



Medium Access Control Sublayer

Chapter 4

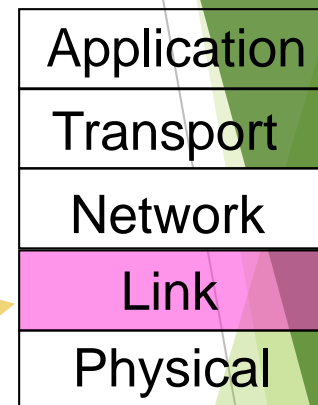
- ▶ Channel Allocation Problem
- ▶ Multiple Access Protocols
- ▶ Ethernet
- ▶ Wireless LANs
- ▶ Broadband Wireless
- ▶ Bluetooth
- ▶ RFID
- ▶ Data Link Layer Switching

The MAC Sublayer

Responsible for deciding who sends next on a multi-access link

- ▶ An important part of the link layer, especially for LANs

Indirizzo univoco. Ad esempio le WLAN (Wireless LAN) sono dei canali di comunicazione broadcast



MAC is in here!

Channel Allocation Problem (1)

For fixed channel and traffic from N users

- ▶ Divide up bandwidth using FTM, TDM, CDMA, etc.
- ▶ This is a static allocation, e.g., FM radio

This static allocation performs poorly for bursty traffic

- ▶ Allocation to a user will sometimes go unused

Si può pensare, ad esempio, di utilizzare tecniche come FDM per ripartire i frame ai loro destinatari. Allora ad ogni utente alloco una frequenza specifica

Channel Allocation Problem

(2)

Dynamic allocation gives the channel to a user when they need it.
Potentially N times as efficient for N users.

Schemes vary with assumptions:

Assumption	Implication
Independent traffic	Often not a good model, but permits analysis
Single channel	No external way to coordinate senders
Observable collisions	Needed for reliability; mechanisms vary
Continuous or slotted time	Slotting may improve performance
Carrier sense	Can improve performance if available

Multiple Access Protocols

- ▶ ALOHA »
- ▶ CSMA (Carrier Sense Multiple Access) »
- ▶ Collision-free protocols »
- ▶ Limited-contention protocols »
- ▶ Wireless LAN protocols »

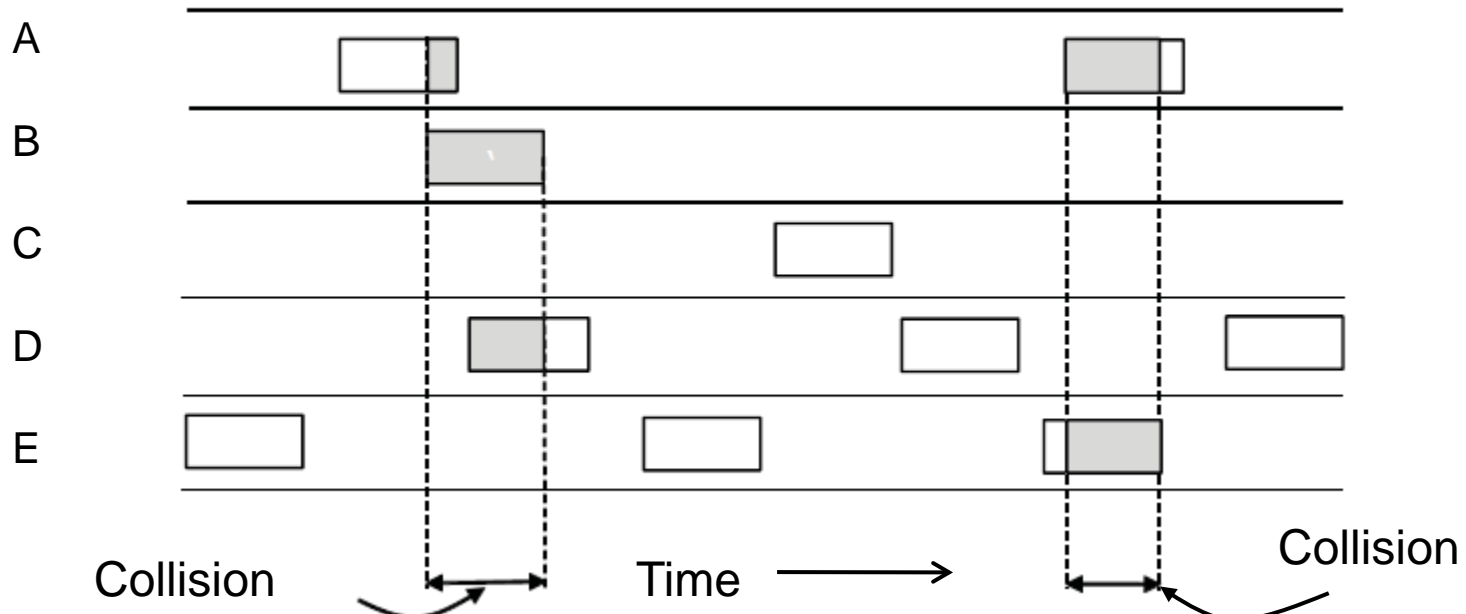
ALOHA (1)

I frame sono inviati dagli utenti appena sono disponibili. Non previene collisioni e, in caso i frame sono danneggiati

In **pure ALOHA**, users transmit frames whenever they have data; users retry after a random time for collisions

- Efficient and low-delay under low load

User

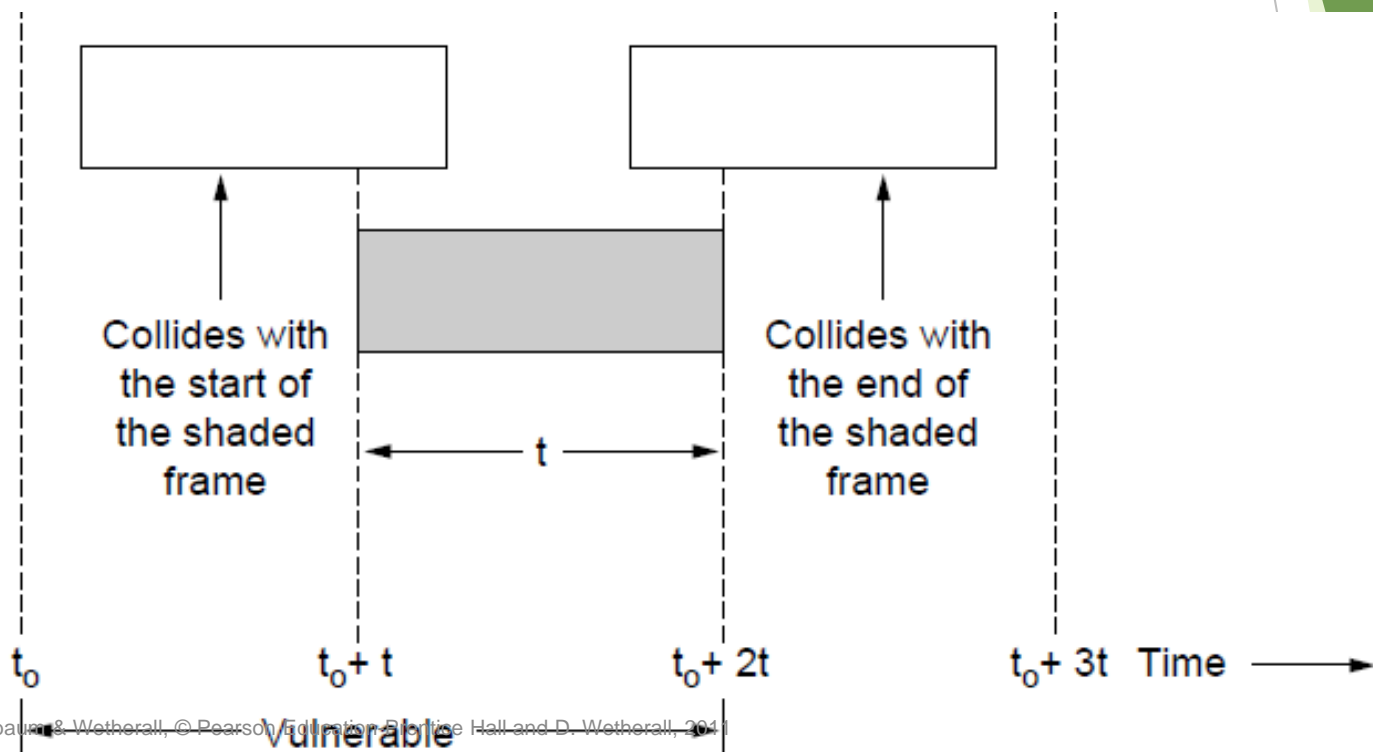


ALOHA (2)

I frame generati dalla stazione si possono modellare come distribuzioni di Poisson.

Collisions happen when other users transmit during a vulnerable period that is twice the frame time

- ▶ Synchronizing senders to slots can reduce collisions

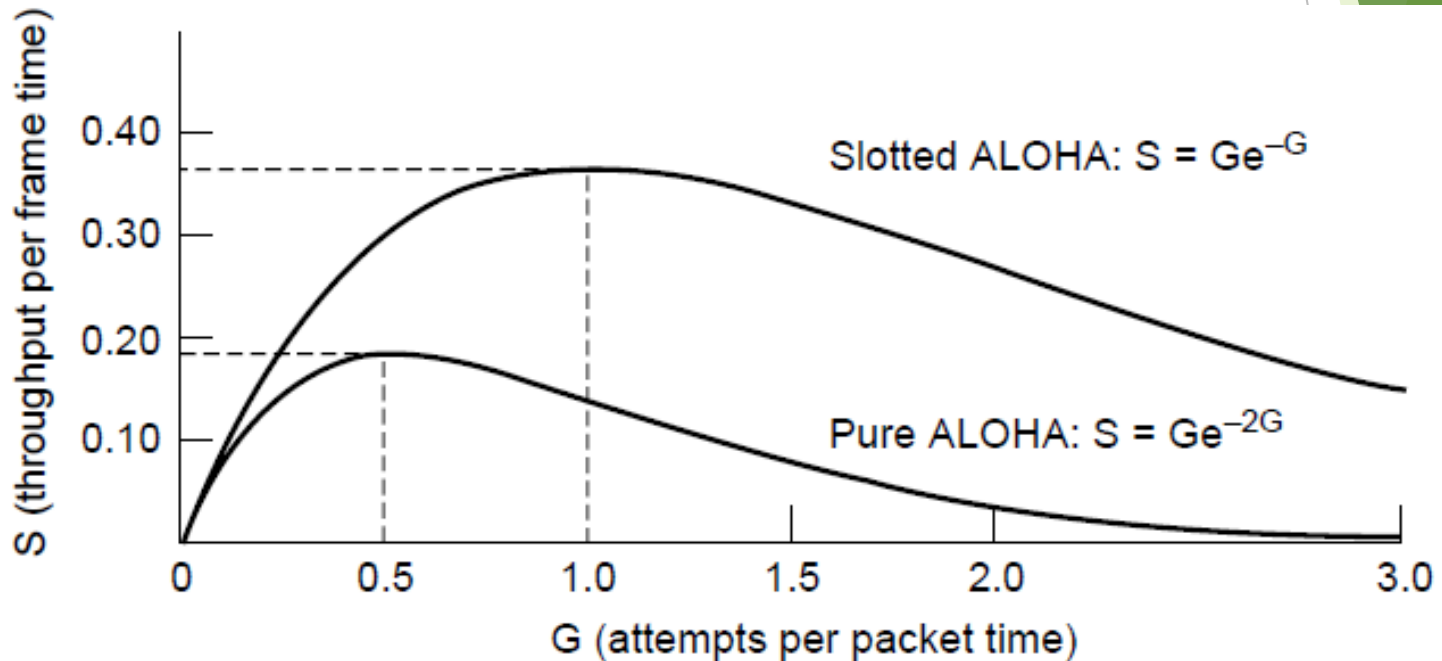


ALOHA (3)

Analogo al Pure ALOHA ma divide il tempo in intervalli temporali discreti, chiamati slots, i quali corris

Slotted ALOHA is twice as efficient as pure ALOHA

- ▶ Low load wastes slots, high loads causes collisions
- ▶ Efficiency up to $1/e$ (37%) for random traffic models



CSMA (1)

La base è ALOHA. Prima di inviare i mittenti esamina il canale se altri stanno trasmettendo a loro volta. Se il canale è libero, il mittente trasmette.

CSMA improves on ALOHA by sensing the channel!

- ▶ User doesn't send if it senses someone else

Variations on what to do if the channel is busy:

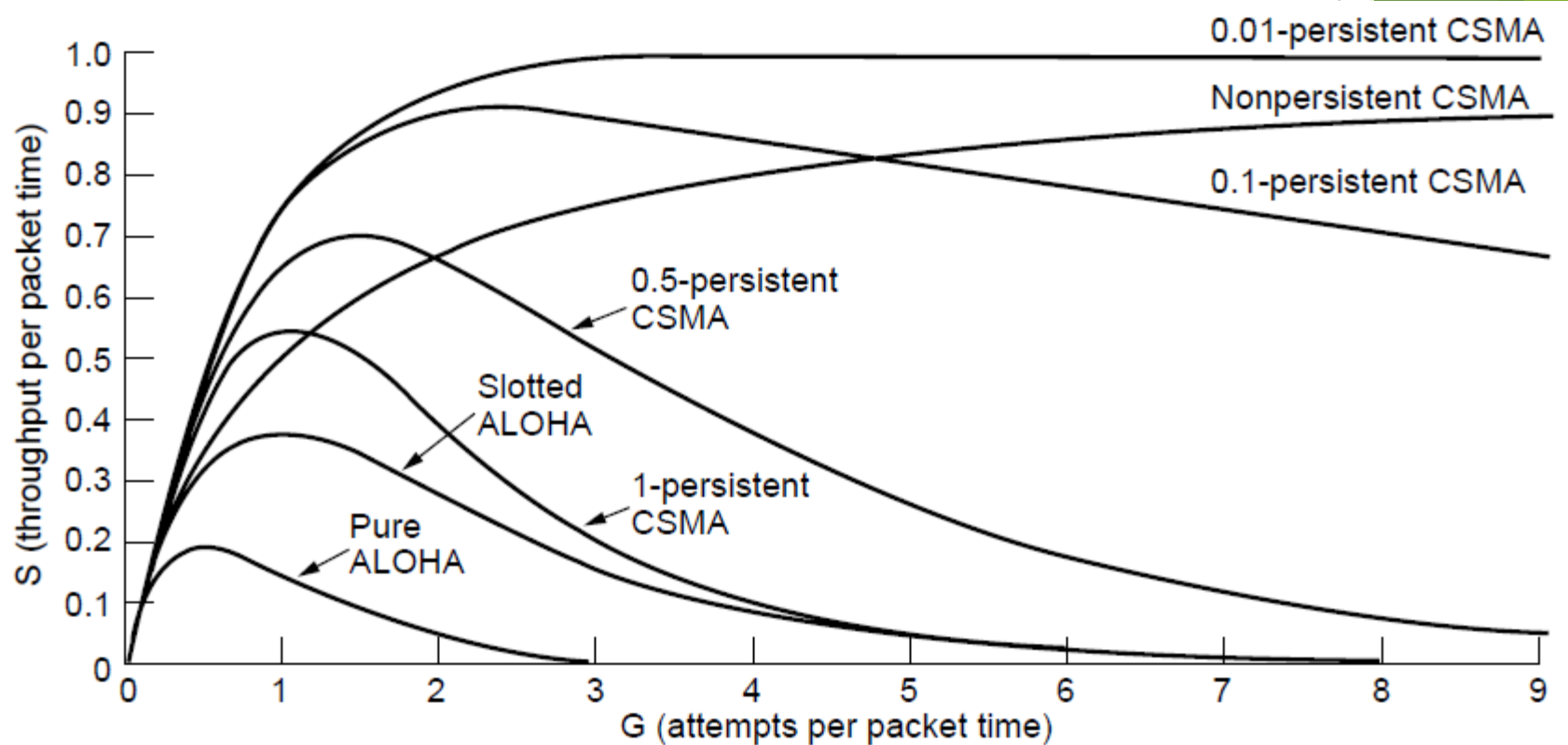
- ▶ 1-persistent (greedy) sends as soon as idle
- ▶ Nonpersistent waits a random time then tries again
- ▶ p-persistent sends with probability p when idle

p-persistent: la stazione trasmette con una probabilità p quando lo trova idle. 1-persistent: appena ha da inviare, il mittente esamina continuamente il canale.

CSMA (2) – Persistence

Minore è la probabilità di trasmissione, maggiore è la probabilità di trasmissione corretta.

