ETSF05 – Internet Protocols

# ARQ
# PPP
# TDM
# Synchronous Optical Networks
# xDSL
# WLAN

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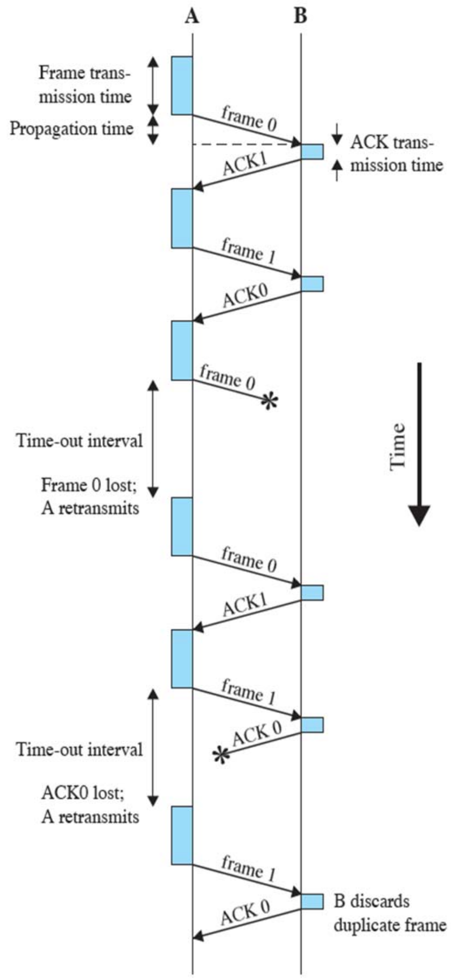
# Routing

- Konsten att bygga least-cost trees
  - Från sändare till mottagare
  - Från varje nod till varje annan nod
- Tre principer
  - Distance Vector
  - Link State
  - Path Vector
    - Policy-based routing

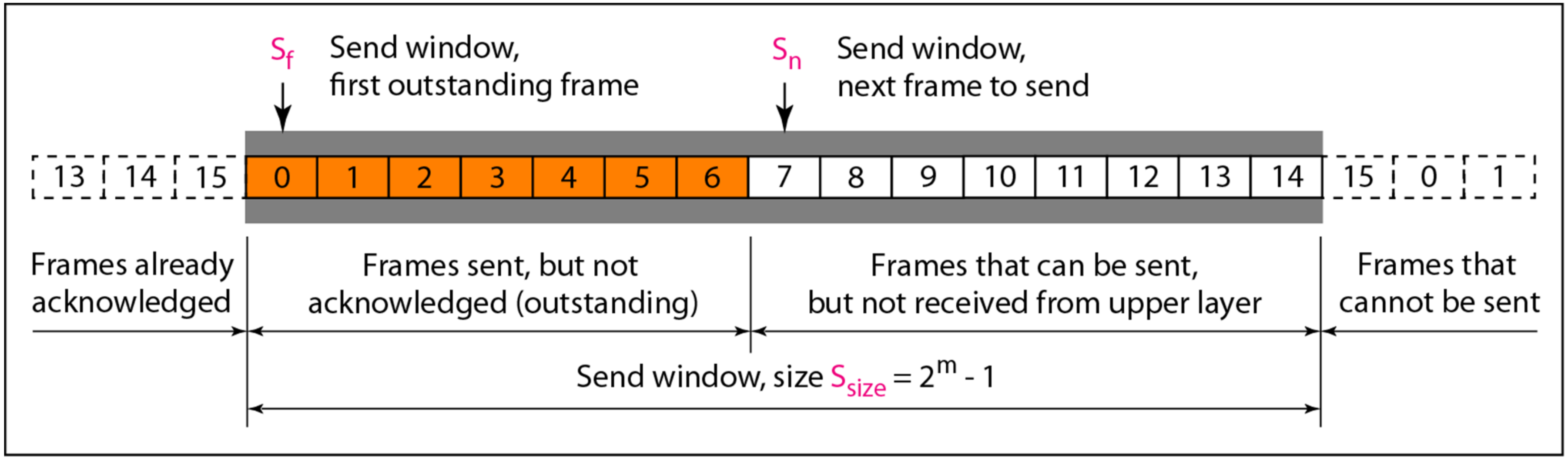
# Stop-and-wait ARQ

- Too much waiting
- Solution
  - Keep the pipe full
  - But not too full

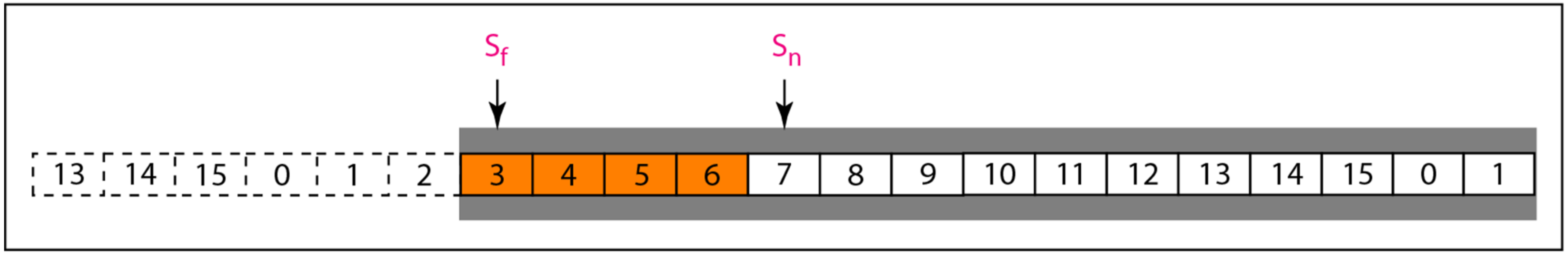
- Sliding window
  - Size matters
  - Window size < $2^m$



# Sliding window

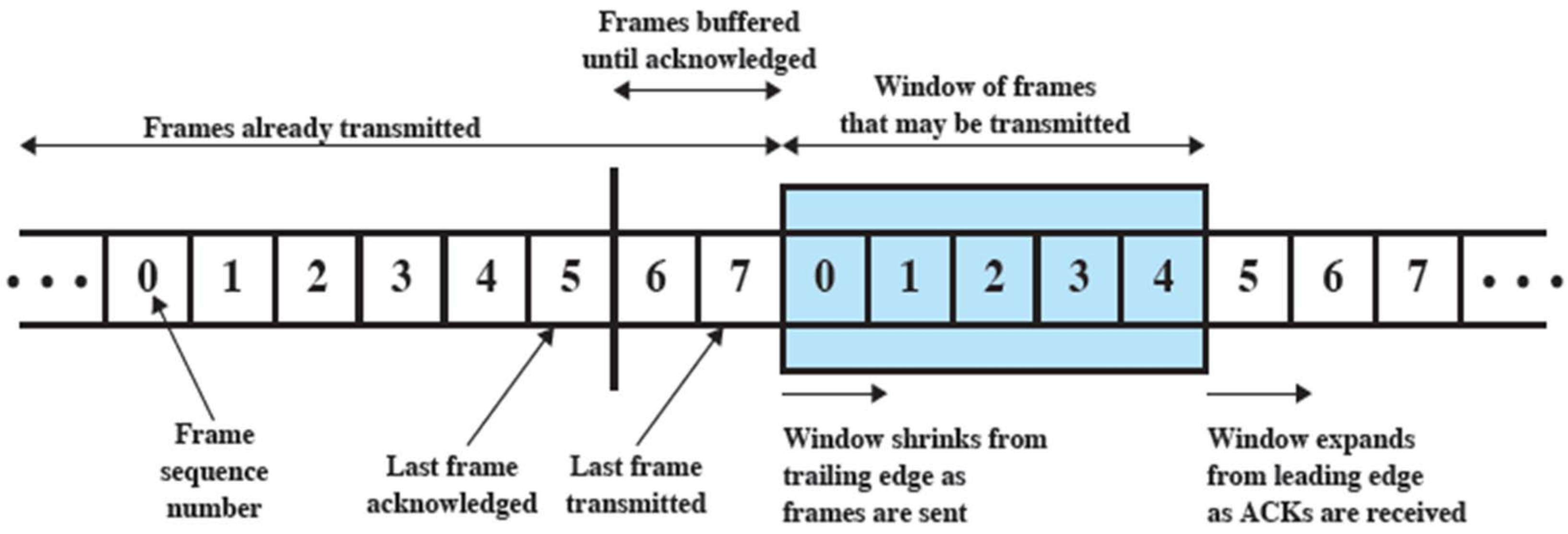



a. Send window before sliding



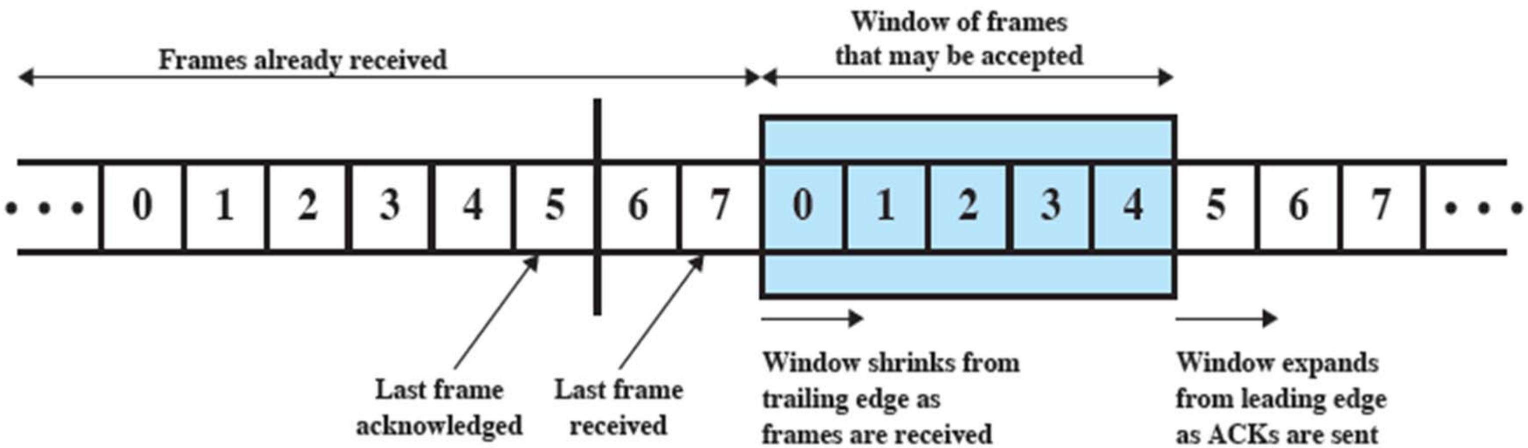

b. Send window after sliding

# Sliding window (sender)



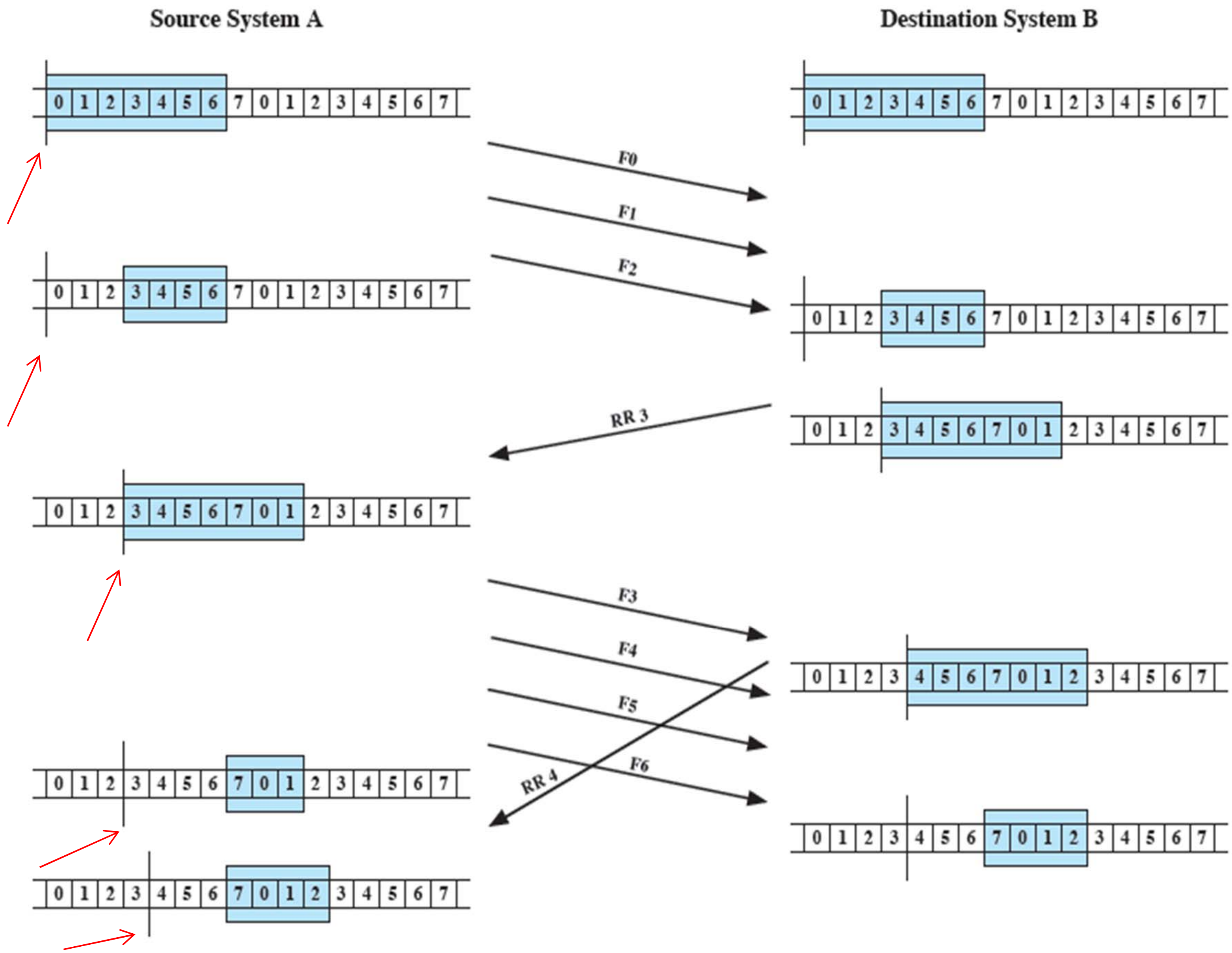

(a) Sender's perspective

# Sliding window (receiver)

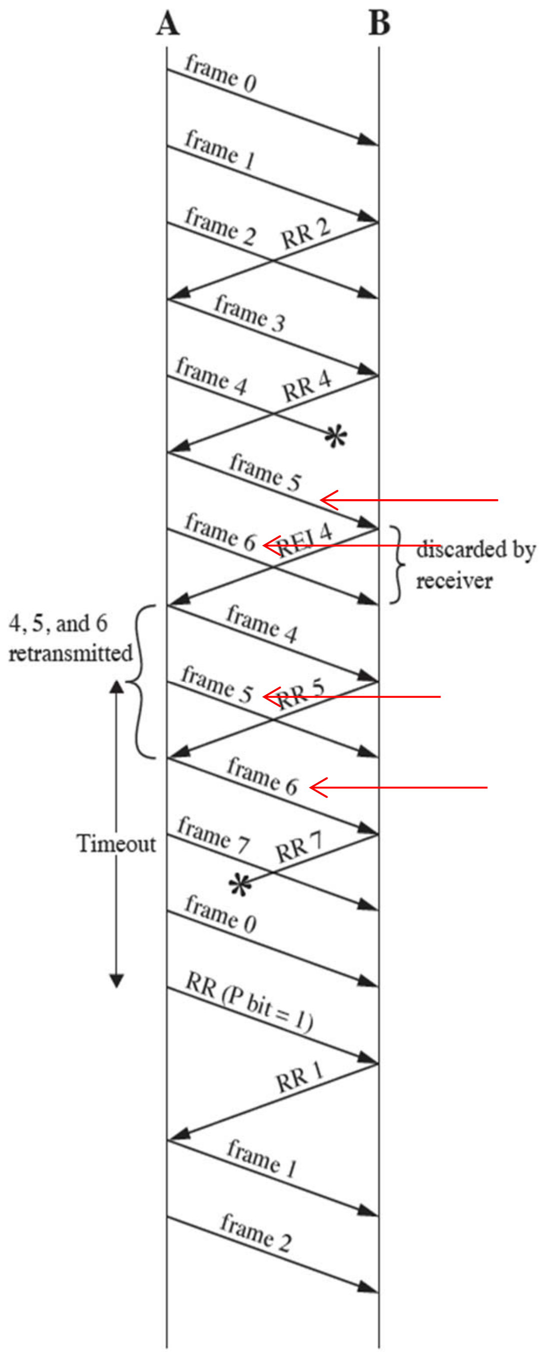



(b) Receiver's perspective

# Sliding window (max wnd sz = 7)



# Go-Back-N




(a) Go-back-N ARQ

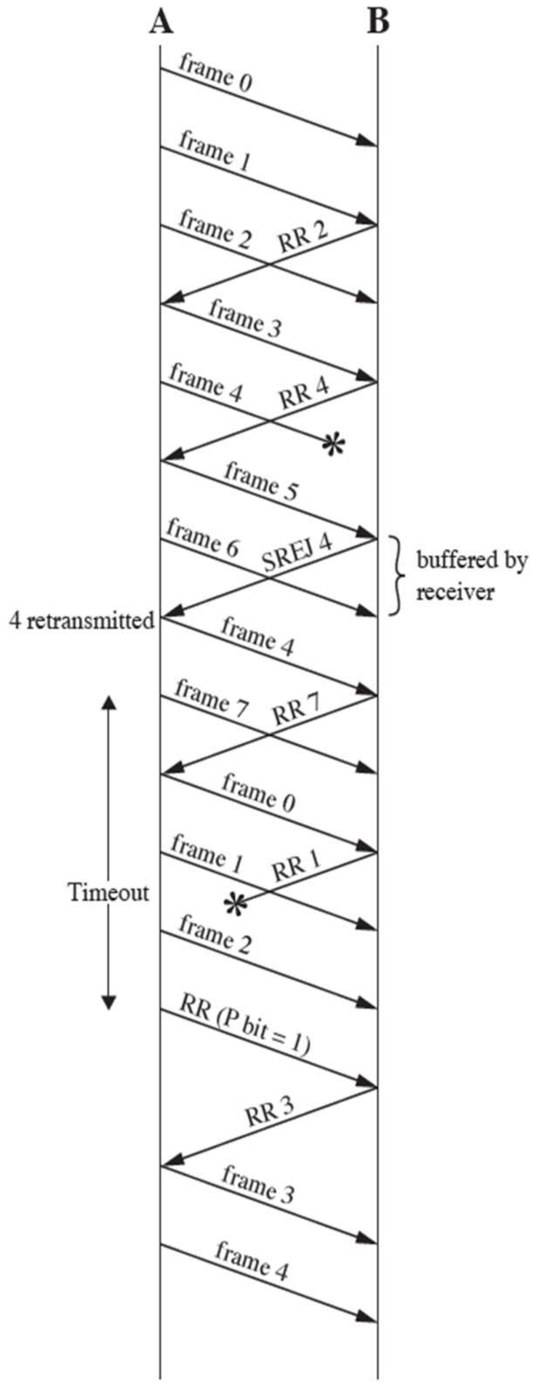
# Go-Back-N ARQ (the Stalling Way; skiljer sig från Kihl-Andersson i detaljer)

- Most commonly used error control
- Based on sliding-window
- Use window size to control number of outstanding frames
- While no errors occur, the destination will acknowledge incoming frames as usual
  - RR=receive ready, or piggybacked acknowledgment
- If the destination station detects an error in a frame, it may send a negative acknowledgment
  - REJ=reject
  - Destination will discard that frame and all future frames until the frame in error is received correctly
  - Transmitter must go back and retransmit that frame and all subsequent frames

# Selective-Reject (ARQ) (Stalling)

- Also called selective retransmission
- Only rejected frames are retransmitted
- Subsequent frames are accepted by the receiver and buffered
- Minimizes retransmission
- Receiver must maintain large enough buffer
- More complex logic in transmitter
  - Less widely used
- Useful for satellite links with long propagation delays

# Selective Repeate



(b) Selective-reject ARQ

# Selective repeat ARQ

- Why?
  - Too many datagrams to re-transmit
- What if?
  - Just send lost frames
- Higher efficiency
  - To the cost of higher receiver complexity

