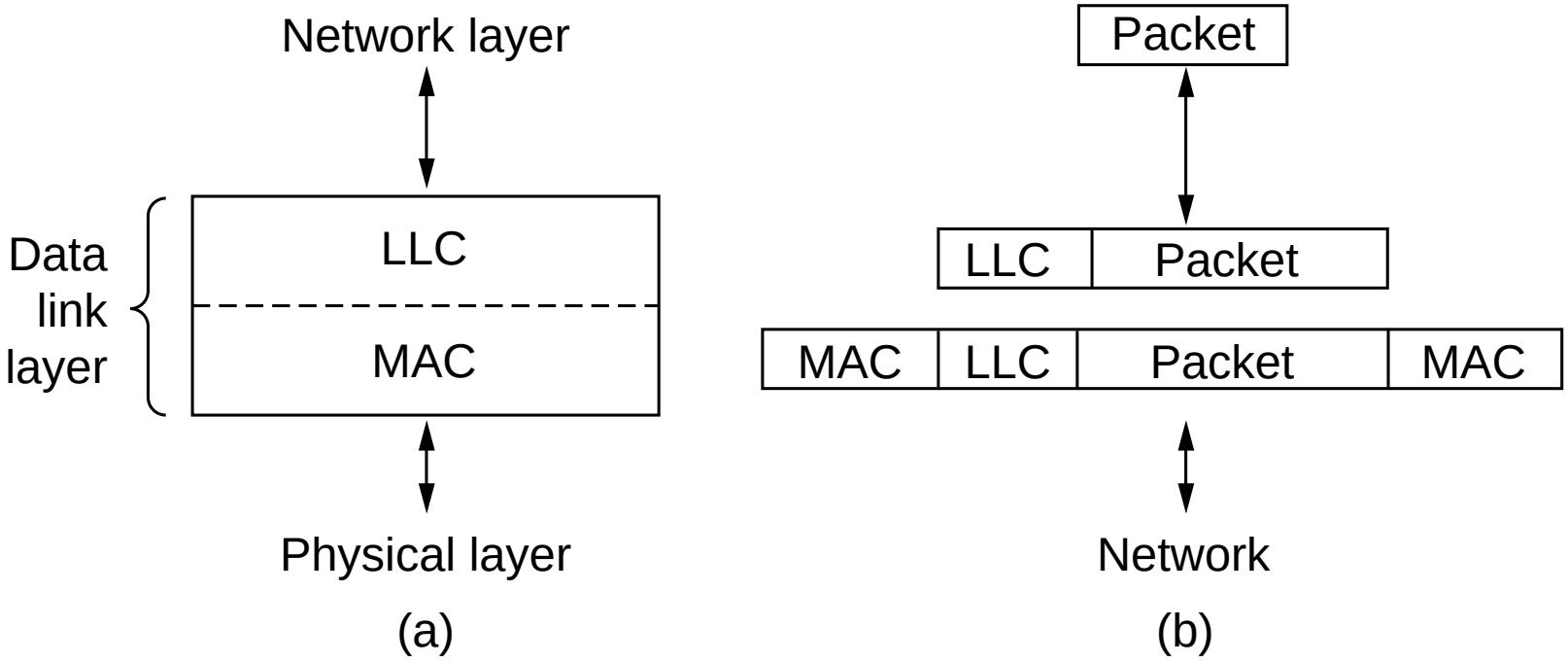
Gigabit Ethernet
It's not Ethernet

- Full duplex
  - switched, no collisions
  - not CSMA/CD
  - segment length determined by signalling properties
- Half duplex
  - hubs, collisions
  - 100 times faster, 25 meter maximum length
  - carrier extension–hardware pad to 512 bytes (9% effi ciency)
  - frame bursting–sender sends combined packets up to 512 bytes

Gigabit Ethernet Cabling

Name	Cable	Max seg	Advantages
1000Base-SX	Fiber optics	550 m	Multimode fi ber (50, 62.5 microns)
1000Base-LX	Fiber optics	5000 m	Single (10μ) or multi-mode (50, 60.5 μ)
1000Base-CX	2 pairs of STP	25 m	Shielded twisted pair
1000Base-T	4 pairs of UTP	100 m	Standard cat 5 UTP

IEEE 802.2: Logical Link Control



(a) Position of LLC, (b) Protocol formats

Ethernet Retrospective

- Simple – cheap, reliable, and easy to mainain
- Evolution

Topics

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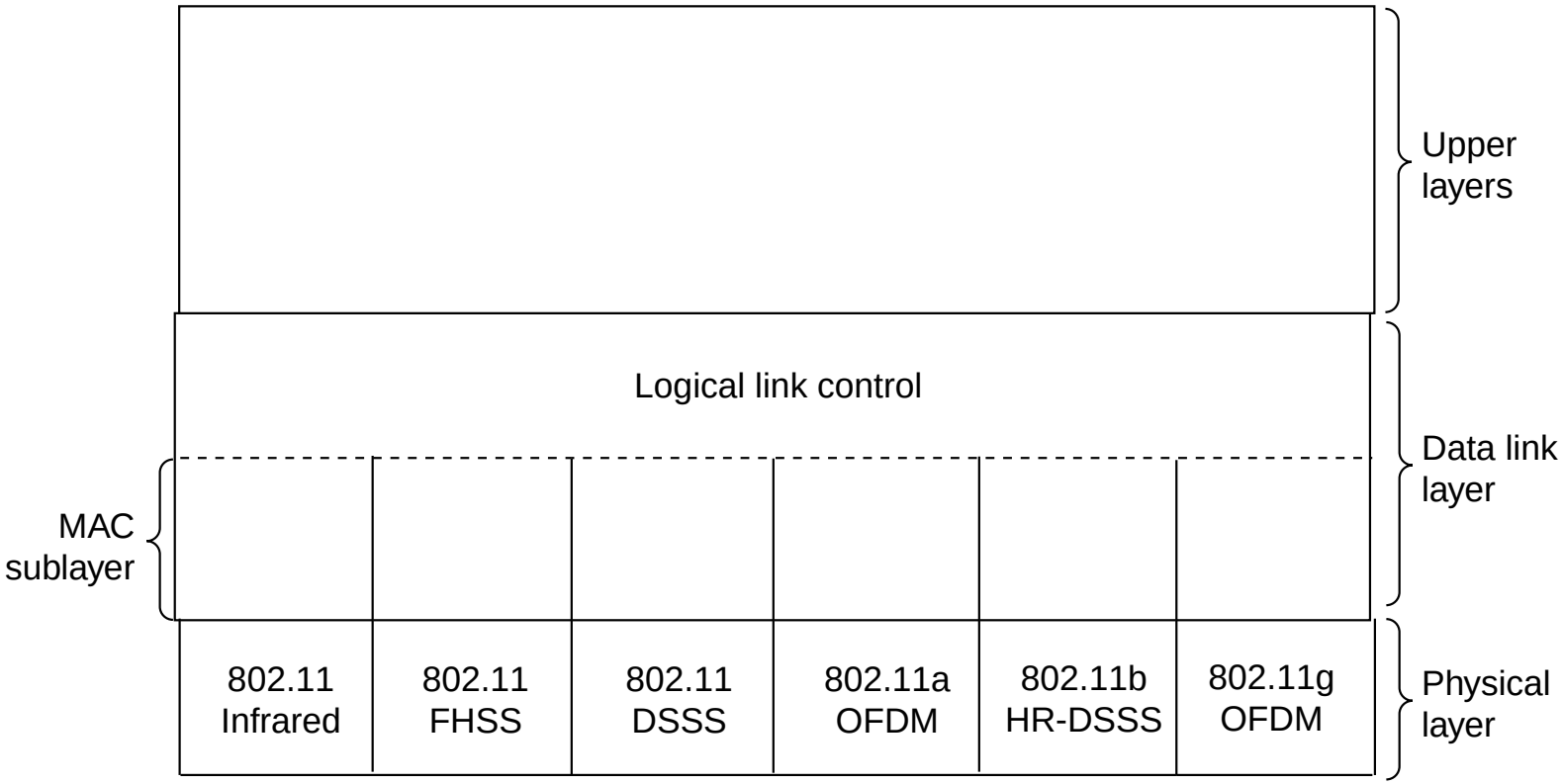
802.11 Protocol Stack