CSMA outperforms ALOHA, and being less persistent is better under high load



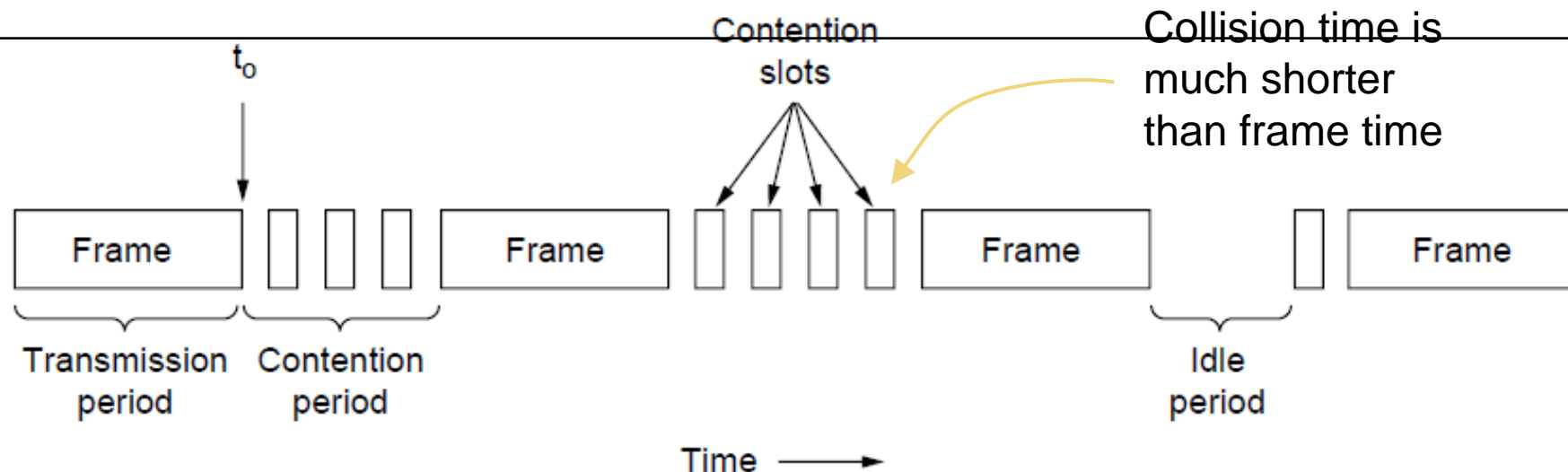
Bisogna essere sicuri di trasmettere quando il canale non è occupato. Però se due stazioni trasmettono contemporaneamente quando il canale è libero, i segnali

CSMA (3) – Collision Detection

CSMA/CD improvement is to detect/abort collisions

- ▶ Reduced contention times improve performance

Fattore importante è sapere quanto tempo deve aspettare una stazione per capire se è avvenuta una collisione. Per fare ciò bisogna calcolare il tempo necessario



Collision-Free (1) - Bitmap

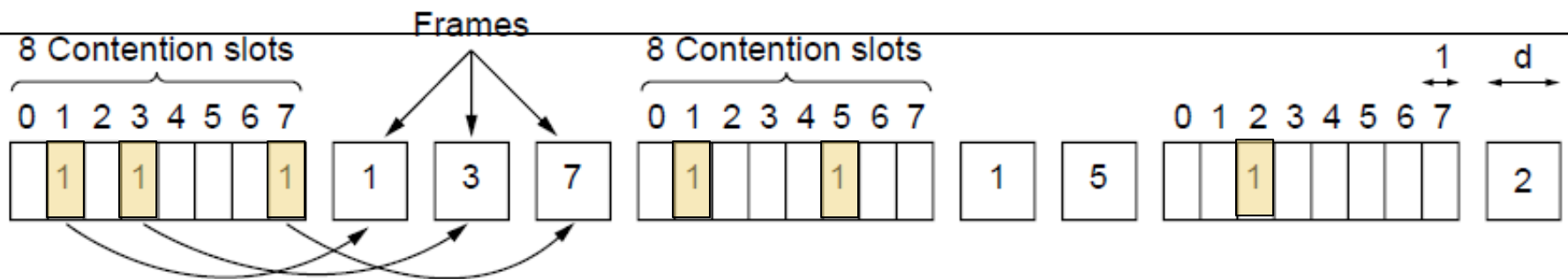
Collision-free protocols avoid collisions entirely

- ▶ Senders must know when it is their turn to send

The basic bit-map protocol:

- ▶ Sender set a bit in contention slot if they have data
- ▶ Senders send in turn; everyone knows who has data

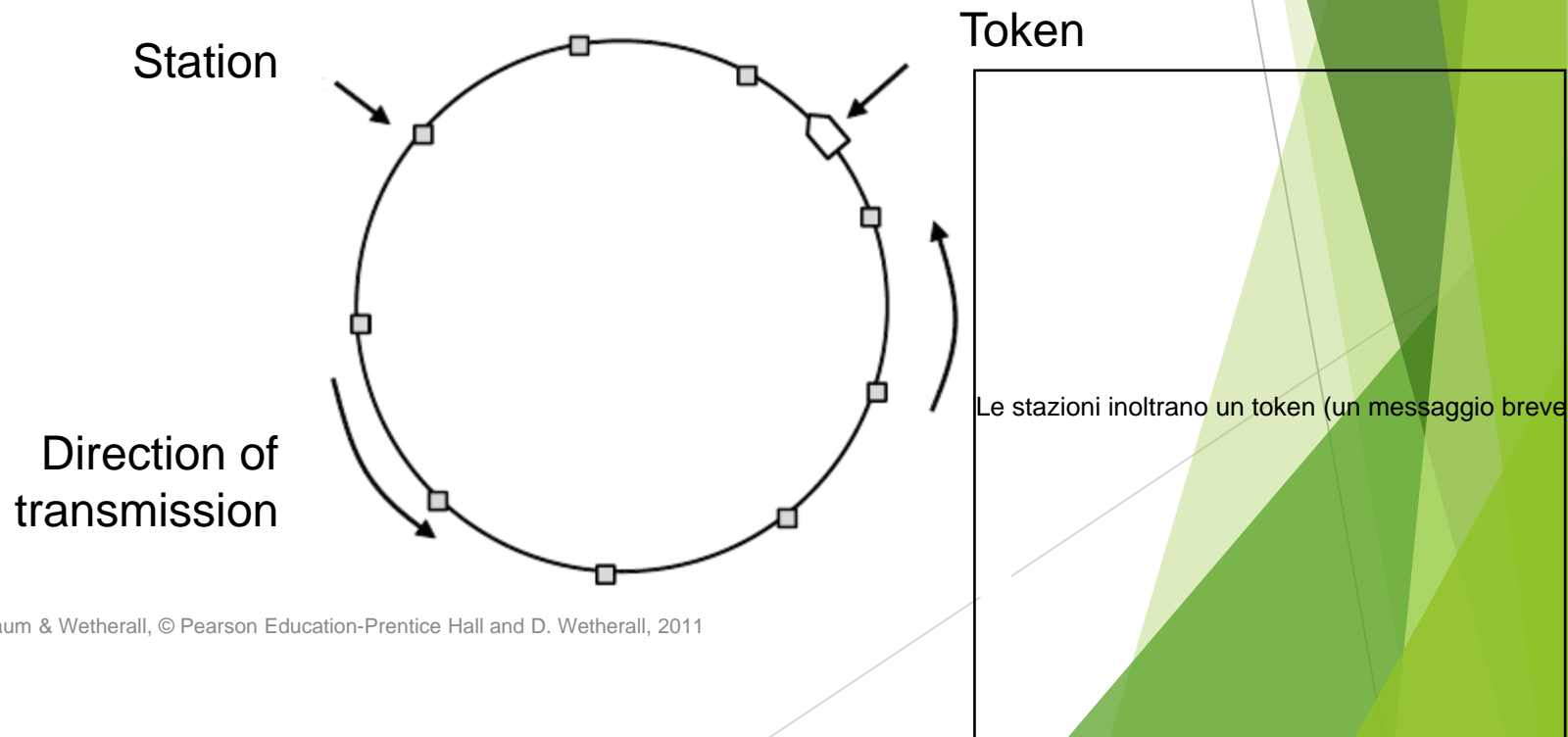
Il protocollo si divide in due momenti: di contesa e di trasmissione dei dati. Durante il periodo di contesa ogni stazione, al proprio turno invia un bit 1 se ha frame



Collision-Free (2) - Token Ring

Token sent round ring defines the sending order

- ▶ Station with token may send a frame before passing
- ▶ Idea can be used without ring too, e.g., token bus

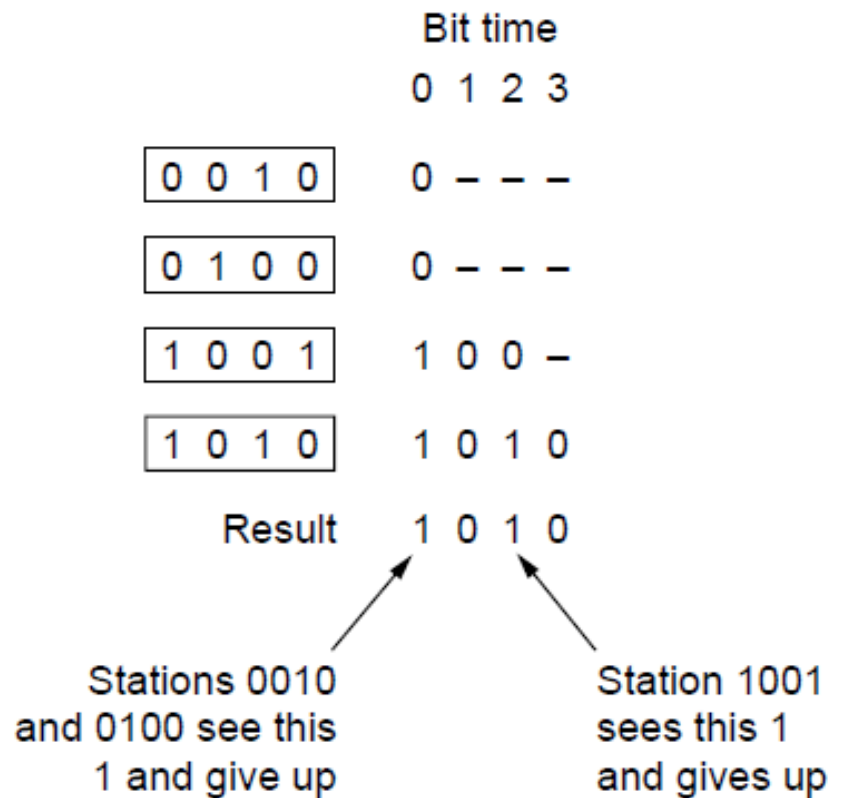


Collision-Free (3) - Countdown

Binary countdown improves on the bitmap protocol

- ▶ Stations send their address in contention slot (log N bits instead of N bits)
- ▶ Medium ORs bits; stations give up when they send a "0" but see a "1"
- ▶ Station that sees its full address is next to send

Ogni stazione che vuole utilizzare il canale trasmette a tutti gli altri il suo indirizzo



In caso di carico leggero è preferibile tollerare collisioni (dato che saranno rare), piuttosto che aumentare il delay. In caso opposto di canale molto carico, la contes

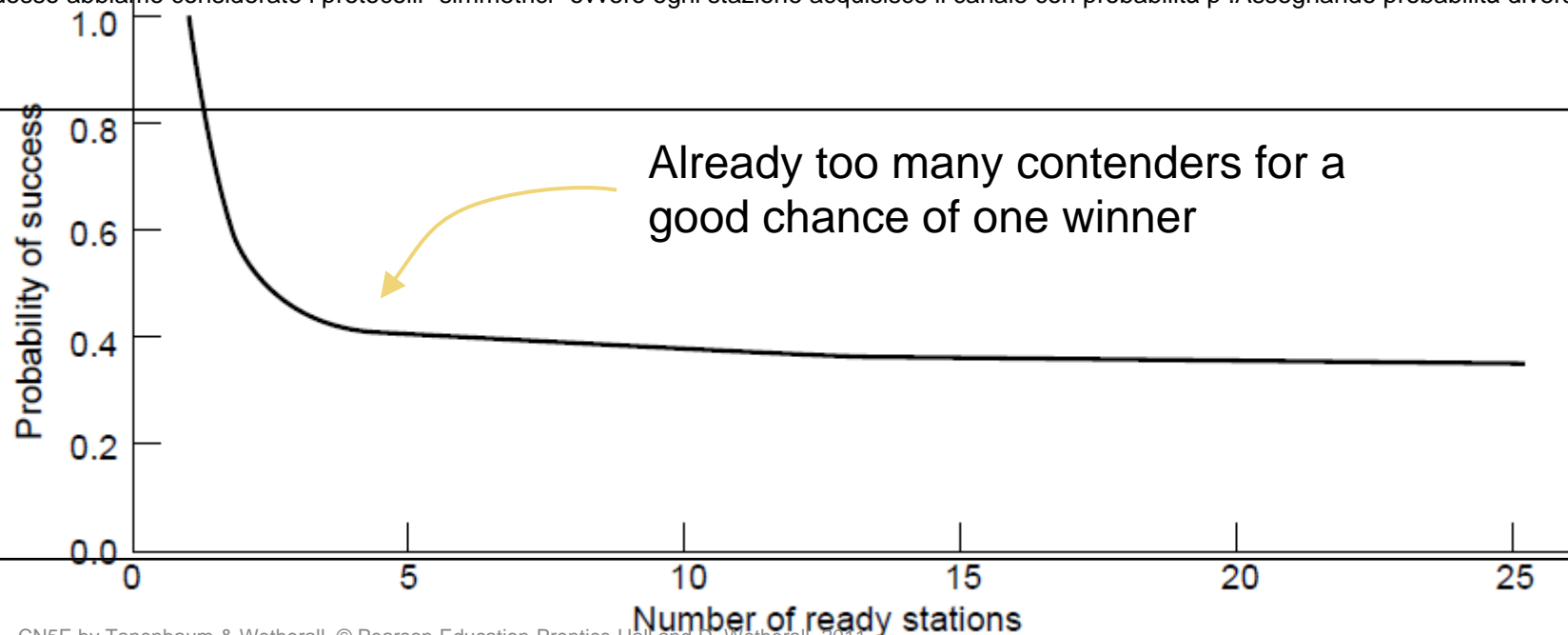
Limited-Contention Protocols

(1)

Idea is to divide stations into groups within which only a very small number are likely to want to send

- ▶ Avoids wastage due to idle periods and collisions

Fino ad adesso abbiamo considerato i protocolli "simmetrici" ovvero ogni stazione acquisisce il canale con probabilità p . Assegnando probabilità diverse a gruppi



CN5E by Tanenbaum & Wetherall, © Pearson Education-Prentice Hall and D. Wetherall, 2011

Prendiamo per esempio il caso in cui ogni gruppo è composto da due stazioni e che ogni stazione ha probabilità p di acquisire il canale. La probabilità che entram

Limited Contention (2) - Adaptive Tree Walk

Tree divides stations into groups (nodes) to poll

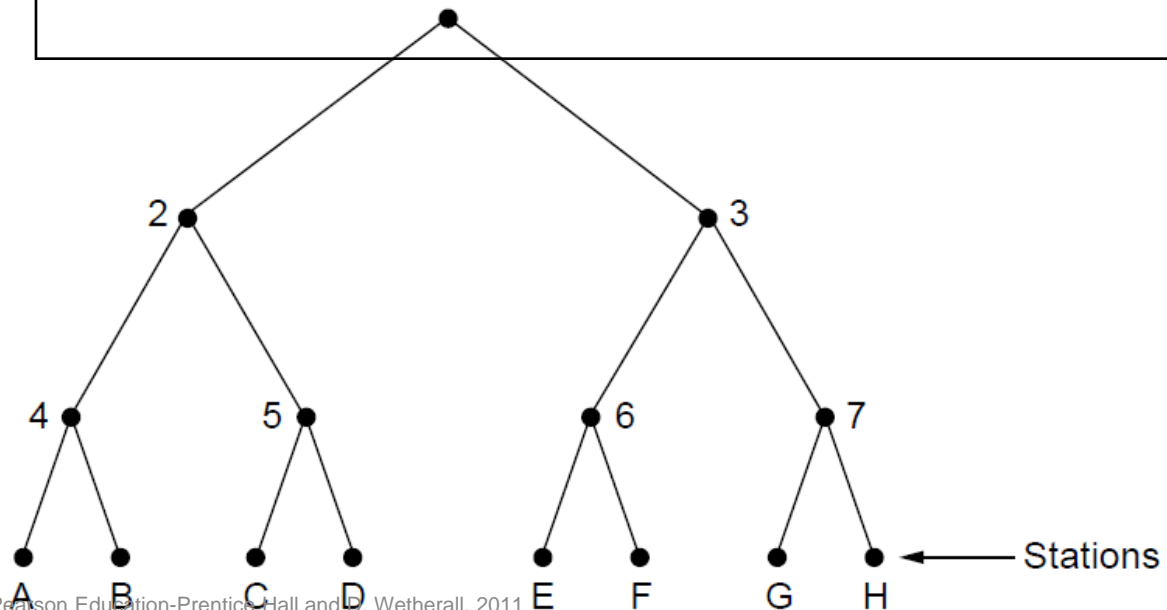
- ▶ Depth first search under nodes with poll collisions
- ▶ Start search at lower levels if >1 station expected

Level 0

Level 1

Level 2

Le stazioni vengono strutturate in un albero binario. In caso di collisioni, si ricerca ricorsivamente nei nodi le stazioni



Wireless LAN Protocols (1)

Wireless has complications compared to wired.