# Bra exempel för självstudier!

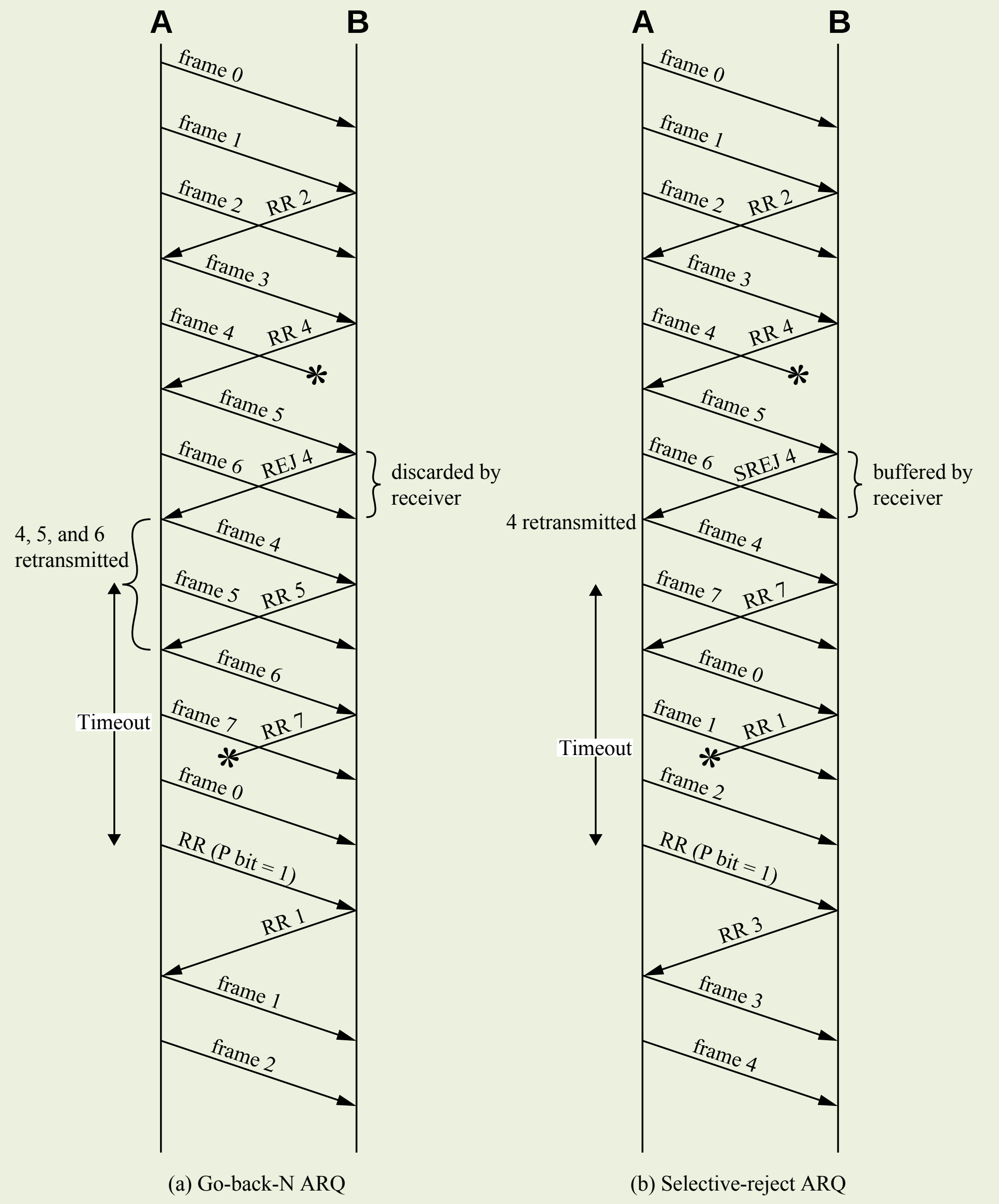
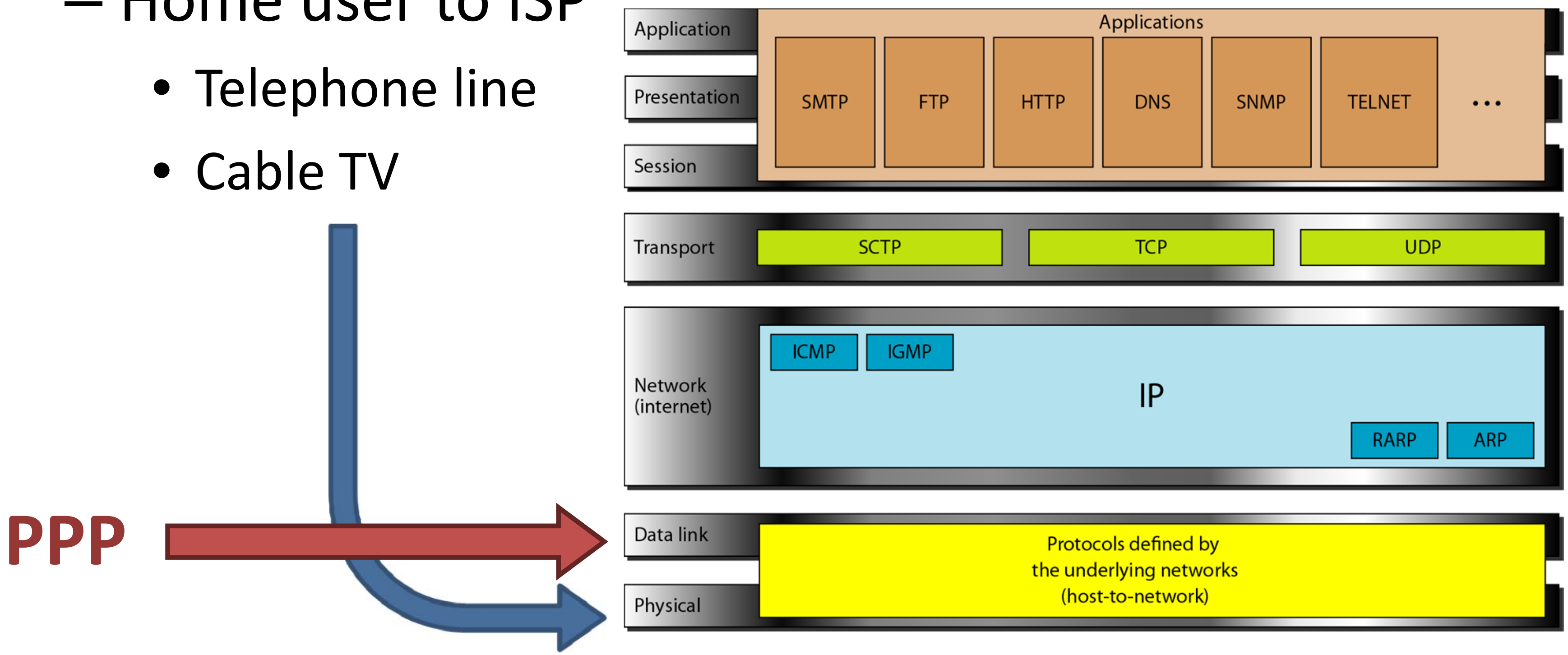



**Figure 7.6 Sliding-Window ARQ Protocols**

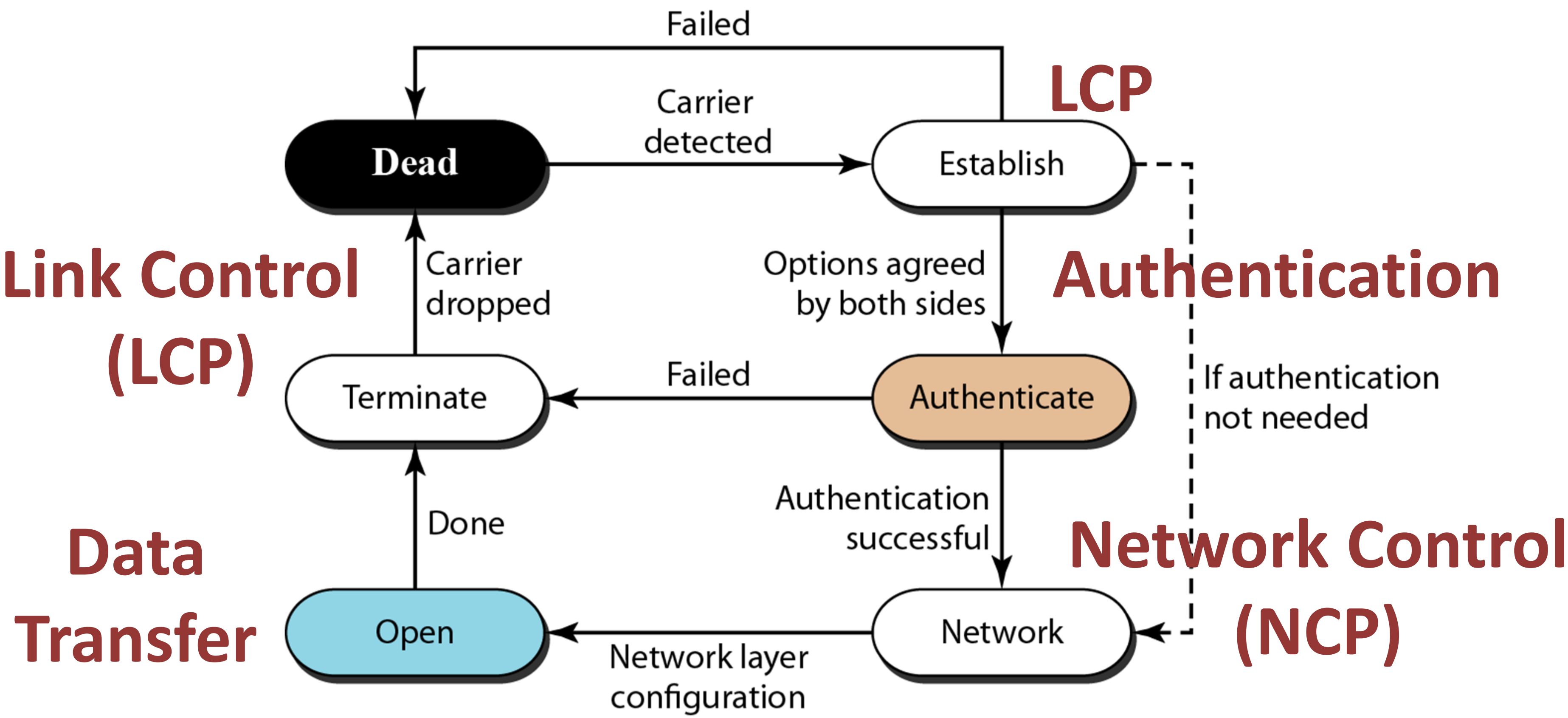
# Point-to-point protocol (PPP)

- Direct connection between two nodes
  - Internet access
  - Home user to ISP
    - Telephone line
    - Cable TV



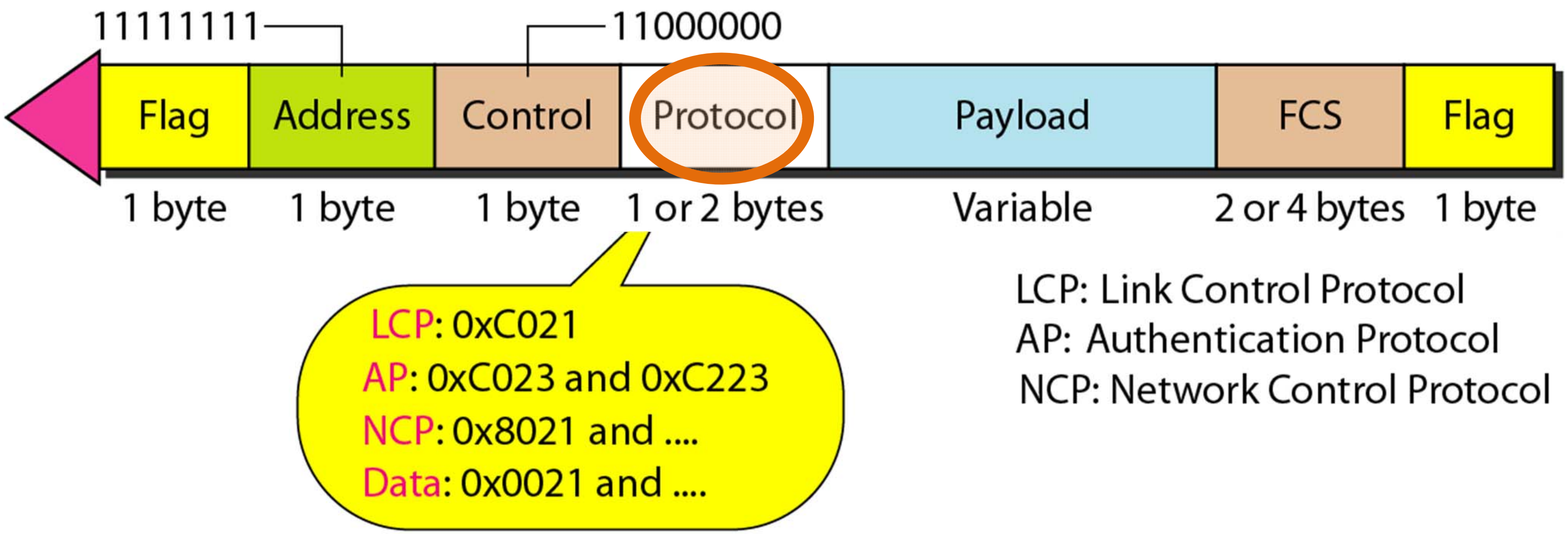
# State transitions in PPP

- We need more protocols



# PPP frame format

- Support for several (sub)protocols
- Address & control not used
- Maximum payload 1500 bytes



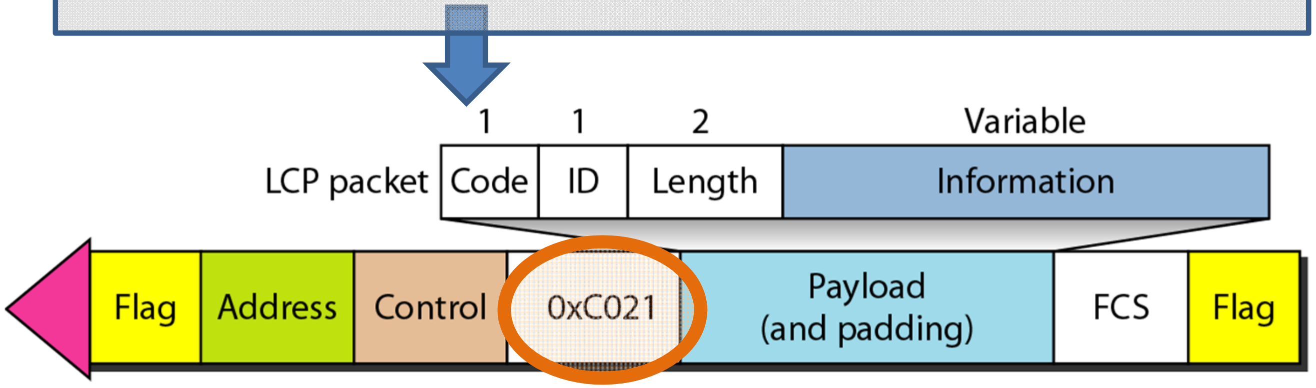
# Link control protocol (LCP)

- Establish
- Configure
- Terminate

Options

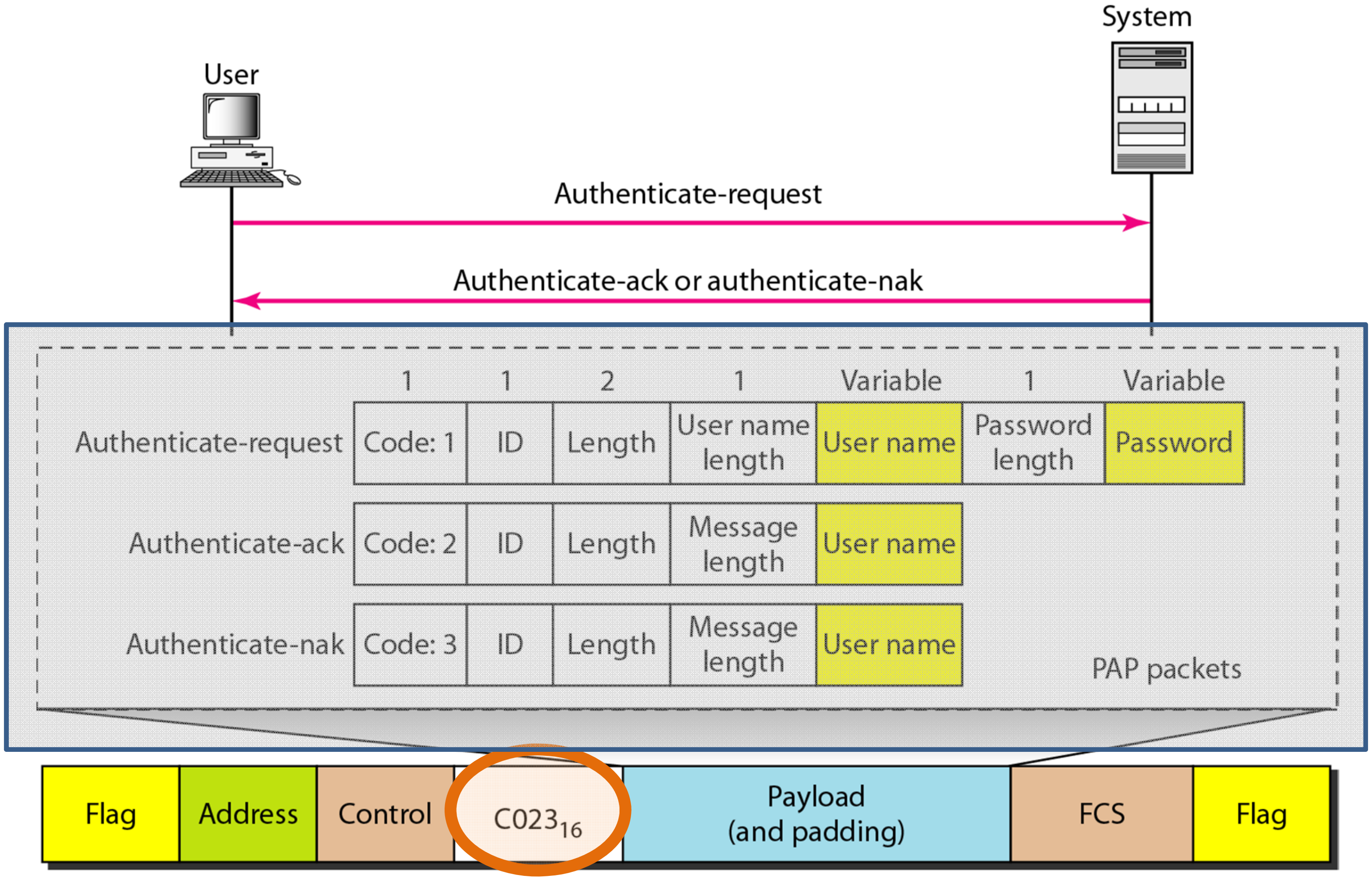
- Maximum receive unit (payload size)
- Authentication protocol (none/PAP/CHAP)
- Protocol field compression (on/off),
- Address and control field compression (on/off)

| *Code* | *Packet Type* | *Description* |
|---|---|---|
| 0x01 | Configure-request | Contains the list of proposed options and their values |
| 0x02 | Configure-ack | Accepts all options proposed |
| 0x03 | Configure-nak | Announces that some options are not acceptable |
| 0x04 | Configure-reject | Announces that some options are not recognized |
| 0x05 | Terminate-request | Request to shut down the line |
| 0x06 | Terminate-ack | Accept the shutdown request |
| 0x07 | Code-reject | Announces an unknown code |
| 0x08 | Protocol-reject | Announces an unknown protocol |
| 0x09 | Echo-request | A type of hello message to check if the other end is alive |
| 0x0A | Echo-reply | The response to the echo-request message |
| 0x0B | Discard-request | A request to discard the packet |



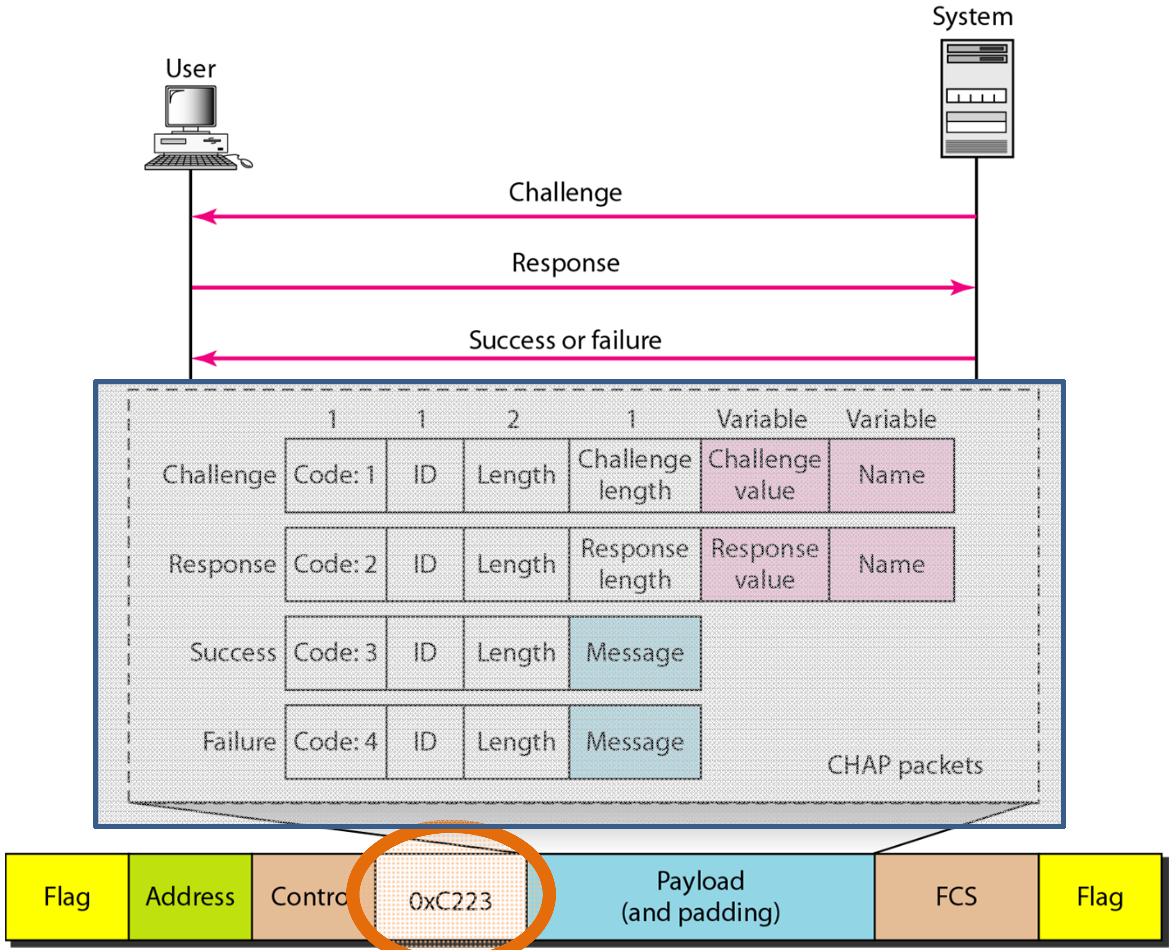
# Authentication protocols (AP)

- Password authentication (PAP)



# Authentication protocols (AP)

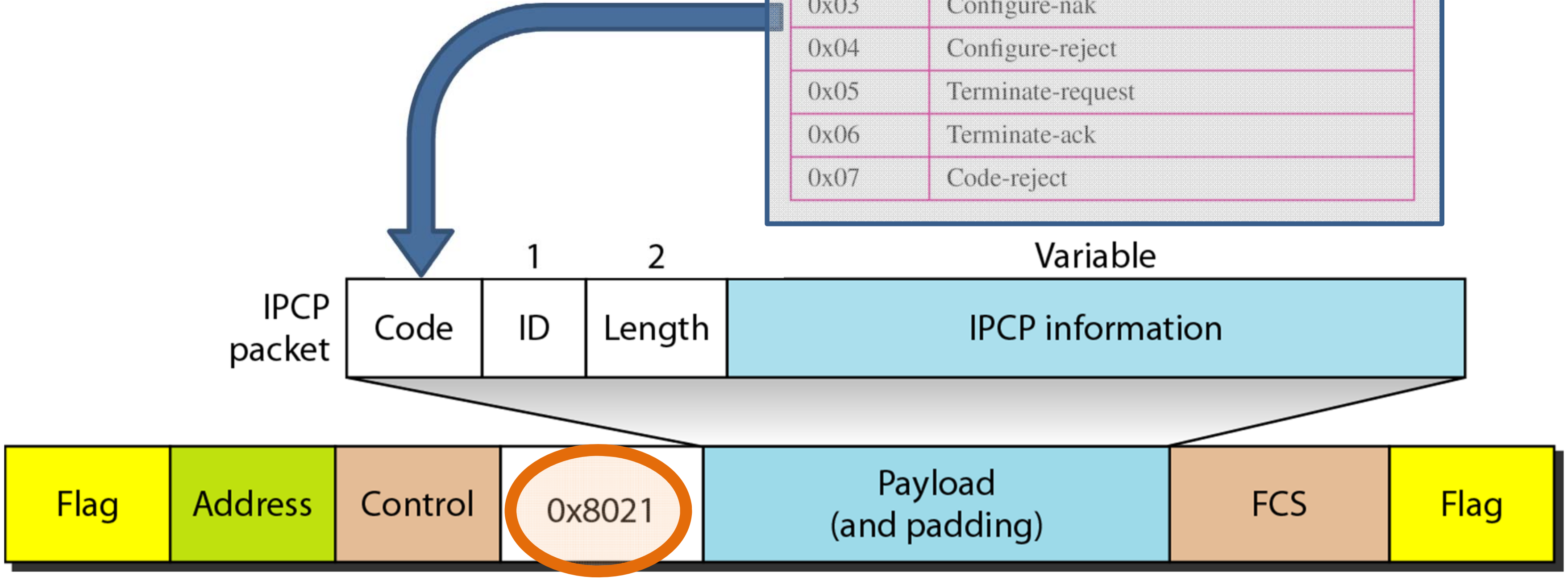
- Challenge handshake authentication (CHAP)