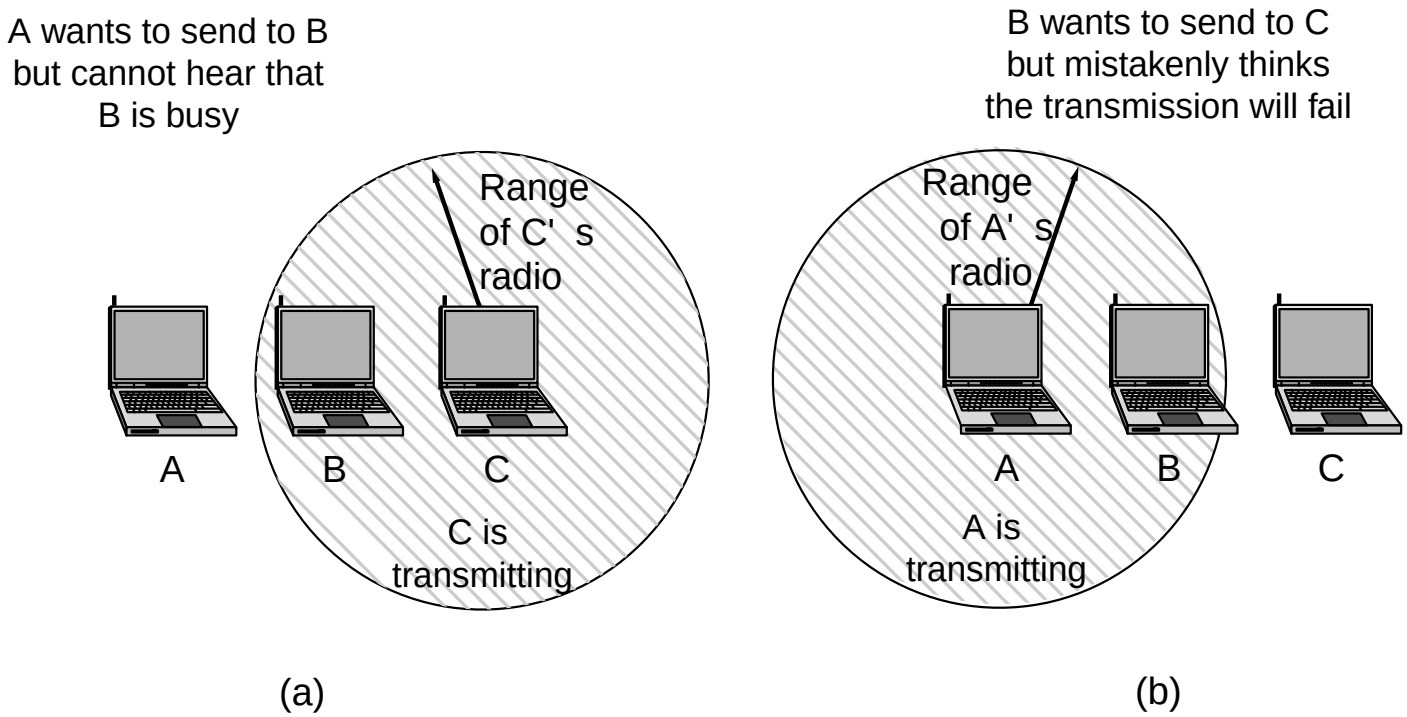
802.11 Physical Layer

- 802.11a
  - OFDM Othogonal Frequency Division Multiplexing
  - up to 54 Mbps
  - 52 frequencies: 48 for data, 4 for synchronization
- 802.11b
  - HR-DSSS High Rate Direct Sequence Spread Spectrum
  - 1, 2, 5.5, and 11 Mbps
  - 7 times the range of 802.11a
- 802.11g (enhanced 802.11b)

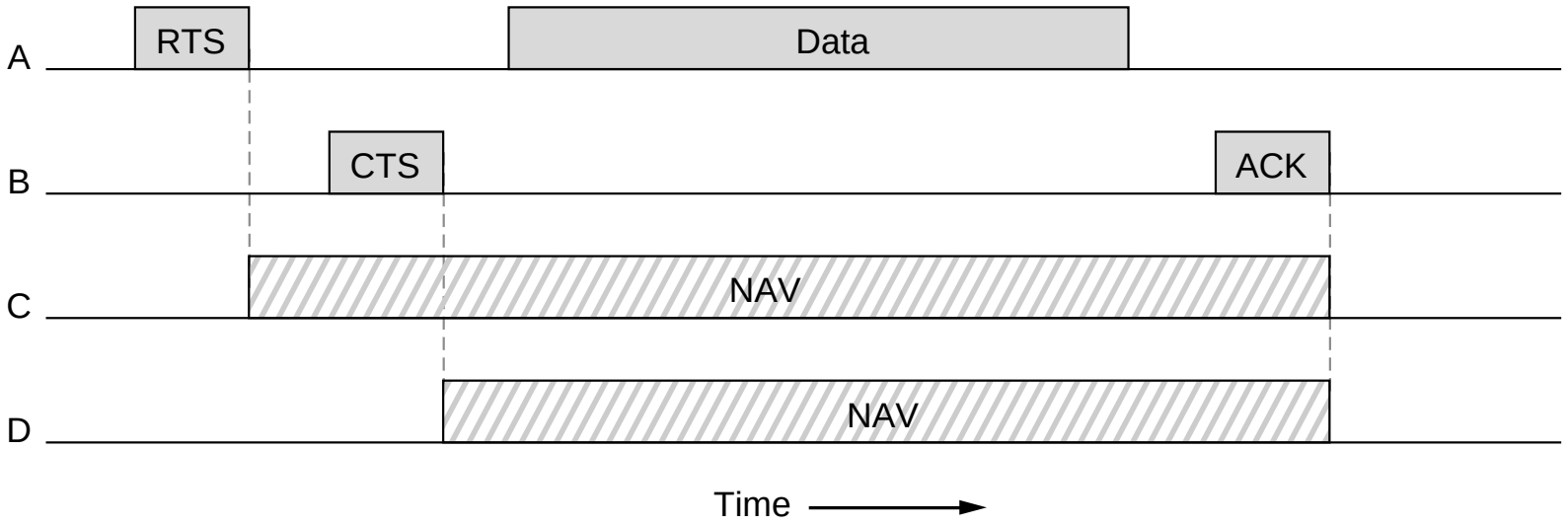
802.11 MAC Sublayer Protocol

- Hidden and Exposed stations
- Radios are half duplex (can't listen while sending)
- Modes
  - DCF Distributed Coordination Function
  - PCF Point Coordination Function
    - base station, polls for frames to send
    - beacon frame
- CSMA/CA