Nodes may have different coverage regions

- ▶ Leads to hidden and exposed terminals

Nodes can't detect collisions, i.e., sense while sending

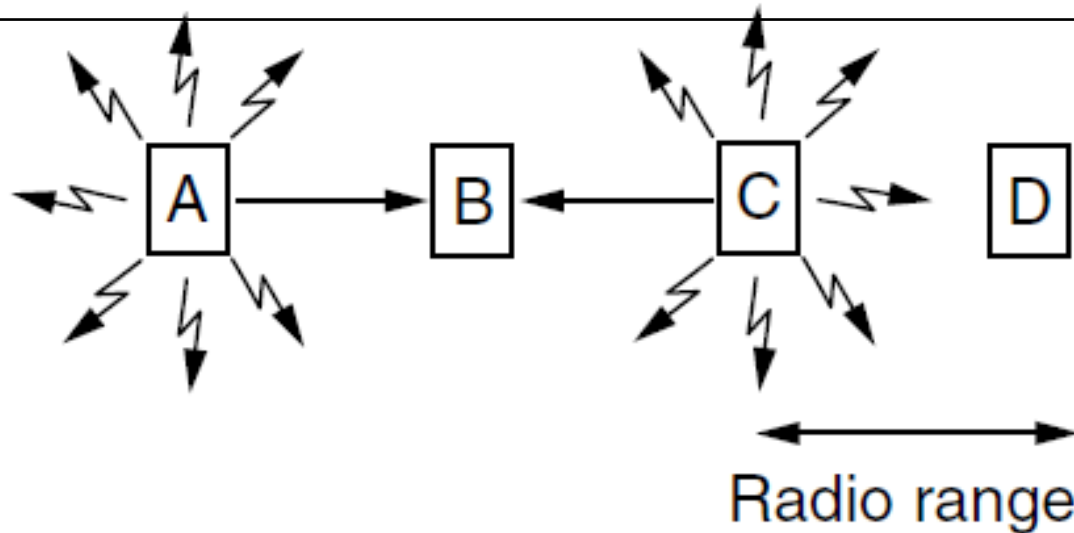
- ▶ Makes collisions expensive and to be avoided

Wireless LANs (2) - Hidden terminals

Hidden terminals are senders that cannot sense each other but nonetheless collide at intended receiver

- ▶ Want to prevent; loss of efficiency
- ▶ A and C are hidden terminals when sending to B

A e C non sono in range ognuno dall'altro e quindi se trasmettono contemporaneamente i pacchetti collideranno e saranno danneggiati. Il problema risiede soltar

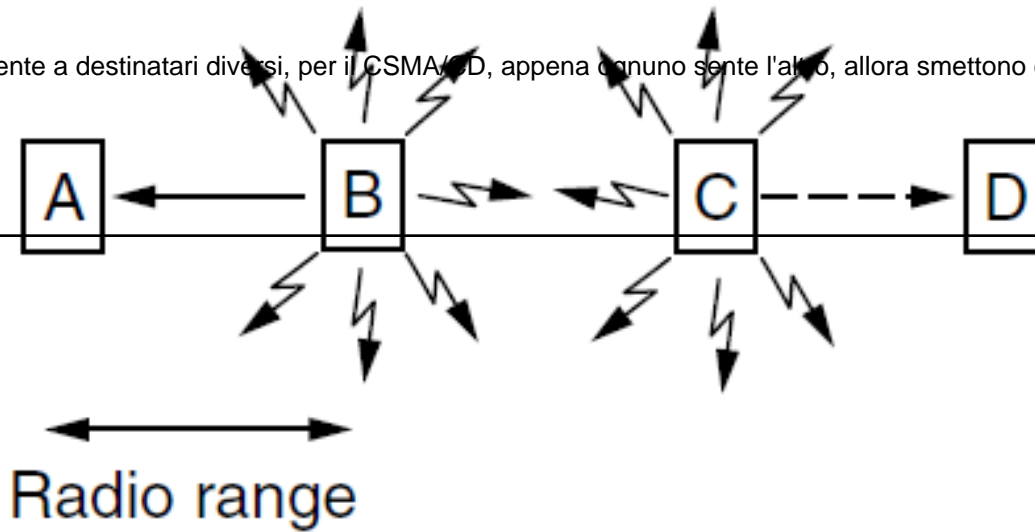


Wireless LANs (3) - Exposed terminals

Exposed terminals are senders who can sense each other but still transmit safely (to different receivers)

- ▶ Desirably concurrency; improves performance
- ▶ B → A and C → D are exposed terminals

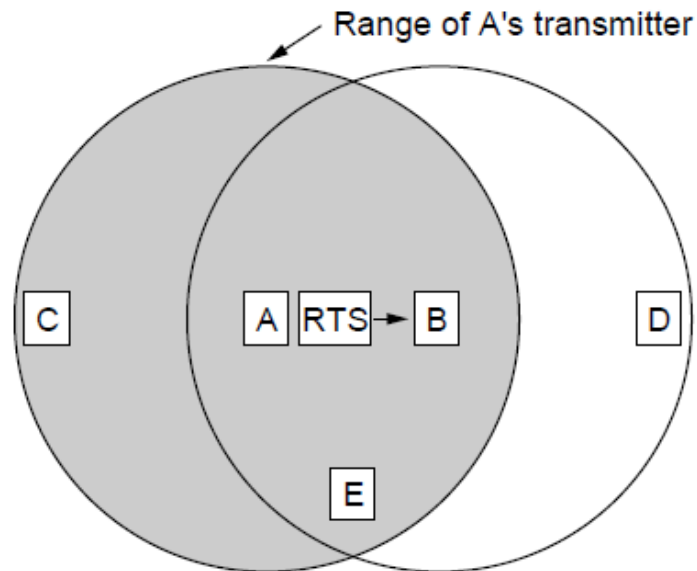
Se B e C inviano contemporaneamente a destinatari diversi, per il CSMA/CD, appena ognuno sente l'altro, allora smettono di trasmettere. Il messaggio è d



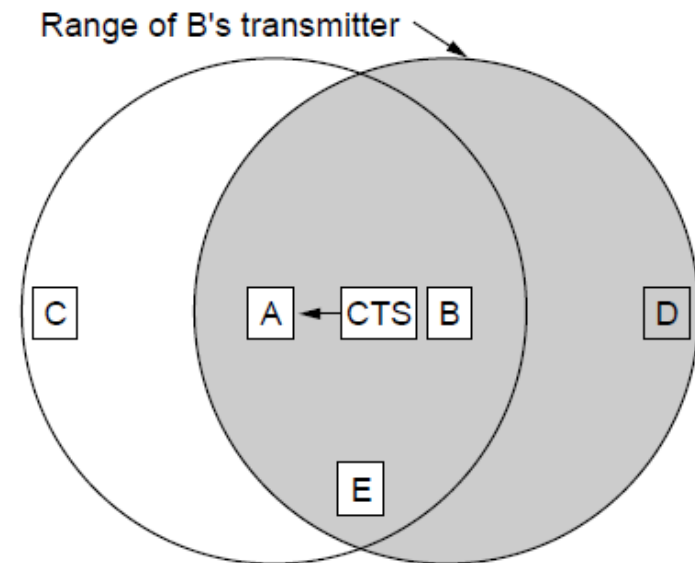
Wireless LANs (4) – MACA

MACA protocol grants access for A to send to B:

- ▶ A sends RTS to B [left]; B replies with CTS [right]
- ▶ A can send with exposed but no hidden terminals



A sends RTS to B; C and E
hear and defer for CTS



B replies with CTS; D and E
hear and defer for data

Ethernet

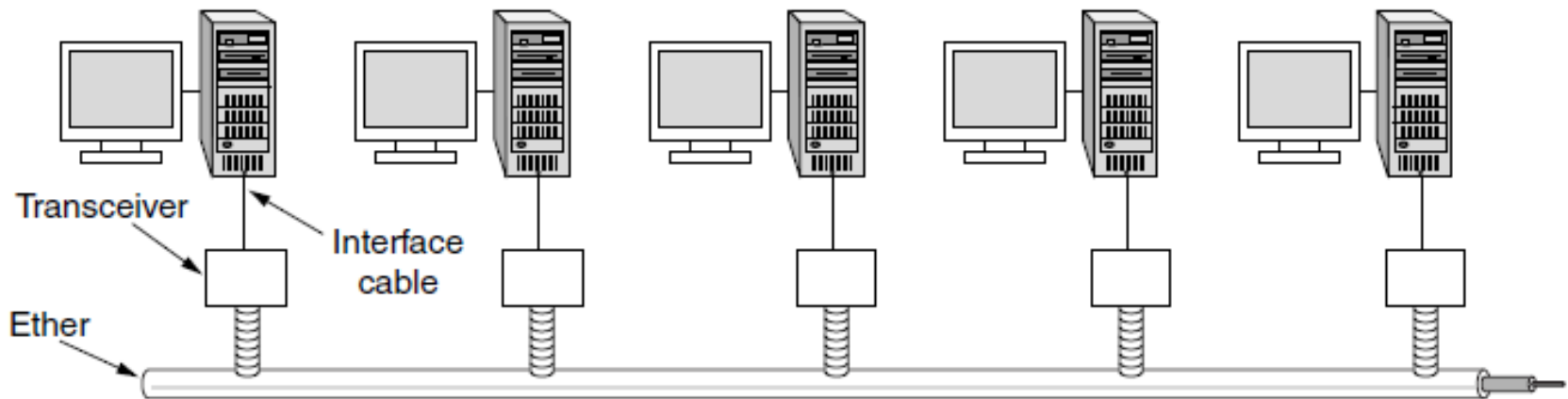
- ▶ Classic Ethernet » Singolo cavo coassiale che connette tutti i computer
- ▶ Switched/Fast Ethernet » Cavi (con attacco RJ45) che connettono i computer a switch che gestiscono il traffico
- ▶ Gigabit/10 Gigabit Ethernet » Standard di velocità della Switched ethernet. 1 Gigabit corrisponde a 1000 Megabit

Classic Ethernet (1) – Physical Layer

One shared coaxial cable to which all hosts attached

- ▶ Up to 10 Mbps, with Manchester encoding
- ▶ Hosts ran the classic Ethernet protocol for access

Dei dispositivi chiamati ripetitori (repeaters) rigenerano e ritrasmettono il segnale in entrambe le direzioni. Il software riconosce la rete come un



Il messaggio da trasmettere é diviso in frame, ognuno dei quali é composto come in figura. Ogni frame inizia il preambolo che é composto da 8 bytes ognuno dei quali ha pattern 10

Classic Ethernet (2) - MAC

Se il primo bit trasmesso dell'indirizzo del destinatario é 0, allora é un indirizzo ordinario, se é a 1 allora indirizza un gruppo, cosicché tutte le macchine facenti parte di q

MAC protocol is 1-persistent CSMA/CD (earlier)

- ▶ Random delay (backoff) after collision is computed with BEB (Binary Exponential Backoff)
- ▶ Frame format is still used with modern Ethernet.

CSMA/CD con Binary Exponential Backoff: é una versione di CDMA/CD con slot pari a 2tau. In generale, alla i-esima collisione, é scelto un numero randomico compres

Bytes	8	6	6	2	0-1500	0-46	4
Ethernet (DIX)	Preamble	Destination address	Source address	Type	Data	Pad	Check-sum

802.3 é uno standard successivo dell'ethernet che non é stato molto utilizzato.

IEEE 802.3	Preamble	S o F	Destination address	Source address	Length	Data	Pad	Check-sum
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I primi tre byte sono identificativi del costruttore, mentre gli ultimi tre sono univoci per quell' singolo NIC (Network Interface Controller) assegnati dal costruttore stesso. Seguono due

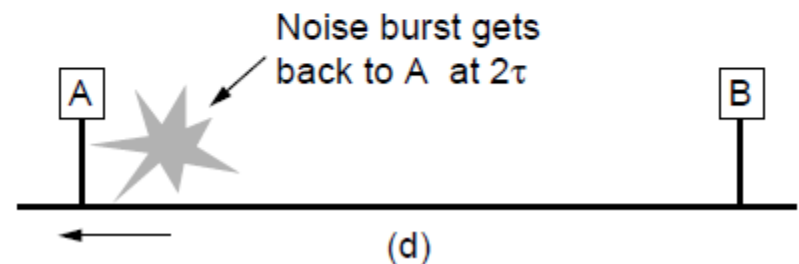
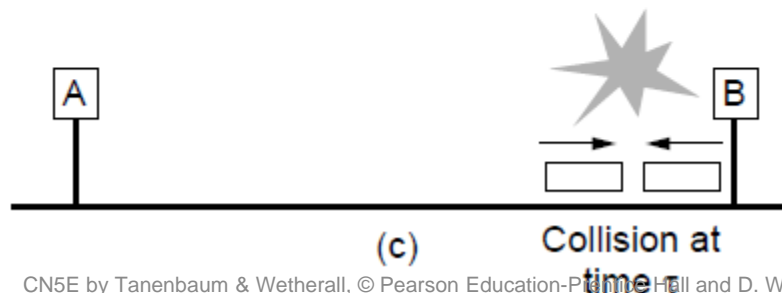
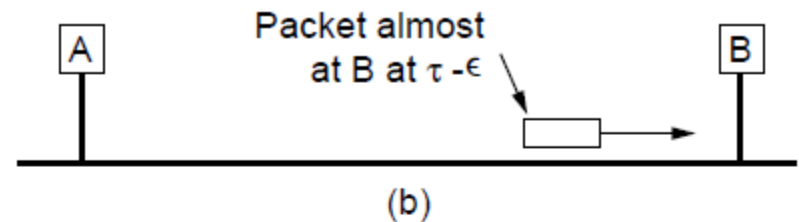
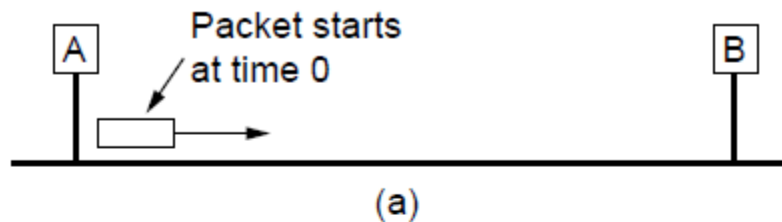
Un altro motivo per il limite massimo è dovuto al tempo di rilevamento di collisione. Come mostrato in figura, il tempo di rilevamento della collisione è al massimo 2τ , con τ tempo

Classic Ethernet (3) – MAC

Se una stazione inoltra un messaggio breve, può accadere che finisca di inoltrare prima che il segnale della collisione lo raggiunga, concludendo erroneamente d

Collisions can occur and take as long as 2τ to detect

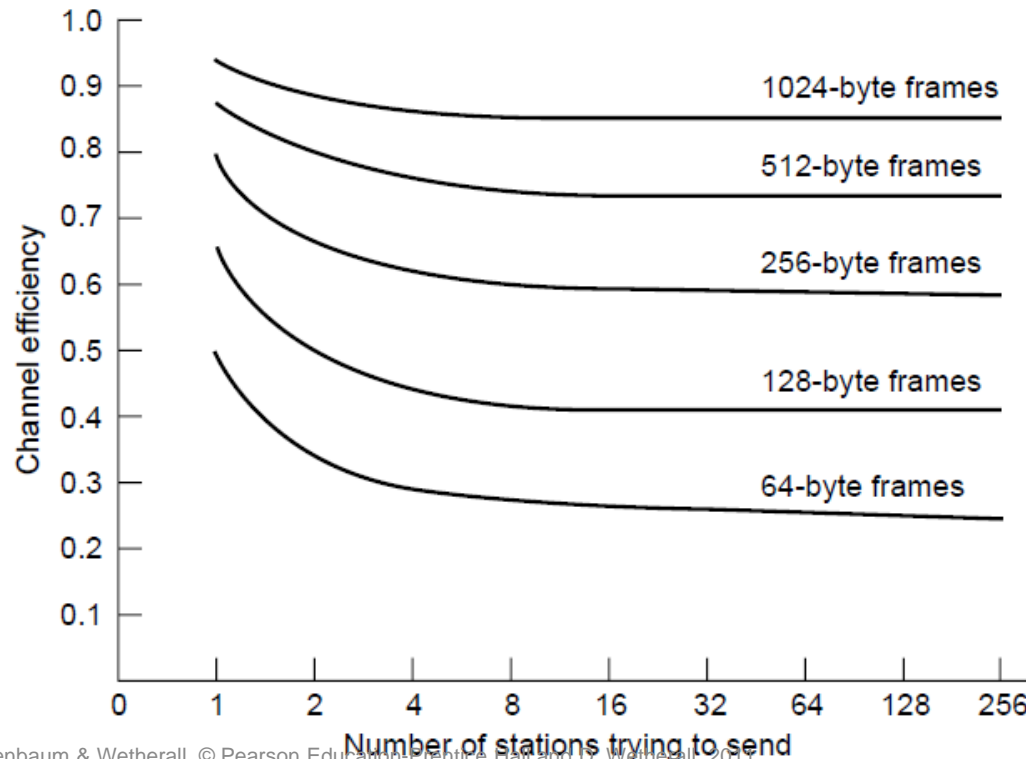
- ▶ τ is the time it takes to propagate over the Ethernet
- ▶ Leads to minimum packet size for reliable detection



Classic Ethernet (4) - Performance

Efficient for large frames, even with many senders

- Degrades for small frames (and long LANs)



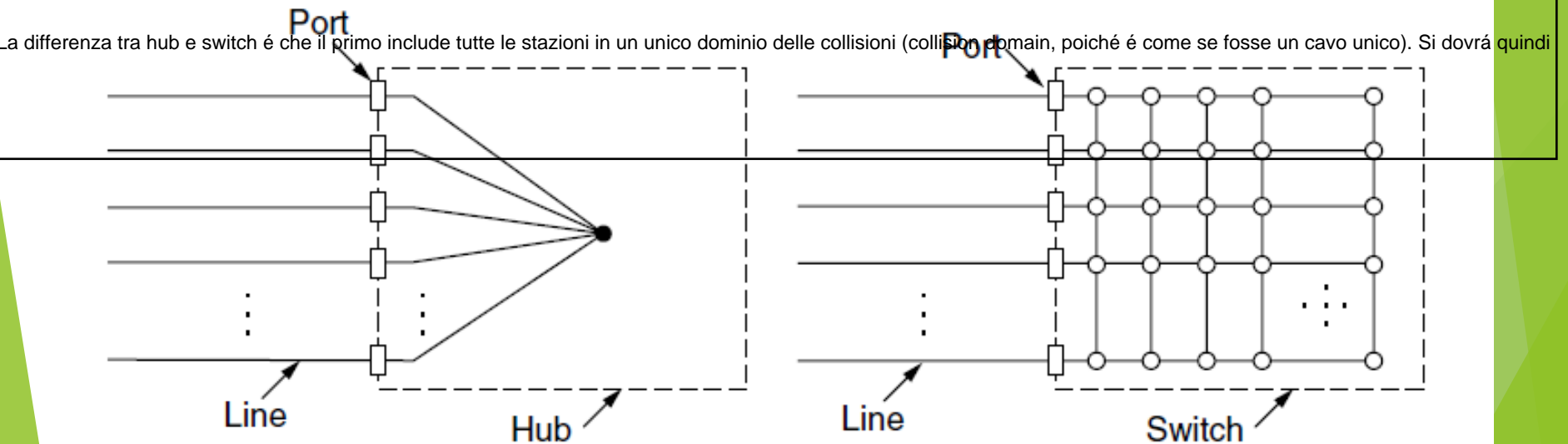
10 Mbps Ethernet,
64 byte min. frame

Hubs: sono dispositivi che connettono gli input insieme, come se fossero una unica linea di trasmissione. Non incrementano la capacità, perché, logicamente, equivale a un singolo cavo.

