2. The Physical Layer

- Defines the mechanical, electrical, and timing interface
- Transmission media
- Examples of communication systems

2.1 The Theoretical Basis for Data Communication

- Fourier Analysis
- Bandwidth-Limited Signals
- Maximum Data Rate of a Channel

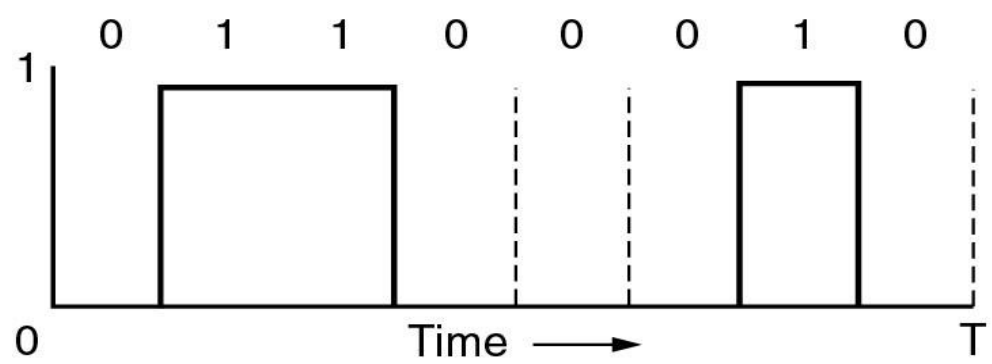
2.1.1 Fourier Analysis

- Any periodic function g(t) with period T

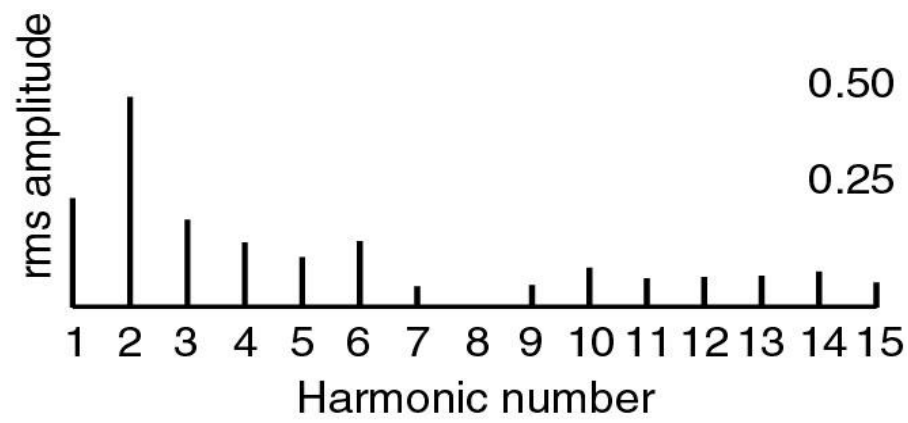
$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$

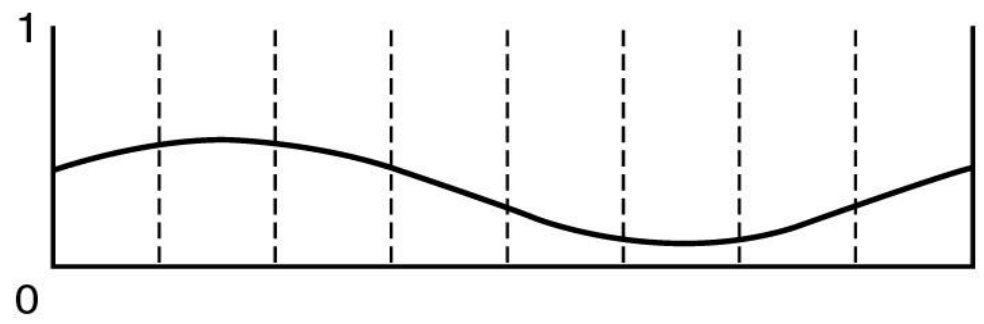
- Amplitudes
- Frequency
- A data signal can be imagined that it repeats the entire pattern over and over forever

2.1.2 Bandwidth-Limited Signals(1)

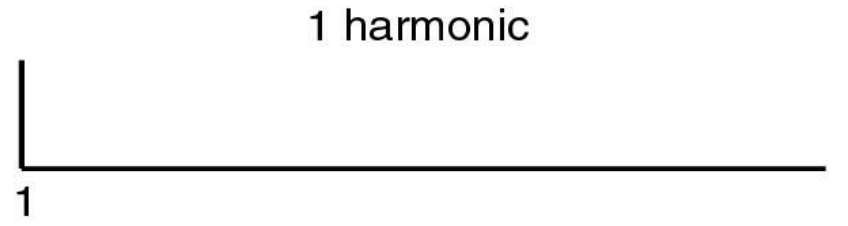


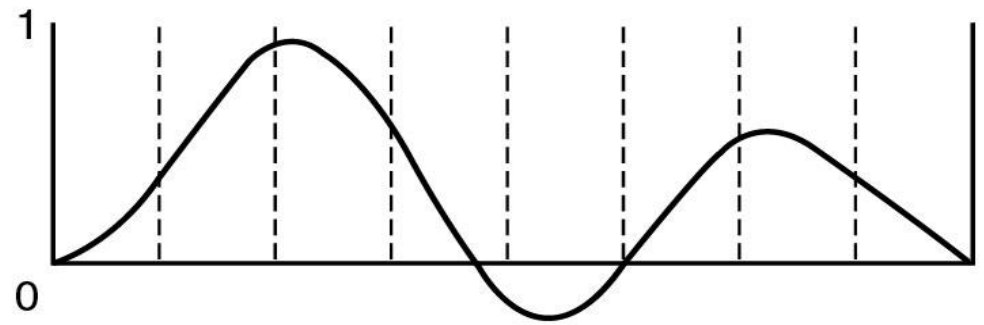
(a)



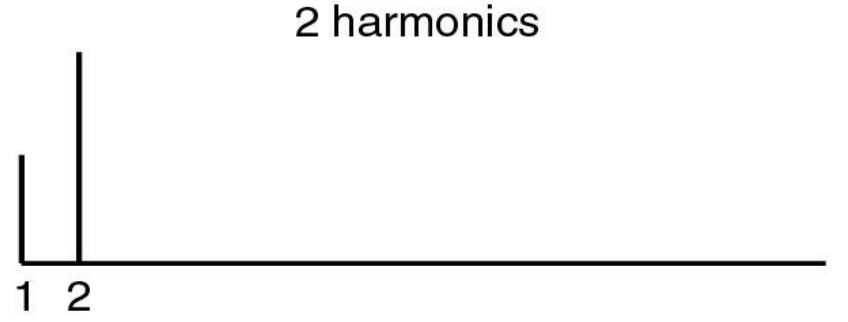


(b)