802.11
Hidden and Exposed Stations

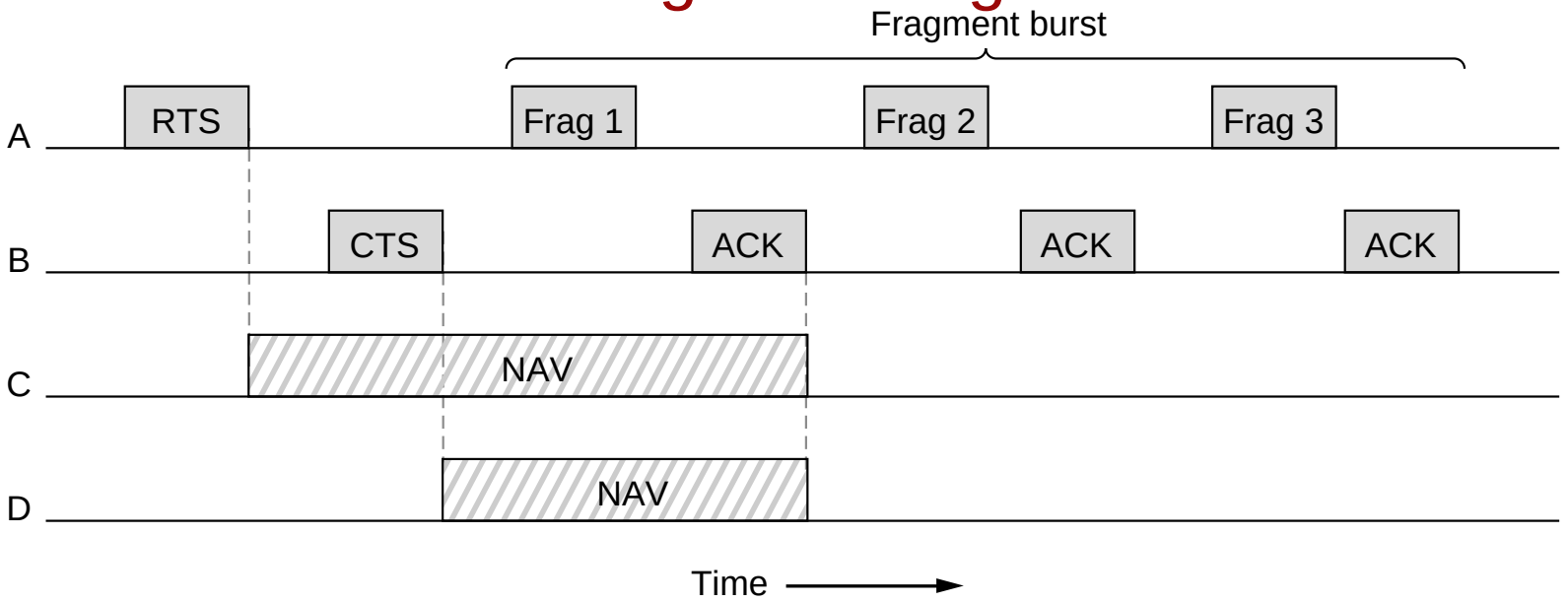


802.11
Virtual Channel Sensing

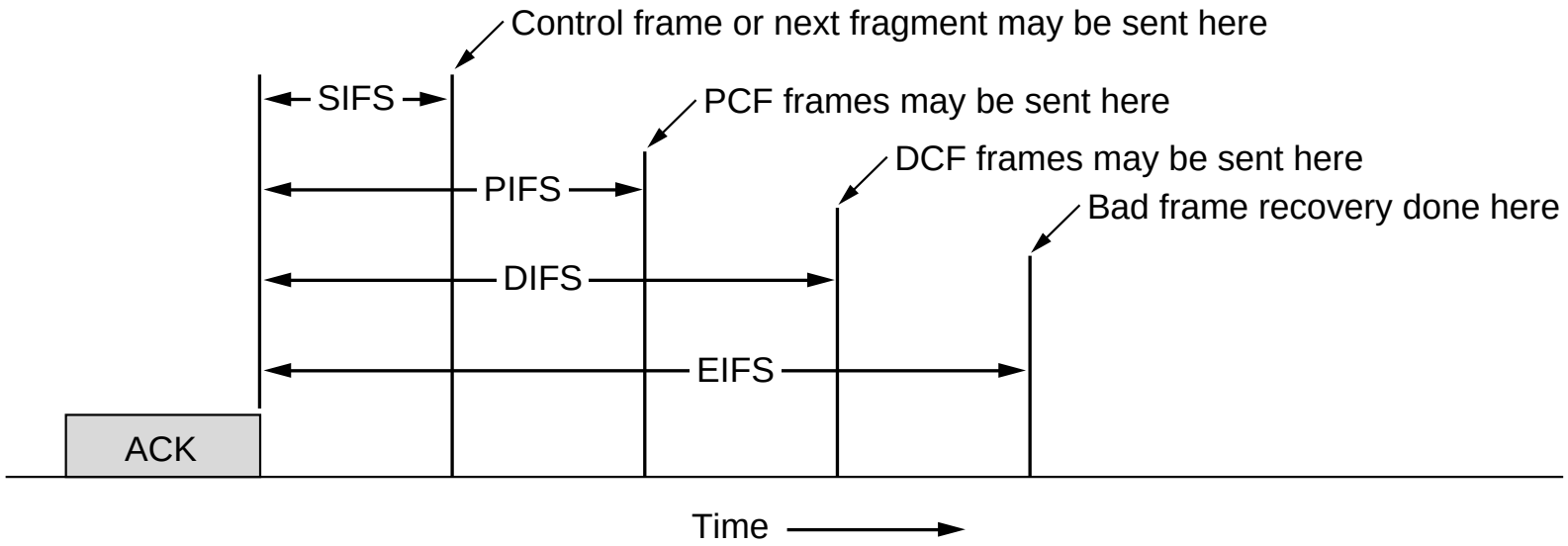


802.11 Fragment Burst

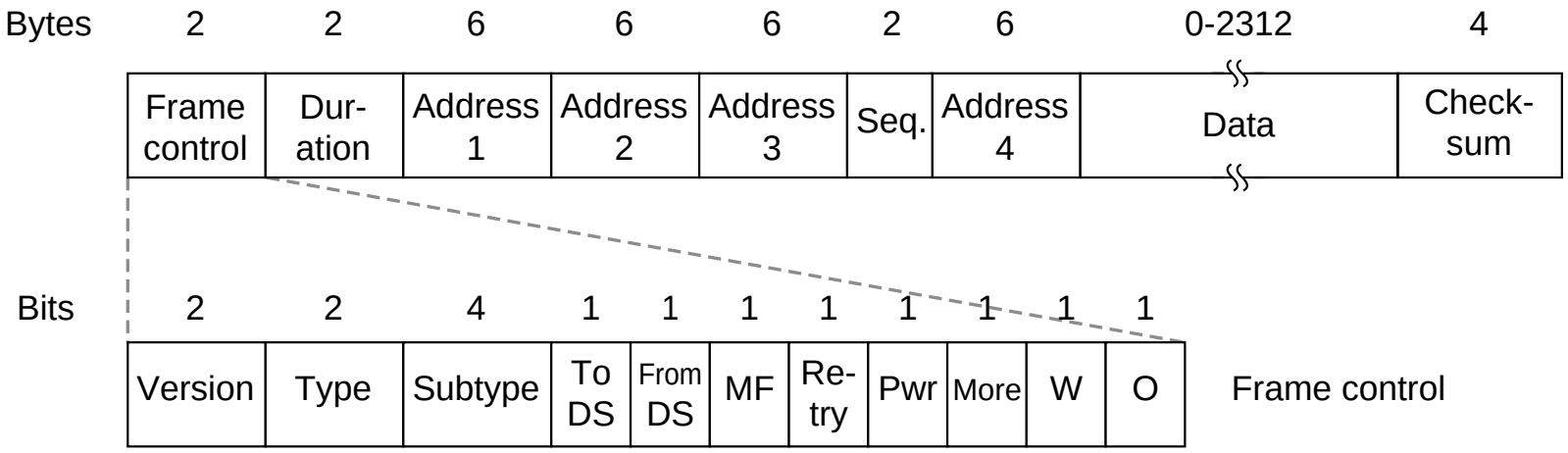
Errors are related to fragment length



802.11
Combining PCF and DCF



802.11 Protocol Stack



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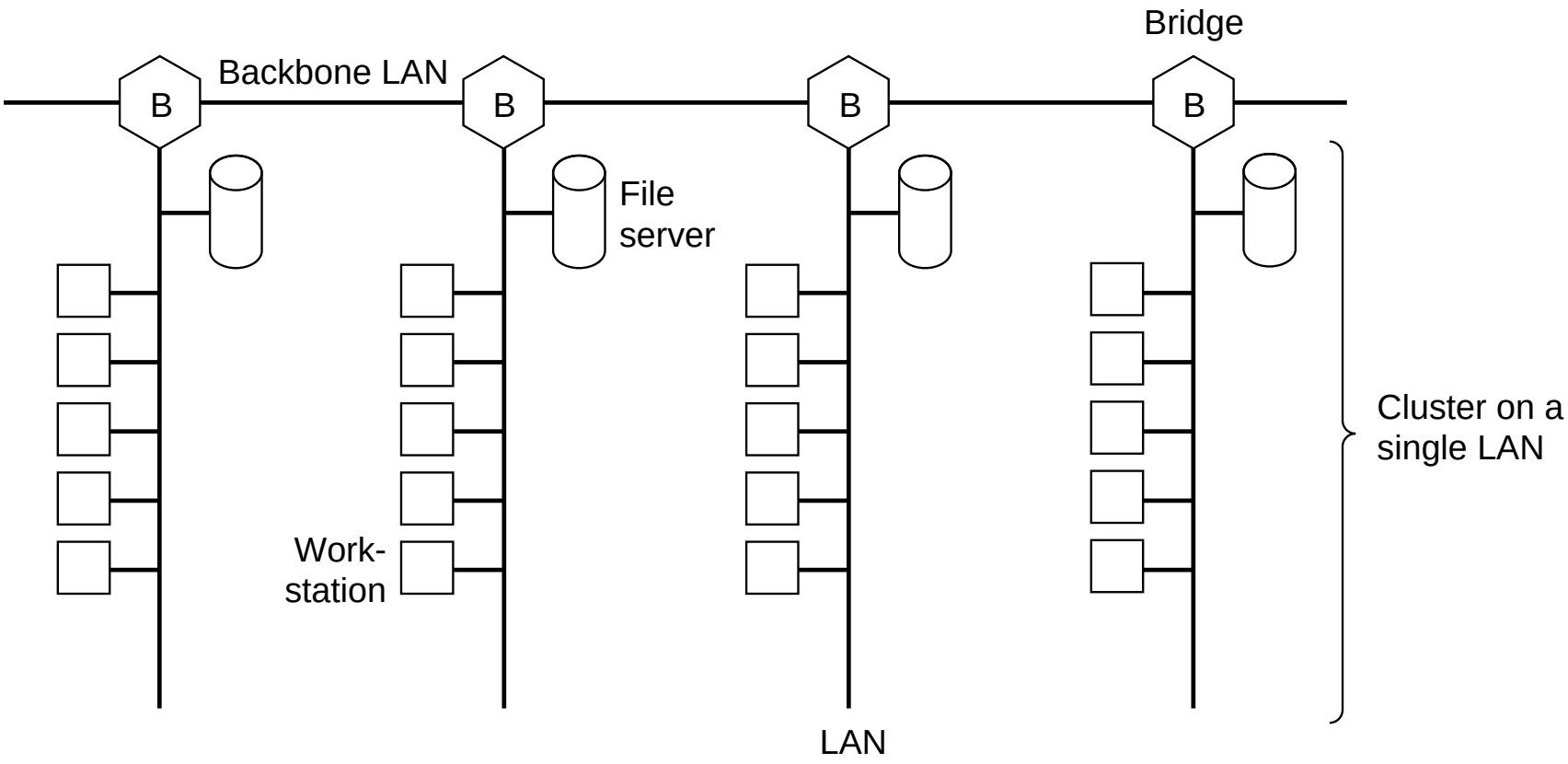