Switched/Fast Ethernet (1)

Quando uno switch riceve un frame da una delle stazioni, connessa ad una delle sue porte, controlla l'indirizzo portato nel e lo inoltra solo nelle porte associate ai destinatari del frame.

- ▶ Hubs wire all lines into a single CSMA/CD domain
- ▶ Switches isolate each port to a separate domain
 - ▶ Much greater throughput for multiple ports
 - ▶ No need for CSMA/CD with full-duplex lines

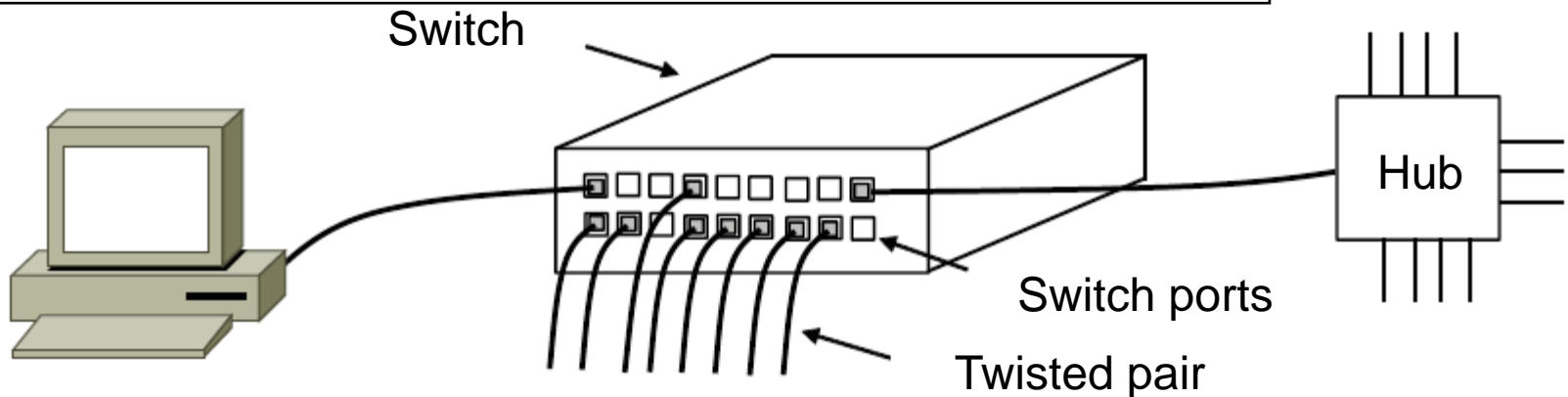


Switched/Fast Ethernet (2)

Switches can be wired to computers, hubs and switches

- ▶ Hubs concentrate traffic from computers
- ▶ More on how to switch frames the in 4.8

Evoluzione della switched ethernet attualmente in uso. È retrocompatibile con le versioni precedenti di ethernet, poiché tutti utilizzano la



Switched/Fast Ethernet (3)

Fast Ethernet extended Ethernet from 10 to 100 Mbps

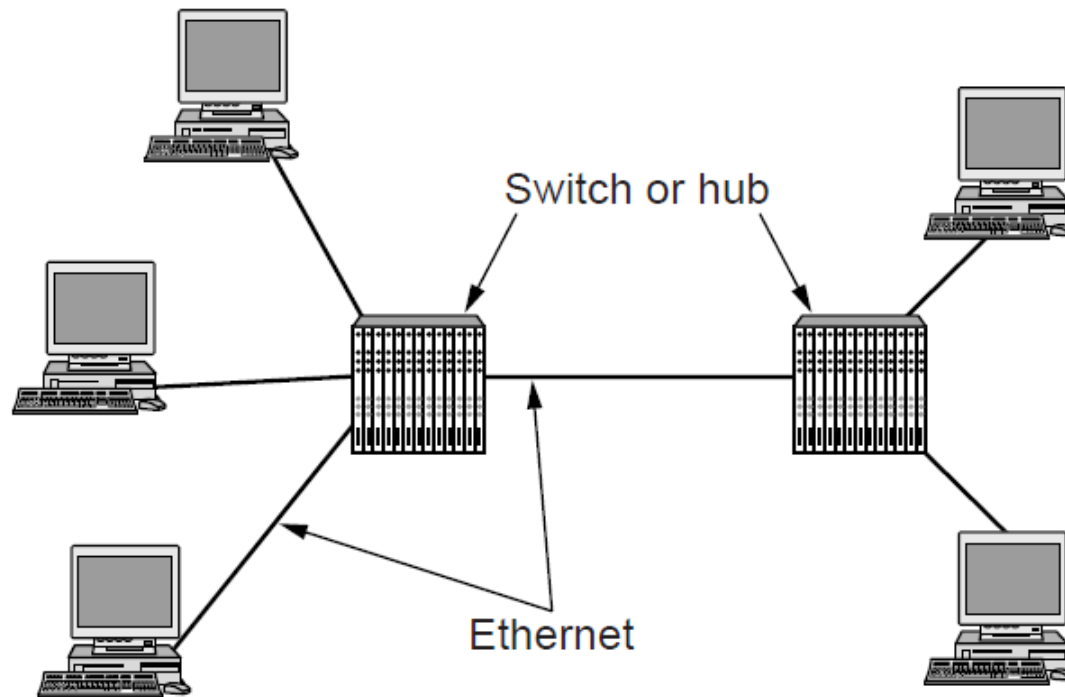
- ▶ Twisted pair (with Cat 5) dominated the market

Name	Cable	Max. segment	Advantages
100Base-T4	Twisted pair	100 m	Uses category 3 UTP
100Base-TX	Twisted pair	100 m	Full duplex at 100 Mbps (Cat 5 UTP)
100Base-FX	Fiber optics	2000 m	Full duplex at 100 Mbps; long runs

Gigabit / 10 Gigabit Ethernet (1)

Switched Gigabit Ethernet is now the garden variety

- ▶ With full-duplex lines between computers/switches



Gigabit / 10 Gigabit Ethernet

(1) ▶ Gigabit Ethernet is commonly run over twisted pair

Name	Cable	Max. segment	Advantages
1000Base-SX	Fiber optics	550 m	Multimode fiber (50, 62.5 microns)
1000Base-LX	Fiber optics	5000 m	Single (10 μ) or multimode (50, 62.5 μ)
1000Base-CX	2 Pairs of STP	25 m	Shielded twisted pair
1000Base-T	4 Pairs of UTP	100 m	Standard category 5 UTP

▶ 4

Name	Cable	Max. segment	Advantages
10GBase-SR	Fiber optics	Up to 300 m	Multimode fiber (0.85 μ)
10GBase-LR	Fiber optics	10 km	Single-mode fiber (1.3 μ)
10GBase-ER	Fiber optics	40 km	Single-mode fiber (1.5 μ)
10GBase-CX4	4 Pairs of twinax	15 m	Twinaxial copper
10GBase-T	4 Pairs of UTP	100 m	Category 6a UTP

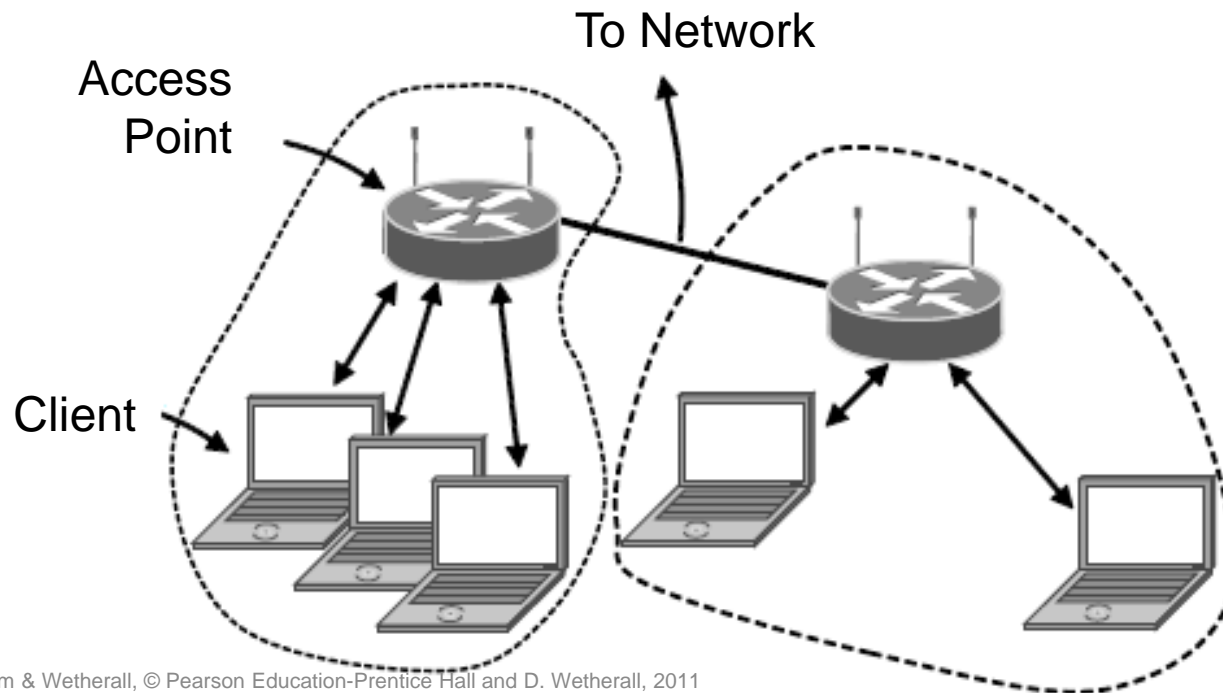
Wireless LANs

- ▶ 802.11 architecture/protocol stack »
- ▶ 802.11 physical layer »
- ▶ 802.11 MAC »
- ▶ 802.11 frames »

802.11 Architecture/Protocol Stack (1)

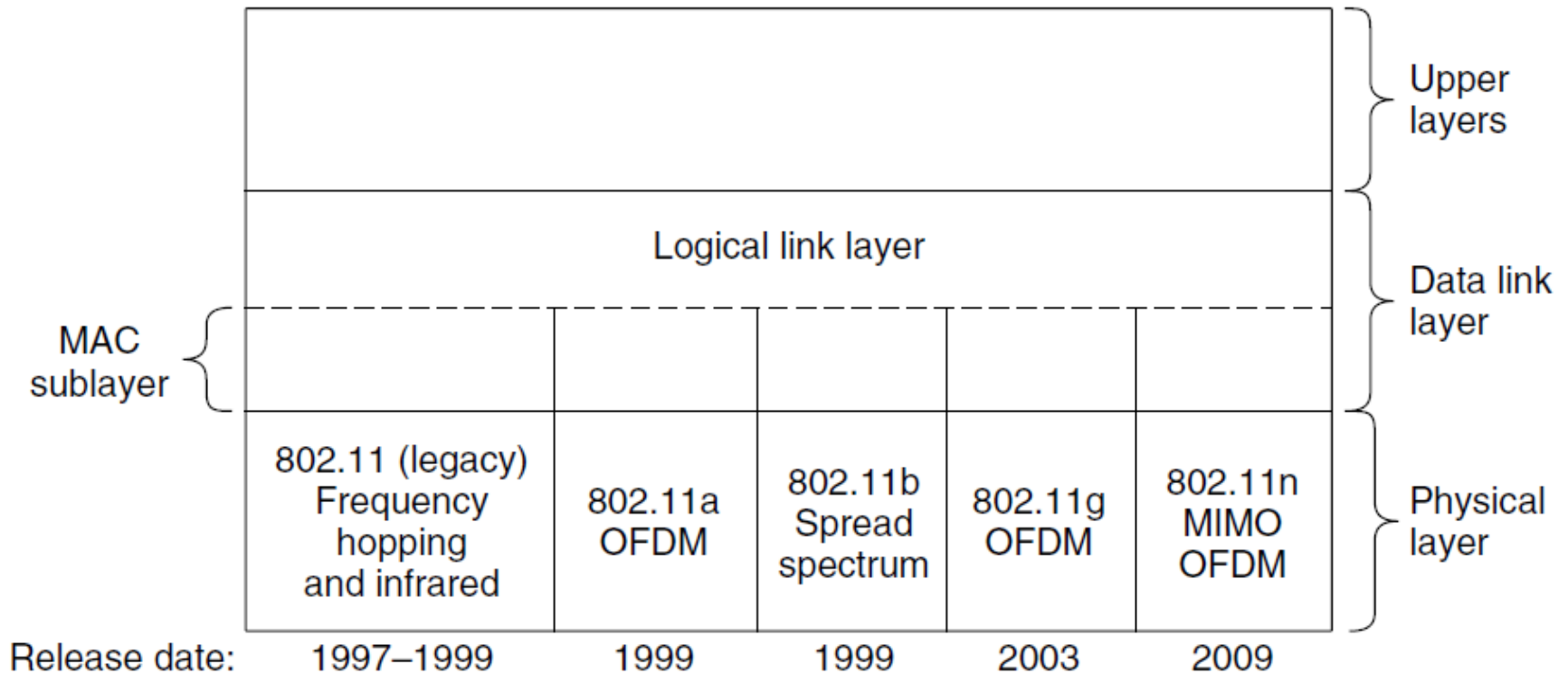
Wireless clients associate to a wired AP (Access Point)

- ▶ Called infrastructure mode; there is also ad-hoc mode with no AP, but that is rare.