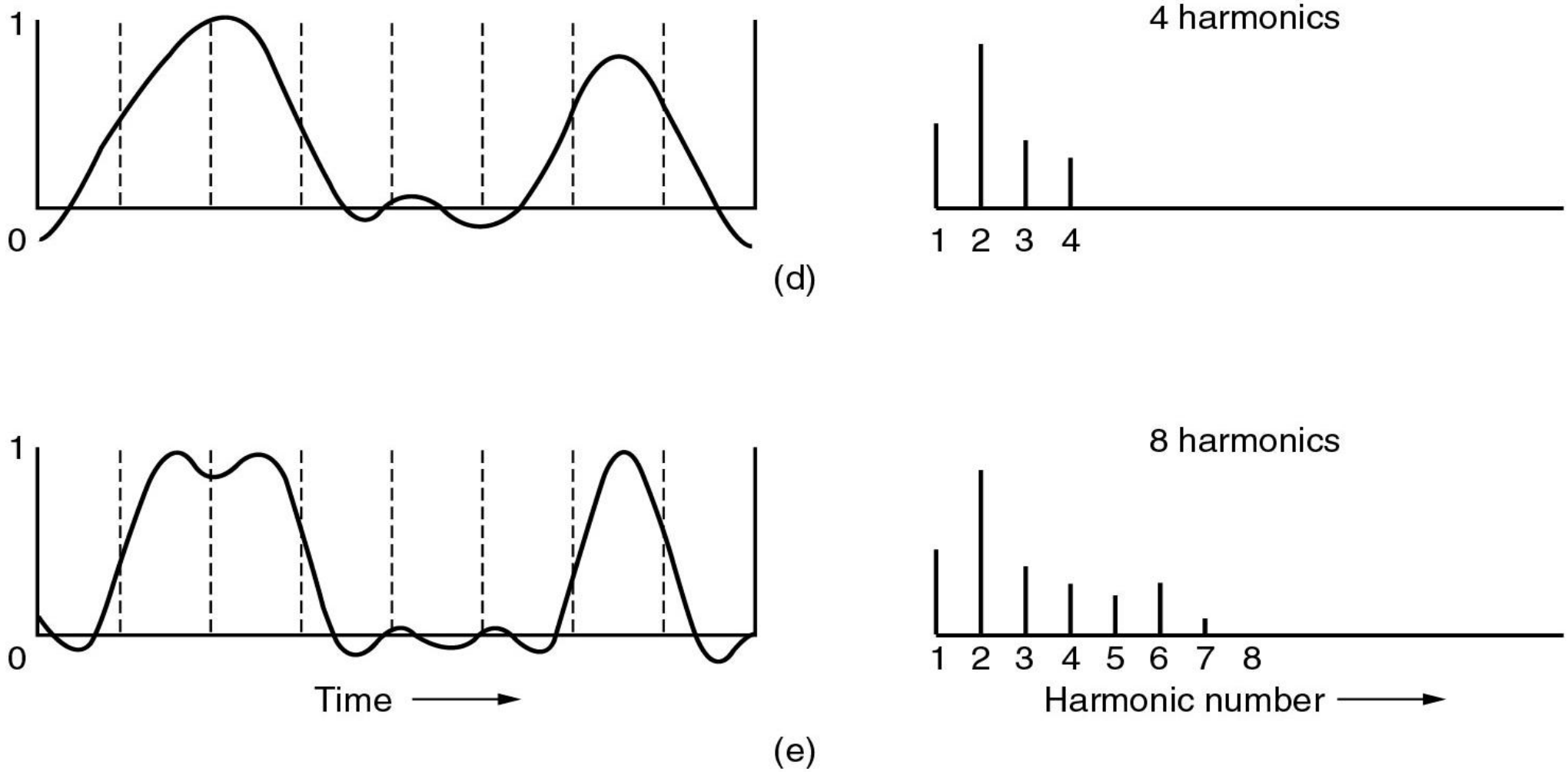




(c)



2.1.2 Bandwidth-Limited Signals(2)



2.1.2 Bandwidth-Limited Signals(3)

- Relation between data rate and harmonics on voice-grade line (3000Hz bandwidth)

Bps	T (msec)	First harmonic (Hz)	# Harmonics sent
300	26.67	37.5	80
600	13.33	75	40
1200	6.67	150	20
2400	3.33	300	10
4800	1.67	600	5
9600	0.83	1200	2
19200	0.42	2400	1
38400	0.21	4800	0

- Bandwidth limited data rate

2.1.3 The Maximum Data Rate of a channel

- Nyquist's theorem

  maximum data rate = $2H \log_2 V$ bits/sec

- Shannon's theorem

  maximum data rate = $H \log_2 (1+S/N)$ bits/sec

- Example (Modem,Telephone Line):

  S/N = 1000,

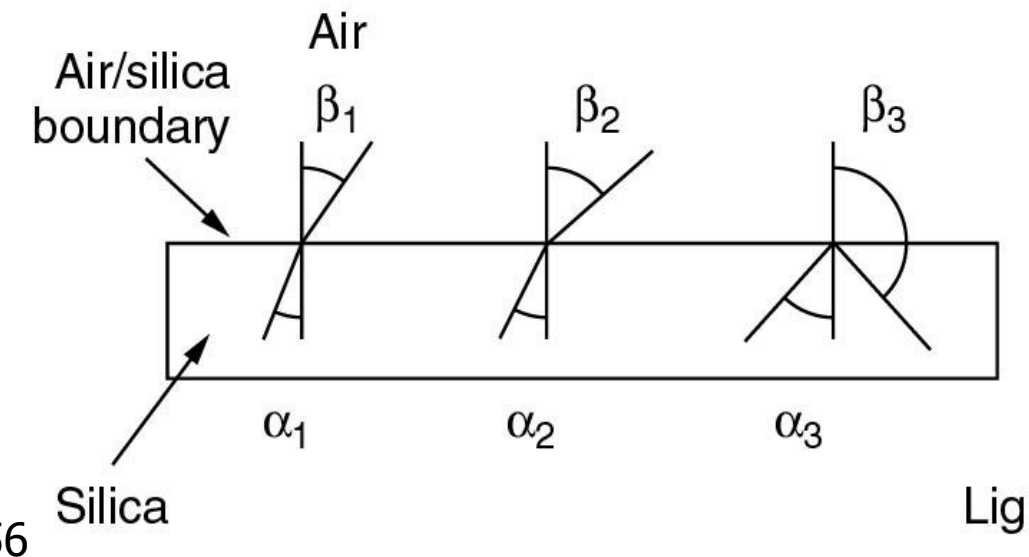
  maximum data rate ≈ 7H = 28kbps

2.2 Guided Transmission Media

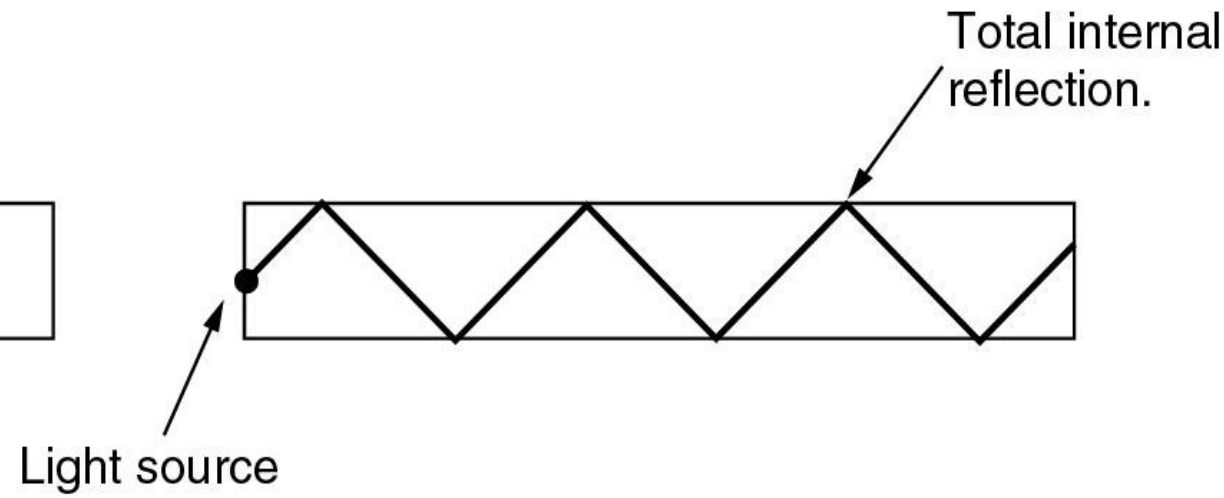
- Twisted Pair
  - the twisted wire radiates less effectively
- Coaxial Cable
- Fiber Optics

Fiber Optics

- Three components:
  - Light source,transmission medium,detector
  - A pulse of light indicates a 1 bit and the absence of light indicates a 0 bit
- Light through fiber
- Multimode & single mode fiber