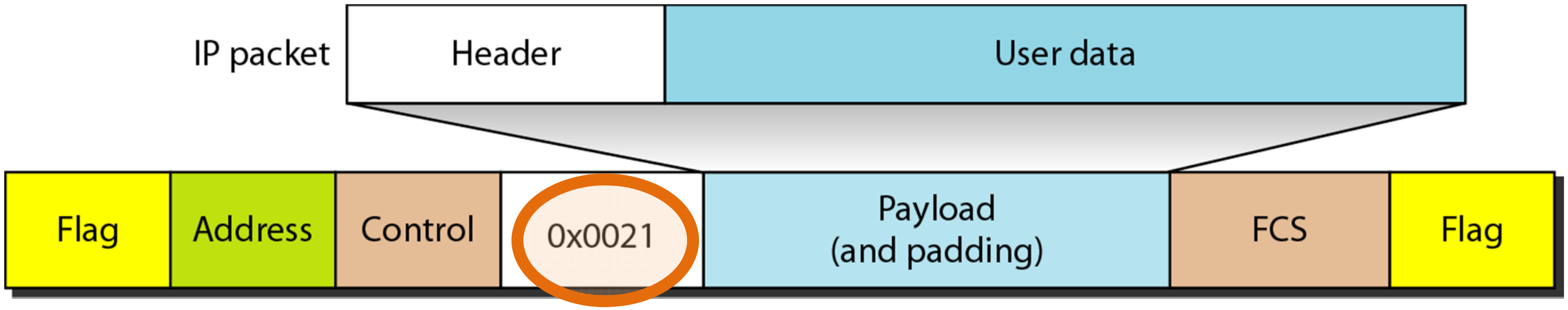
# Network control protocols (NCP)

- Preparations for the network layer
  - IPCP for Internet

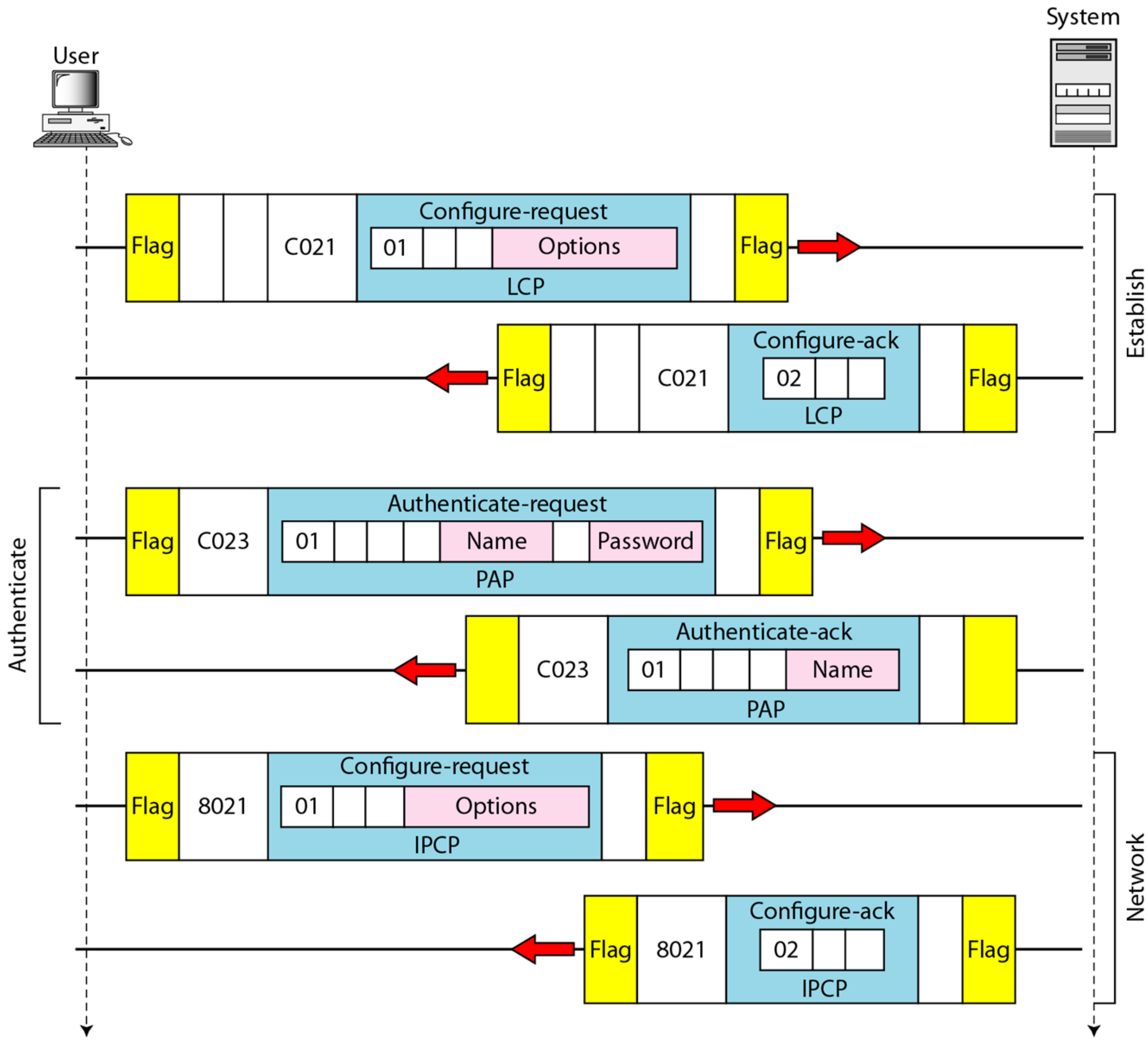
| *Code* | *IPCP Packet* |
|---|---|
| 0x01 | Configure-request |
| 0x02 | Configure-ack |
| 0x03 | Configure-nak |
| 0x04 | Configure-reject |
| 0x05 | Terminate-request |
| 0x06 | Terminate-ack |
| 0x07 | Code-reject |



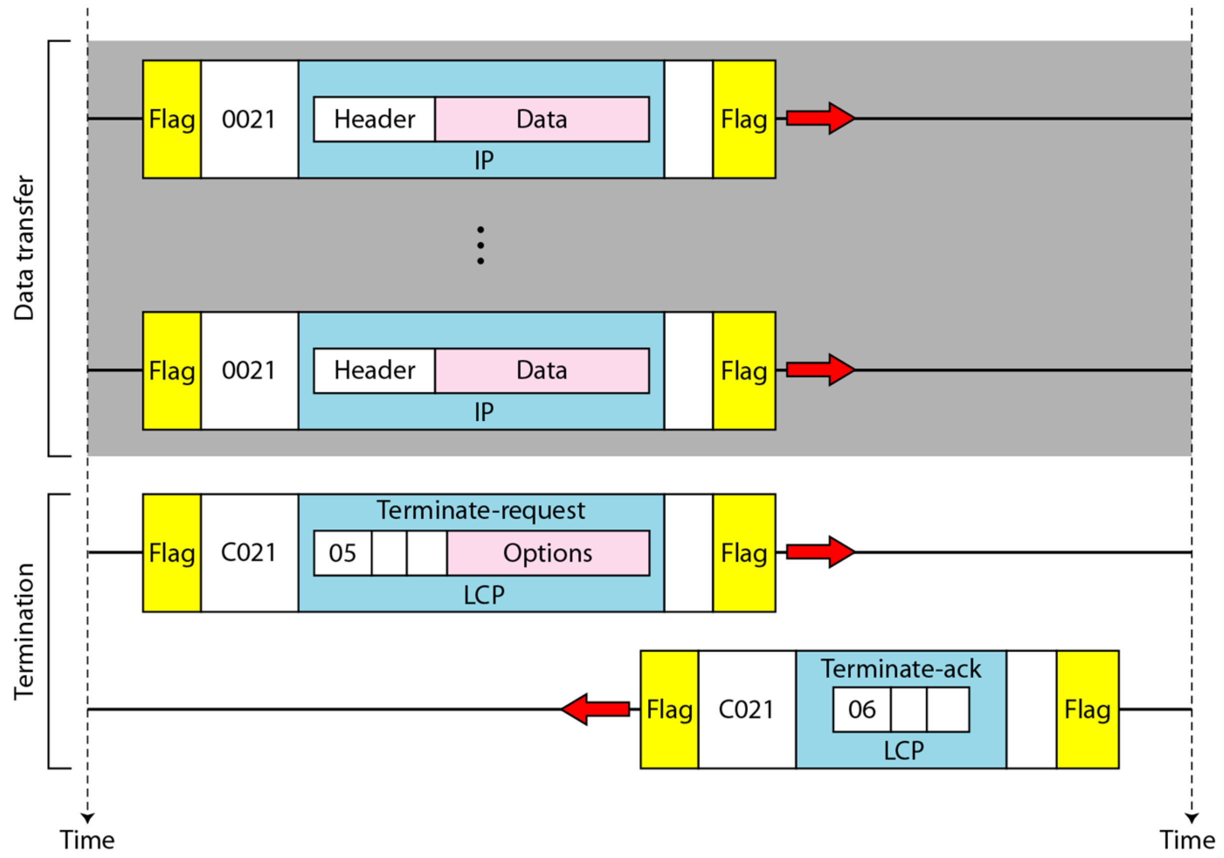
# IP datagram encapsulation in PPP



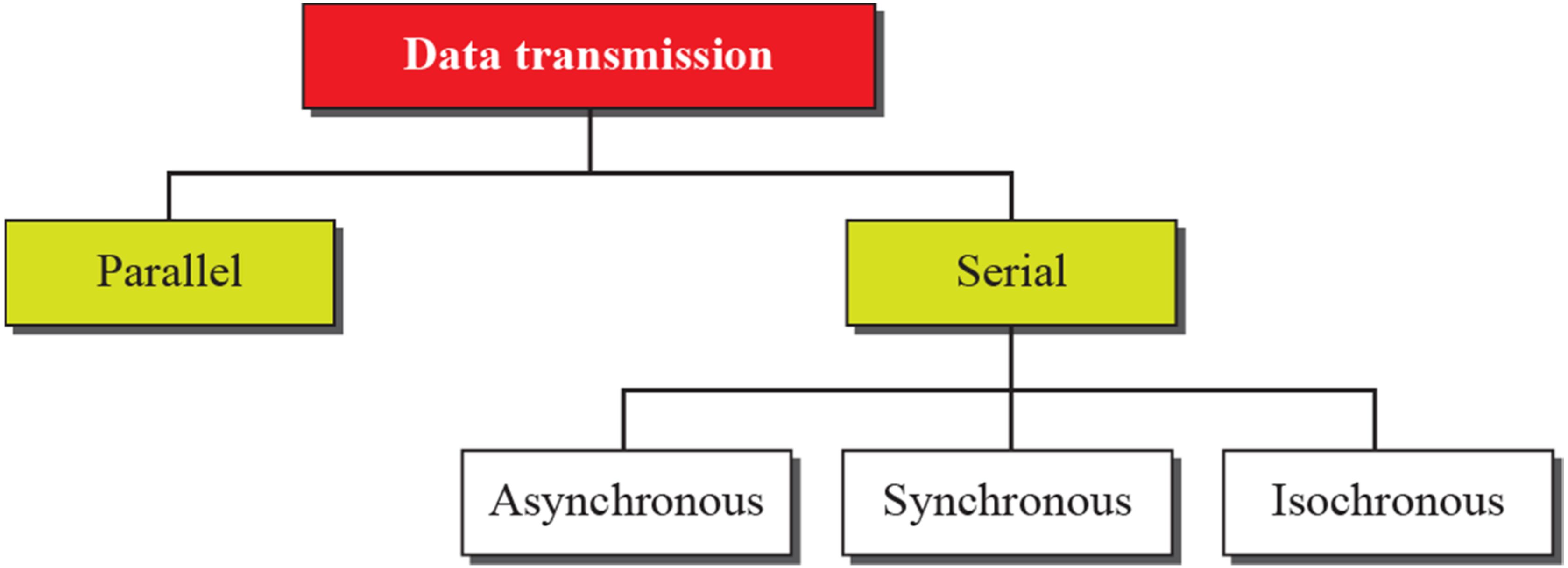
# PPP session example



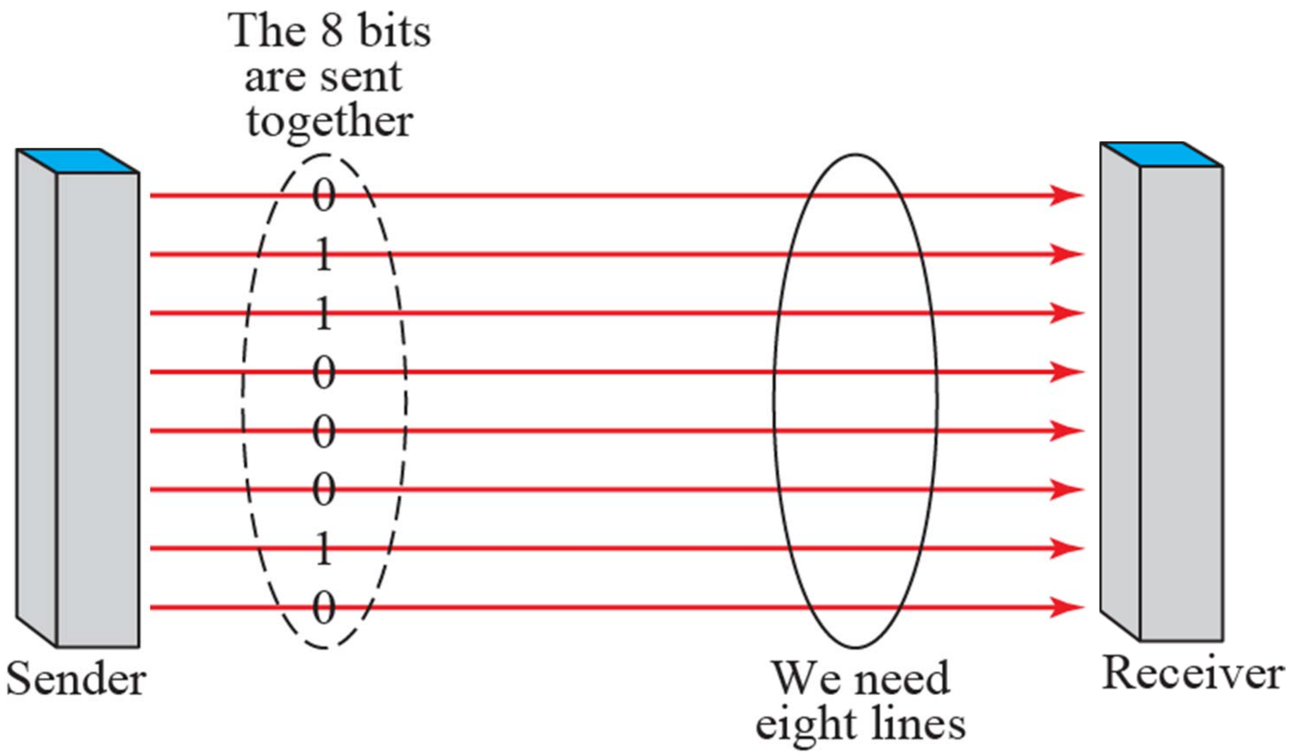
# PPP session example (cont.)