802.11 Architecture/Protocol Stack (2)

MAC is used across different physical layers



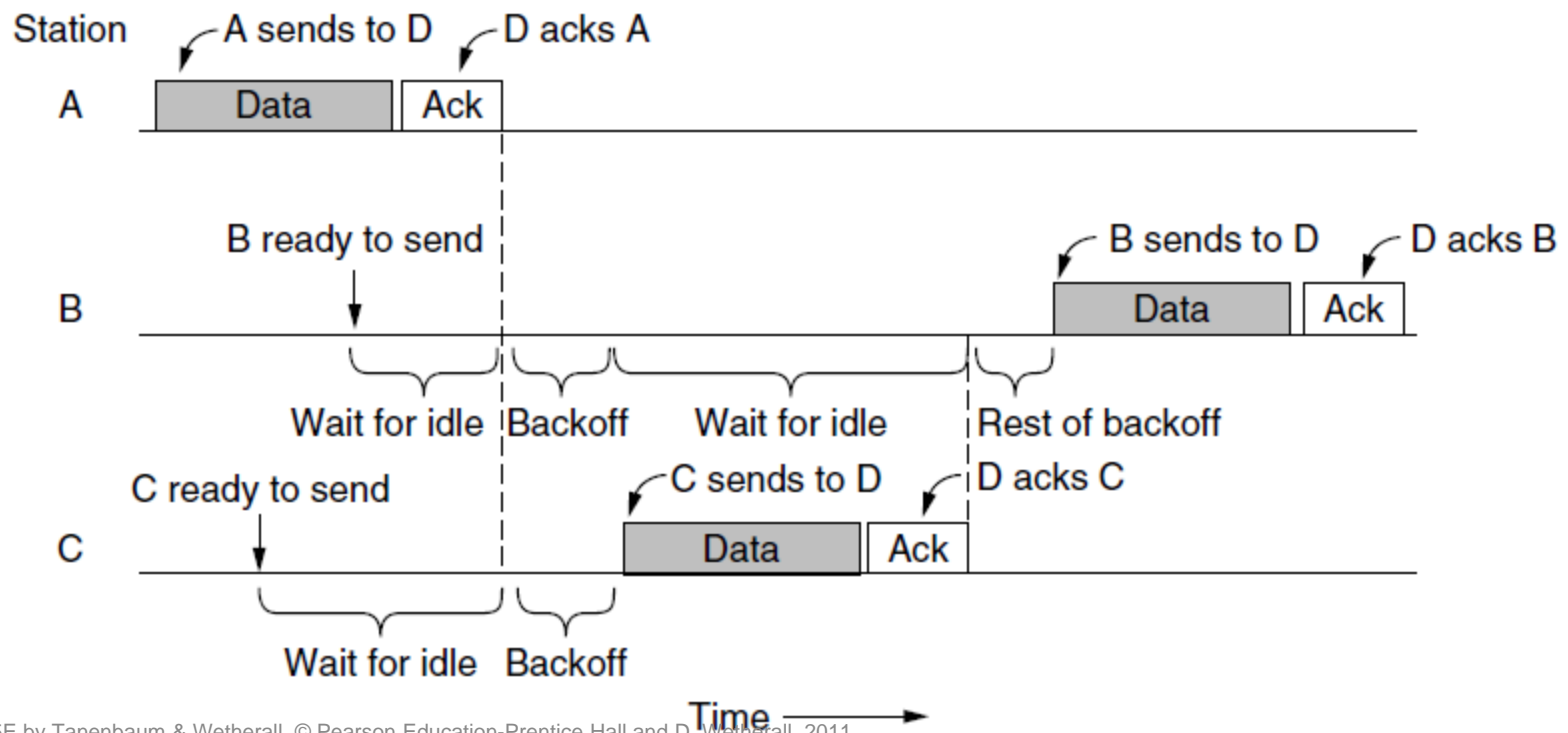
802.11 physical layer

- ▶ NICs are compatible with multiple physical layers
 - ▶ E.g., 802.11 a/b/g

Name	Technique	Max. Bit Rate
802.11b	Spread spectrum, 2.4 GHz	11 Mbps
802.11g	OFDM, 2.4 GHz	54 Mbps
802.11a	OFDM, 5 GHz	54 Mbps
802.11n	OFDM with MIMO, 2.4/5 GHz	600 Mbps

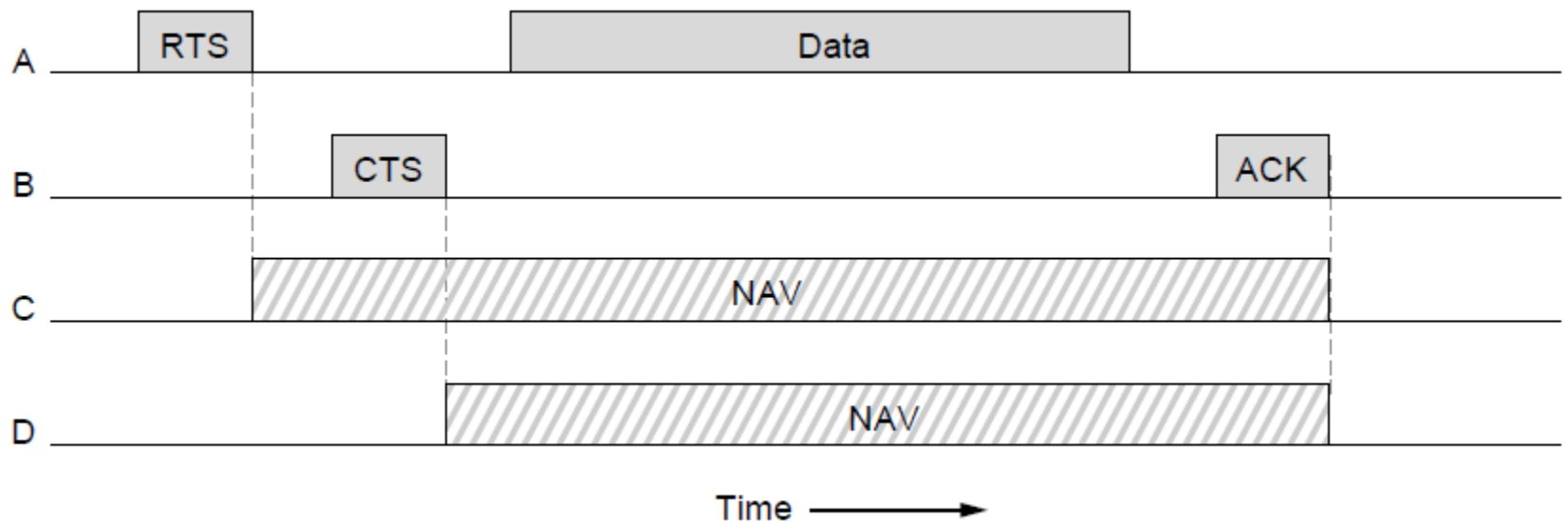
802.11 MAC (1)

- ▶ CSMA/CA inserts backoff slots to avoid collisions
- ▶ MAC uses ACKs/retransmissions for wireless errors



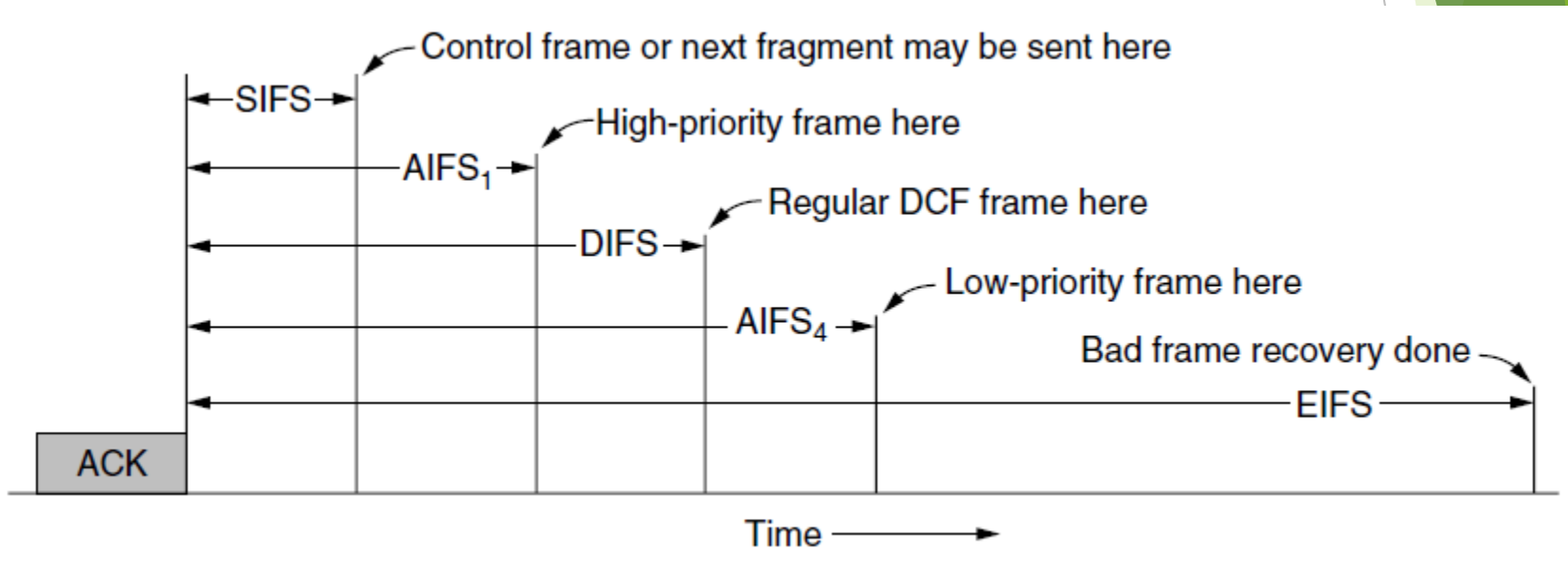
802.11 MAC (2)

Virtual channel sensing with the NAV and optional RTS/CTS (often not used) avoids hidden terminals



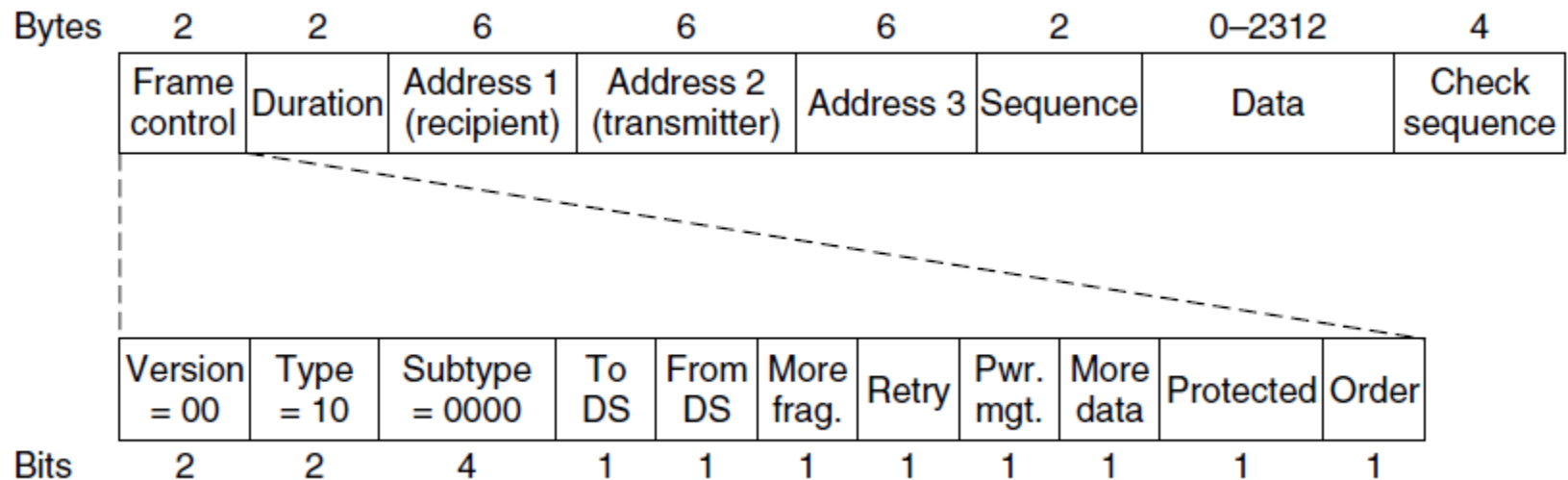
802.11 MAC (3)

- ▶ Different backoff slot times add quality of service
 - ▶ Short intervals give preferred access, e.g., control, VoIP
- ▶ MAC has other mechanisms too, e.g., power save



802.11 Frames

- ▶ Frames vary depending on their type (Frame control)
- ▶ Data frames have 3 addresses to pass via APs

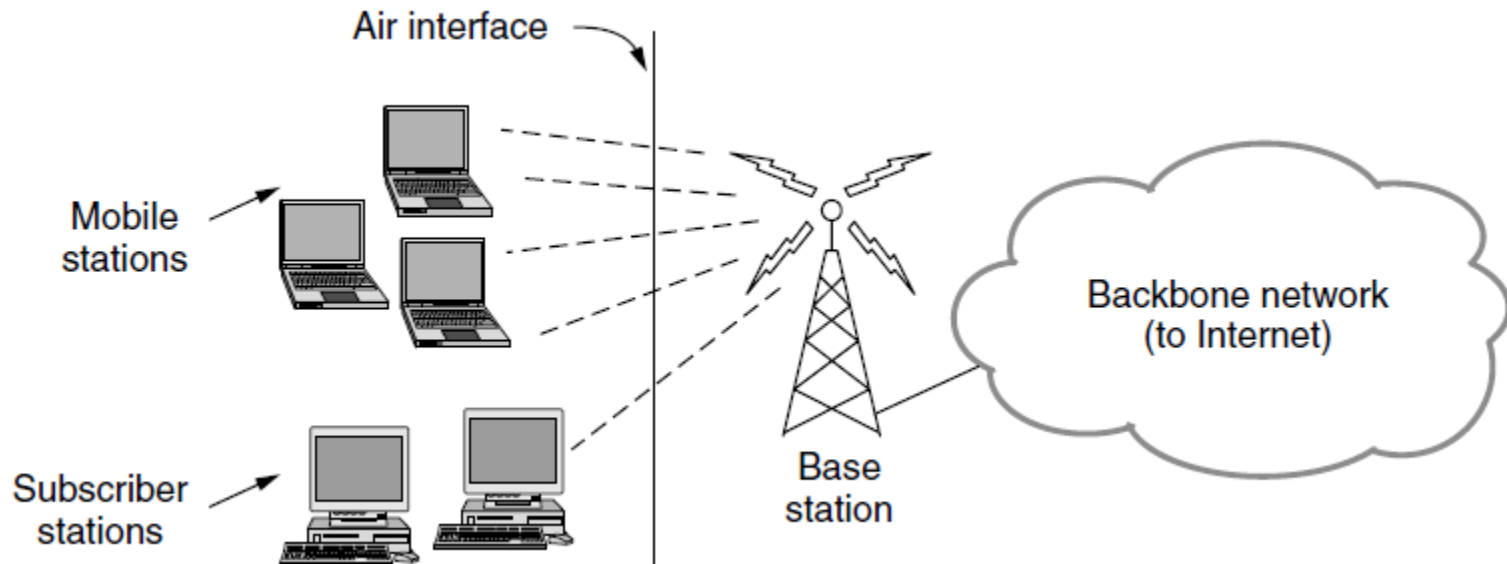


Broadband Wireless

- ▶ 802.16 Architecture / Protocol Stack »
- ▶ 802.16 Physical Layer »
- ▶ 802.16 MAC »
- ▶ 802.16 Frames »

802.16 Architecture/Protocol Stack (1)

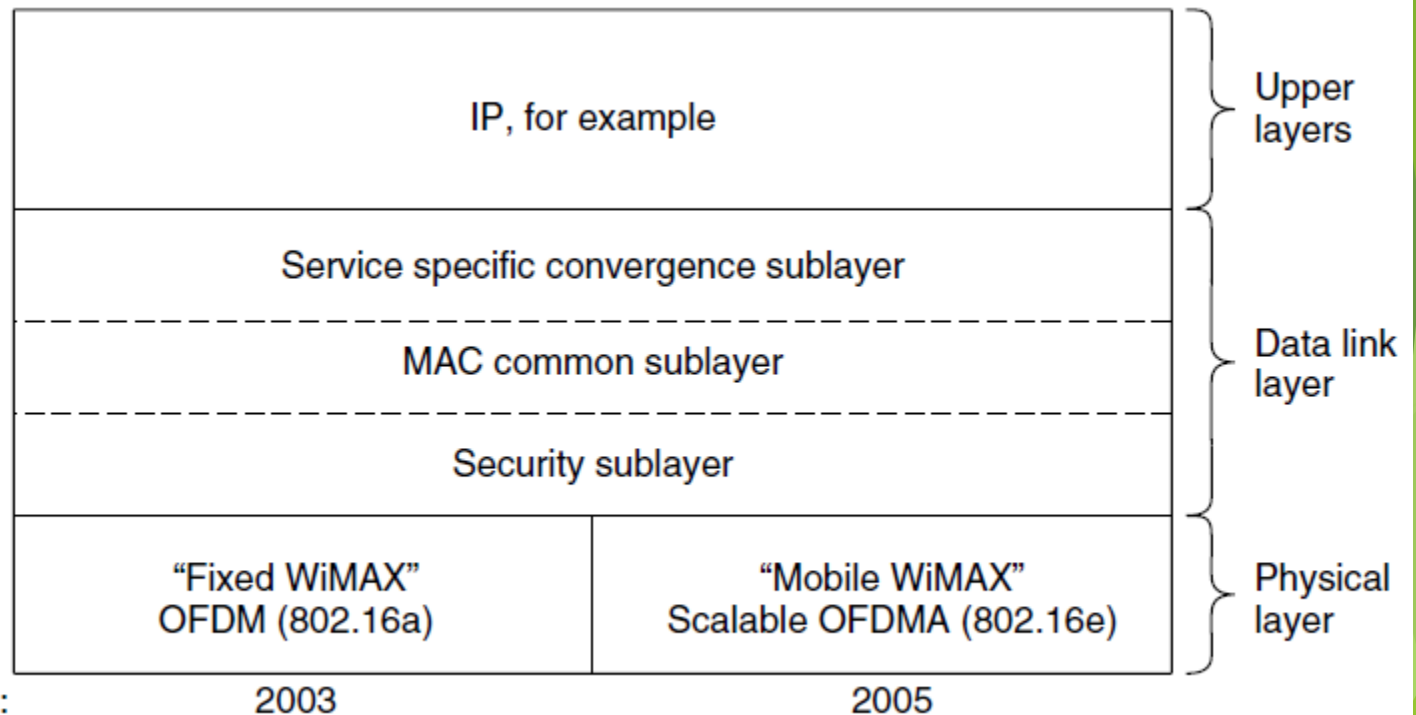
Wireless clients connect to a wired basestation (like 3G)