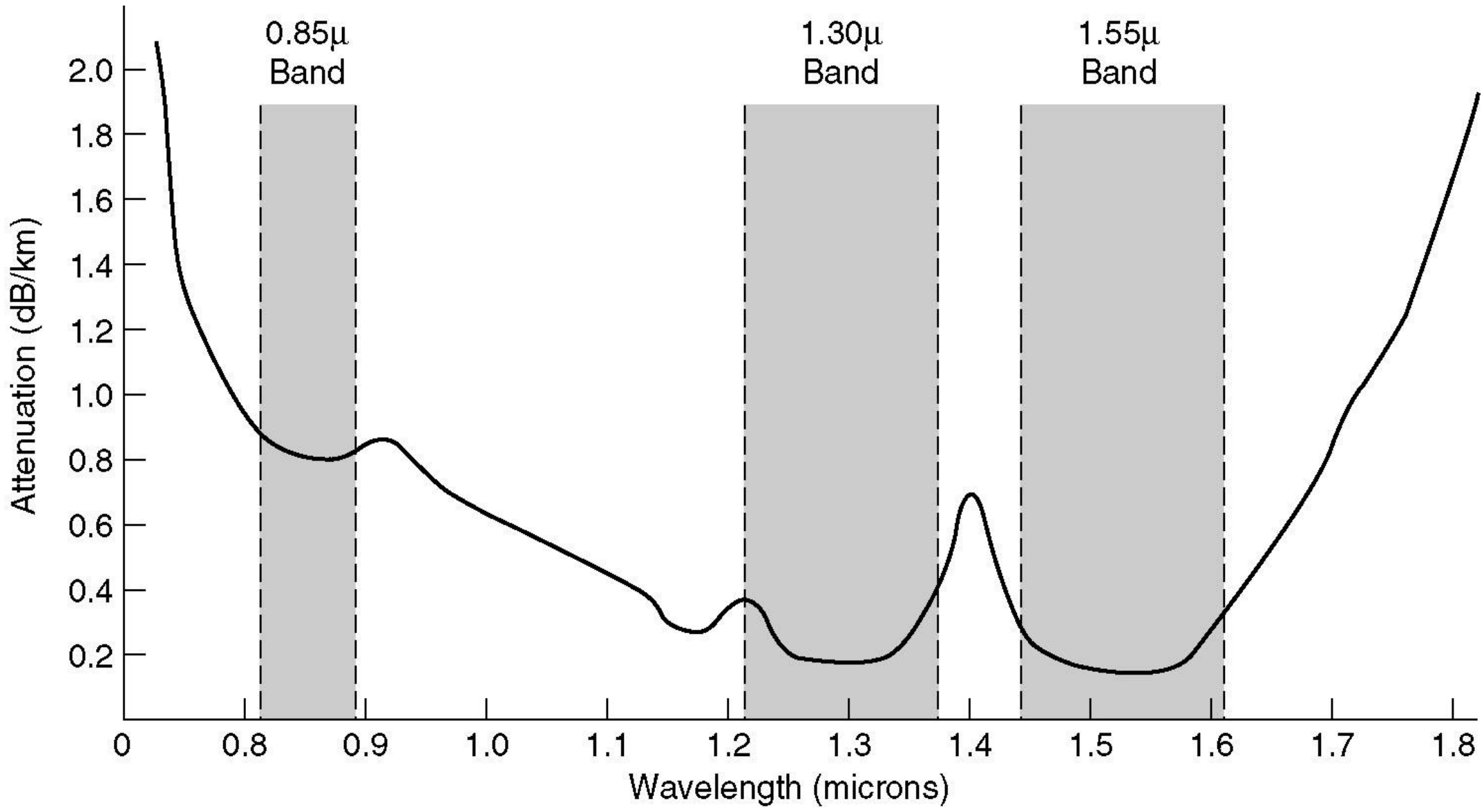


(a)



(b)

Attenuation of light through fiber in the infrared region



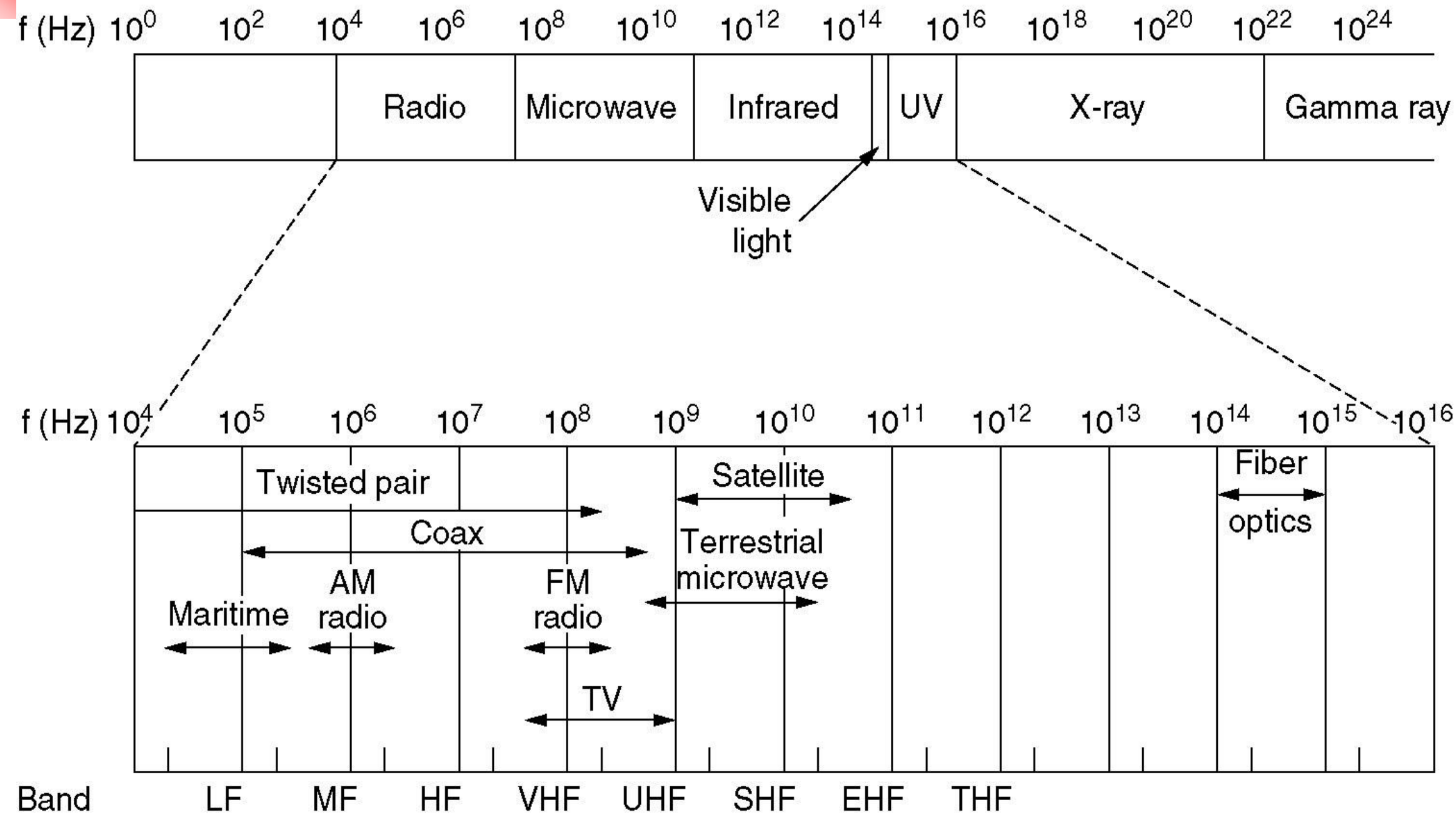
Information Wave Carried

- Frequency and wave length Λ f = c
- to finite differences $\Delta f = \frac{c\Delta\lambda}{\lambda^2}$
  - 1.30-micron band, $\lambda = 1.3 \times 10^{-6}$
  - $\delta\lambda = 0.17 \times 10^{-6}$
  - δf is about $3*10^{13}$Hz = 30THz
  - 8 bits/Hz, we get 240 Tbps.
- A few bits per Hertz at low frequencies
- Often 8 bits at high frequencies

2.3 Wireless Transmission

- The Electromagnetic Spectrum
- Radio Transmission
- Microwave Transmission
- Infrared Waves
- Lightwave Transmission

2.3.1 The Electromagnitic Spectrum



The Electromagnitic Spectrum *

- VLF = Very Low Frequency
- LF = Low Frequency
- MF = Medium Frequency
- HF = High Frequency
- VHF = Very High Frequency (Mobile Radio)
- UHF = Ultra High Frequency (Mobile Radio,Wireless LAN)
- SHF = Super High Frequency (Wireless LAN, Satellite)
- EHF = Extra High Frequency
- THF = Tremendously High Frequency
- UV = Ultraviolet Light