Bridging LANs Example



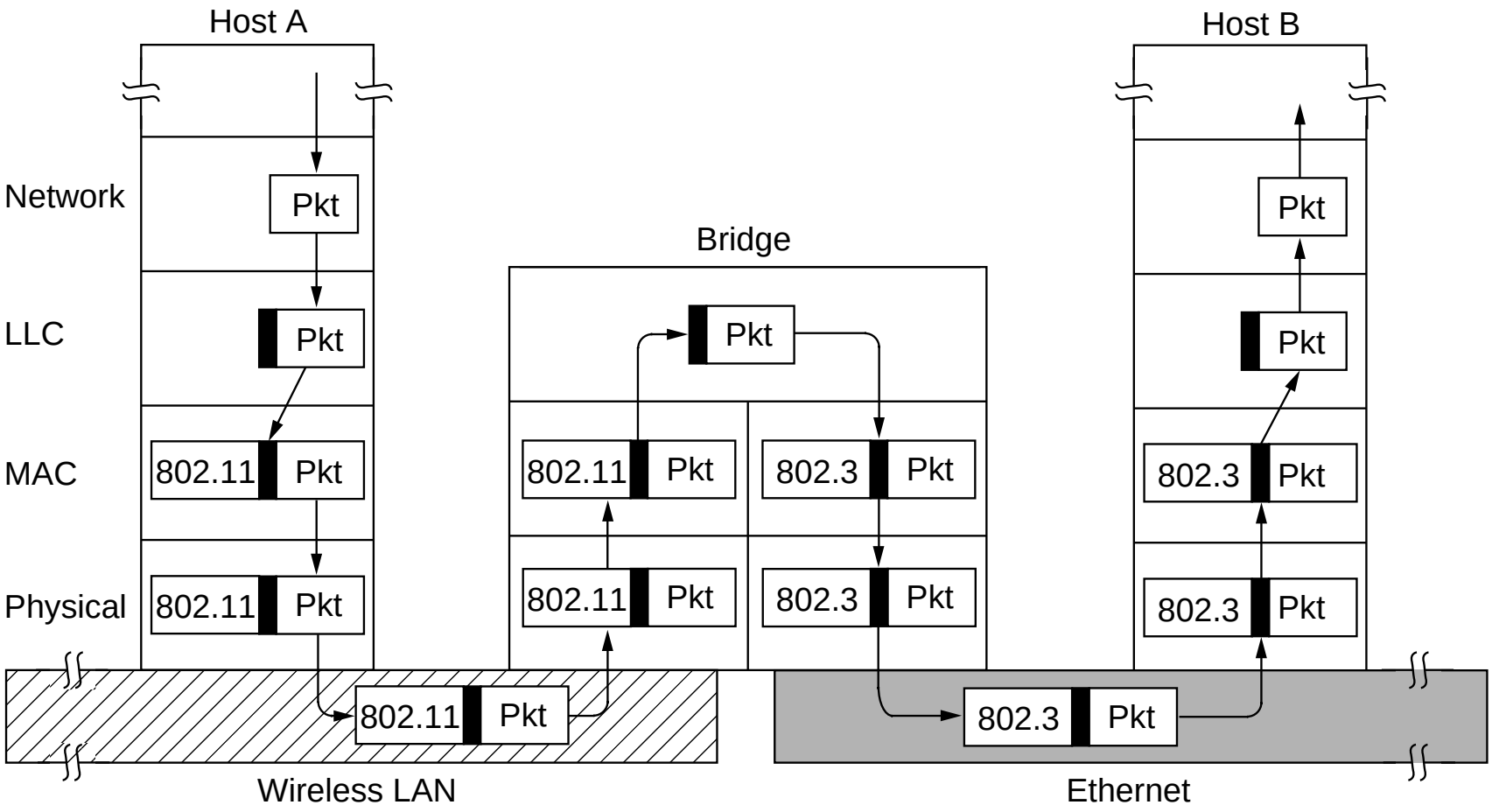
Bridging LANs Reasons

- Autonomy: partitioning reflects political boundaries
- Geography: partitioning reflects geographic distance
- Load: partition to isolate load
- Distance: further than 2500 meters
- Reliability: limit the effect of a bad node
- Security: limit the spread of sensitive information (promiscuous mode)