802.16 Architecture/Protocol Stack (2)

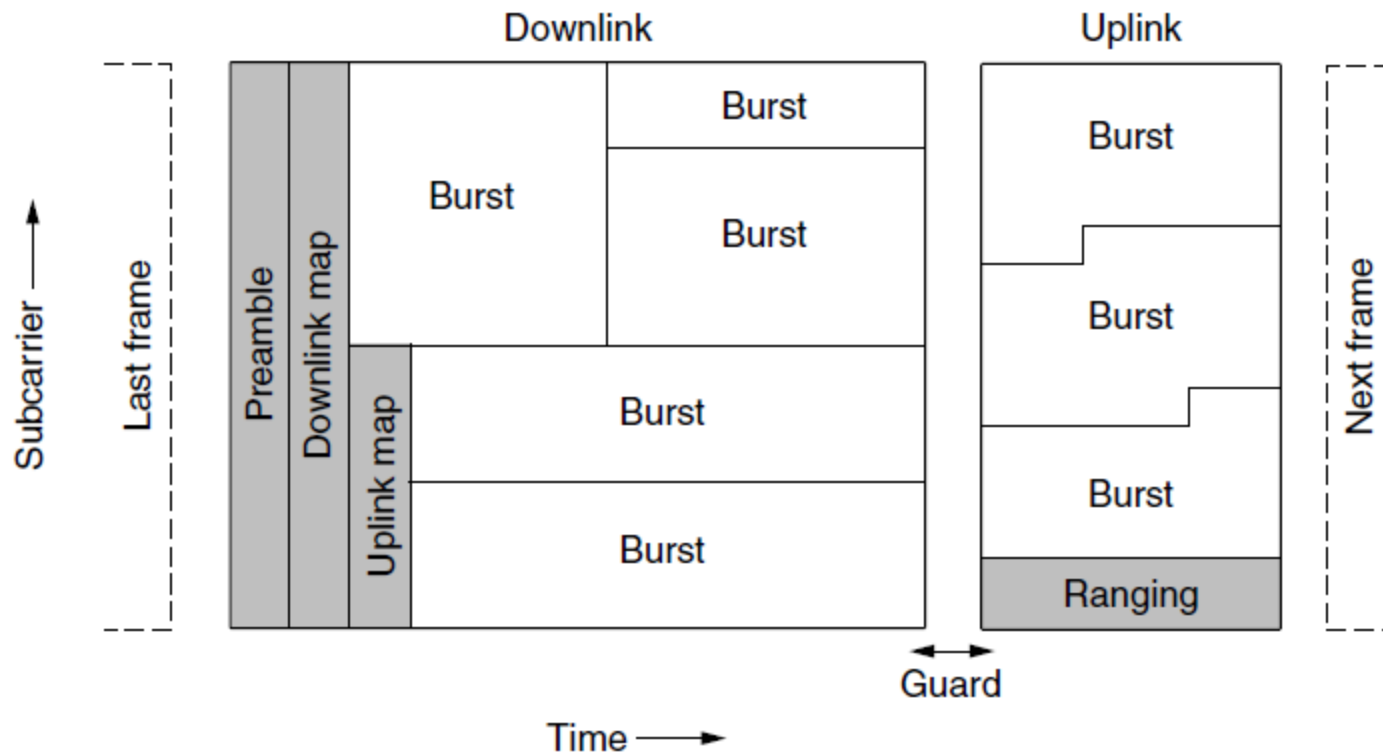
MAC is connection-oriented; IP is connectionless

- Convergence sublayer maps between the two



802.16 Physical Layer

Based on OFDM; base station gives mobiles bursts (subcarrier/time frame slots) for uplink and downlink



802.16 MAC

Connection-oriented with base station in control

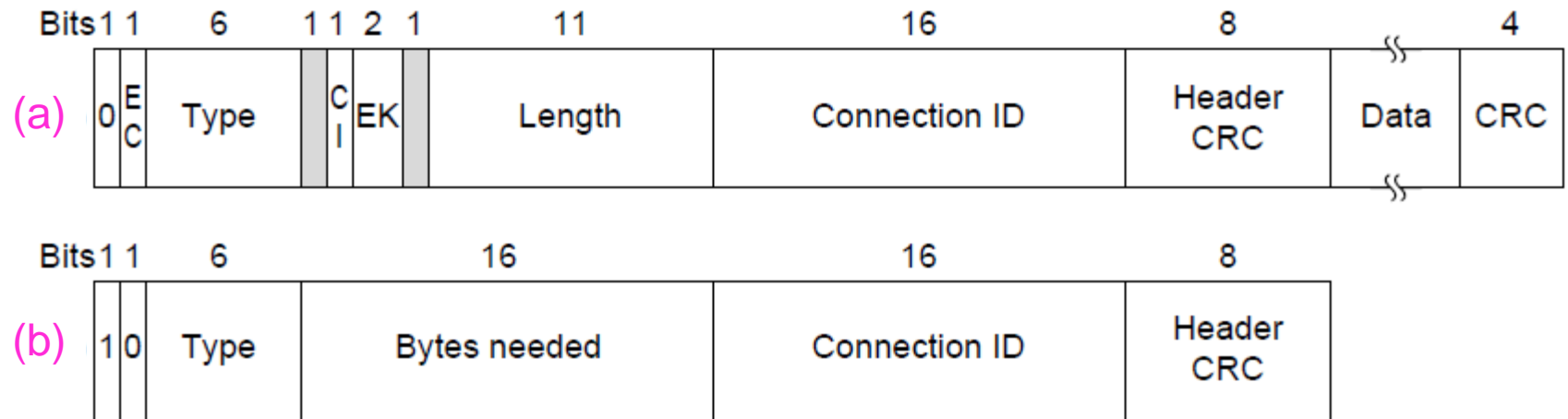
- ▶ Clients request the bandwidth they need

Different kinds of service can be requested:

- ▶ Constant bit rate, e.g., uncompressed voice
- ▶ Real-time variable bit rate, e.g., video, Web
- ▶ Non-real-time variable bit rate, e.g., file download
- ▶ Best-effort for everything else

802.16 Frames

- ▶ Frames vary depending on their type
- ▶ Connection ID instead of source/dest addresses



(a) A generic frame. (b) A bandwidth request frame

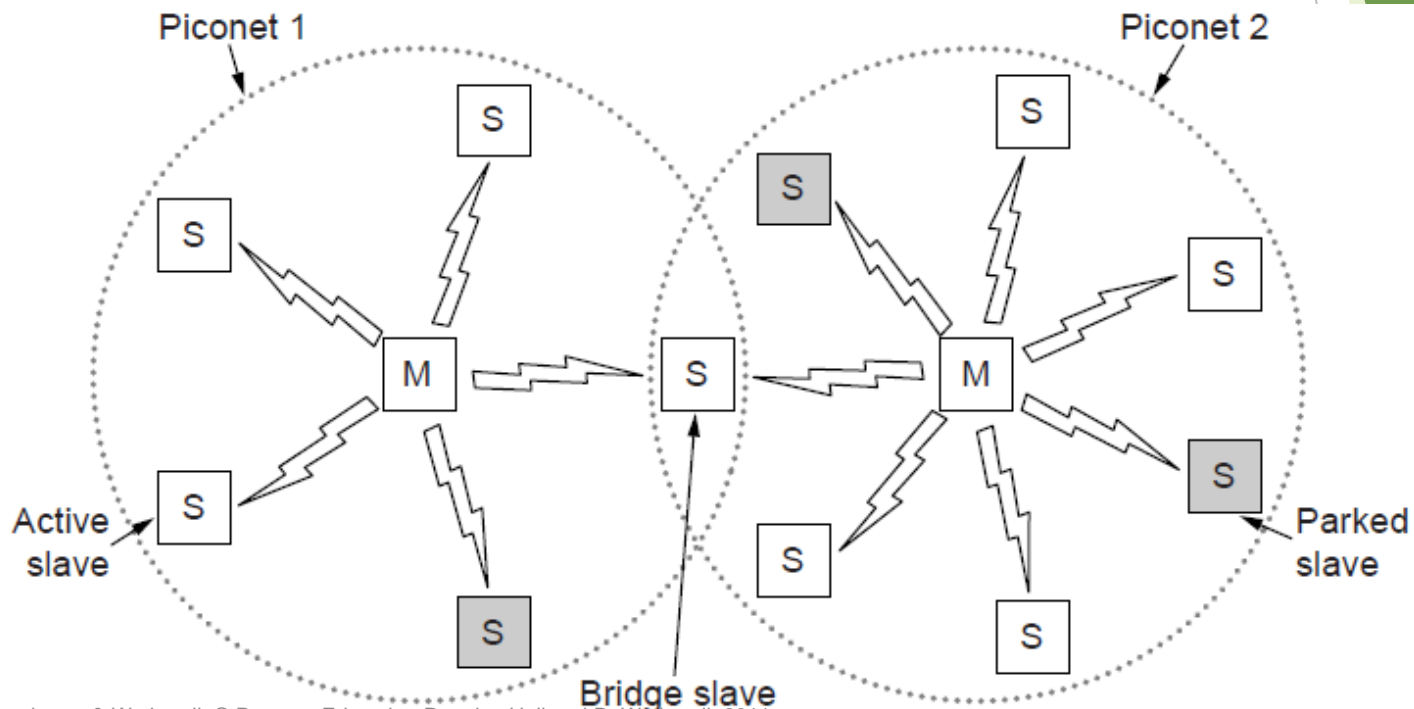
Bluetooth

- ▶ Bluetooth Architecture »
- ▶ Bluetooth Applications / Protocol »
- ▶ Bluetooth Radio / Link Layers »
- ▶ Bluetooth Frames »

Bluetooth Architecture

Piconet master is connected to slave wireless devices

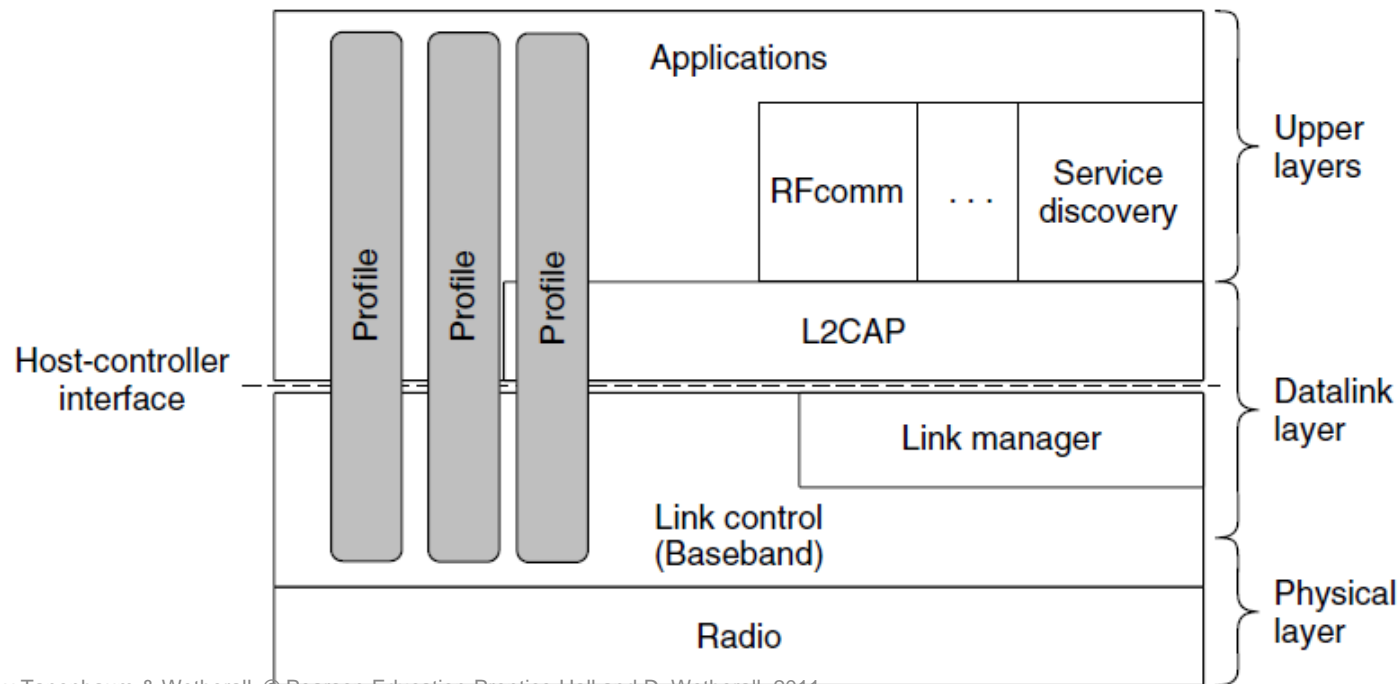
- ▶ Slaves may be asleep (parked) to save power
- ▶ Two piconets can be bridged into a scatternet



Bluetooth Applications / Protocol Stack

Profiles give the set of protocols for a given application

- ▶ 25 profiles, including headset, intercom, streaming audio, remote control, personal area network, ...



Bluetooth Radio / Link Layers

Radio layer

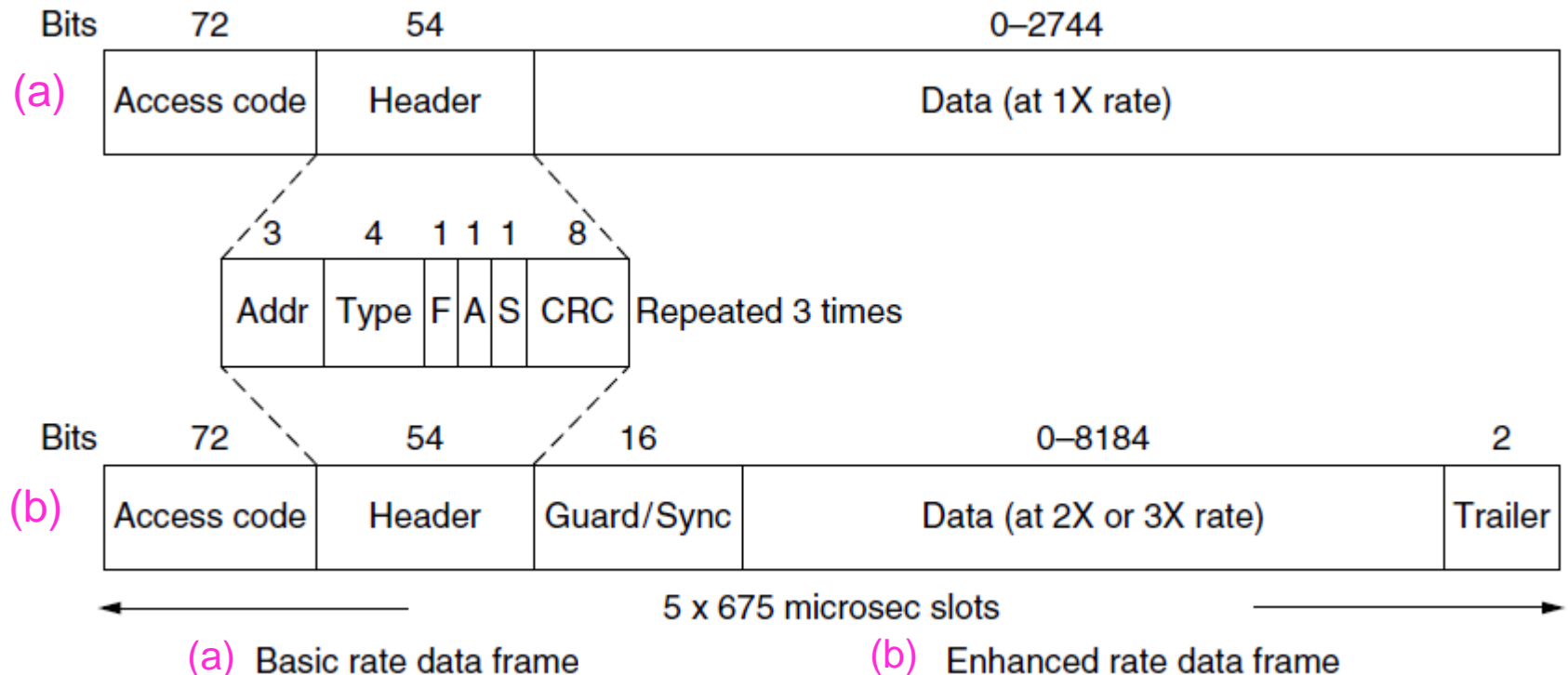
- ▶ Uses adaptive frequency hopping in 2.4 GHz band

Link layer

- ▶ TDM with timeslots for master and slaves
- ▶ Synchronous CO for periodic slots in each direction
- ▶ Asynchronous CL for packet-switched data
- ▶ Links undergo pairing (user confirms passkey/PIN) to authorize them before use

Bluetooth Frames

Time is slotted; enhanced data rates send faster but for the same time; addresses are only 3 bits for 8 devices