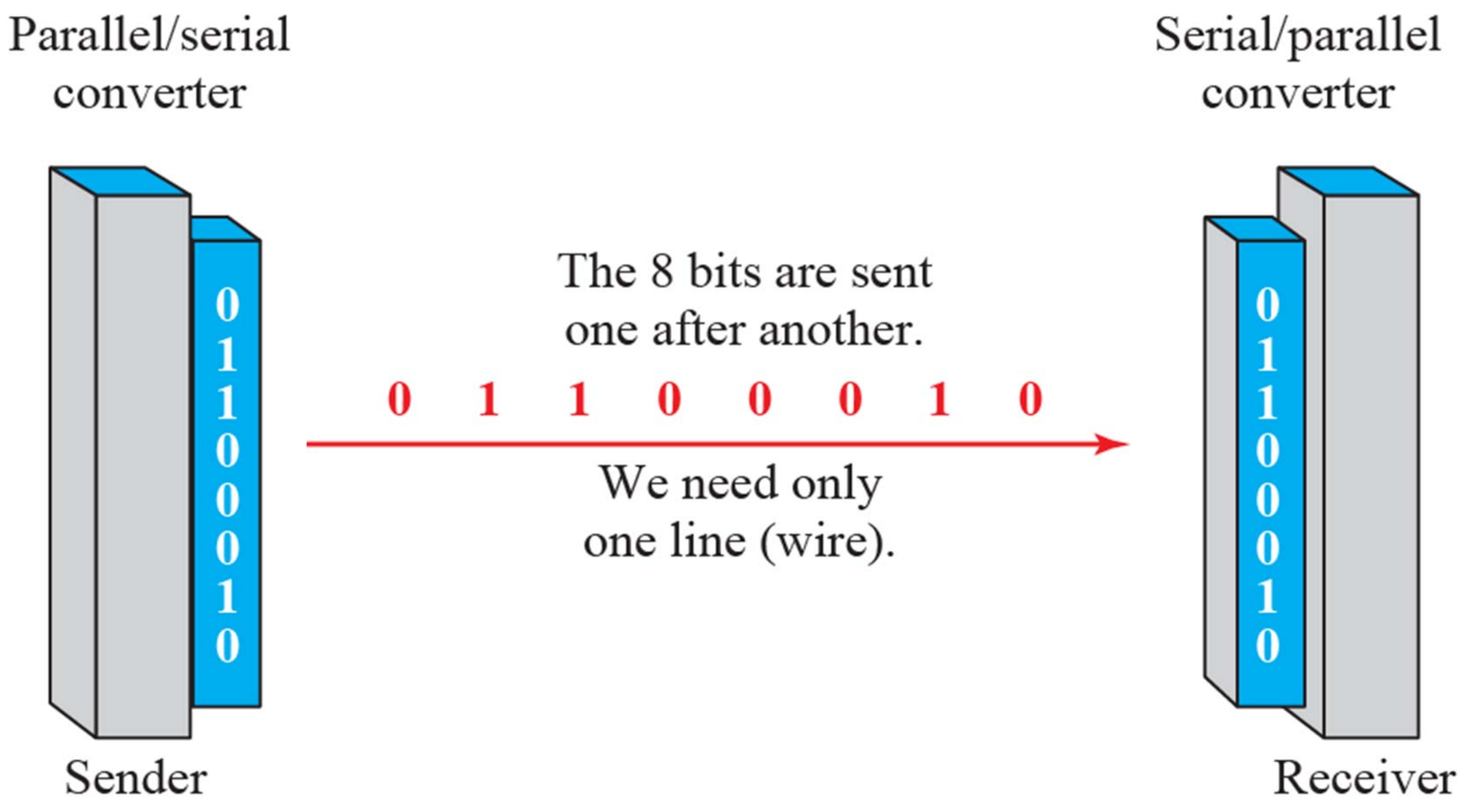
# Transmission modes



# Parallell transmission

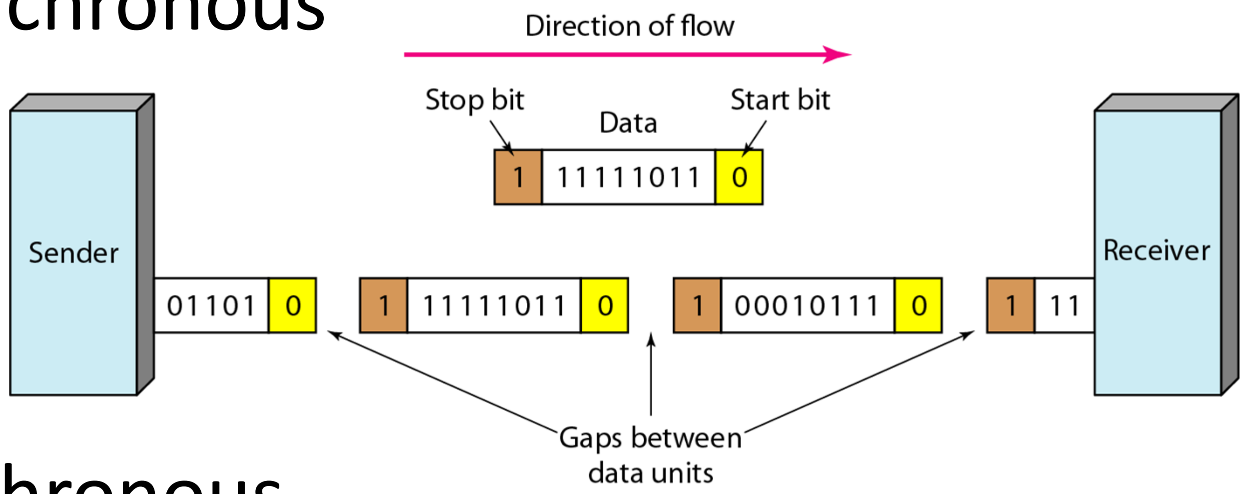


# Serial transmission

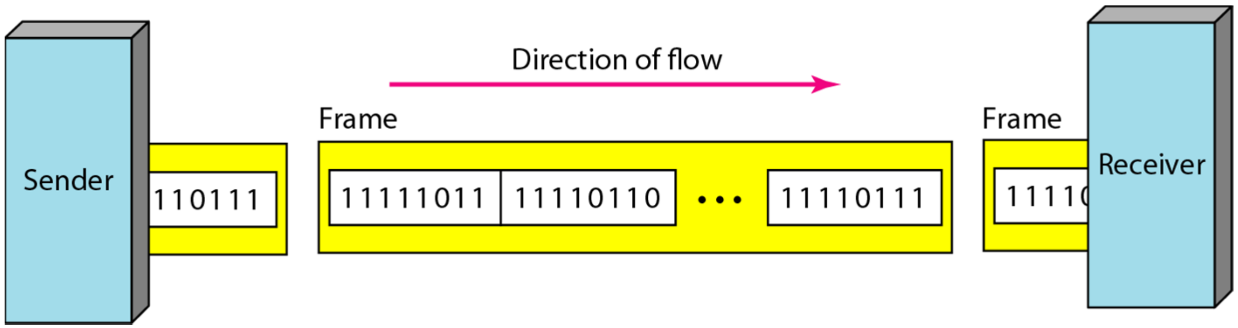


# Transmission modes

- Asynchronous




- Synchronous



# Multiplexing, princip

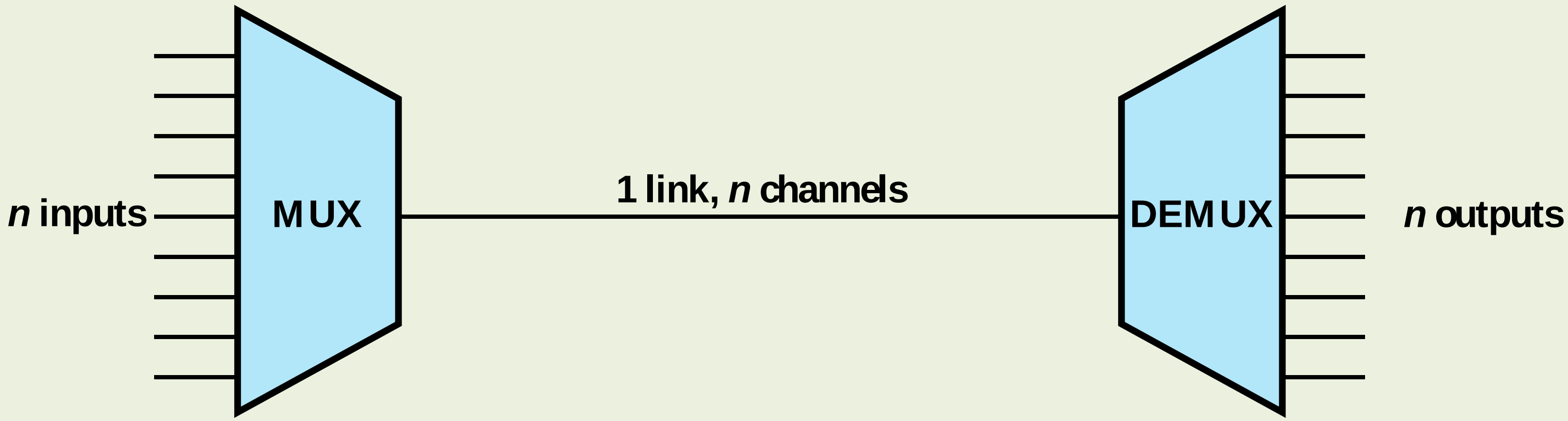



Figure 8.1 Multiplexing

# FDM vs TDM

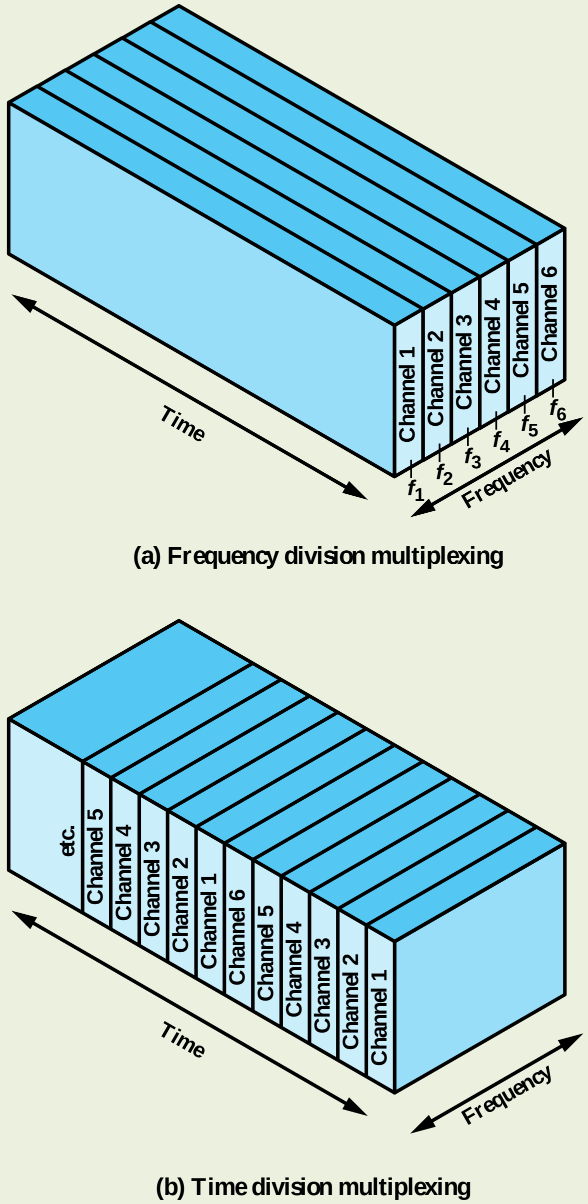



Figure 8.2 FDM and TDM

# Synkron TDM

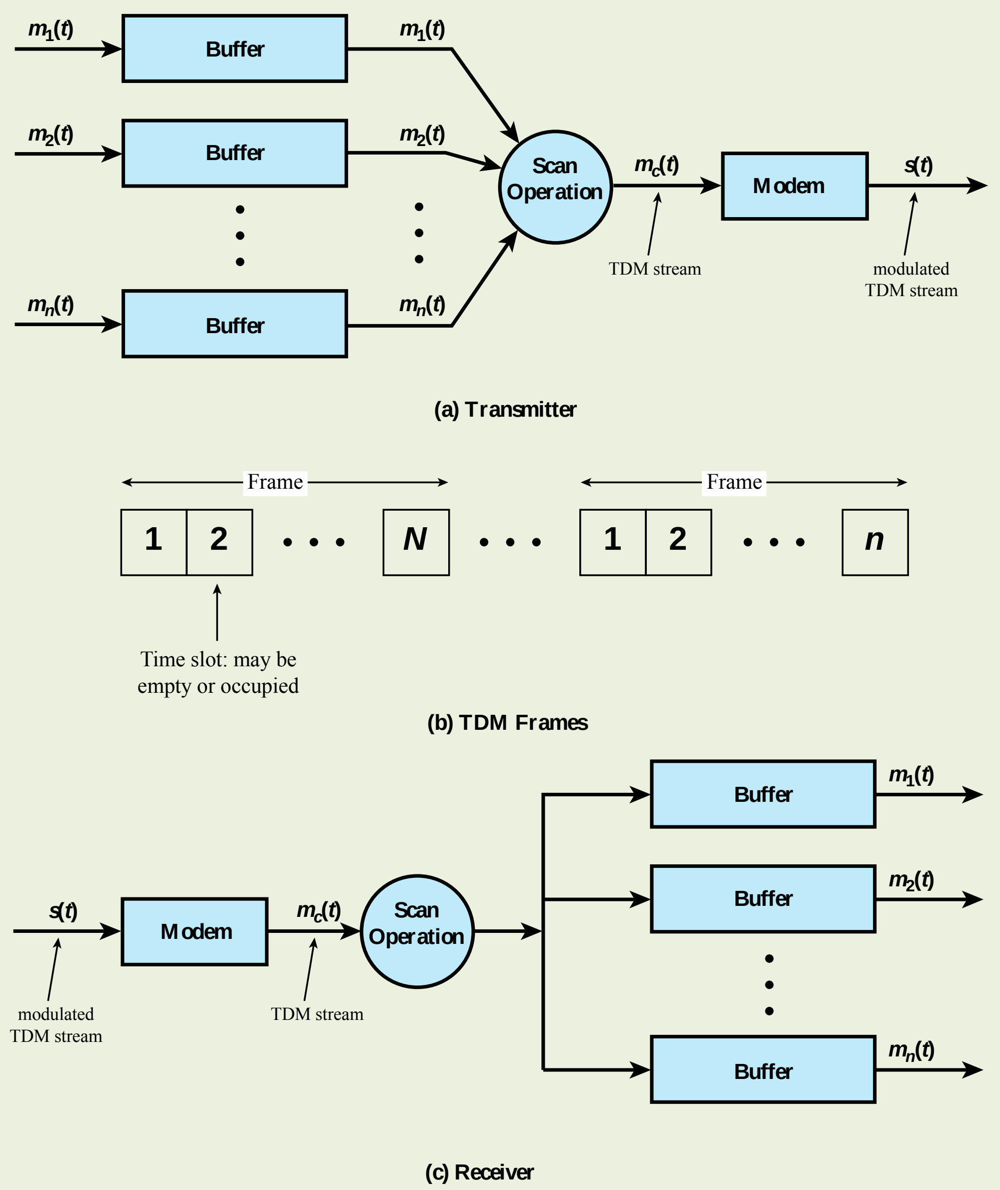


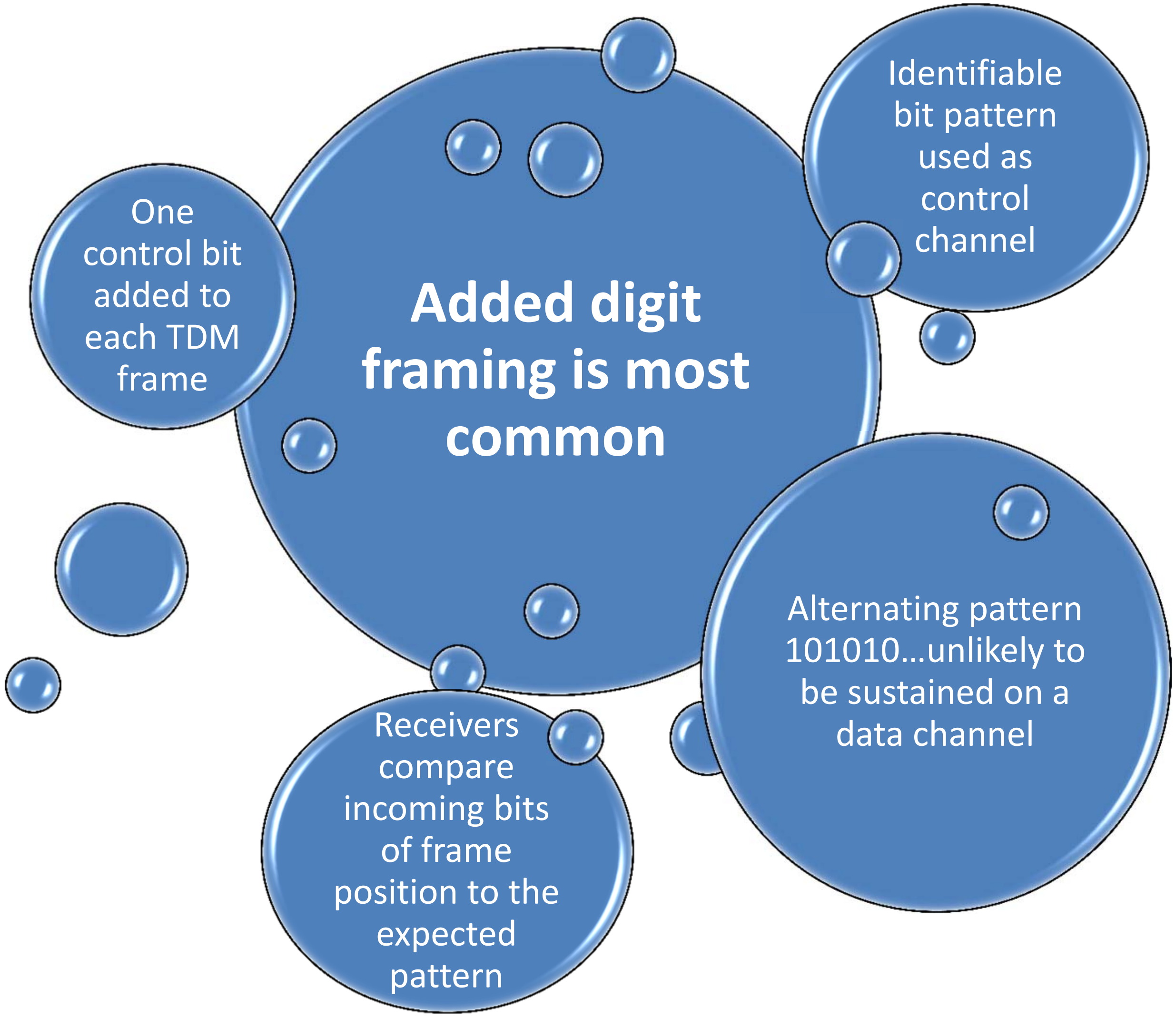

Figure 8.6 Synchronous TDM System

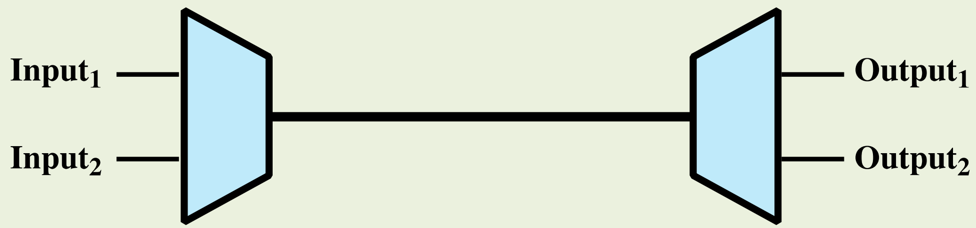
# TDM Link Control

- Data link control protocols not needed
  - Time is control parameter
- TDM system control data use control fields
- No headers and trailers
- Flow control
  - Data rate of multiplexed line is fixed
  - If one channel receiver can not receive data, the others must carry on
  - Corresponding source must be quenched
  - Leaving empty slots
- Error control
  - Errors detected and handled on individual channel

# Framing

- No flag or SYNC characters bracketing TDM frames
- Must still provide synchronizing mechanism between source and destination clocks






**(a) Configuration**

Input$_1$ • • • • • • • • • • • $F_1$ $f_1$ $f_1$ $d_1$ $d_1$ $d_1$ $C_1$ $A_1$ $F_1$ $f_1$ $f_1$ $d_1$ $d_1$ $d_1$ $C_1$ $A_1$ $F_1$

Input$_2$ • • • $F_2$ $f_2$ $f_2$ $d_2$ $d_2$ $d_2$ $d_2$ $C_2$ $A_2$ $F_2$ $f_2$ $f_2$ $d_2$ $d_2$ $d_2$ $d_2$ $C_2$ $A_2$ $F_2$

**(b) Input data streams**

• • • $f_2$ $F_1$ $d_2$ $f_1$ $d_2$ $f_1$ $d_2$ $d_1$ $d_2$ $d_1$ $C_2$ $d_1$ $A_2$ $C_1$ $F_2$ $A_1$ $f_2$ $F_1$ $f_2$ $f_1$ $d_2$ $f_1$ $d_2$ $d_1$ $d_2$ $d_1$ $d_2$ $d_1$ $C_2$ $C_1$ $A_2$ $A_1$ $F_2$ $F_1$

**(c) Multiplexed data stream**

Legend: F = flag field; A = address field; C = control field; d = one octet of data field; f = one octet of FCS field

# Figure 8.7 Use of Data Link Control on TDM Channels

# Pulse Stuffing is a common solution

| Have outgoing data rate (excluding framing bits) higher than sum of incoming rates | Stuff extra dummy bits or pulses into each incoming signal until it matches local clock | Stuffed pulses inserted at fixed locations in frame and removed at demultiplexer |
|---|---|---|

- Problem of synchronizing various data sources
- Variation among clocks could cause loss of synchronization
- Issue of data rates from different sources not related by a simple rational number

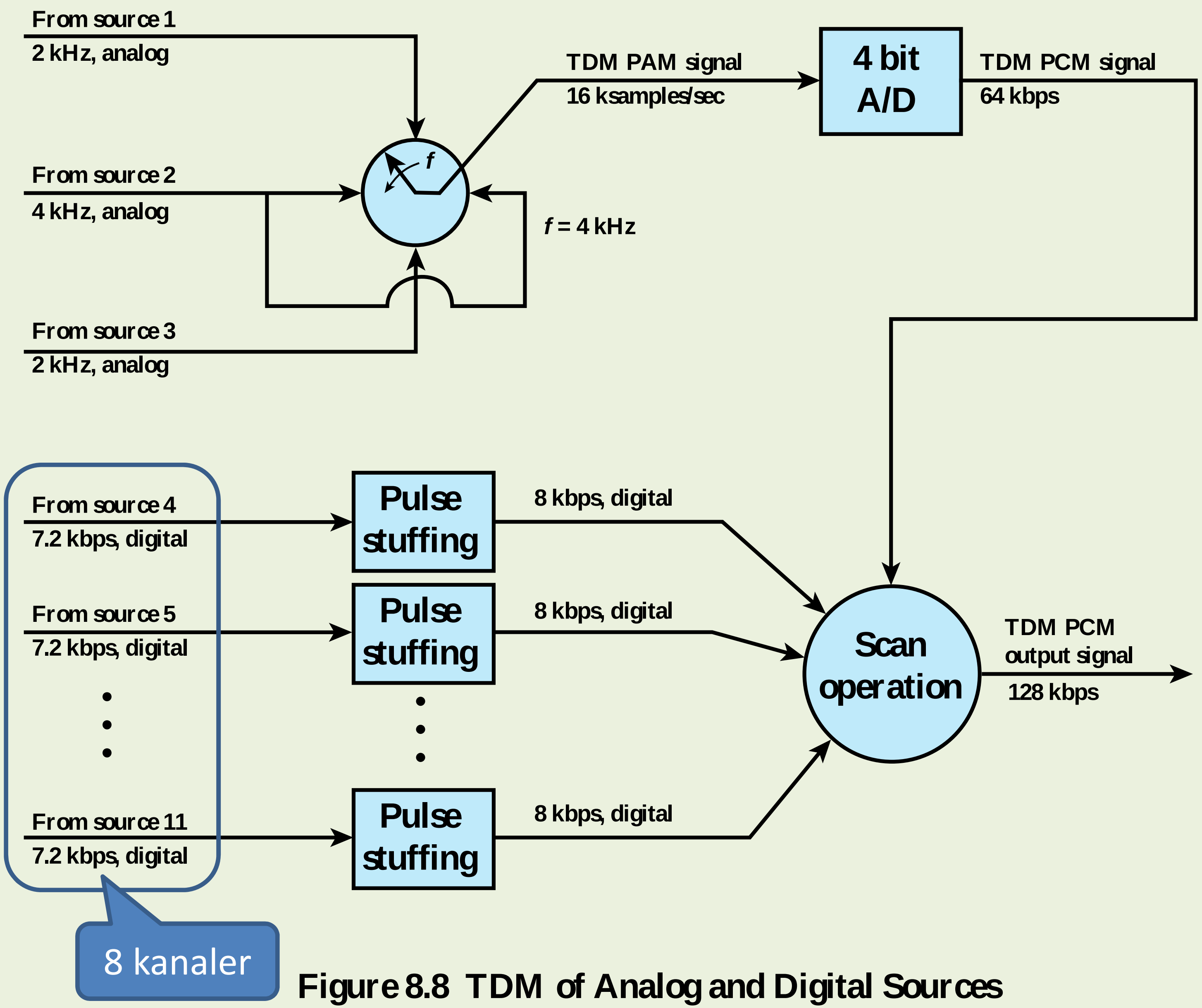



Figure 8.8 TDM of Analog and Digital Sources

# Table 8.3

## North American and International TDM Carrier Standards

| North American | | | International (ITU-T) | | |
|---|---|---|---|---|---|
| Designation | Number of Voice Channels | Data Rate (Mbps) | Level | Number of Voice Channels | Data Rate (Mbps) |
| DS-1 | 24 | 1.544 | 1 | 30 | 2.048 |
| DS-1C | 48 | 3.152 | 2 | 120 | 8.448 |
| DS-2 | 96 | 6.312 | 3 | 480 | 34.368 |
| DS-3 | 672 | 44.736 | 4 | 1920 | 139.264 |
| DS-4 | 4032 | 274.176 | 5 | 7680 | 565.148 |

# Synchronous Optical Networks

- SONET, developed by ANSI

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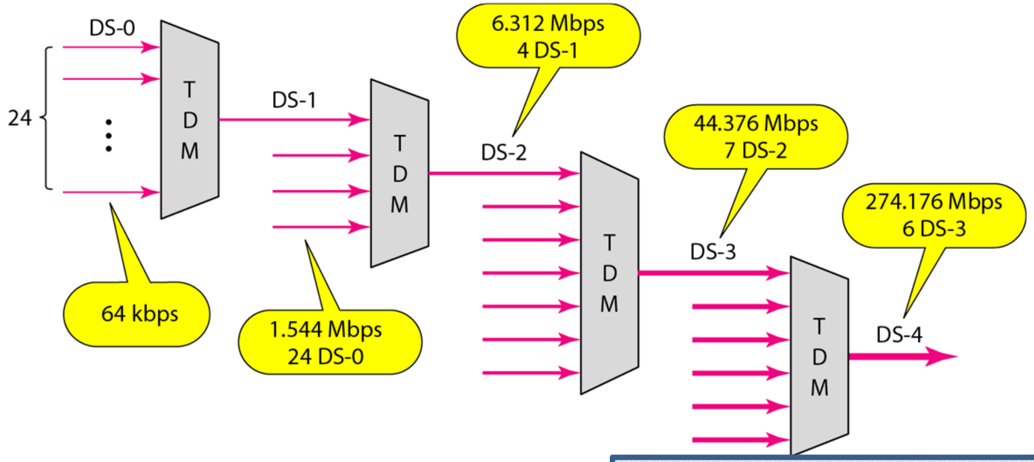
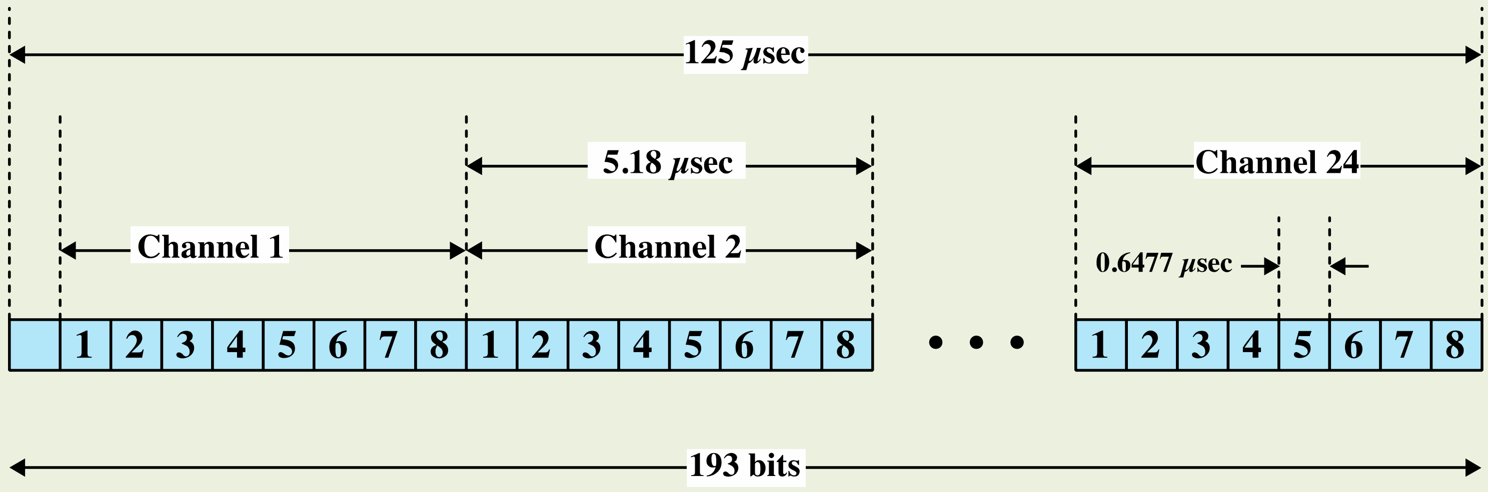
# Synchronous Digital Hierarchy

- SDH, developed by ITU-T

# Digital hierarchy on optical links




| *STS* | *OC* | *Rate (Mbps)* | *STM* |
|---|---|---|---|
| STS-1 | OC-1 | 51.840 | |
| STS-3 | OC-3 | 155.520 | **STM-1** |
| STS-9 | OC-9 | 466.560 | **STM-3** |
| STS-12 | OC-12 | 622.080 | **STM-4** |
| STS-18 | OC-18 | 933.120 | **STM-6** |
| STS-24 | OC-24 | 1244.160 | **STM-8** |
| STS-36 | OC-36 | 1866.230 | **STM-12** |
| STS-48 | OC-48 | 2488.320 | **STM-16** |
| STS-96 | OC-96 | 4976.640 | **STM-32** |
| STS-192 | OC-192 | 9953.280 | **STM-64** |




Notes:

1. The first bit is a framing bit, used for synchronization.
2. Voice channels:
   - 8-bit PCM used on five of six frames.
   - 7-bit PCM used on every sixth frame; bit 8 of each channel is a signaling bit.
3. Data channels:
   - Channel 24 is used for signaling only in some schemes.
   - Bits 1-7 used for 56 kbps service
   - Bits 2-7 used for 9.6, 4.8, and 2.4 kbps service.