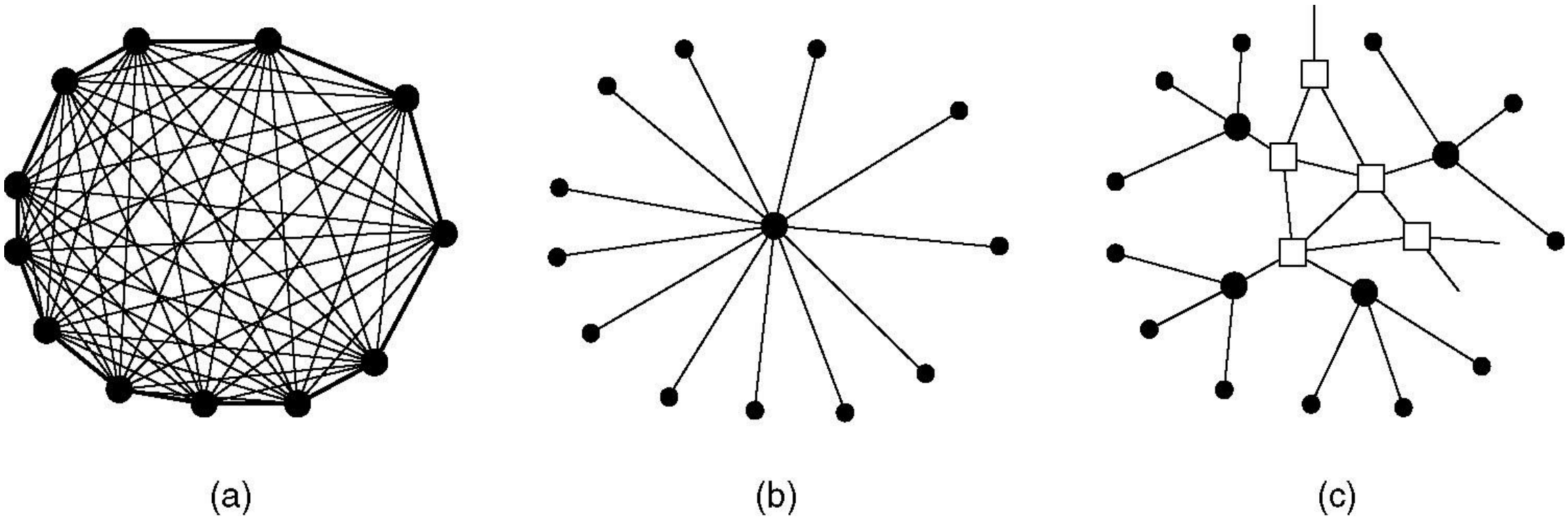
Frequencies and regulations

	Europe	USA	Japan
Mobile phones	**NMT** 453-457MHz, 463-467 MHz; **GSM** 890-915 MHz, 935-960 MHz; 1710-1785 MHz, 1805-1880 MHz	**AMPS**, **TDMA**, **CDMA** 824-849 MHz, 869-894 MHz; **TDMA**, **CDMA**, **GSM** 1850-1910 MHz, 1930-1990 MHz;	**PDC** 810-826 MHz, 940-956 MHz; 1429-1465 MHz, 1477-1513 MHz
Cordless telephones	**CT1+** 885-887 MHz, 930-932 MHz; **CT2** 864-868 MHz **DECT** 1880-1900 MHz	**PACS** 1850-1910 MHz, 1930-1990 MHz **PACS-UB** 1910-1930 MHz	**PHS** 1895-1918 MHz **JCT** 254-380 MHz
Wireless LANs	**IEEE 802.11** 2400-2483 MHz **HIPERLAN 1** 5176-5270 MHz	**IEEE 802.11** 2400-2483 MHz	**IEEE 802.11** 2471-2497 MHz

2.5 The Public Switch Telephone Network (PSTN)

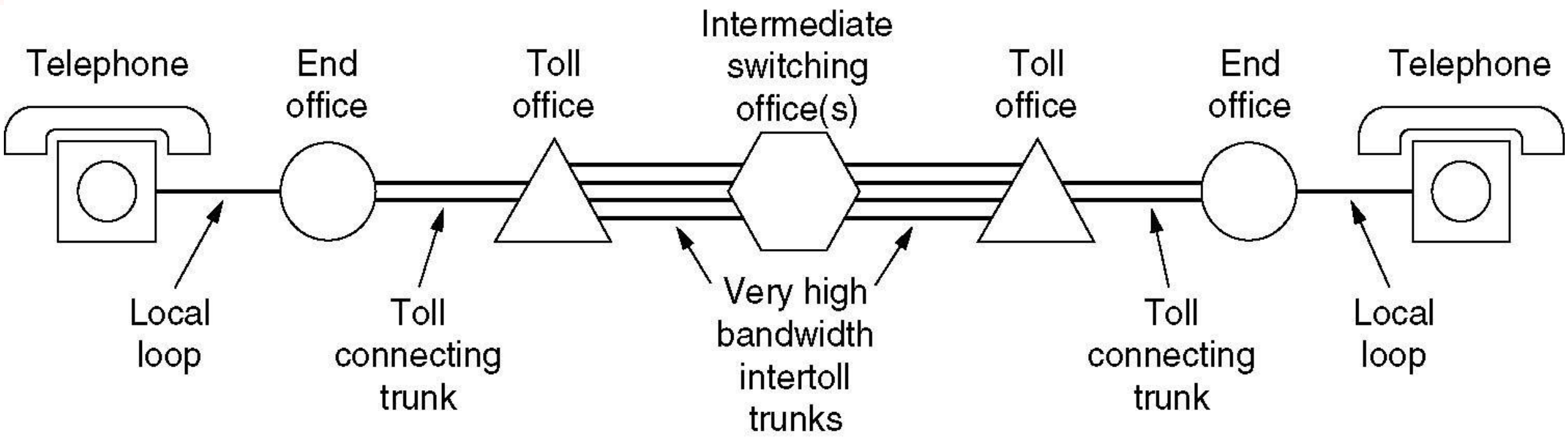
- Structure of the Telephone System
- The Local Loop: Modems, ADSL and Wireless
- Trunks and Multiplexing
- Switching

2.5.1 Structure of the Telephone System



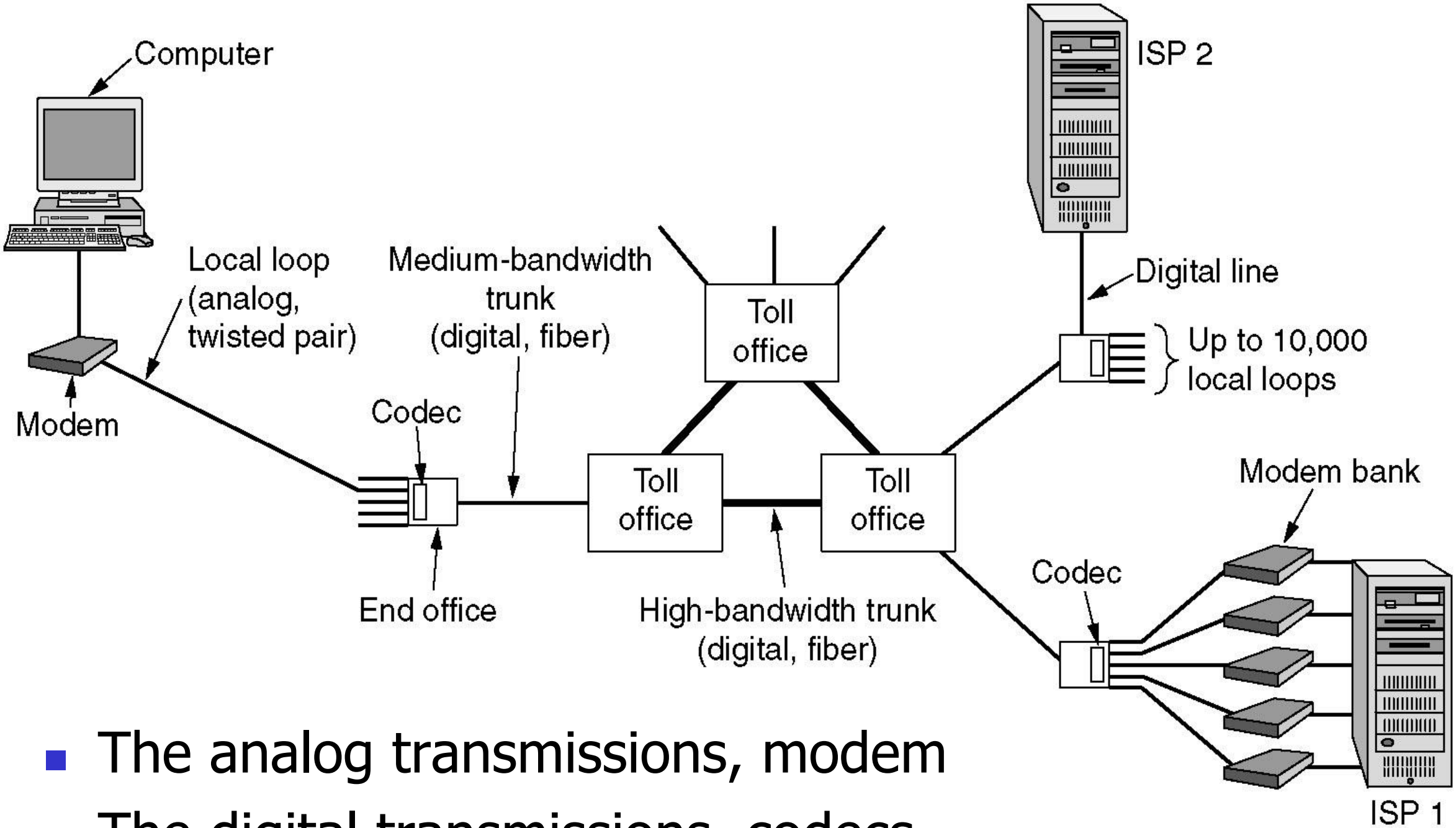
- (a) Fully-interconnected network.
- (b) Centralized switch.
- (c) Two-level hierarchy