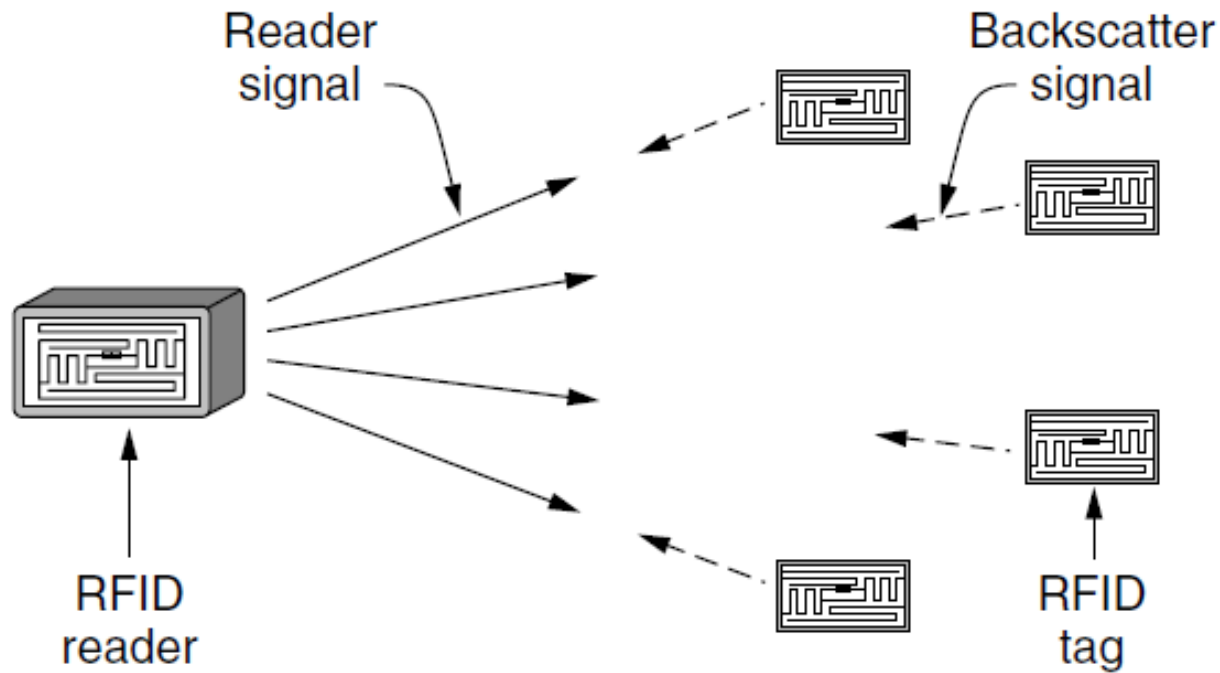


RFID

- ▶ Gen 2 Architecture »
- ▶ Gen 2 Physical Layer »
- ▶ Gen 2 Tag Identification Layer »
- ▶ Gen 2 Frames »

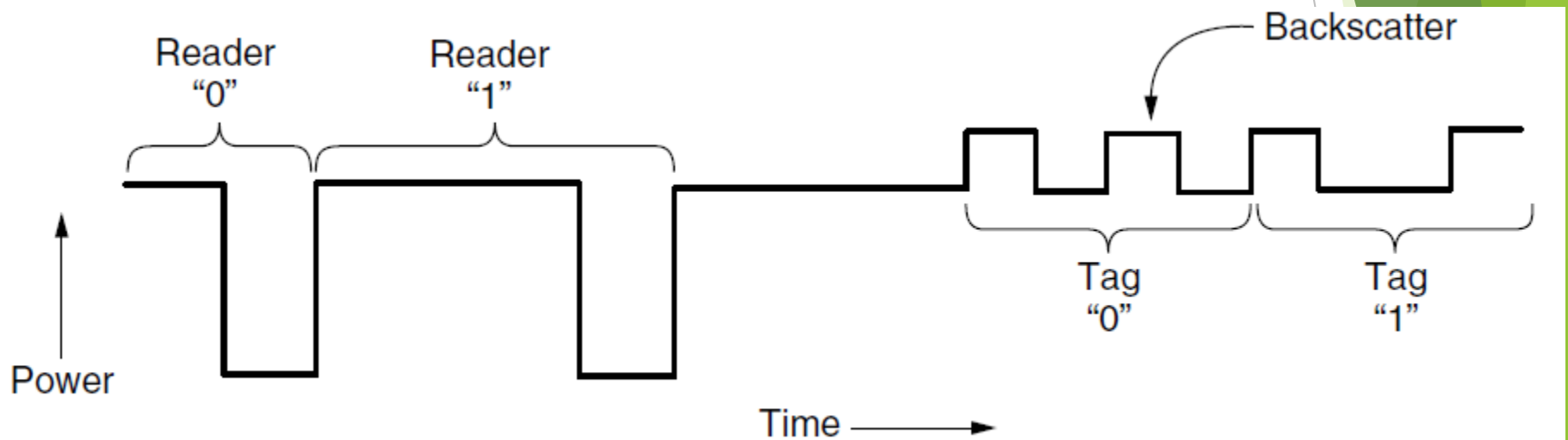
Gen 2 Architecture

Reader signal powers tags; tags reply with backscatter



Gen 2 Physical Layer

- ▶ Reader uses duration of on period to send 0/1
- ▶ Tag backscatters reader signal in pulses to send 0/1



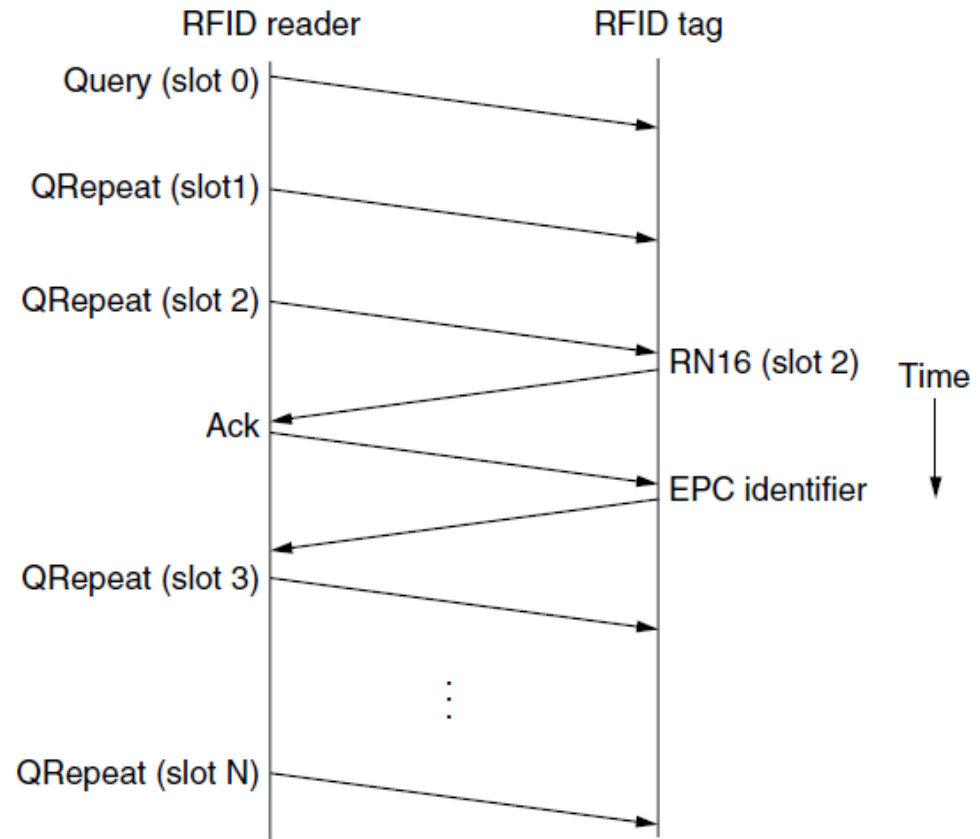
Gen 2 Tag Identification Layer

Reader sends query and sets slot structure

Tags reply (RN16) in a random slot; may collide

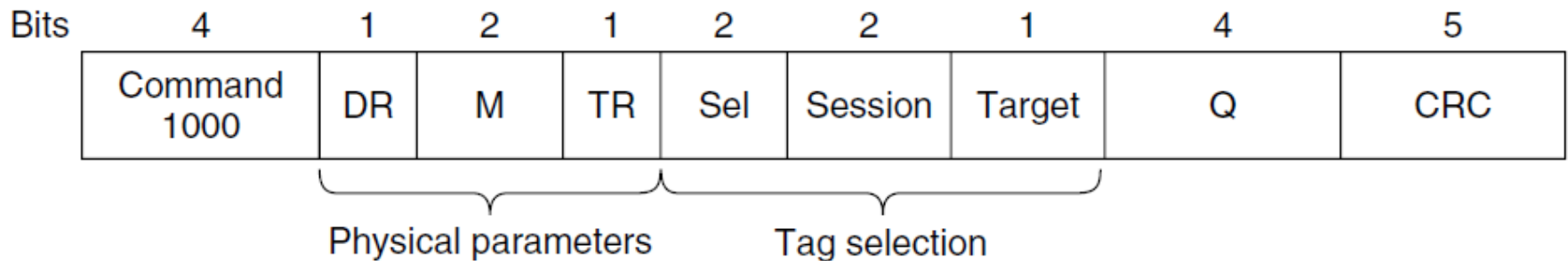
Reader asks one tag for its identifier (ACK)

Process continues until no tags are left



Gen 2 Frames

- ▶ Reader frames vary depending on type (Command)
 - ▶ Query shown below, has parameters and error detection
- ▶ Tag responses are simply data
 - ▶ Reader sets timing and knows the expected format



Query message

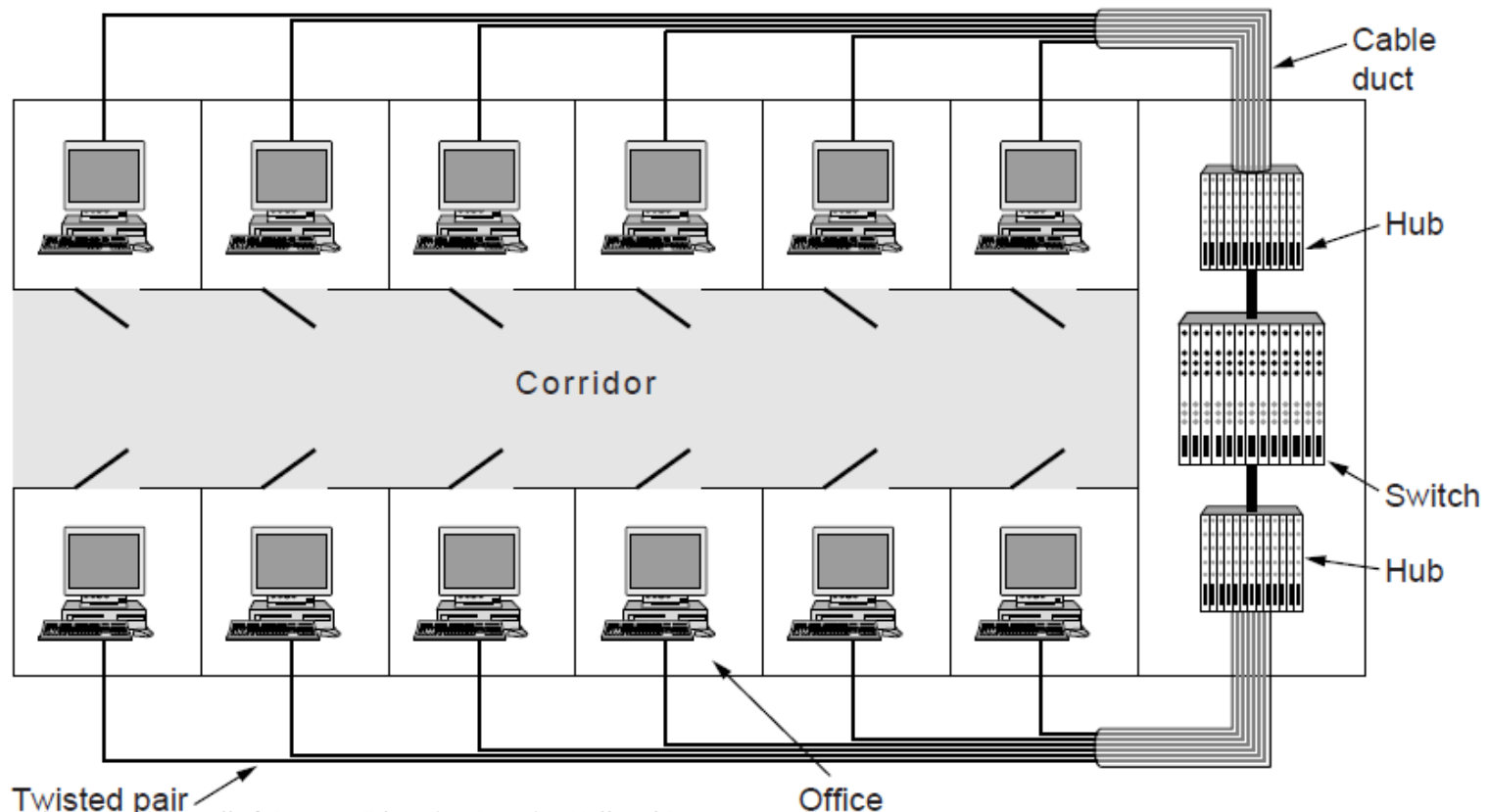
Data Link Layer Switching

- ▶ Uses of Bridges »
- ▶ Learning Bridges »
- ▶ Spanning Tree »
- ▶ Repeaters, hubs, bridges, ..., routers, gateways »
- ▶ Virtual LANs »

Uses of Bridges

I bridge sono dispositivi che uniscono due o più reti. Nella ethernet classica si usavano i bridge, nella switch

- ▶ Common setup is a building with centralized wiring
 - ▶ Bridges (switches) are placed in or near wiring closets



I bridge accettano tutti i frame e in base all'indirizzo presente decidono se scartarlo (se non é indirizzato a una stazione connessa al bridge) o inoltrarlo in una porta specifica. Ogni

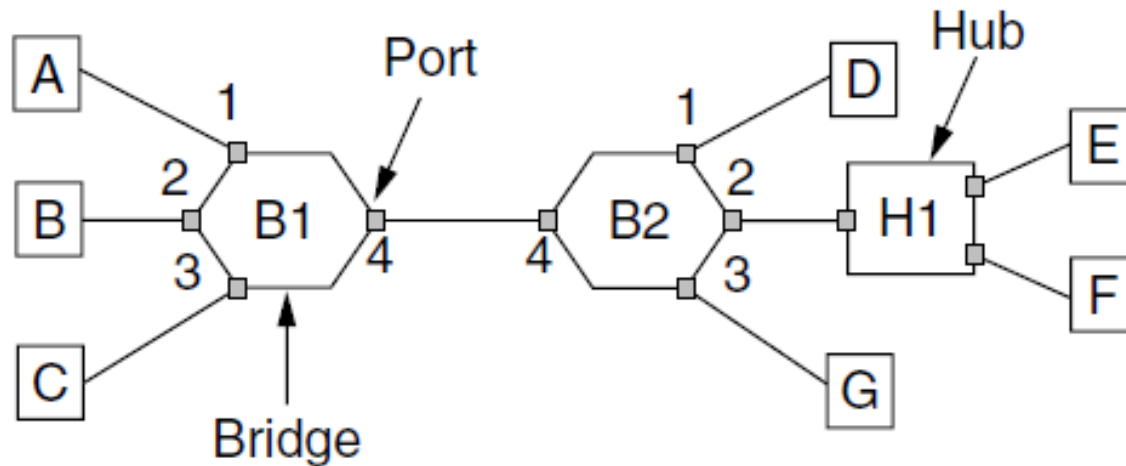
Learning Bridges (1)

Questo algoritmo si chiama "backward learning". Attraverso l'indirizzo del mittente e la porta dalla quale hanno ricevuto il frame, riempiono la tabella. Ogni volta che viene ricevuto

A bridge operates as a switched LAN (not a hub)

- Computers, bridges, and hubs connect to its ports

Ogni volta che un bridge riceve un frame controlla l'indirizzo e: - se é indirizzato alla porta dalla quale ha ricevuto il frame, allora lo scarta; - altrimenti se le porte da cui riceve e de



Learning Bridges (2)

Backward learning algorithm picks the output port:

- ▶ Associates source address on frame with input port
- ▶ Frame with destination address sent to learned port
- ▶ Unlearned destinations are sent to all other ports