**Figure 8.9 DS-1 Transmission Format**

# Network architecture

- Devices and connections

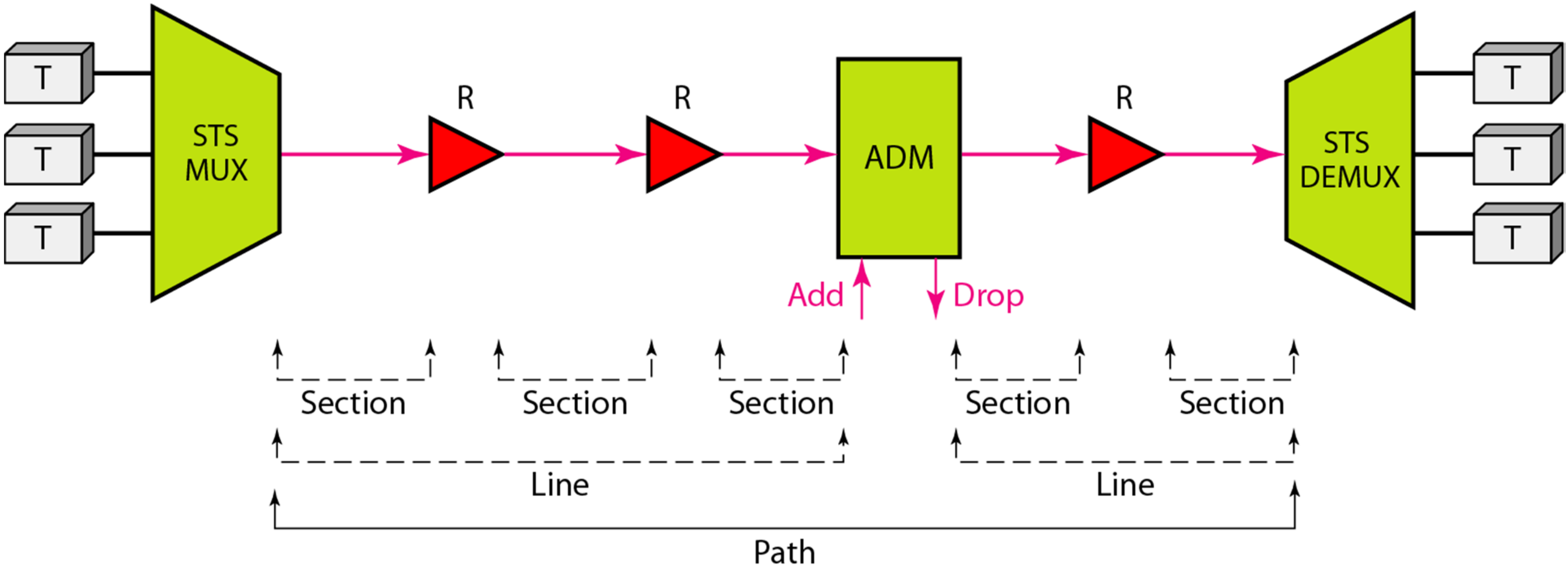
ADM: Add/drop multiplexer

STS MUX: Synchronous transport signal multiplexer

STS DEMUX: Synchronous transport signal demultiplexer

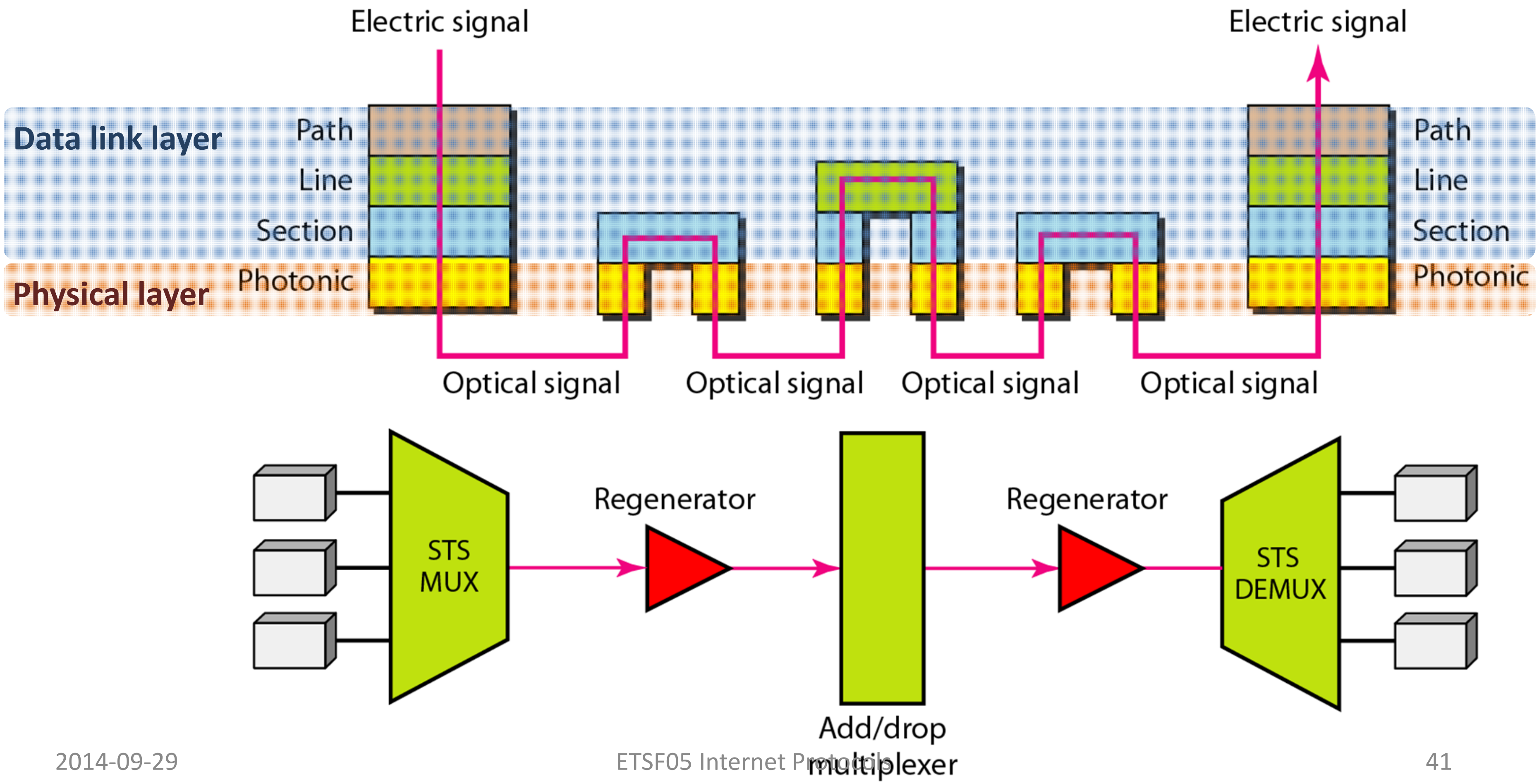
R: Regenerator

T: Terminal



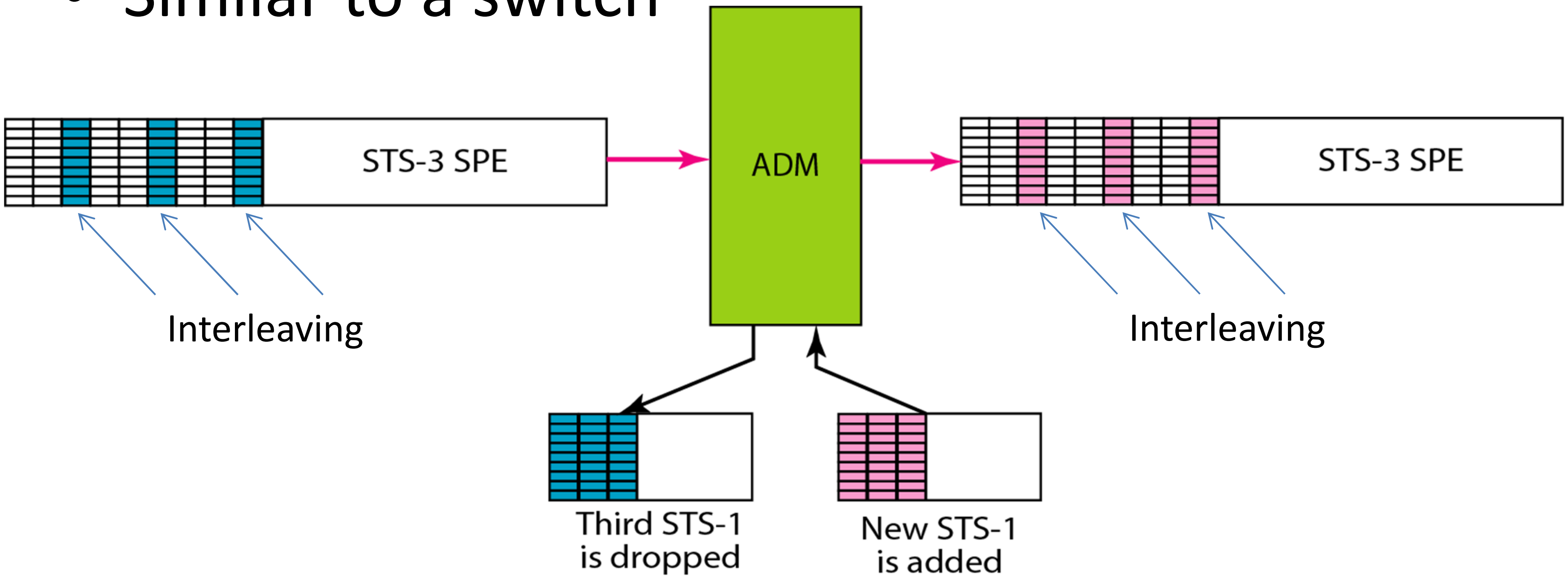
# Network architecture

- Devices and layers



# SONET add/drop multiplexer

- Replaces a signal with another one
- Operates at line layer
- Similar to a switch



# SONET/SDH

- Synchronous Optical Network (ANSI)
- Synchronous Digital Hierarchy (ITU-T)
- High speed capability of optical fiber
- Defines hierarchy of signal rates
  - Synchronous Transport Signal level 1 (STS-1) or Optical Carrier level 1 (OC-1) is 51.84Mbps
  - Carries one DS-3 or multiple (DS1 DS1C DS2) plus ITU-T rates (e.g., 2.048Mbps)
  - Multiple STS-1 combine into STS-N signal
  - ITU-T lowest rate is 155.52Mbps (STM-1)

# Table 8.4
# SONET/SDH Signal Hierarchy

| SONET Designation | ITU-T Designation | Data Rate | Payload Rate (Mbps) |
|---|---|---|---|
| STS-1/OC-1 | | 51.84 Mbps | 50.112 Mbps |
| STS-3/OC-3 | STM-1 | 155.52 Mbps | 150.336 Mbps |
| STS-12/OC-12 | STM-4 | 622.08 Mbps | 601.344 Mbps |
| STS-48/OC-48 | STM-16 | 2.48832 Gbps | 2.405376 Gbps |
| STS-192/OC-192 | STM-64 | 9.95328 Gbps | 9.621504 Gbps |
| STS-768 | STM-256 | 39.81312 Gbps | 38.486016 Gbps |
| STS-3072 | | 159.25248 Gbps | 153.944064 Gbps |

# SONET frames

- Proportional to data rates

| *STS* | *OC* | *Rate (Mbps)* | *STM* |
|---|---|---|---|
| STS-1 | OC-1 | 51.840 | |
| STS-3 | OC-3 | 155.520 | **STM-1** |
| STS-9 | OC-9 | 466.560 | **STM-3** |
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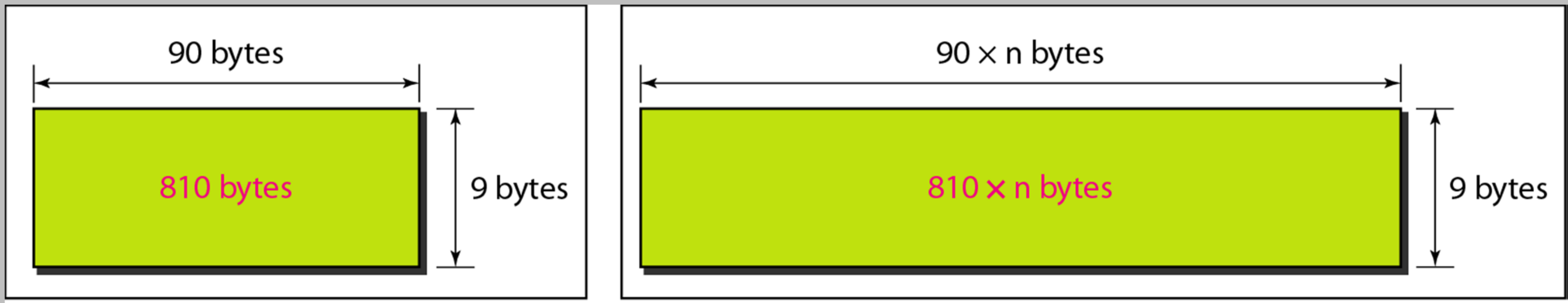
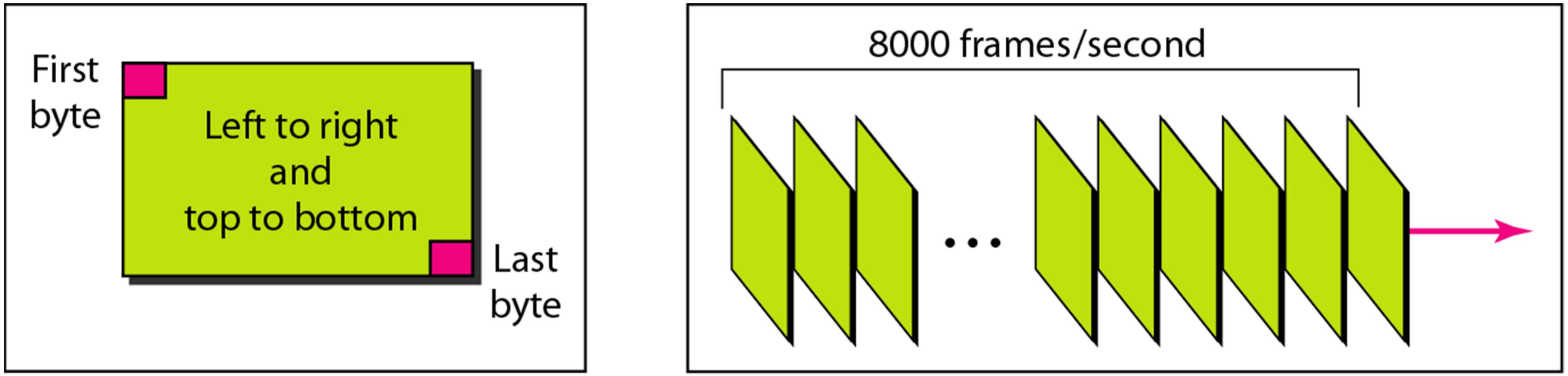
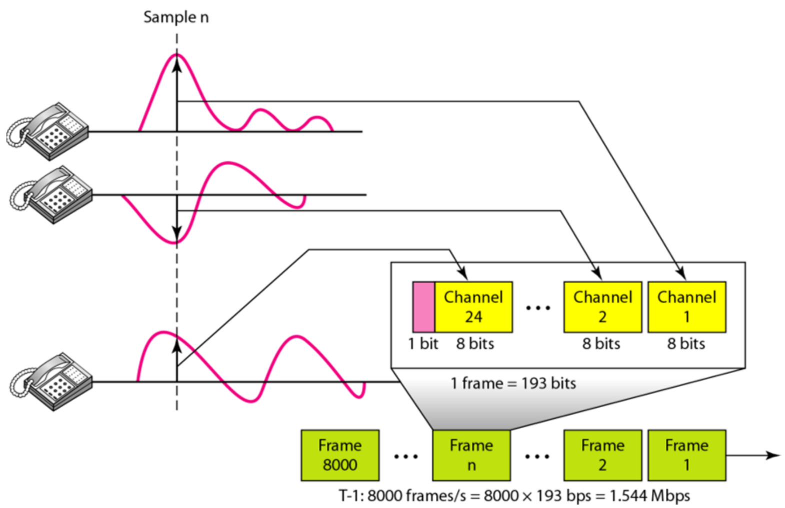


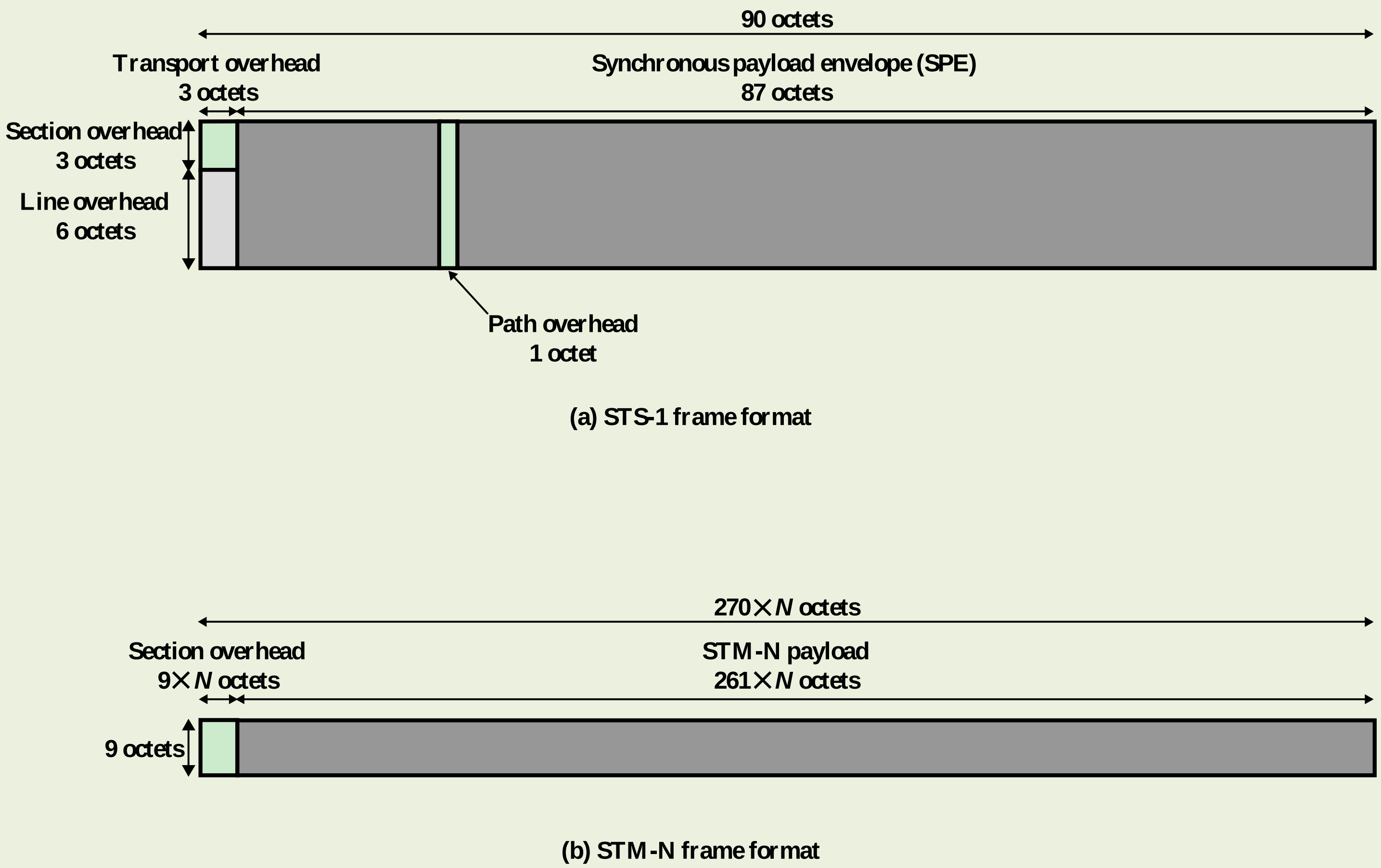
a. STS-1 frame
b. STS-n frame

# SONET frames in transmission



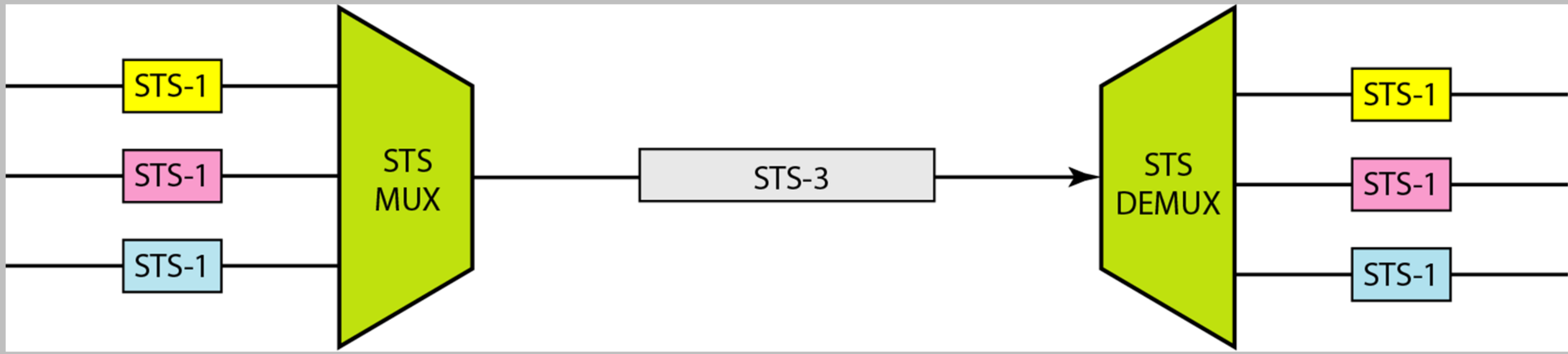
a. Byte transmission
b. Frame transmission