Data Link Layer Switching

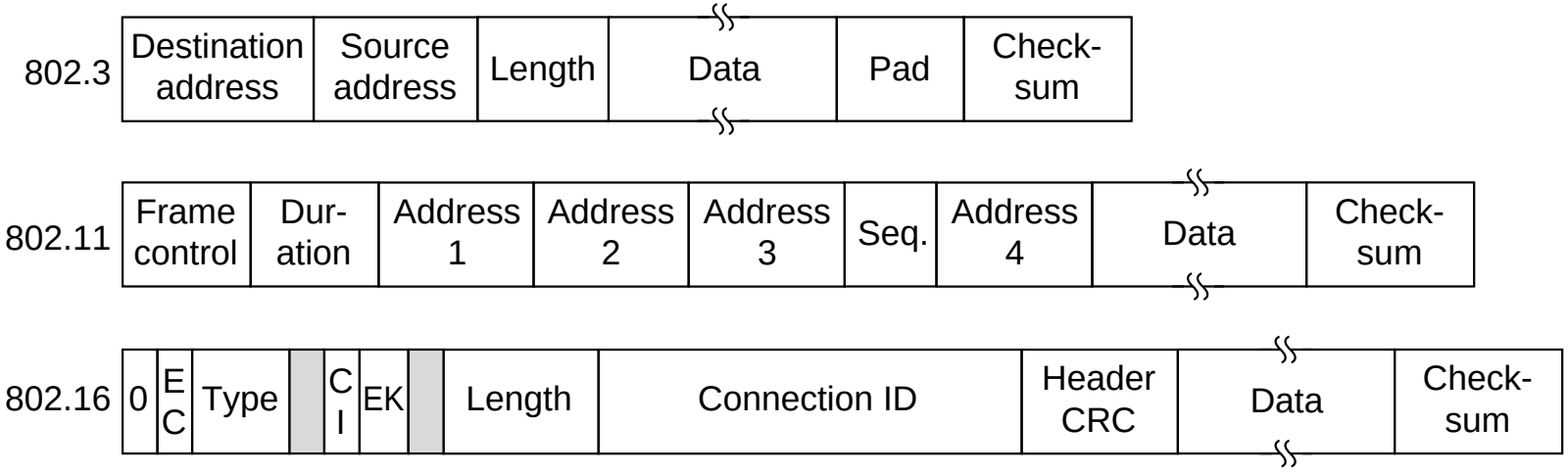
- Bridges from 802.x to 802.y
- Local Internetworking
- Spanning Tree Bridges
- Remote Bridges
- Repeaters, Hubs, Bridges, Switches, Routers, and Gateways
- Virtual LANs

Bridges from 802.x to 802.y
Bridge Function



Bridges from 802.x to 802.y Issues

- Different frame formats



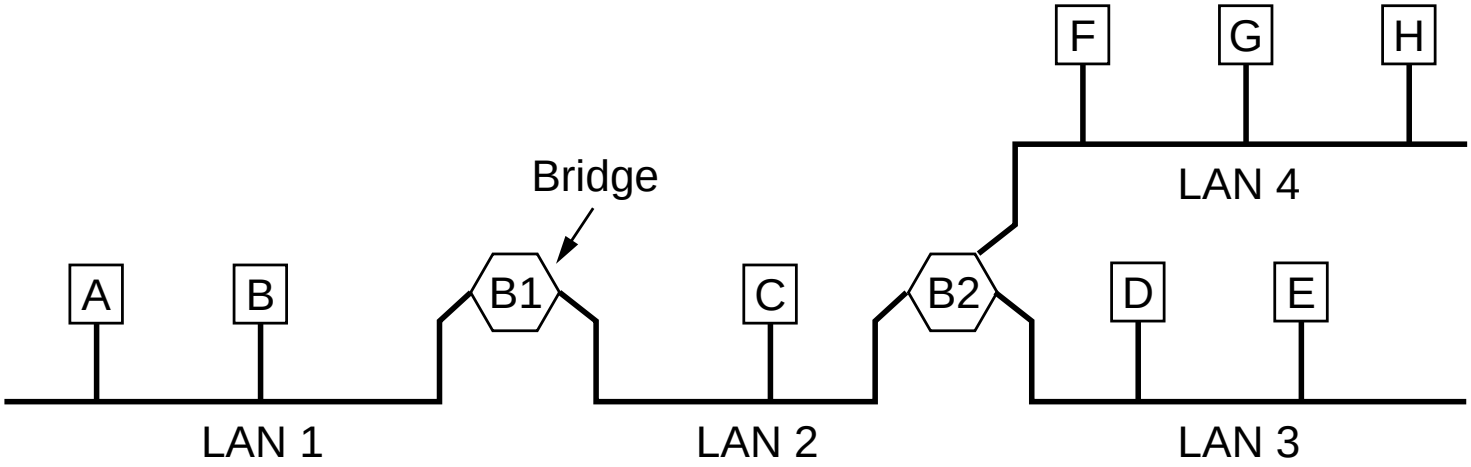
- Different data rates
  - 100 Mbs to 11 Mbps
  - many to one

Bridges from 802.x to 802.y Issues (continued)

- Different maximum frame sizes
  - frames arrive in one piece or they don't
  - no provision for fragmenting and reassembling frames
  - MTU – lacks transparency
- Security
  - encryption on wireless, but not on Ethernet
  - encrypt at higher layers
- Quality of service