A typical circuit route



- Local loops (analog twisted pairs)
- Trunks (digital fiber optics)
- Switching offices
- Analog, low bandwidth

2.5.3 The Local Loop: Modems,ADSL,and wireless



- The analog transmissions, modem
- The digital transmissions, codecs

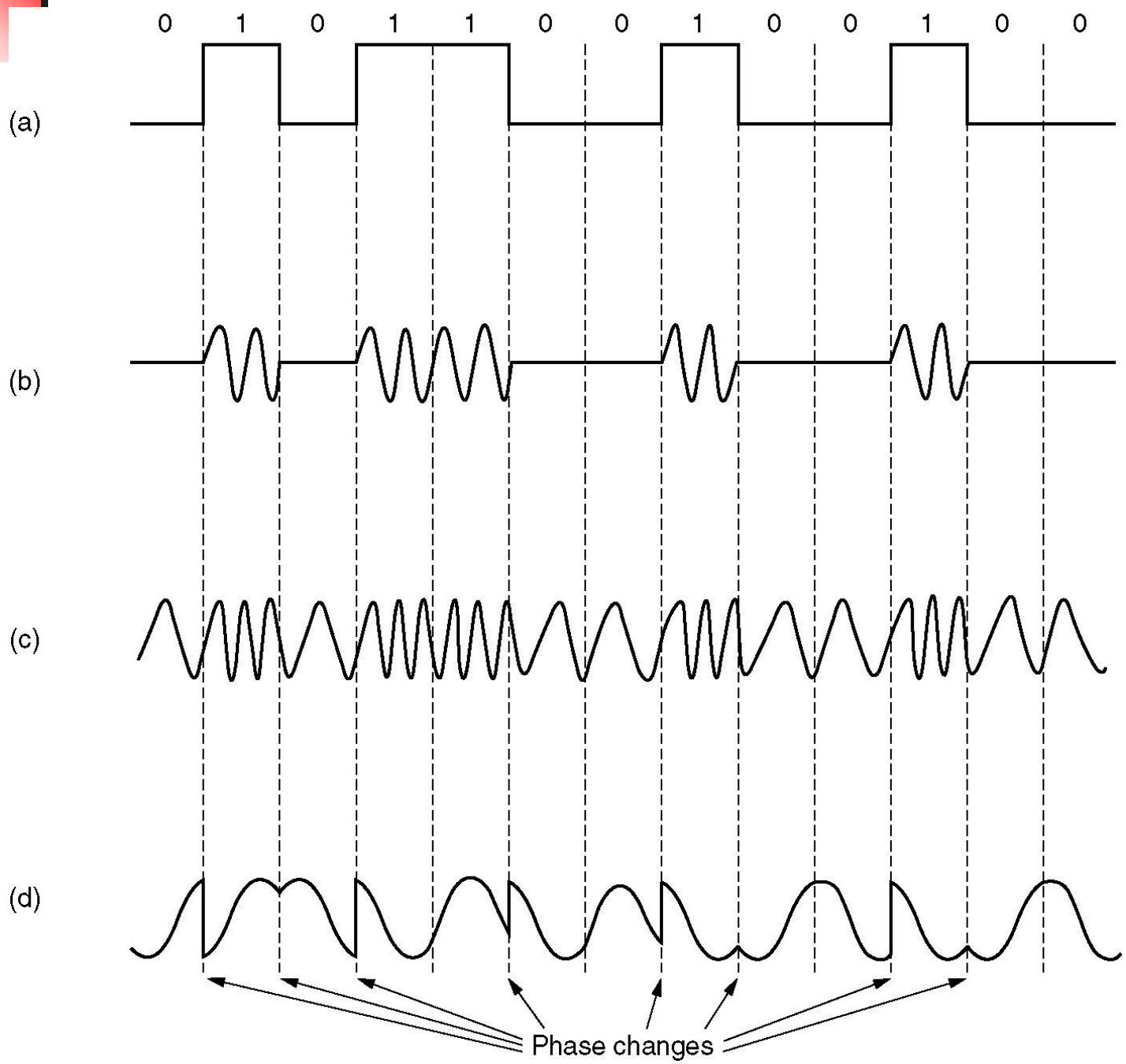
Influence on signal transfer

- Attenuation
  - Loss of energy
  - Depends on frequency and distance
- Distortion
  - Different Fourier component at different speed
- Noise
  - Thermal noise, random , unavoidable
  - Crosstalk
  - Impulse

Some concepts

- **Bandwidth**, the range of frequency
- **Symbol**, one piece info., a sample
- **Baud rate**, number of sample/sec, symbol rate
- **Bit rate**, number of symbol/sec times number of bits/symbol

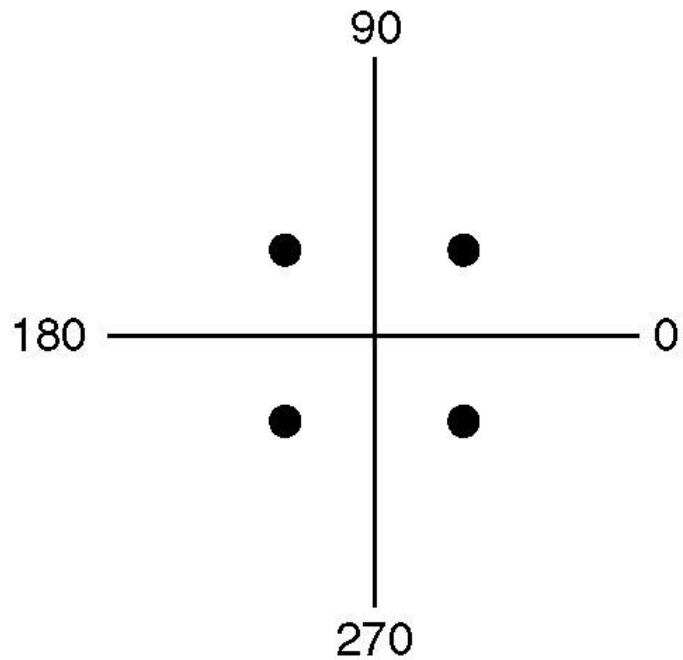
Modems (1)