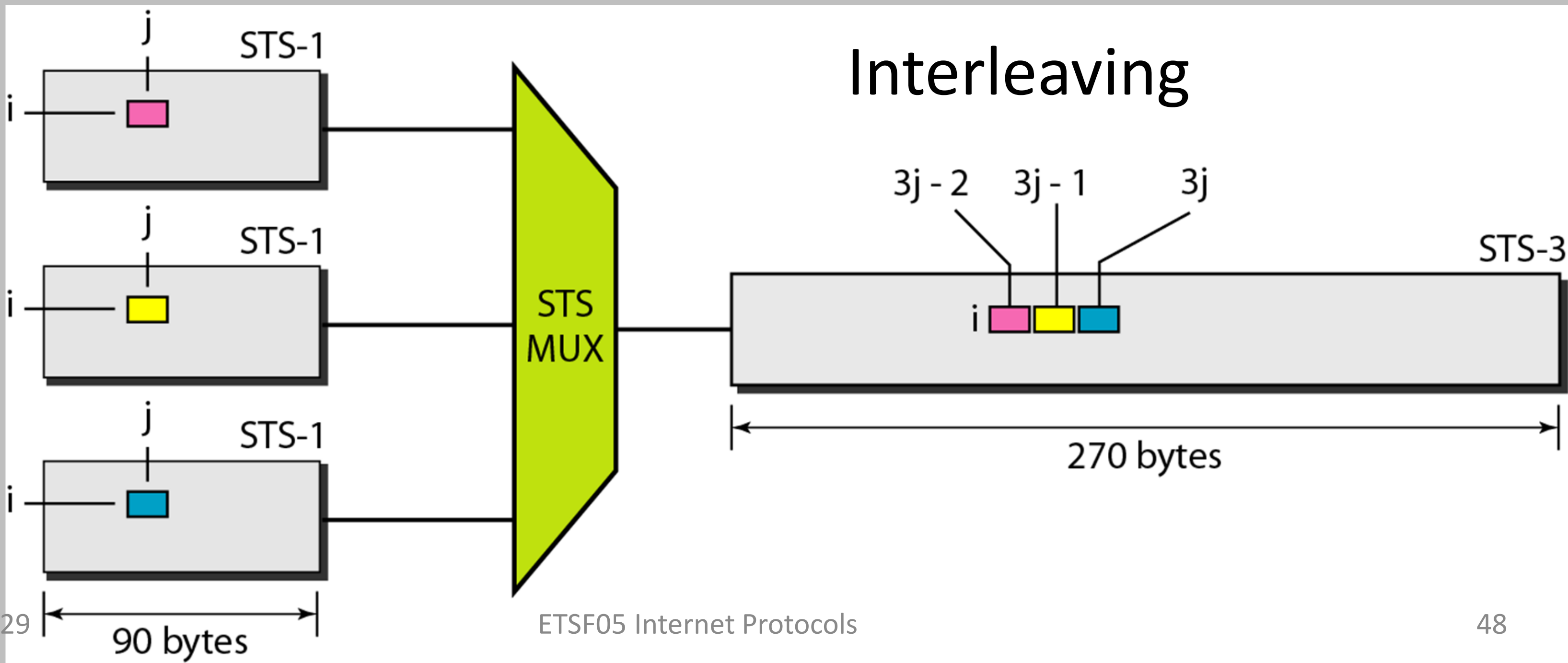





# Figure 8.10 SONET/SDH Frame Formats

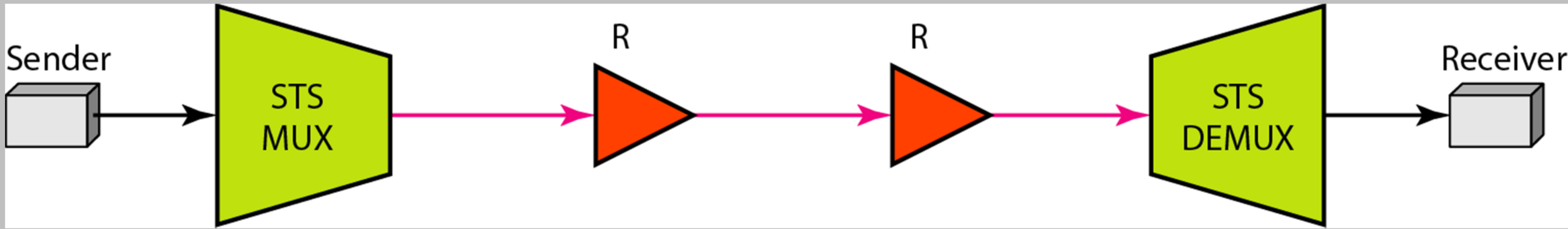
# Multiplexing and byte interleaving



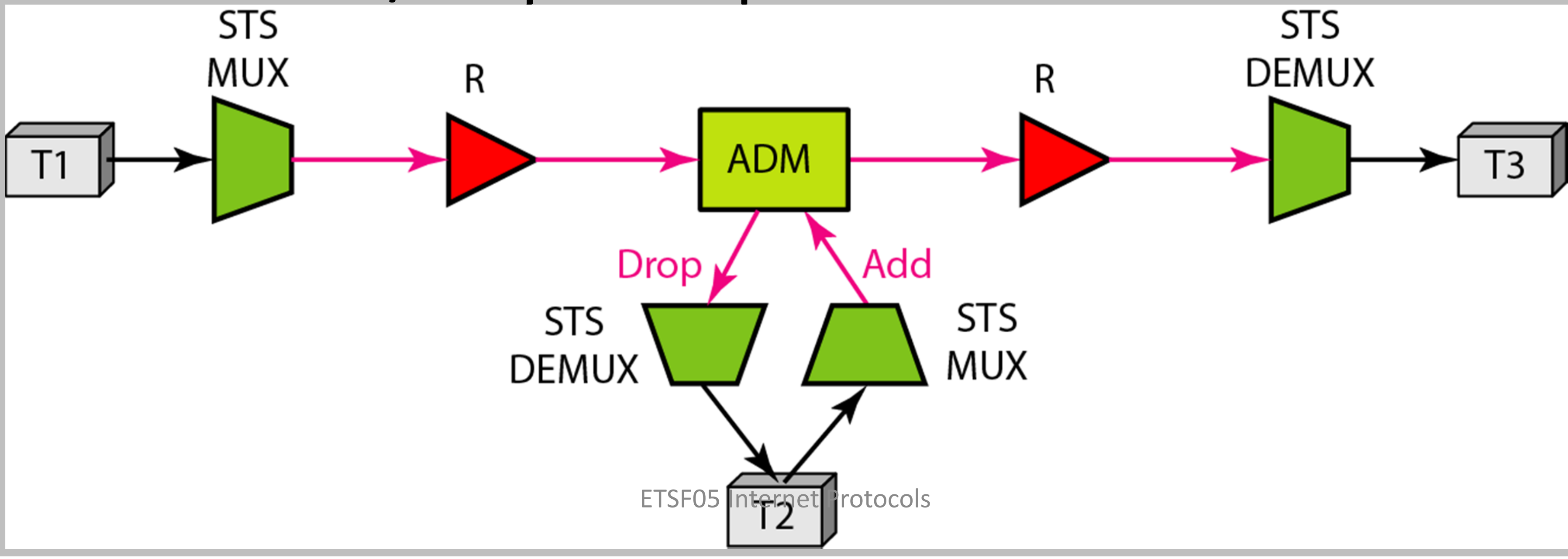



# Linear SONET topology

- Without add/drop multiplexer

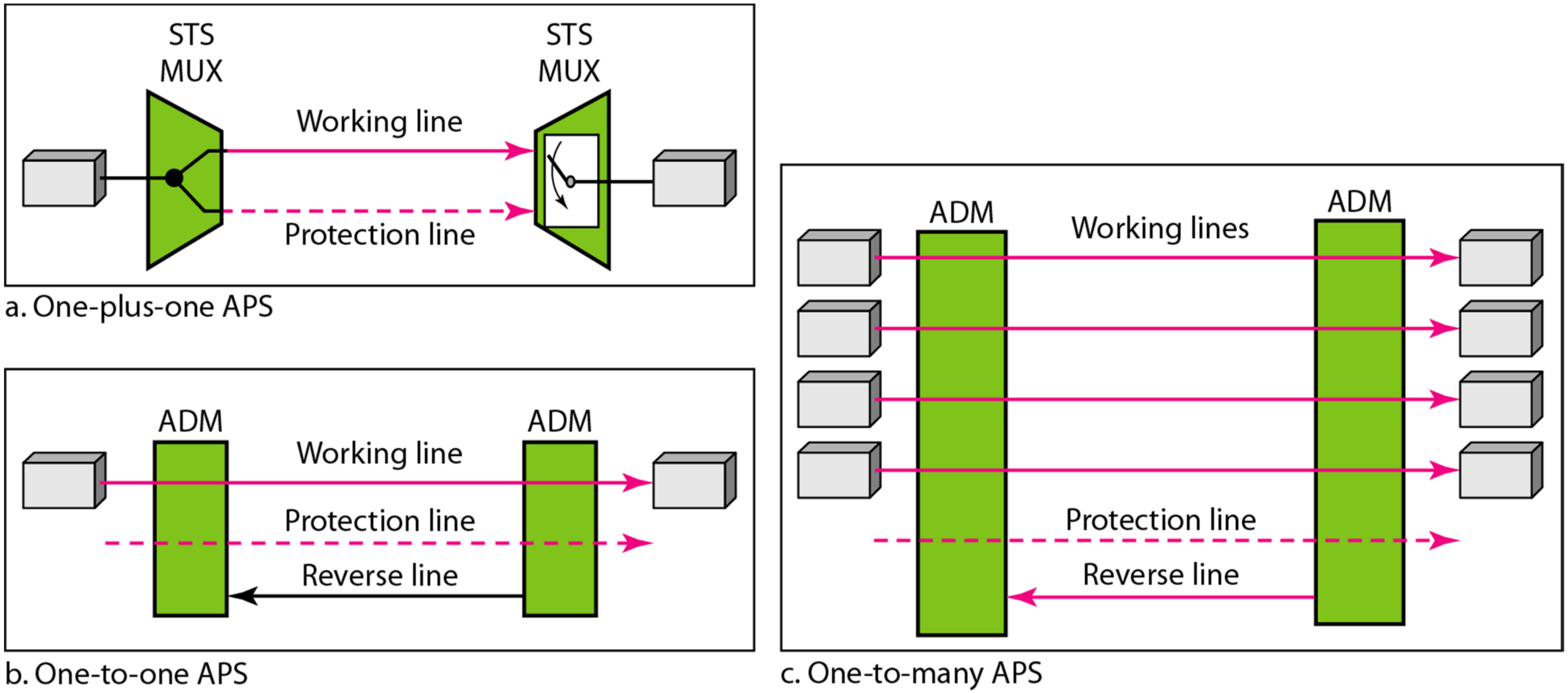



- With add/drop multiplexer

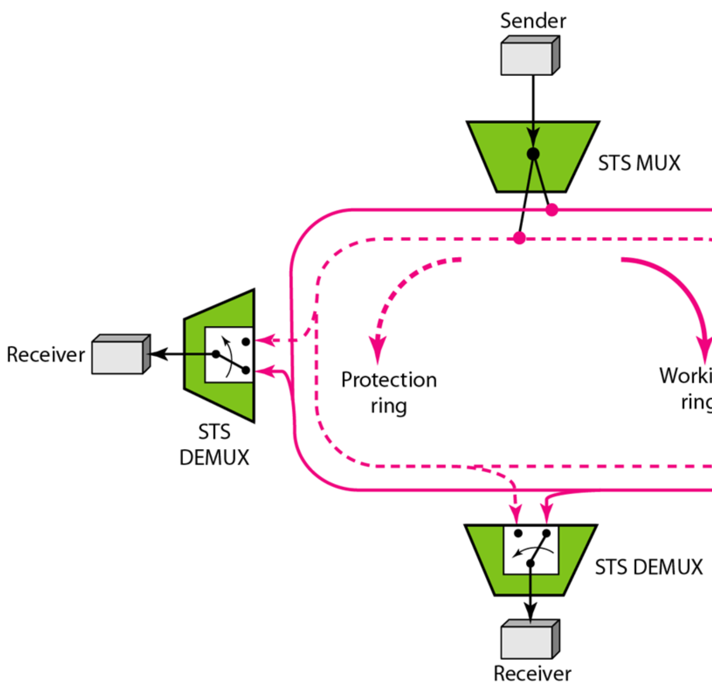


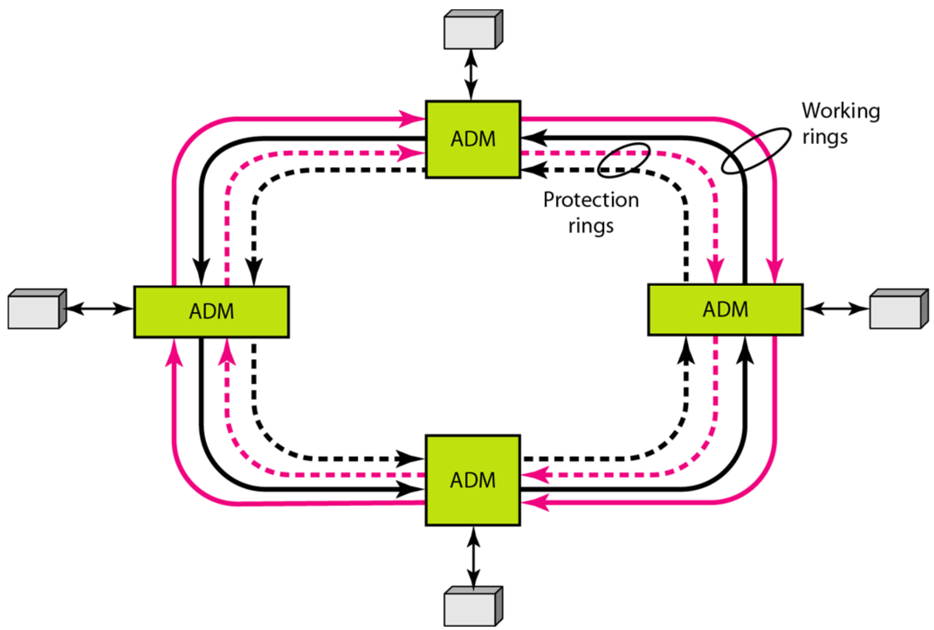
# Automatic protection switching

- Failure protection through line redundancy



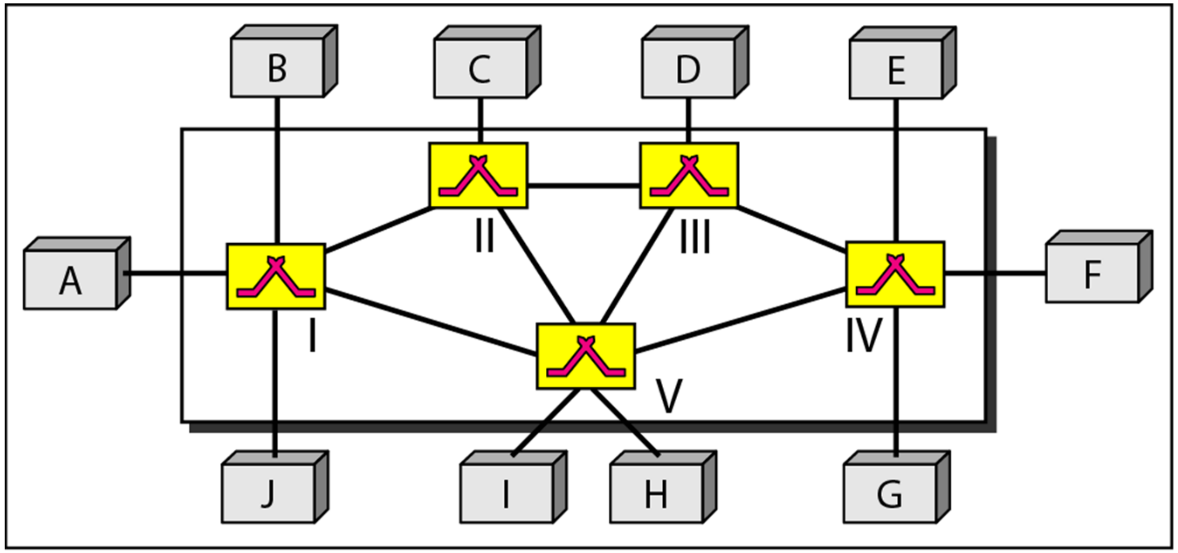
# Ring SONET topology



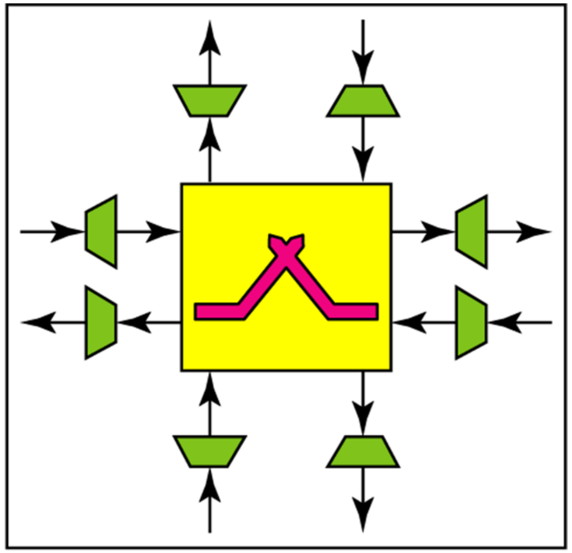



# Mesh SONET topology

- Better scalability
  - Multiplexing/demultiplexing at switches



a. SONET mesh network


b. Cross-connect switch

# Asymmetrical Digital Subscriber Line (ADSL)

- Link between subscriber and network
- Uses currently installed twisted pair cable
- Is Asymmetric - bigger downstream than up
- Uses Frequency Division Multiplexing
  - Reserve lowest 25kHz for voice (POTS)
  - Uses echo cancellation or FDM to give two bands
- Has a range of up to 5.5km

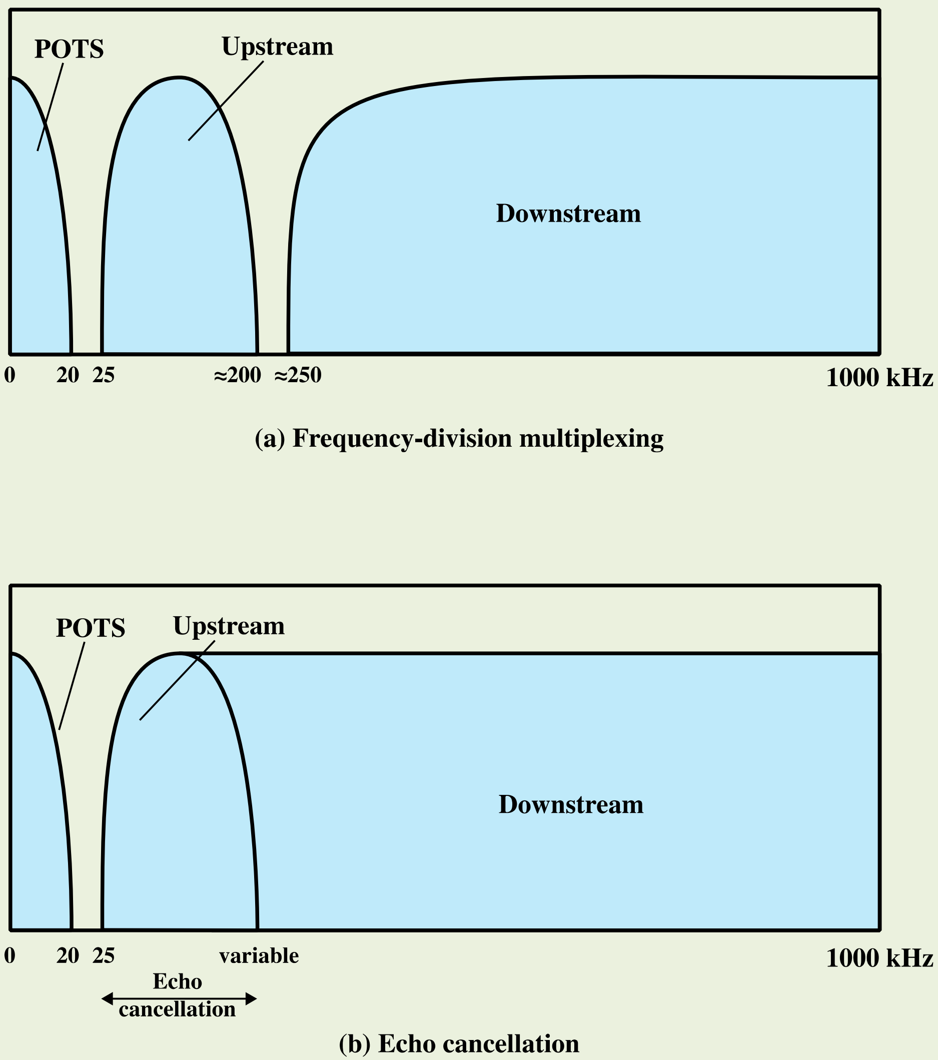



Figure 8.14 ADSL Channel Configuration

# Discrete Multitone (DMT)

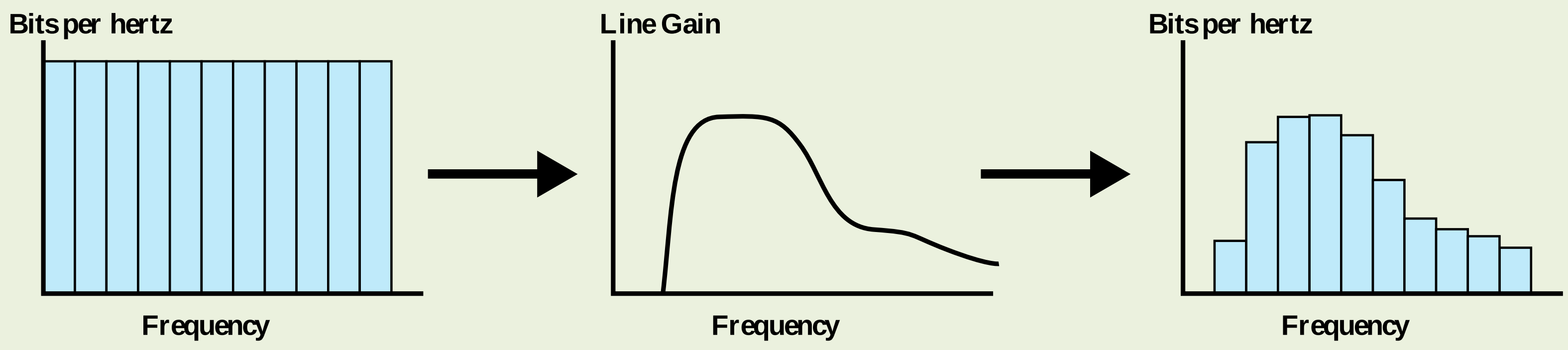



Figure 8.15 DMT Bits per Channel Allocation

- Multiple carrier signals at different frequencies
- Divide into 4kHz subchannels
- Test and use subchannels with better SNR
- 256 downstream subchannels at 4kHz (60kbps)
  - In theory 15.36Mbps, in practice 1.5-9Mbps

QAM=Quadrature Amplitude Modulation

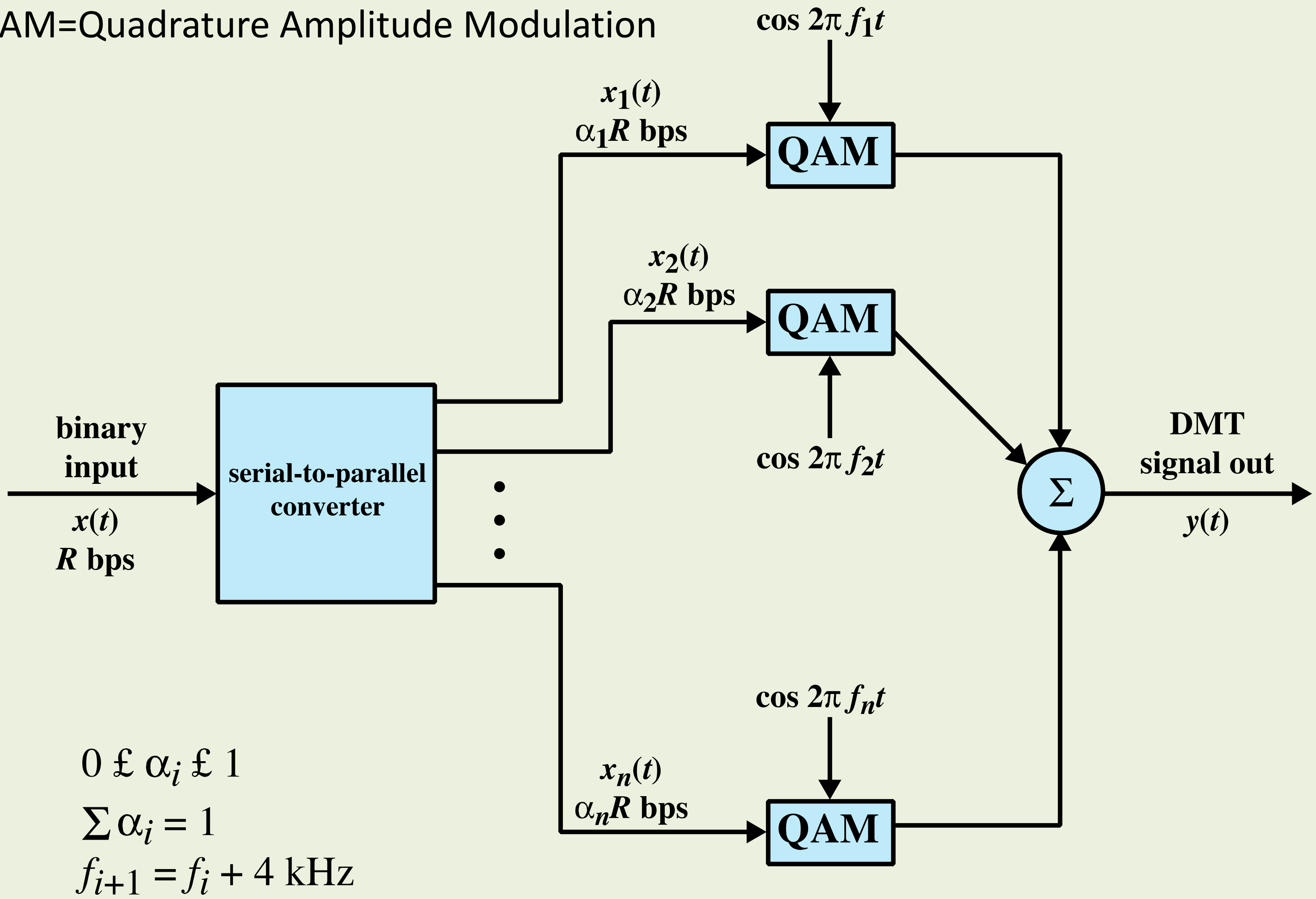
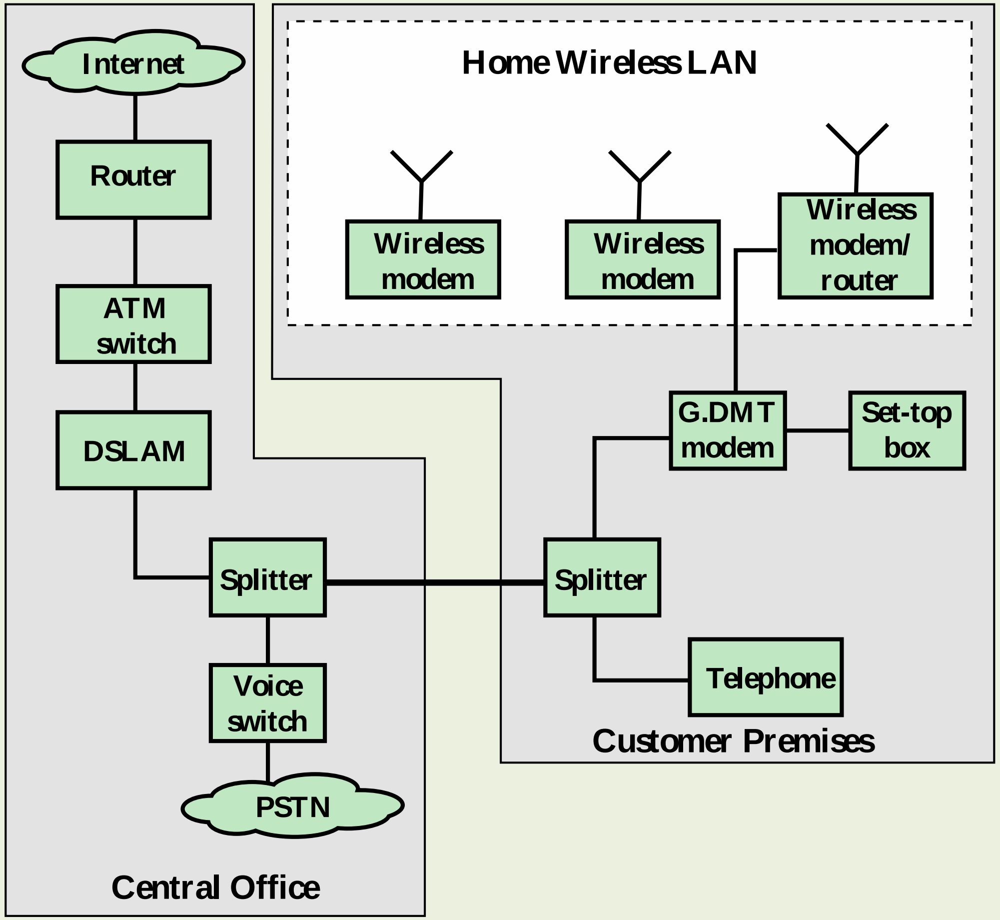