Local Internetworking

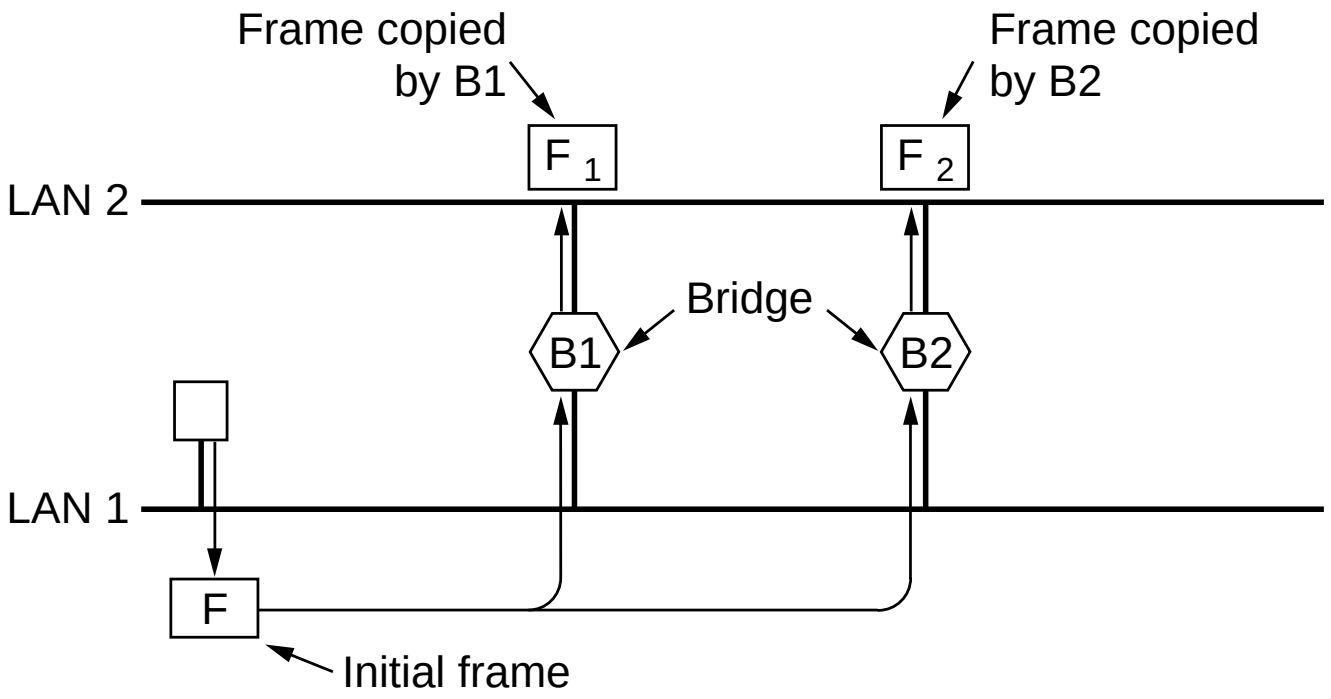
Transparent bridging of Local Ethernets



- For each frame, bridge decides to forward or discard
- Routing table in each bridge, local knowledge only
- Backward learning with decay

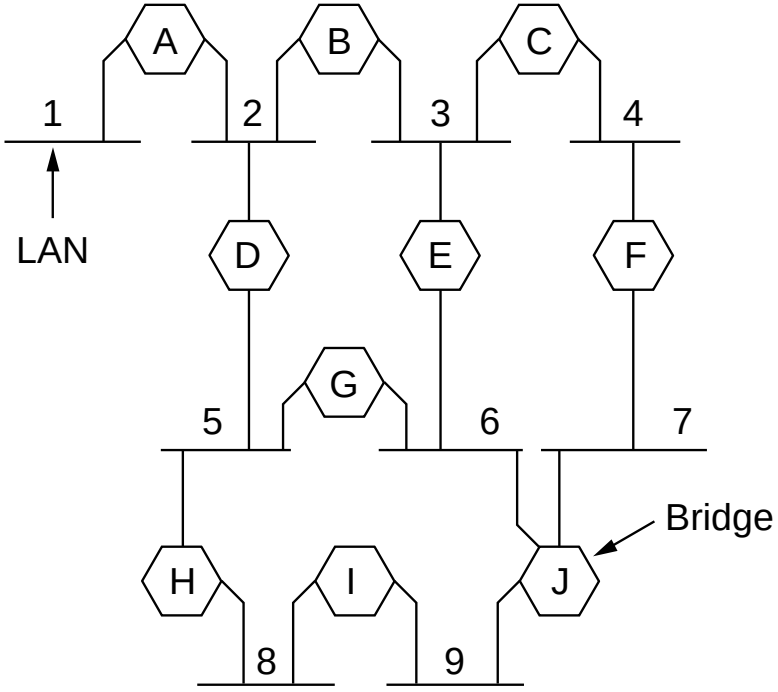
Spanning Tree Bridges Issue

- Multiple bridges in parallel
- Routing loops

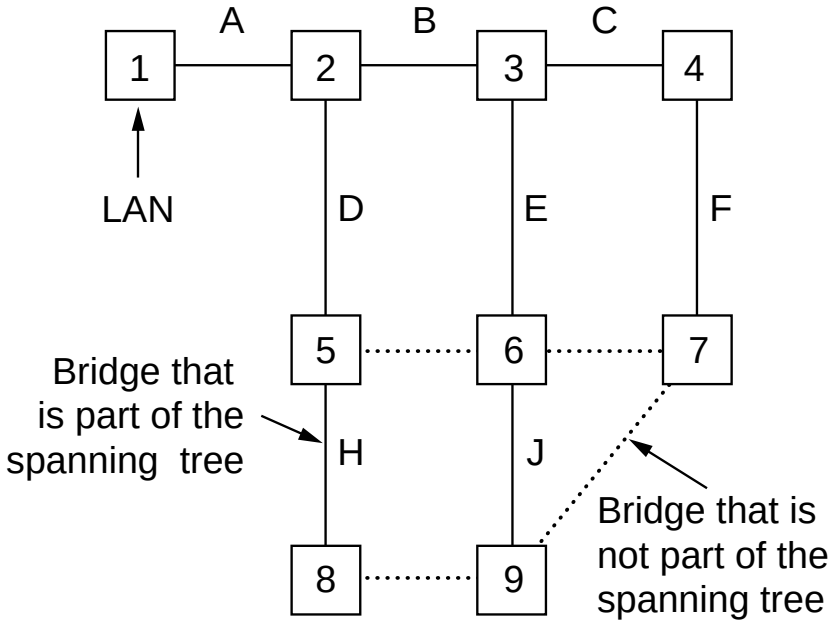


- Build a tree, avoid loops, but ignore some possible links

Spanning Tree Bridges Sample Solution



(a)

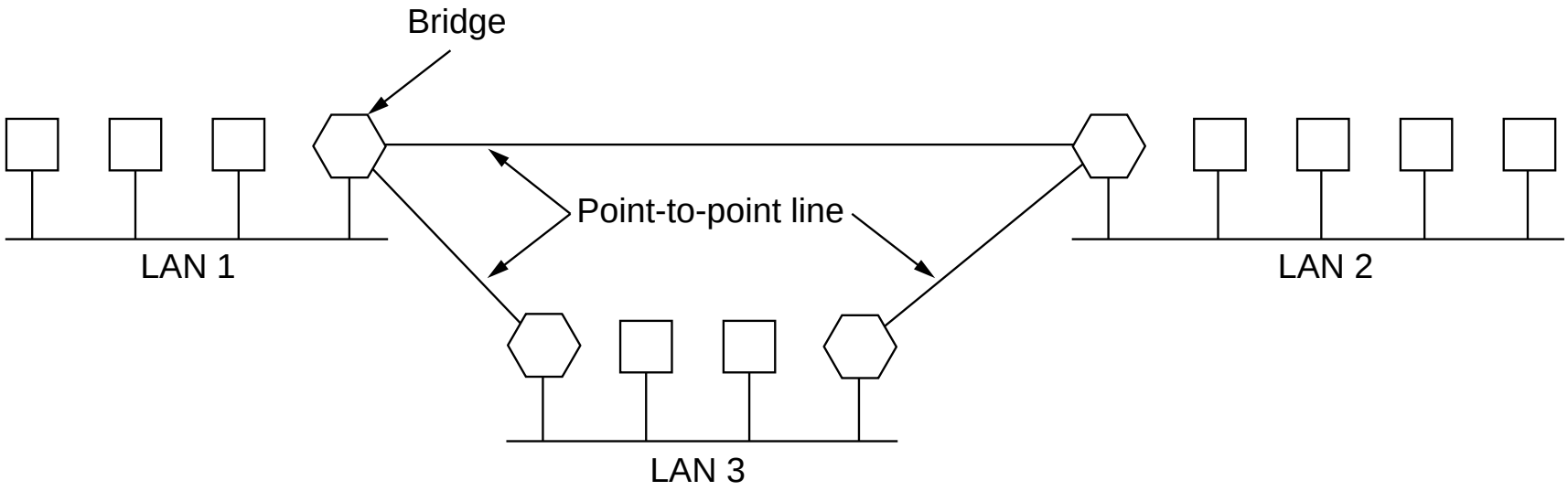


(b)