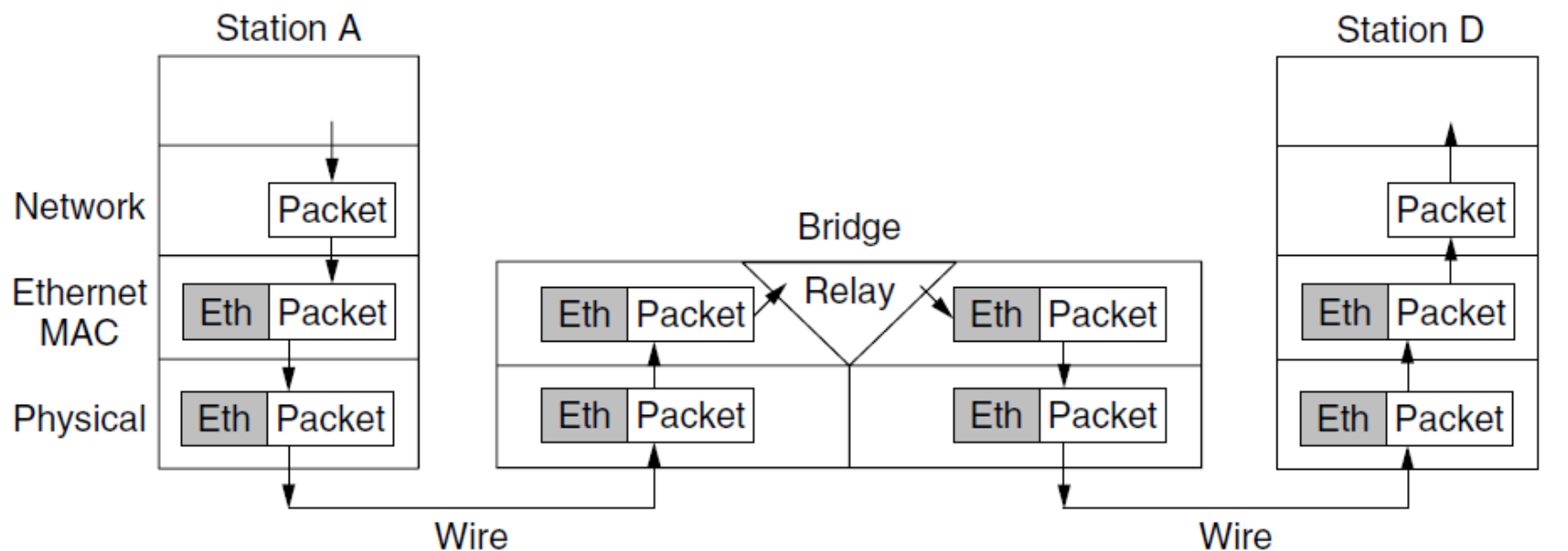
Needs no configuration

- ▶ Forget unused addresses to allow changes
- ▶ Bandwidth efficient for two-way traffic

Learning Bridges (3)

Bridges extend the Link layer:

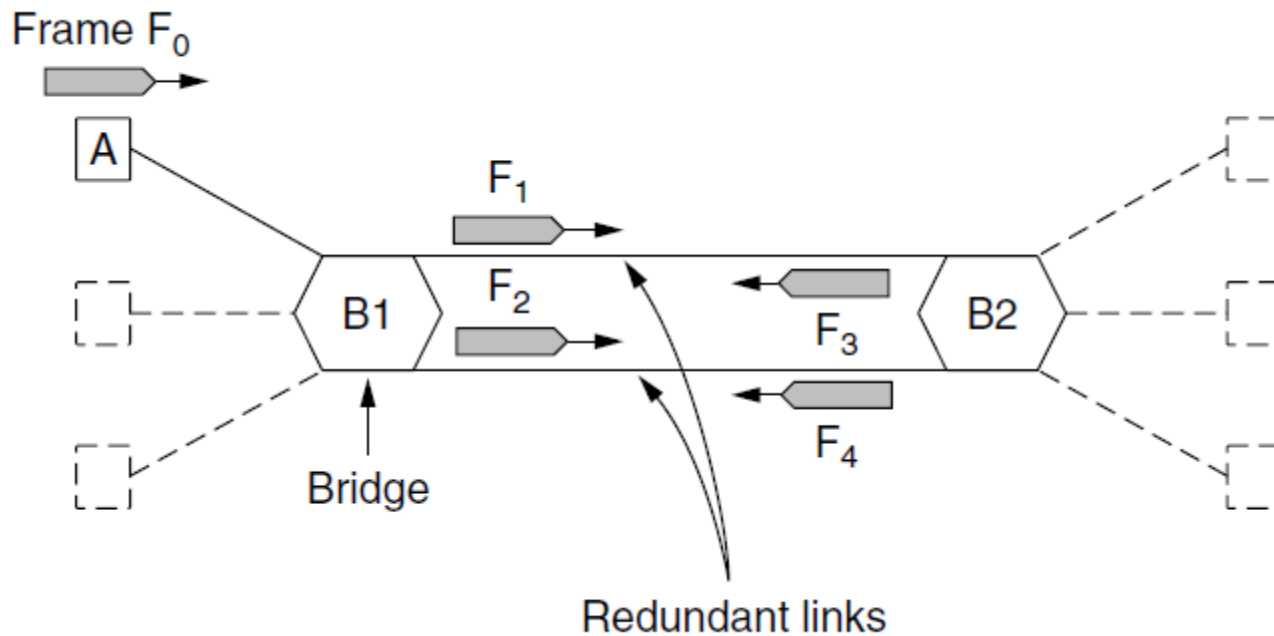
- ▶ Use but don't remove Ethernet header/addresses
- ▶ Do not inspect Network header



Spanning Tree (1) – Problem

Bridge topologies with loops and only backward learning will cause frames to circulate for ever

- Need spanning tree support to solve problem



Spanning Tree (2) – Algorithm

- ▶ Subset of forwarding ports for data is use to avoid loops
- ▶ Selected with the spanning tree distributed algorithm by Perlman

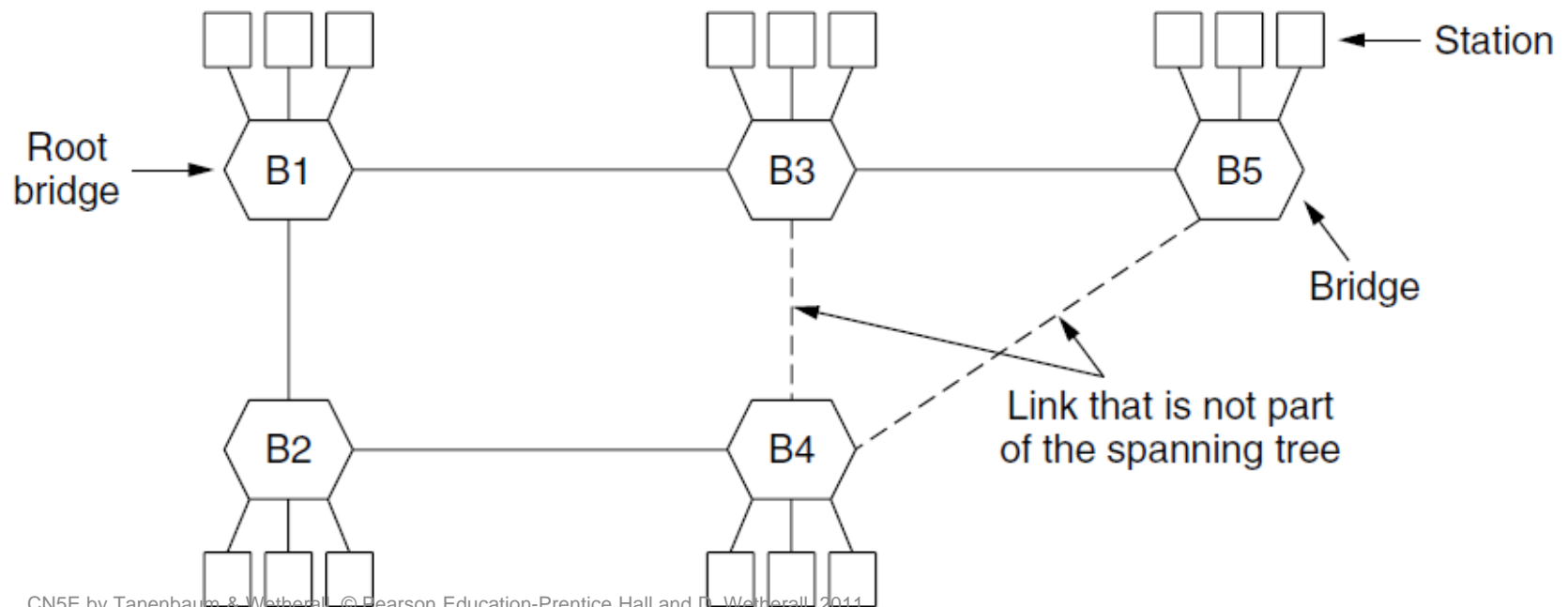
*I think that I shall never see
A graph more lovely than a tree.
A tree whose crucial property
Is loop-free connectivity.
A tree which must be sure to span.
So packets can reach every LAN.
First the Root must be selected
By ID it is elected.
Least cost paths from Root are traced
In the tree these paths are placed.
A mesh is made by folks like me
Then bridges find a spanning tree.*

– Radia Perlman, 1985.

Spanning Tree (3) - Example

After the algorithm runs:

- ▶ B1 is the root, two dashed links are turned off
- ▶ B4 uses link to B2 (lower than B3 also at distance 1)
- ▶ B5 uses B3 (distance 1 versus B4 at distance 2)



Repeaters, Hubs, Bridges, Switches, Routers, & Gateways

Devices are named according to the layer they process

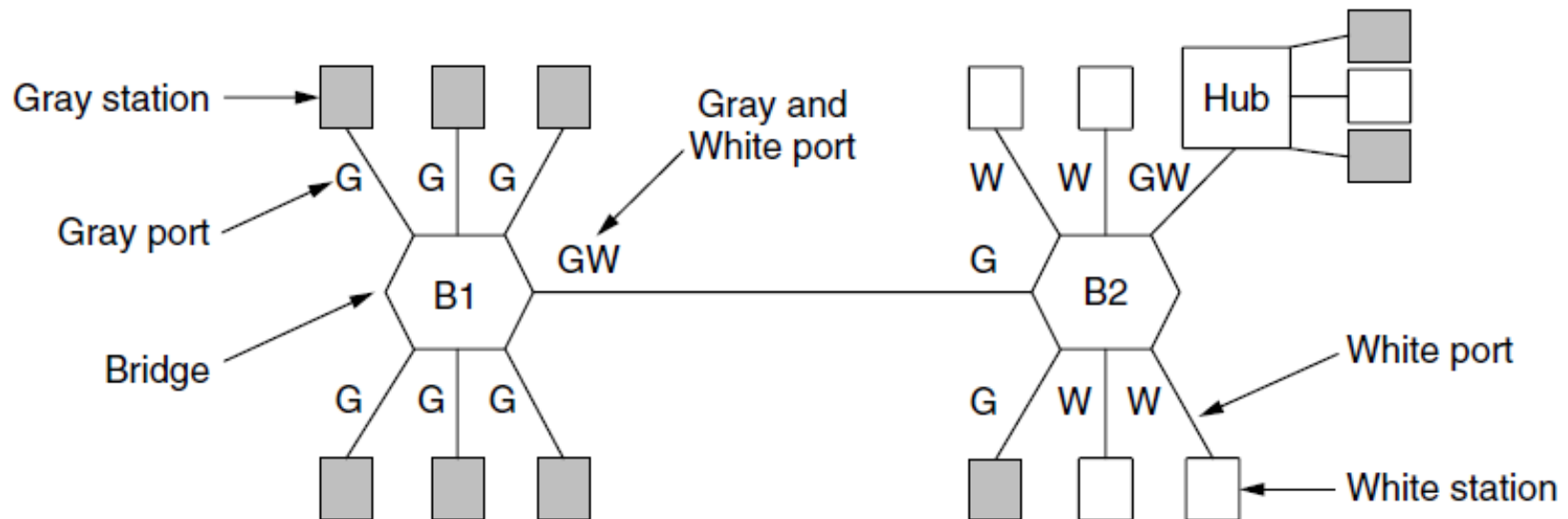
- ▶ A bridge or LAN switch operates in the Link layer

Application layer	Application gateway
Transport layer	Transport gateway
Network layer	Router
Data link layer	Bridge, switch
Physical layer	Repeater, hub

Virtual LANs (1)

VLANs (Virtual LANs) splits one physical LAN into multiple logical LANs to ease management tasks

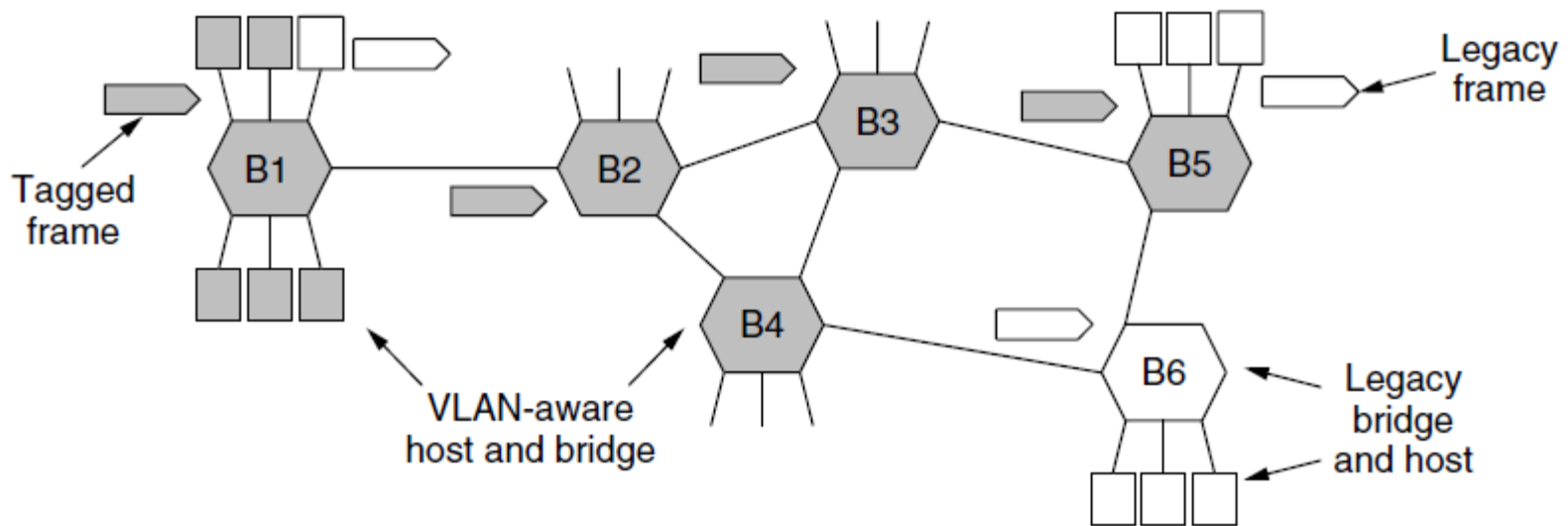
- ▶ Ports are “colored” according to their VLAN



Virtual LANs (2) - IEEE 802.1Q

Bridges need to be aware of VLANs to support them

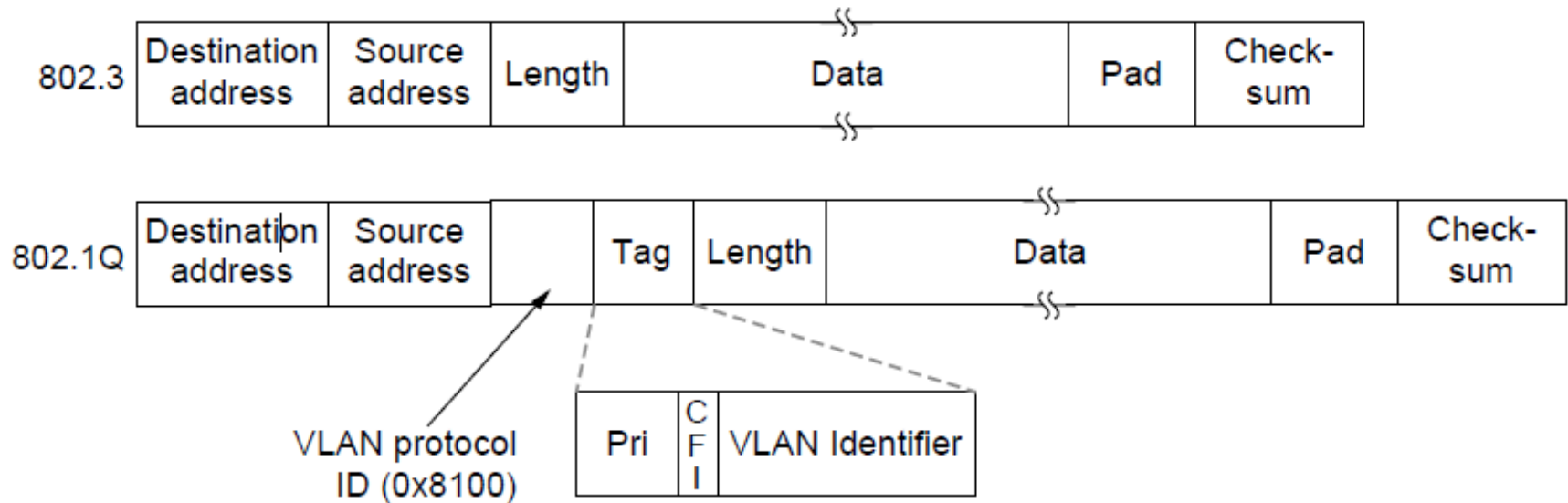
- ▶ In 802.1Q, frames are tagged with their “color”
- ▶ Legacy switches with no tags are supported



Virtual LANs (3) – IEEE 802.1Q

802.1Q frames carry a color tag (VLAN identifier)

- ▶ Length/Type value is 0x8100 for VLAN protocol



End

Chapter 4