**Figure 8.16 DMT Transmitter**




ATM = Asynchronous Transfer Mode
DSLAM = Digital Subscriber Line Access Multiplexer
PSTN = Public Switched Telephone Network
G.DMT = G.992.1 Discrete Multitone

**Figure 8.17 DSL Broadband Access**

# Table 8.6
# Comparison of xDSL Alternatives

| | ADSL | HDSL | SDSL | VDSL |
|---|---|---|---|---|
| **Data rate** | 1.5 to 9 Mbps downstream<br>16 to 640 kbps upstream | 1.544 or 2.048 Mbps | 1.544 or 2.048 Mbps | 13 to 52 Mbps downstream<br>1.5 to 2.3 Mbps upstream |
| **Mode** | Asymmetric | Symmetric | Symmetric | Asymmetric |
| **Copper pairs** | 1 | 2 | 1 | 1 |
| **Range (24-gauge UTP)** | 3.7 to 5.5 km | 3.7 km | 3.0 km | 1.4 km |
| **Signaling** | Analog | Digital | Digital | Analog |
| **Line code** | CAP/DMT | 2B1Q | 2B1Q | DMT |
| **Frequency** | 1 to 5 MHz | 196 kHz | 196 kHz | ≥ 10 MHz |
| **Bits/cycle** | Varies | 4 | 4 | Varies |

UTP = unshielded twisted pair

# WLAN

- IEEE 802.11
- ”Trådlöst Ethernet”
- Tre konfigurationsprinciper

# System med en accesspunkt

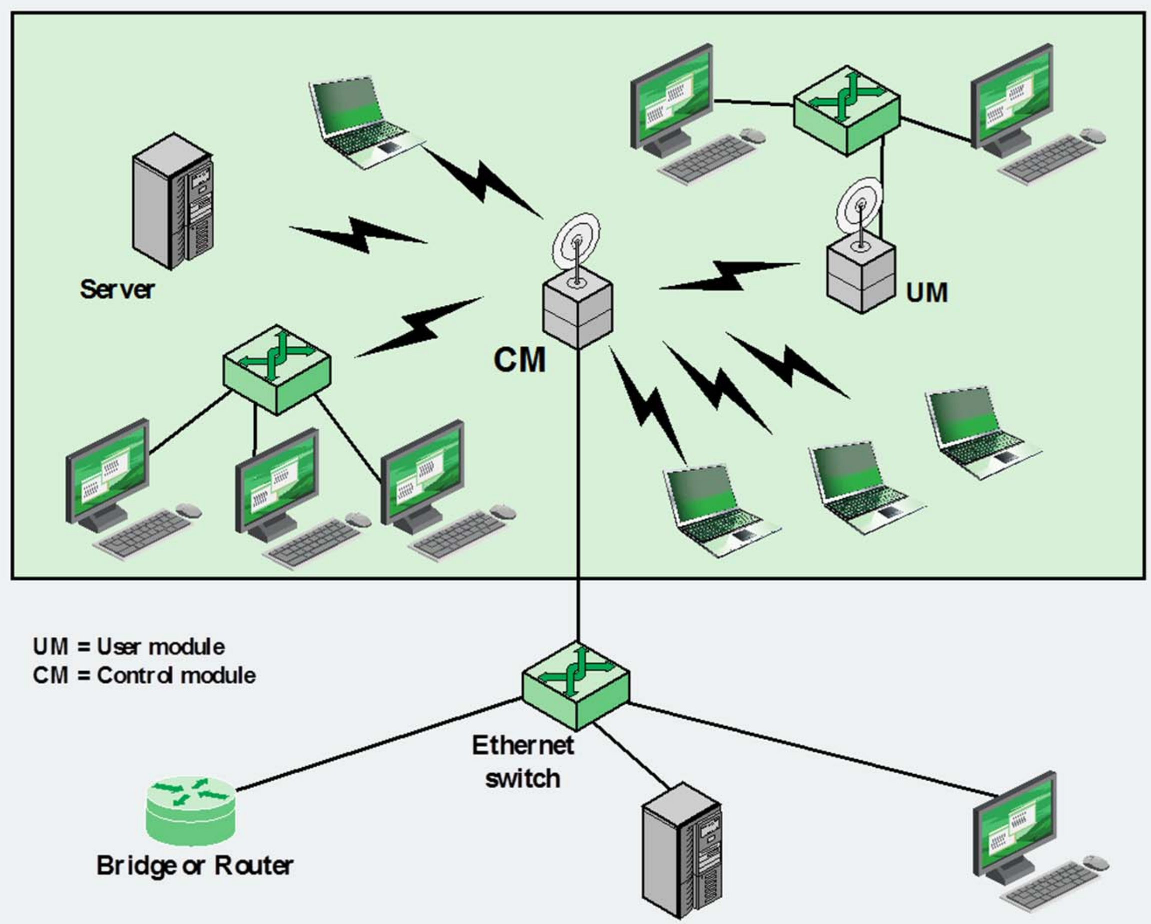



Figure 13.1 Example Single-Cell Wireless LAN Configuration

# System med flera accesspunkter

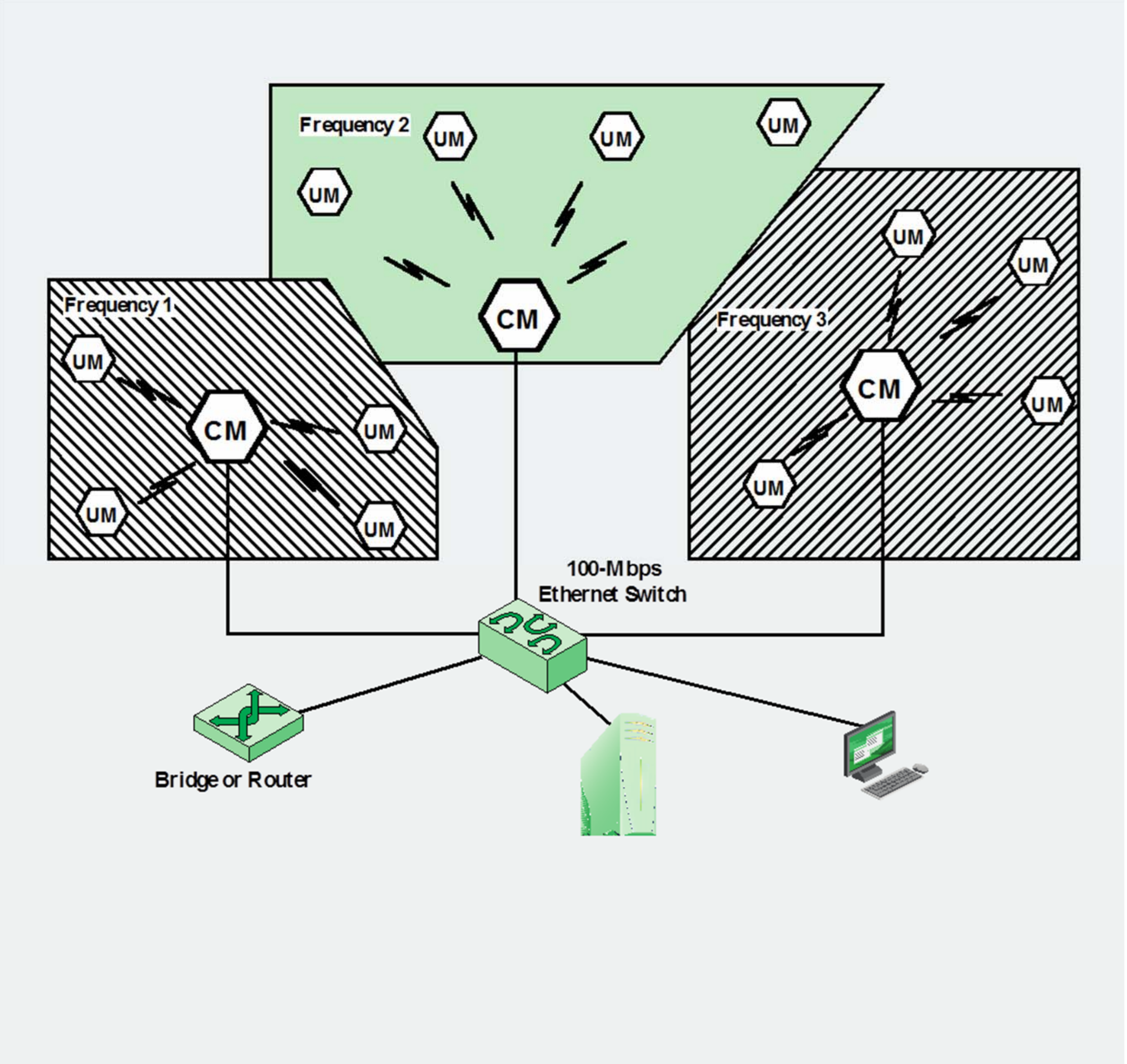



Figure 13.2 Example Multiple-Cell Wireless LAN Configuration

# Ad Hoc (ingen accesspunkt)

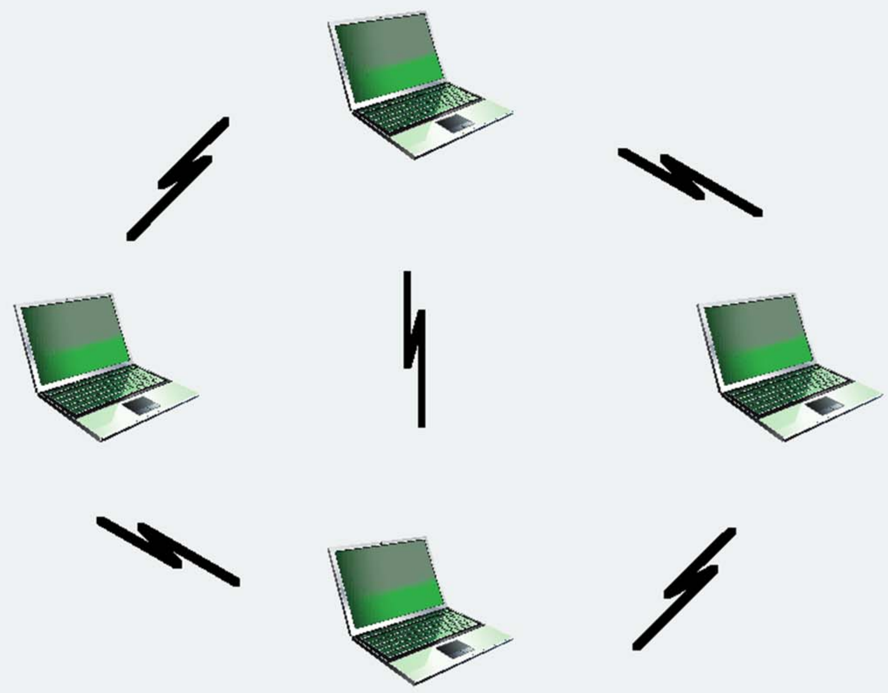


Figure 13.3 Ad Hoc Wireless LAN Configuration

# Wireless LAN Requirements

- Throughput
- Number of nodes
- Connection to backbone LAN
- Service area
- Battery power consumption
- Transmission robustness and security
- Collocated network operation
- License-free operation
- Handoff/roaming
- Dynamic configuration

# Wi-Fi Alliance

- There is always a concern whether products from different vendors will successfully interoperate
- Wireless Ethernet Compatibility Alliance (WECA)
  - Industry consortium formed in 1999
- Renamed the Wi-Fi (Wireless Fidelity) Alliance
  - Created a test suite to certify interoperability for 802.11 products

# Table 13.1
# Key IEEE 802.11 Standards

| Standard | Scope |
|---|---|
| IEEE 802.11a | Physical layer: 5-GHz OFDM at rates from 6 to 54 Mbps |
| IEEE 802.11b | Physical layer: 2.4-GHz DSSS at 5.5 and 11 Mbps |
| IEEE 802.11c | Bridge operation at 802.11 MAC layer |
| IEEE 802.11d | Physical layer: Extend operation of 802.11 WLANs to new regulatory domains (countries) |
| IEEE 802.11e | MAC: Enhance to improve quality of service and enhance security mechanisms |
| IEEE 802.11g | Physical layer: Extend 802.11b to data rates >20 Mbps |
| IEEE 802.11i | MAC: Enhance security and authentication mechanisms |
| IEEE 802.11n | Physical/MAC: Enhancements to enable higher throughput |
| IEEE 802.11T | Recommended practice for the evaluation of 802.11 wireless performance |
| IEEE 802.11ac | Physical/MAC: Enhancements to support 0.5-1 Gbps in 5-GHz band |
| IEEE 802.11ad | Physical/MAC: Enhancements to support ≥ 1 Gbps in the 60-GHz band |

(Table can be found on page 424 in the textbook)

# Table 13.2
# IEEE 802.11 Terminology

| | |
|---|---|
| Access point (AP) | Any entity that has station functionality and provides access to the distribution system via the wireless medium for associated stations |
| Basic service set (BSS) | A set of stations controlled by a single coordination function |
| Coordination function | The logical function that determines when a station operating within a BSS is permitted to transmit and may be able to receive PDUs |
| Distribution system (DS) | A system used to interconnect a set of BSSs and integrated LANs to create an ESS |
| Extended service set (ESS) | A set of one or more interconnected BSSs and integrated LANs that appear as a single BSS to the LLC layer at any station associated with one of these BSSs |
| Frame | Synonym for MAC protocol data unit |
| MAC protocol data unit (MPDU) | The unit of data exchanged between two peer MAC entities using the services of the physical layer |
| MAC service data unit (MSDU) | Information that is delivered as a unit between MAC users |
| Station | Any device that contains an IEEE 802.11 conformant MAC and physical layer |

(Table can be found on page 424 in the textbook)

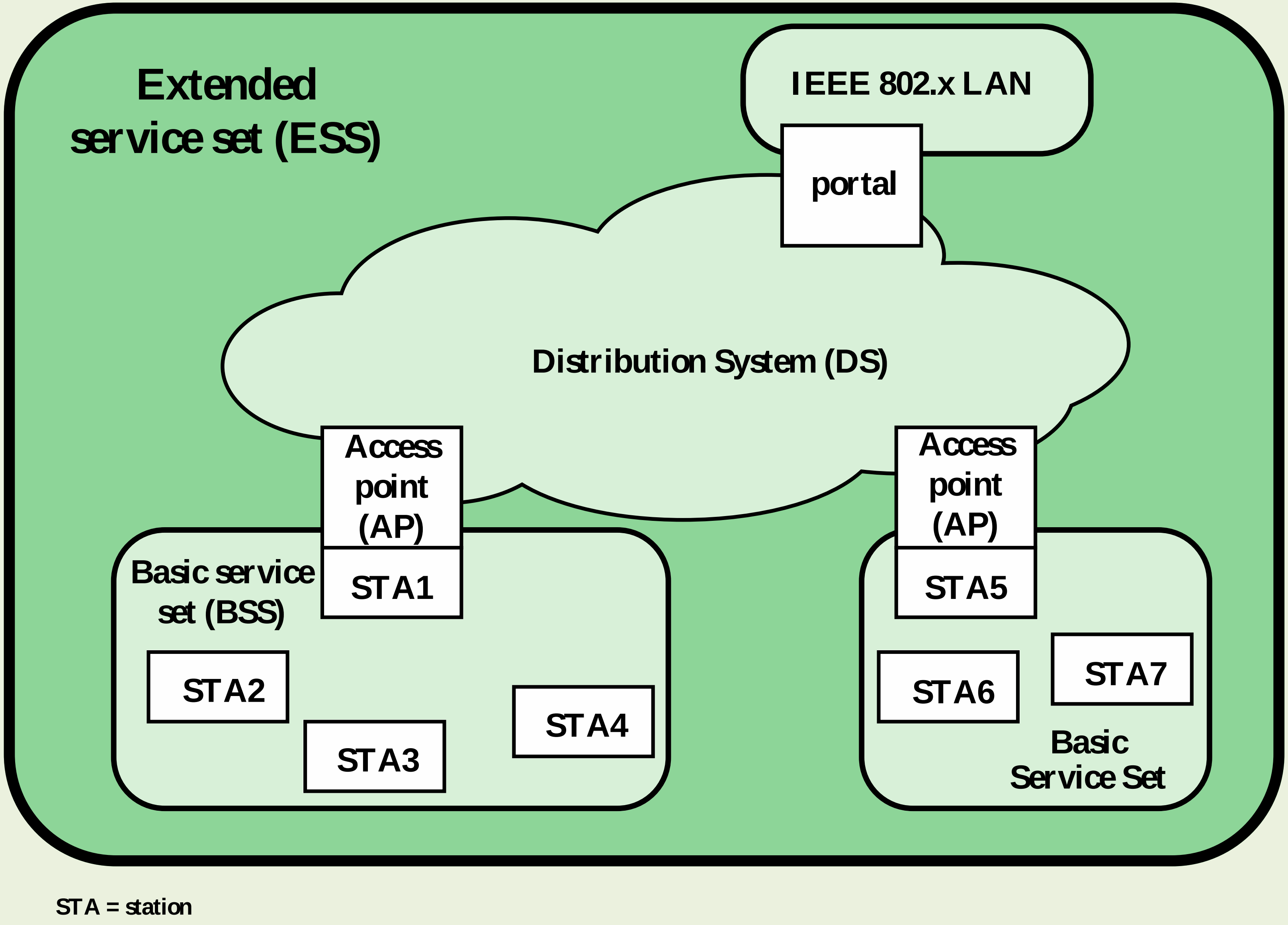
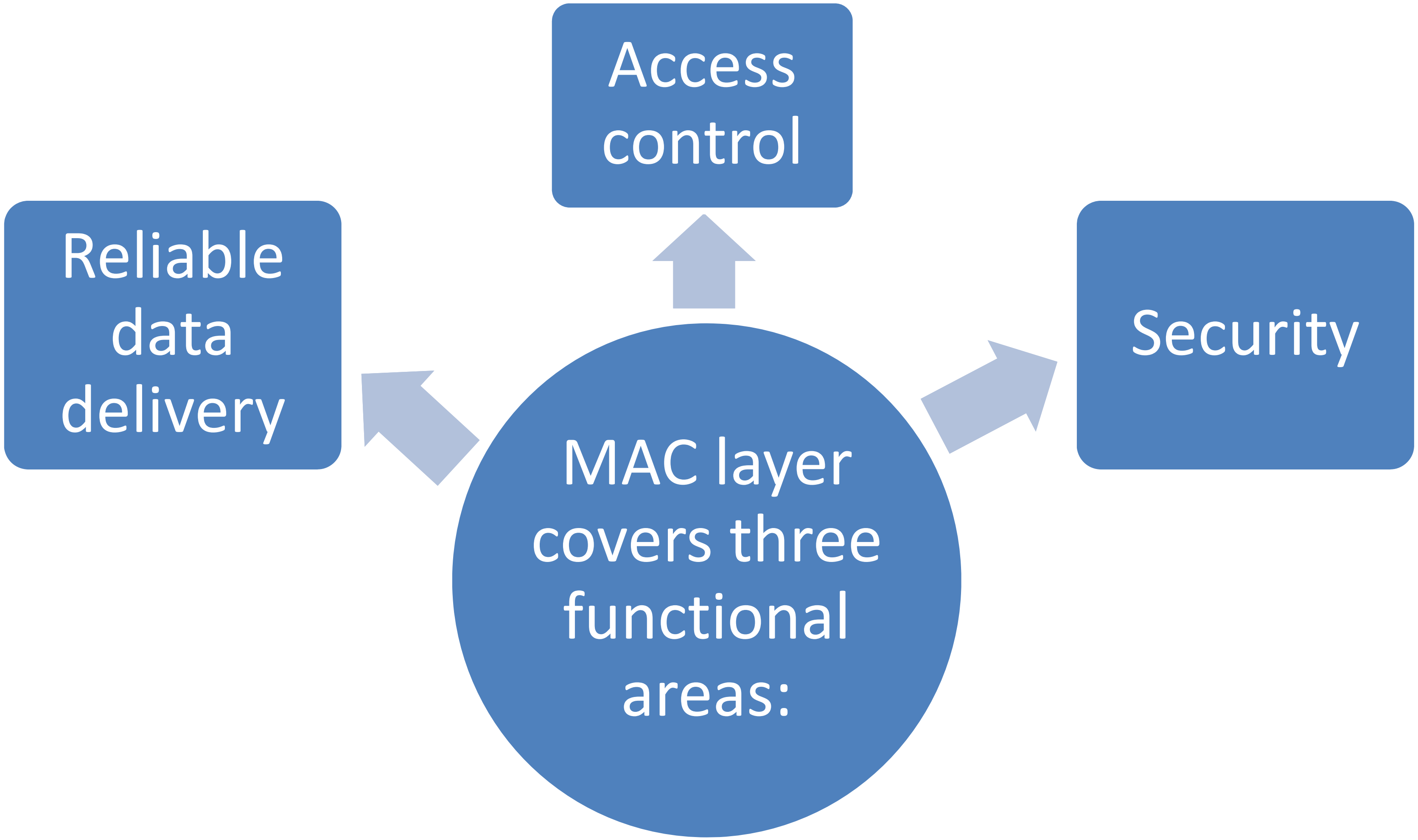



Figure 13.4 IEEE 802.11 Architecture

# Table 13.3
# IEEE 802.11 Services

| Service | Provider | Used to support |
|---|---|---|
| Association | Distribution system | MSDU delivery |
| Authentication | Station | LAN access and security |
| Deauthentication | Station | LAN access and security |
| Dissassociation | Distribution system | MSDU delivery |
| Distribution | Distribution system | MSDU delivery |
| Integration | Distribution system | MSDU delivery |
| MSDU delivery | Station | MSDU delivery |
| Privacy | Station | LAN access and security |
| Reassocation | Distribution system | MSDU delivery |

# Medium Access Control

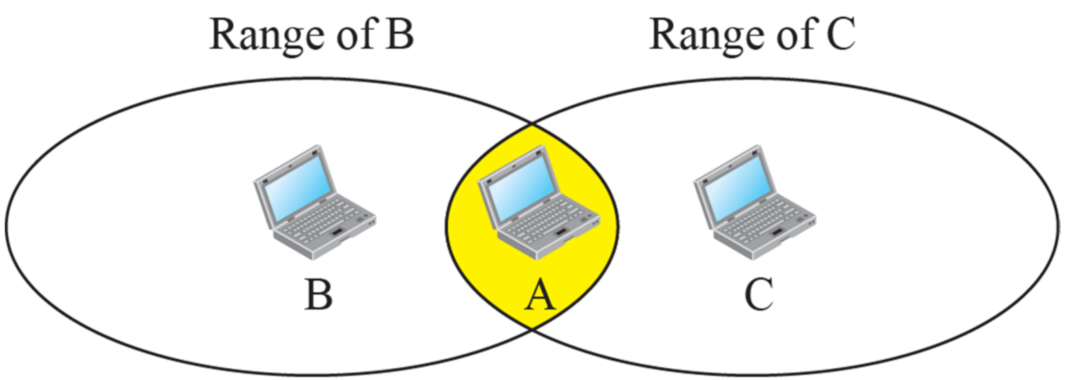


# Reliable Data Delivery

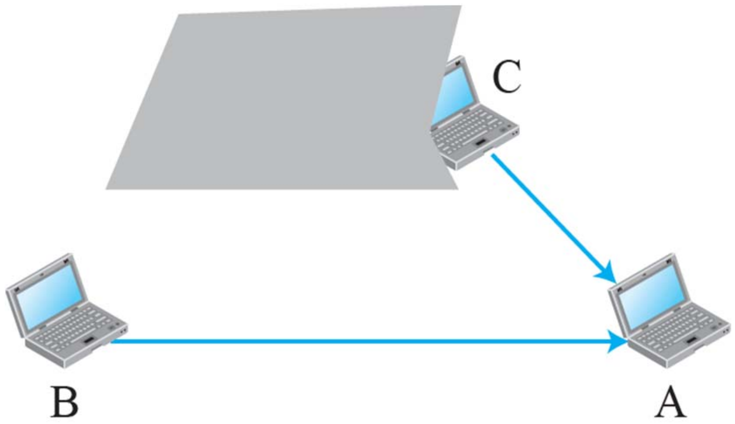
- Can be dealt with at a higher layer
- More efficient to deal with errors at MAC level
- 802.11 includes frame exchange protocol
  - Station receiving frame returns acknowledgment (ACK) frame
  - Exchangetreated as atomic unit
  - If no ACK within short period of time, retransmit

- 802.11 physical and MAC layers unreliable
  - Noise, interference, and other propagation effects result in loss of frames
  - Even with error-correction codes, frames may not successfully be received

# Hidden Node/Station Problem




a. Stations B and C are not in each other's range.