Spanning Tree Bridges Building the Tree

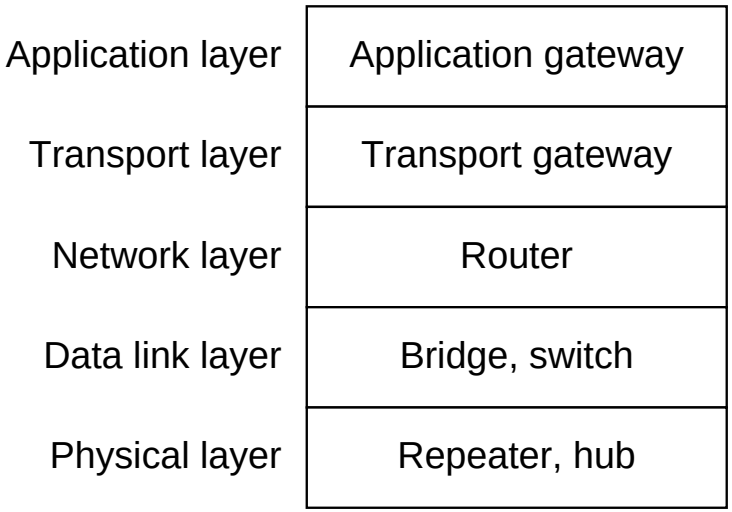
- Selecting a root node
  - broadcast serial numbers
  - select bridge with lowest serial number
- Construct a tree with shortest paths from root to every bridge
- Continue to run algorithm to detect changes in topology

Remote Bridges
PPP Links

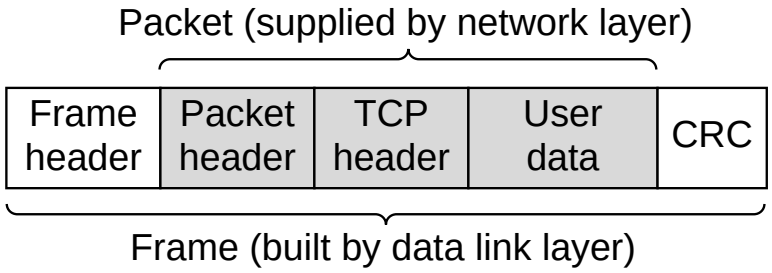


- MAC frames as payload
- Strip MAC header and trailer and forward payload only (may miss errors in bridge memory)

Repeaters, Hubs, Bridges, Switches, Routers and Gateways

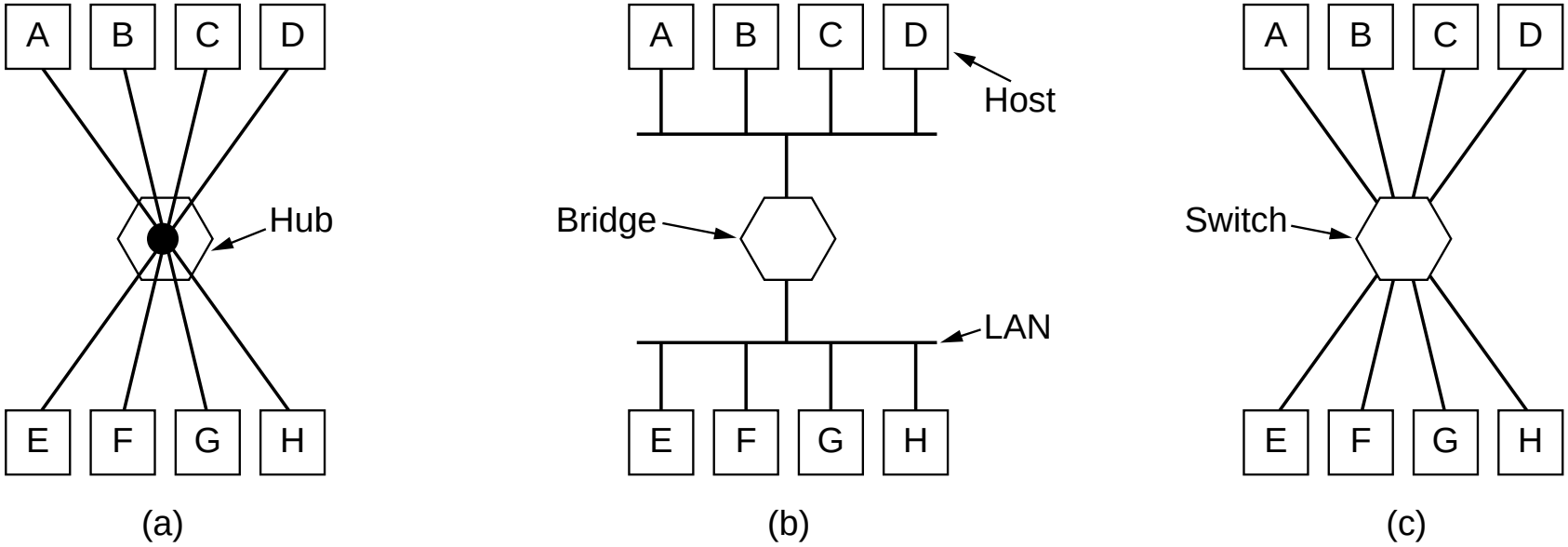


(a)



(b)