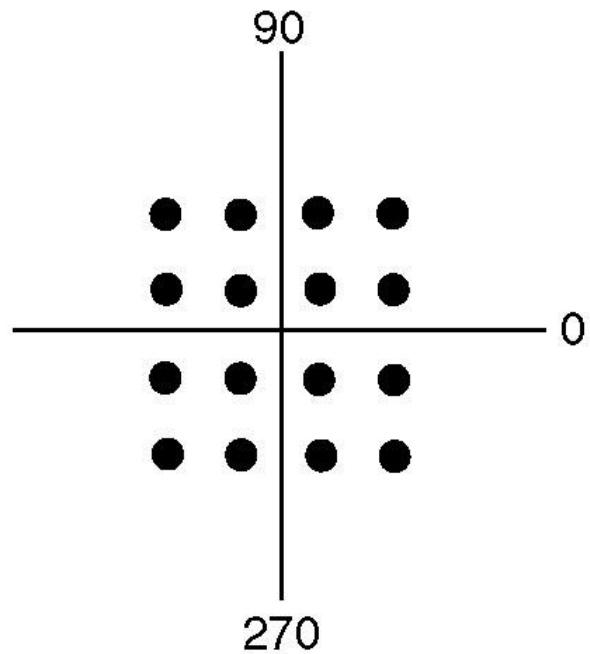
- A binary signal
- Amplitude modulation
- Frequency modulation
- Phase modulation

Modems (2)

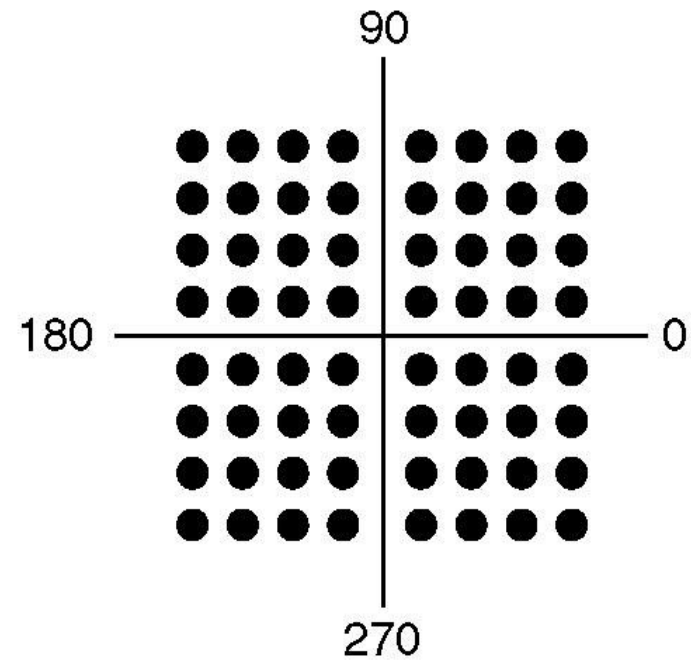
- (a) QPSK.
- (b) QAM-16.
- (c) QAM-64



(a)

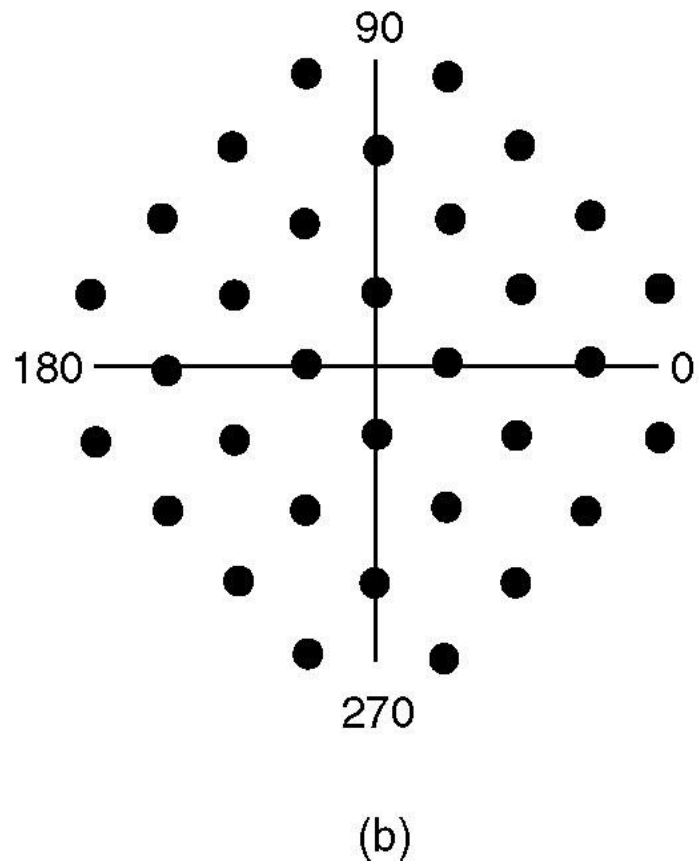


(b)

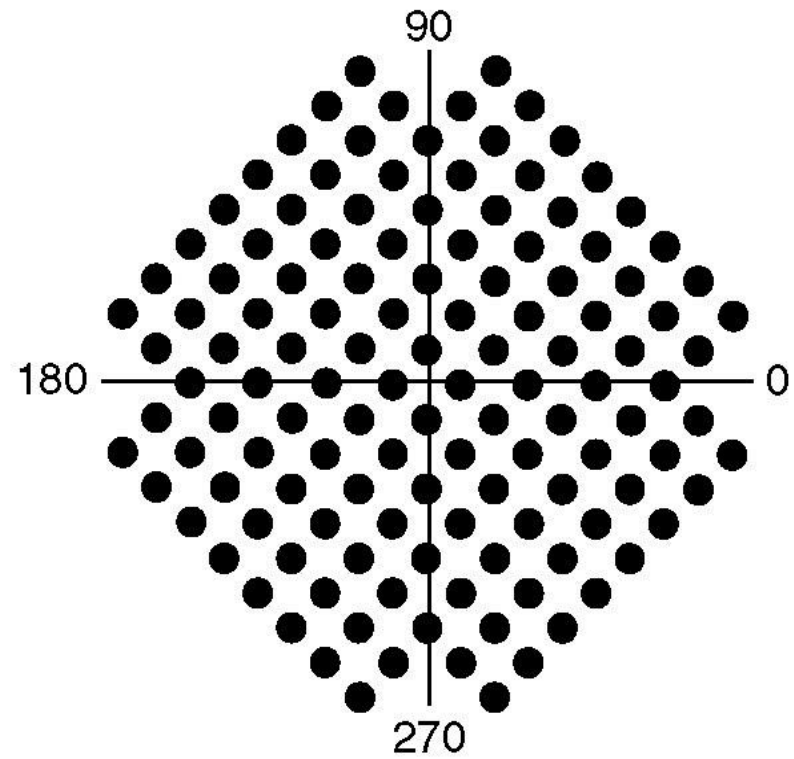


(c)

Modems (3)



(b)