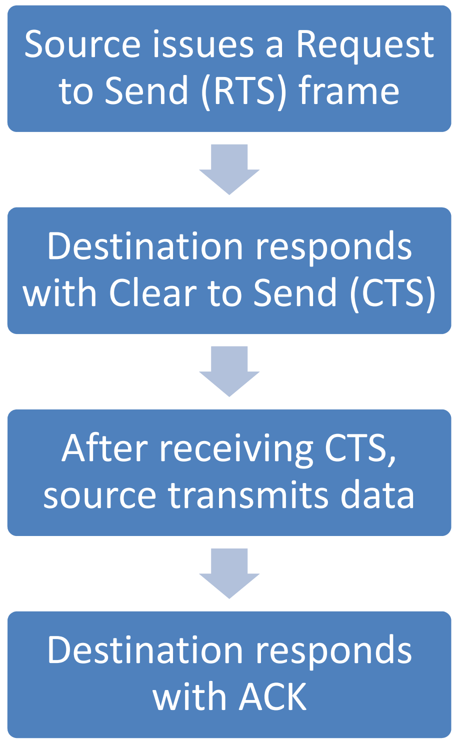



b. Stations B and C are hidden from each other.

# Four Frame Exchange

- RTS alerts all stations within range of source that exchange is under way
- CTS alerts all stations within range of destination
- Other stations don't transmit to avoid collision
- RTS/CTS exchange is a required function of MAC but may be disabled

- Can use four-frame exchange for better reliability



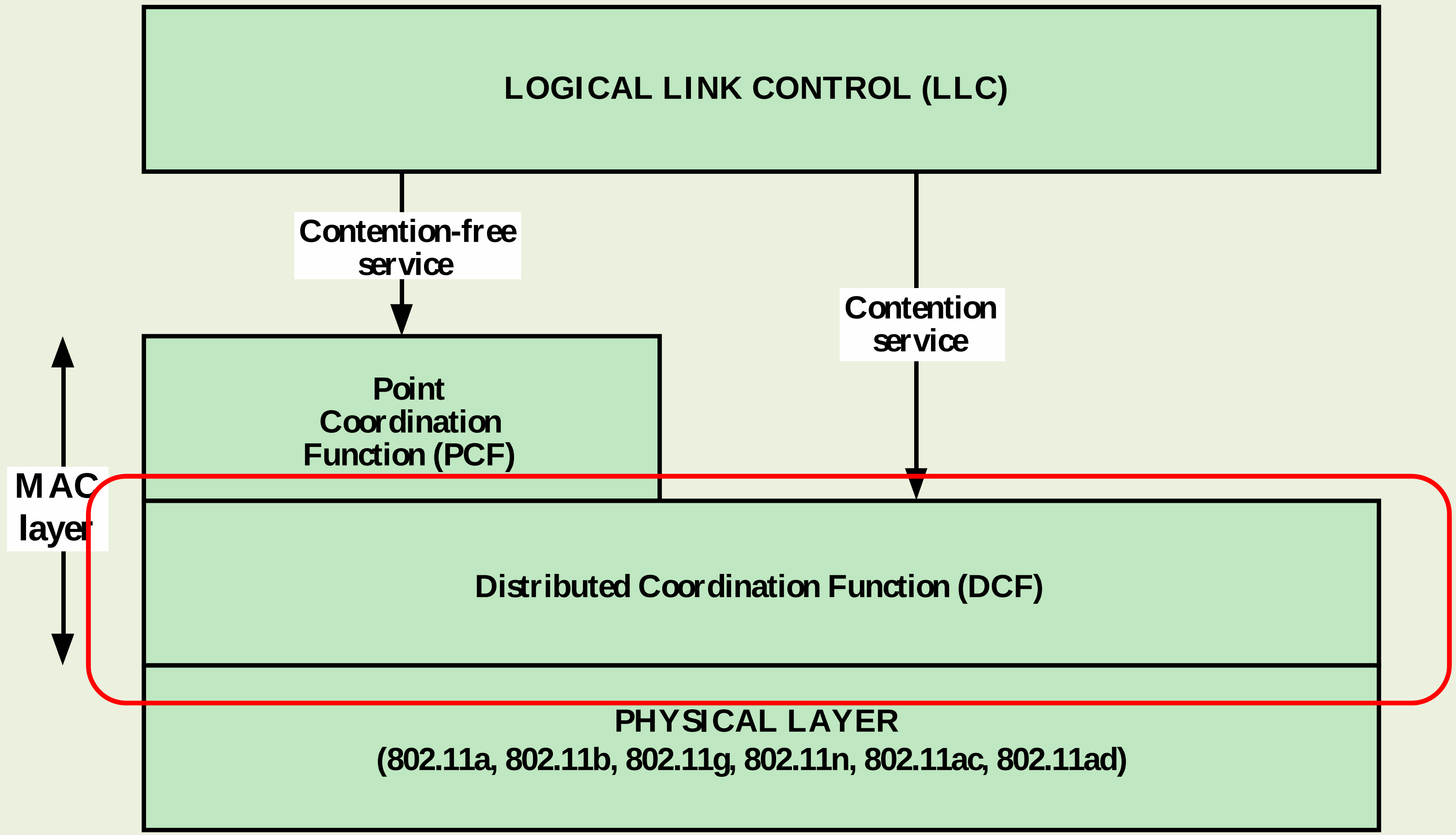
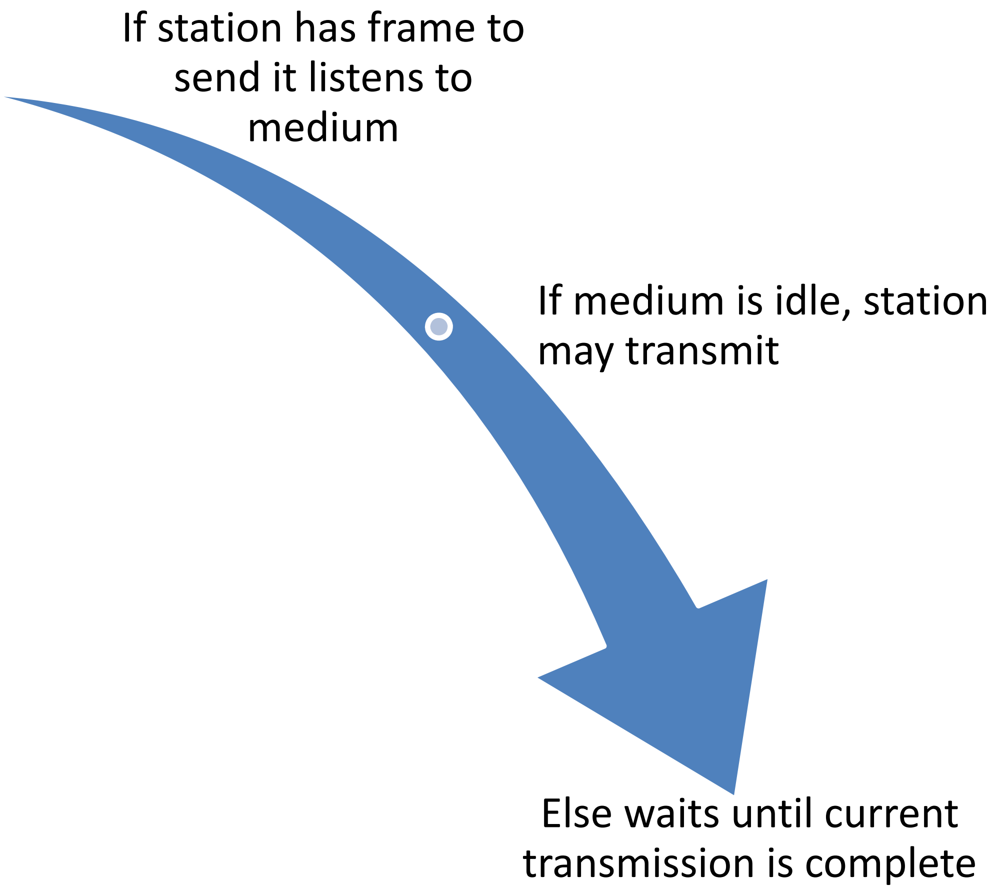



**Figure 13.5 IEEE 802.11 Protocol Architecture**

# Distributed Coordination Function (DCF)

- DCF sublayer uses CSMA algorithm
- Does not include a collision detection function because it is not practical on a wireless network
- Includes a set of delays that amounts as a priority scheme



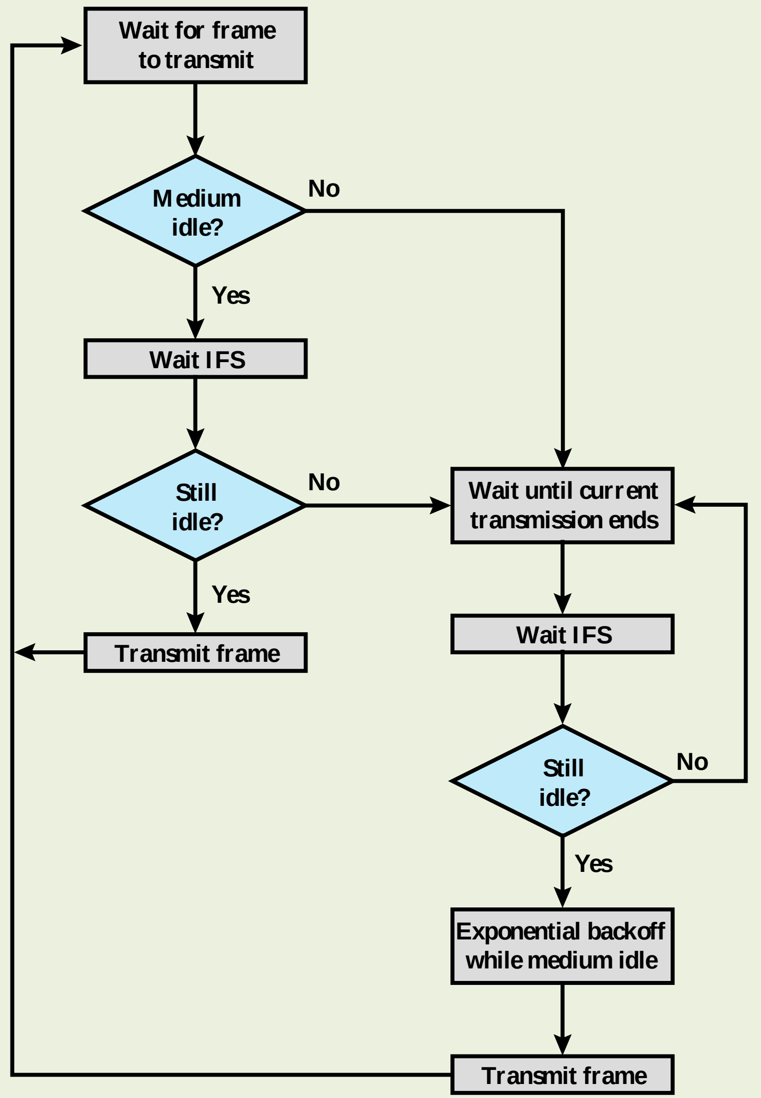



**Figure 13.6 IEEE 802.11 Medium Access Control Logic**

# Priority IFS Values

**SIFS**
(short IFS)

For all immediate response actions

**PIFS**
(point coordination function IFS)

Used by the centralized controller in PCF scheme when issuing polls

**DIFS**
(distributed coordination function IFS)

Used as minimum delay for asynchronous frames contending for access

# Point Coordination Function (PCF)

Alternative access method implemented on top of DCF

Polling by centralized polling master (point coordinator)

Uses PIFS when issuing polls

Point coordinator polls in round-robin to stations configured for polling

When poll issued, polled station may respond using SIFS

If point coordinator receives response, it issues another poll using PIFS

If no response during expected turnaround time, coordinator issues poll

Coordinator could lock out asynchronous traffic by issuing polls

Have a superframe interval defined

# 802.11 MAC ramformat

Två ramtyper

- Kontroll
- Data
- *Management*

Notera fyra adressfält!

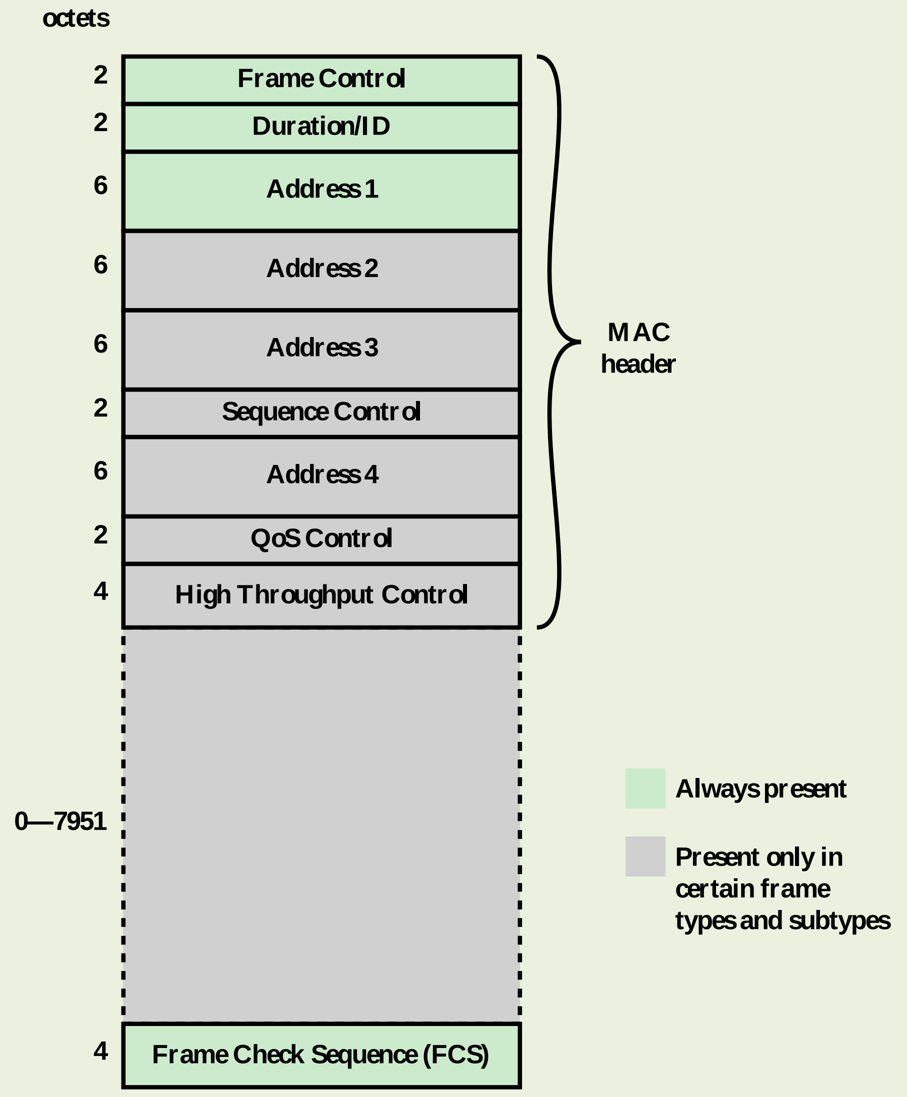



Figure 13.8 IEEE 802.11 MAC Frame Format

# Table 13.4

## IEEE 802.11 Physical Layer Standards

| Standard | 802.11a | 802.11b | 802.11g | 802.11n | 802.11ac | 802.11ad |
|---|---|---|---|---|---|---|
| Year introduced | 1999 | 1999 | 2003 | 2000 | 2012 | 2014 |
| Maximum data transfer speed | 54 Mbps | 11 Mbps | 54 Mbps | 65 to 600 Mbps | 78 Mbps to 3.2 Gbps | 6.76 Gbps |
| Frequency band | 5 GHz | 2.4 GHz | 2.4 GHz | 2.4 or 5 GHz | 5 GHz | 60 GHz |
| Channel bandwidth | 20 MHz | 20 MHz | 20 MHz | 20, 40 MHz | 40, 80, 160 MHz | 2160 MHz |
| Highest order modulation | 64 QAM | 11 CCK | 64 QAM | 64 QAM | 256 QAM | 64 QAM |
| Spectrum usage | DSSS | OFDM | DSSS, OFDM | OFDM | SC-OFDM | SC, OFDM |
| Antenna configuration | 1×1 SISO | 1×1 SISO | 1×1 SISO | Up to 4×4 MIMO | Up to 8×8 MIMO, MU-MIMO | 1×1 SISO |

(Table is on page 436 in textbook)

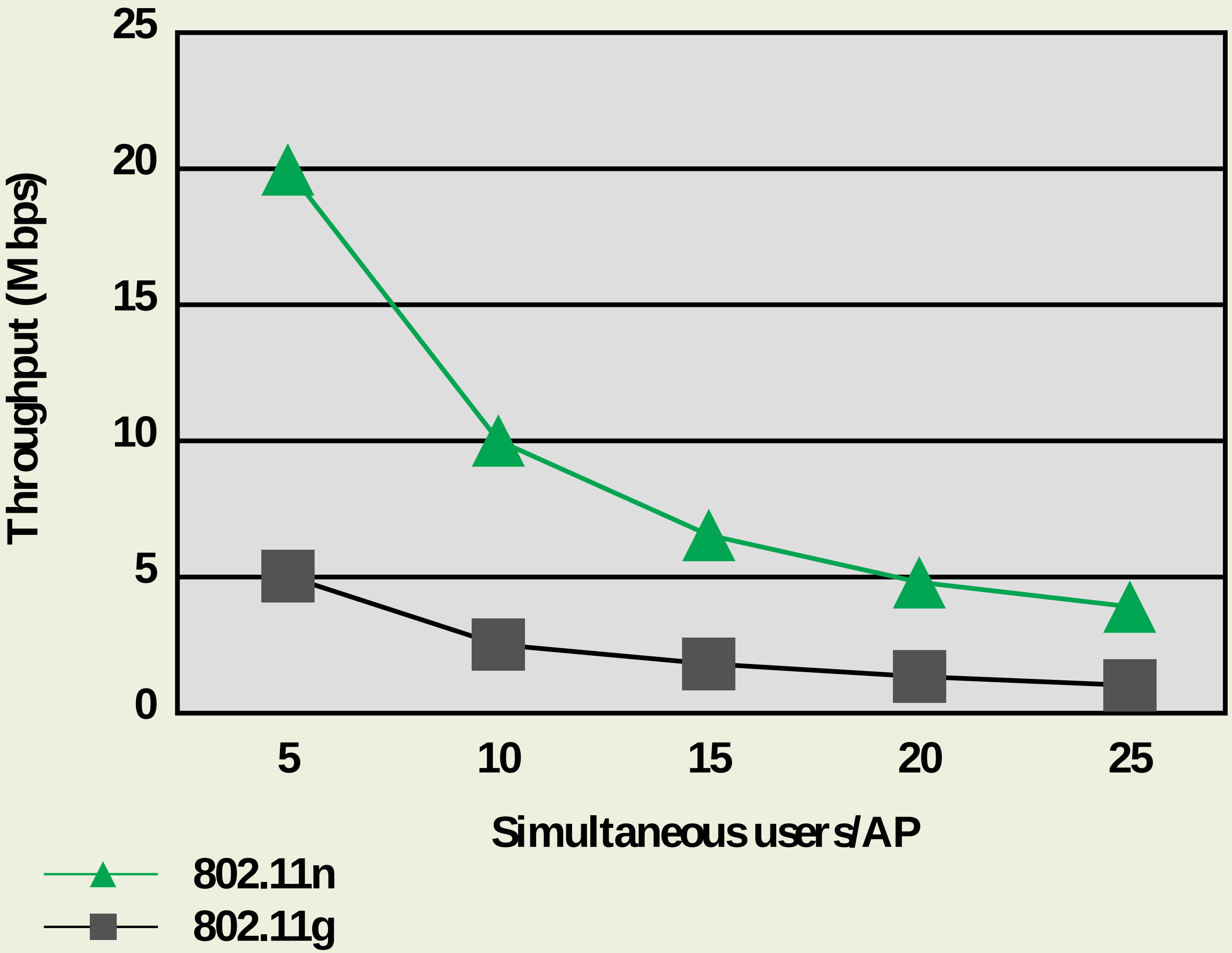



**Figure 13.12 Average Throughput per User**

# Access and Privacy Services Deauthentication and Privacy

- Privacy
  - Used to prevent messages being read by others
  - 802.11 allows optional use of encryption
- Original WEP security features were weak
- Subsequently 802.11i and WPA alternatives evolved giving better security
- Deauthentication
  - Invoked whenever an existing authentication is to be terminated