Hubs, Bridges, and Switches



Cutthrough switches

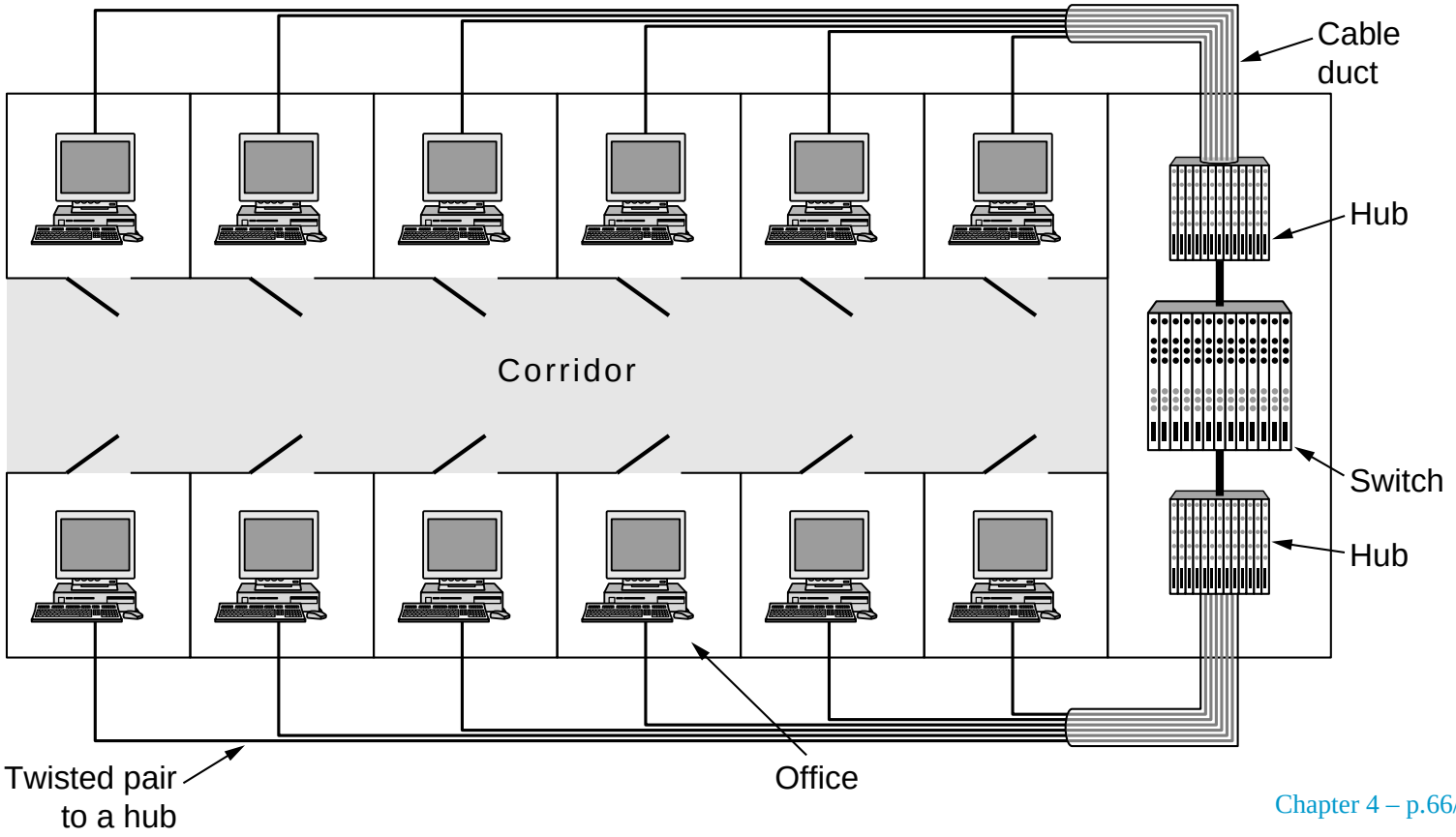
Routers and Gateways

- Routers operate at the network layer
  - strip off MAC header and trailer
  - use destination address (e.g., IP) address in network header for routing
- Transport gateways connect networks using different transport protocols (e.g., TCP and ATM)
- Application gateways, e.g., e-mail to SMS messages

Virtual LANs

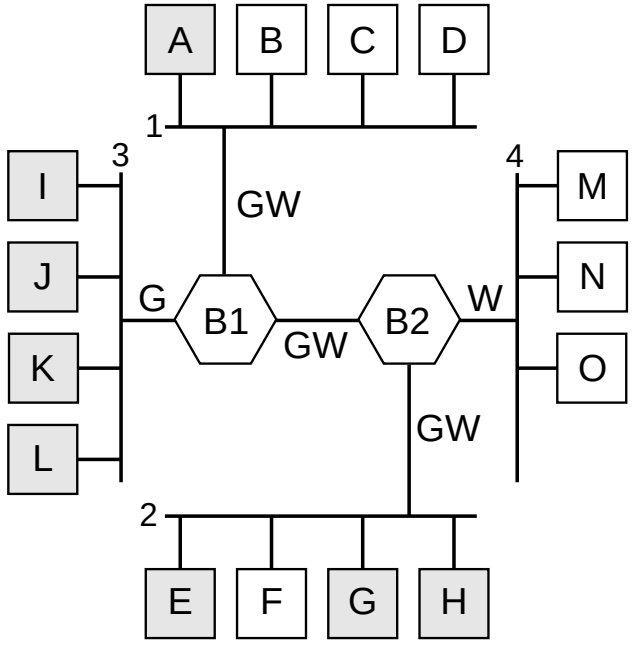
Physical Topology may not match the logical organization

- Security, Load, Broadcast

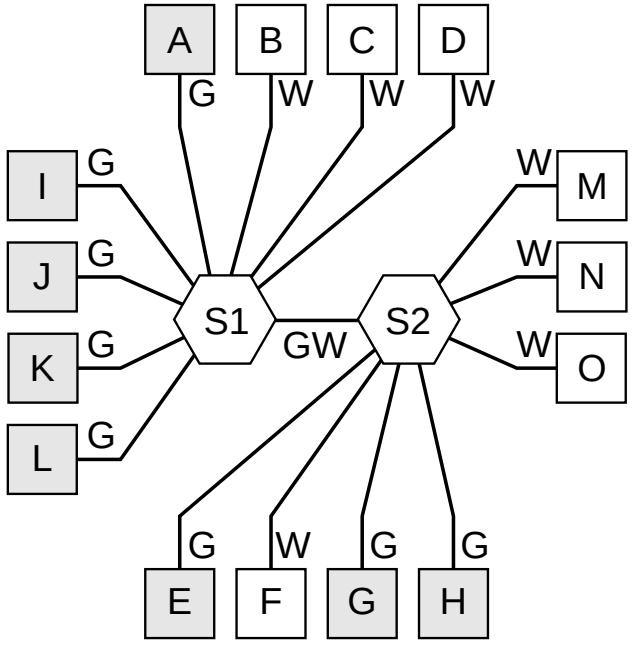


Example VLANs

Port versus MAC versus protocol or IP

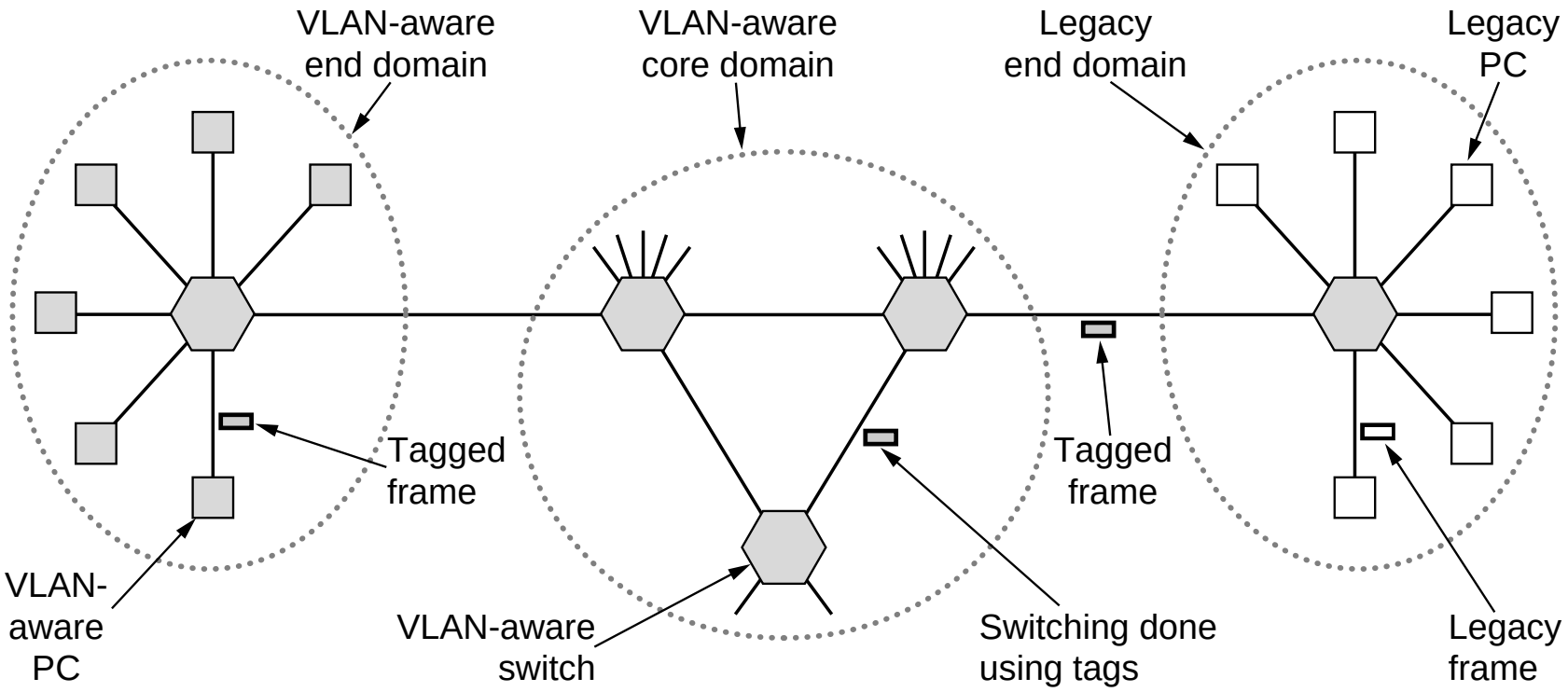


(a)



(b)

802.1Q – Being VLAN Aware Transition



802.1Q Frame Format