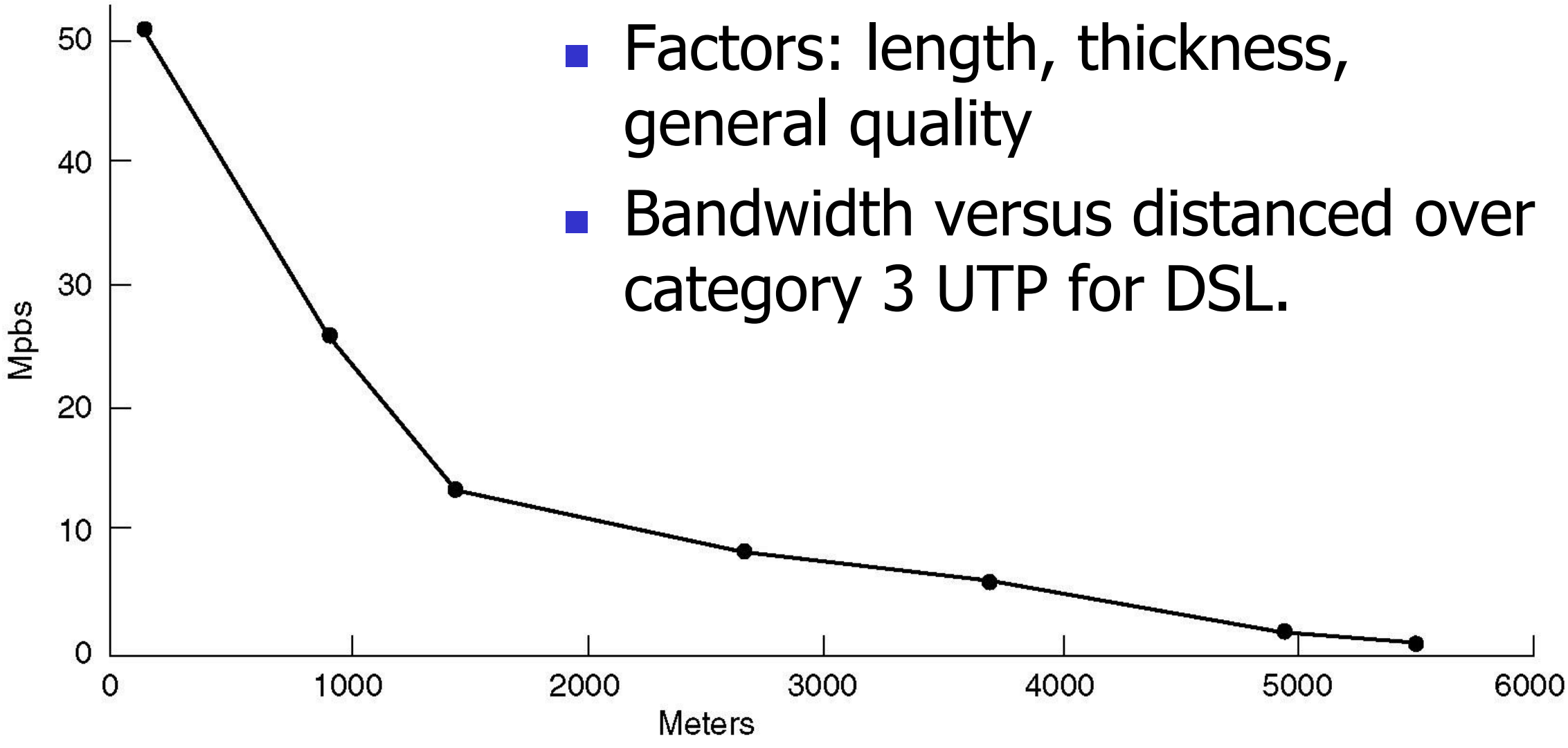


(c)

- (b) V.32 for 9600 bps,2400Baud*(5bit-1)
- (c) V32 bis for 14,400 bps, 2400Baud*(7bit-1)
- V.90 provides a 33.6-kbps upstream channel (user to ISP), but a 56 kbps downstream channel (ISP to user), according the limits of Shannon and Nyquist theorem .

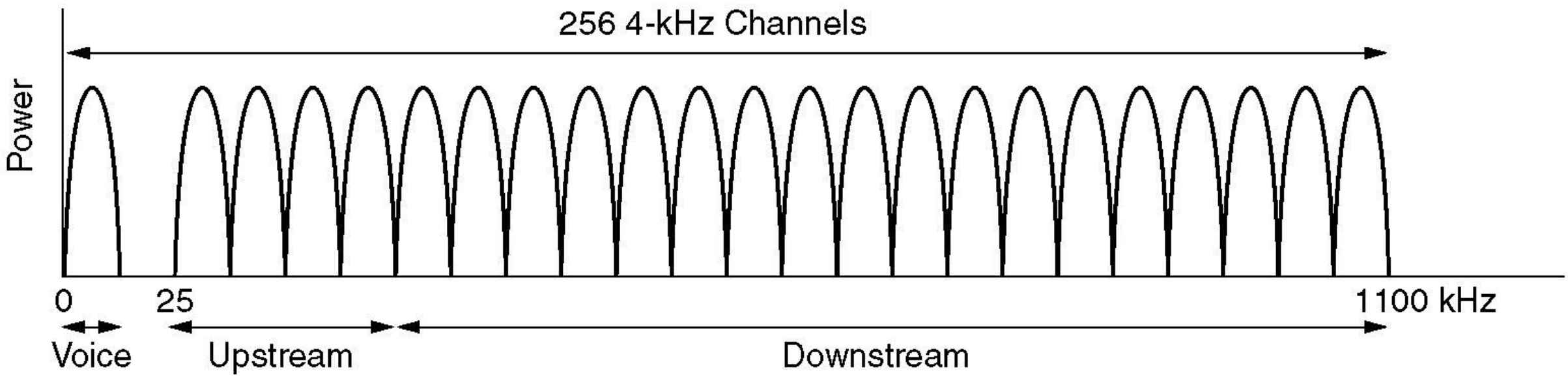
Digital Subscriber Lines (1)

- Making the entire capacity of the local loop available
- Factors: length, thickness, general quality
- Bandwidth versus distanced over category 3 UTP for DSL.



Digital Subscriber Lines (2)

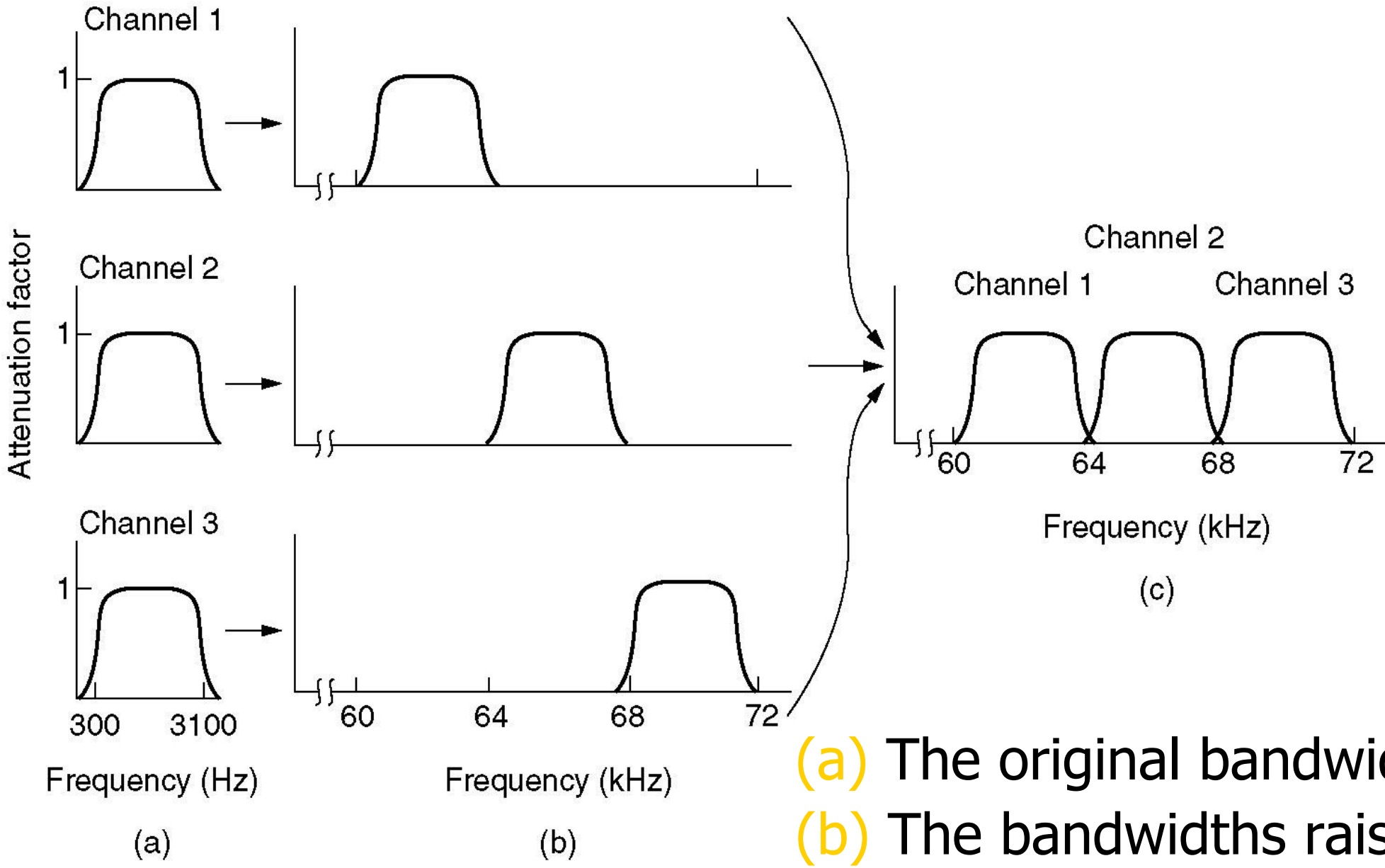
- Over category 3 UTP
- Don’t affect telephones
- Much fast than 56kbps
- Always On
- ADSL using discrete multitone modulation:
  - frequency division multiplexing



2.5.4 Trunks and Multiplexing

- High-bandwidth Trunk
- Multiplexing over a physical trunk
- FDM
- WDM
- TDM (PCM)
- SONET/SDH

Frequency Division Multiplexing

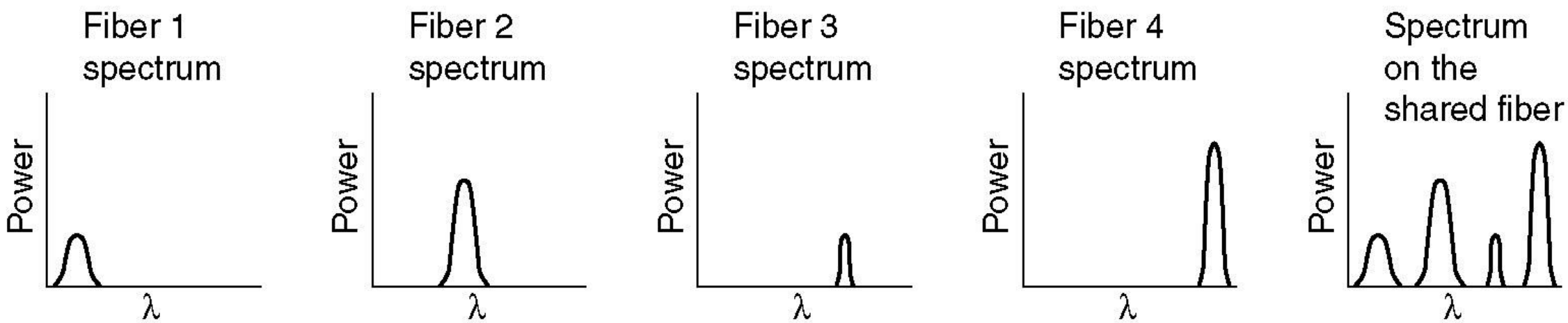


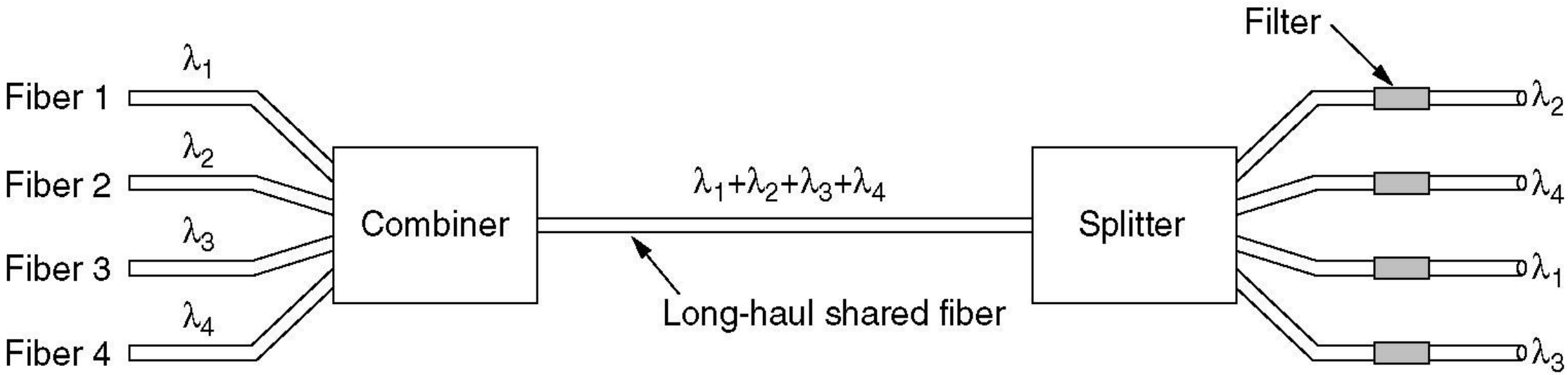
(a) The original bandwidths.

(b) The bandwidths raised in frequency.

(c) The multiplexed channel

Wavelength Division Multiplexing



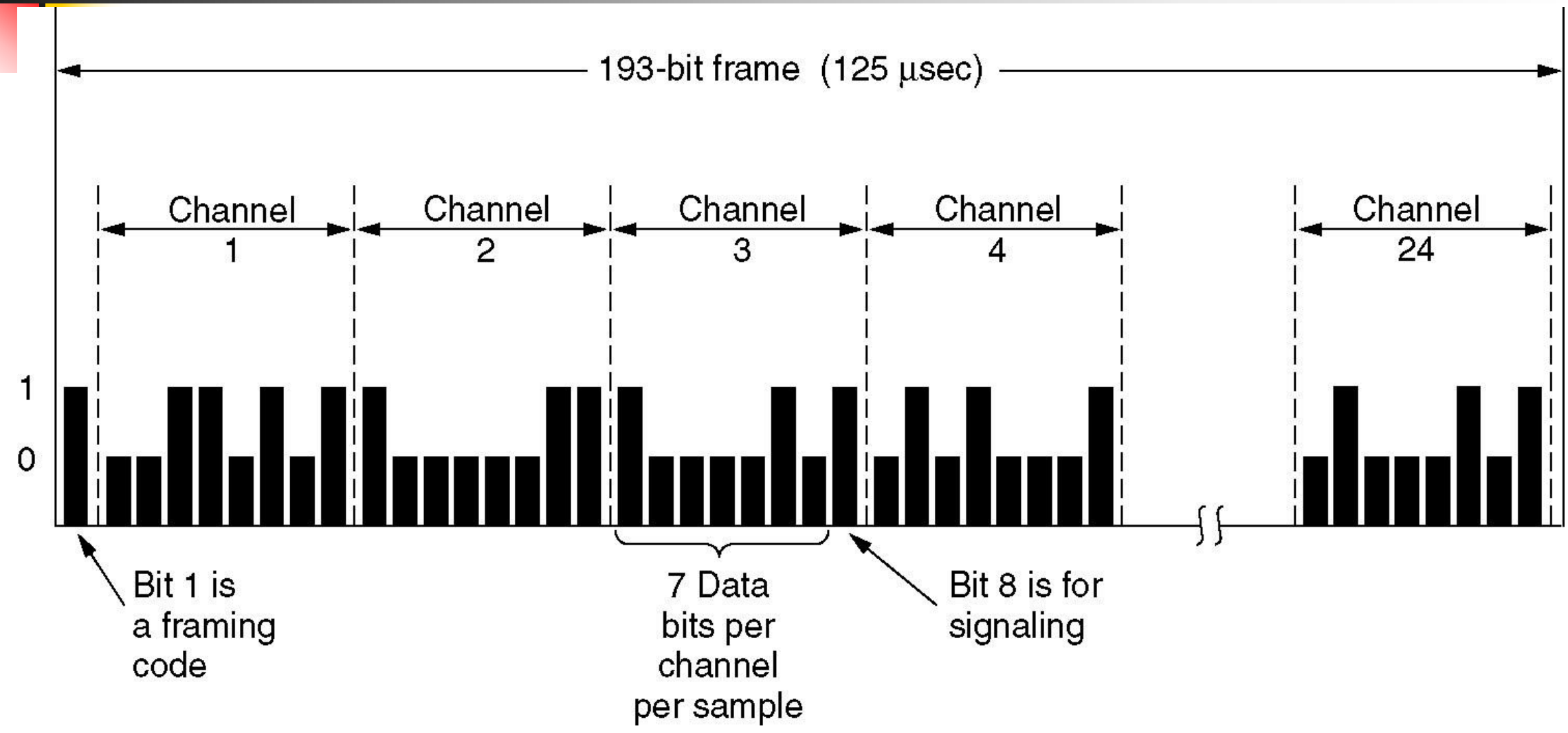


- Just FDM at very high frequencies
- For fiber optic
- DWDM, wavelengths are spaced close together, 0.1nm

Time Division Multiplexing(1)

- Copper line in the telephone system
- Digital data transmission
- PCM, Pulse Code Modulation
  - Nyquist theorem: Making 2N samples per second from N hz bandwidth is sufficient to capture all the information
  - Telephone system: 8000 samples from 4khz channel, 125us/sample
  - 7 or 8 bit/sample
  - Transmission and recover

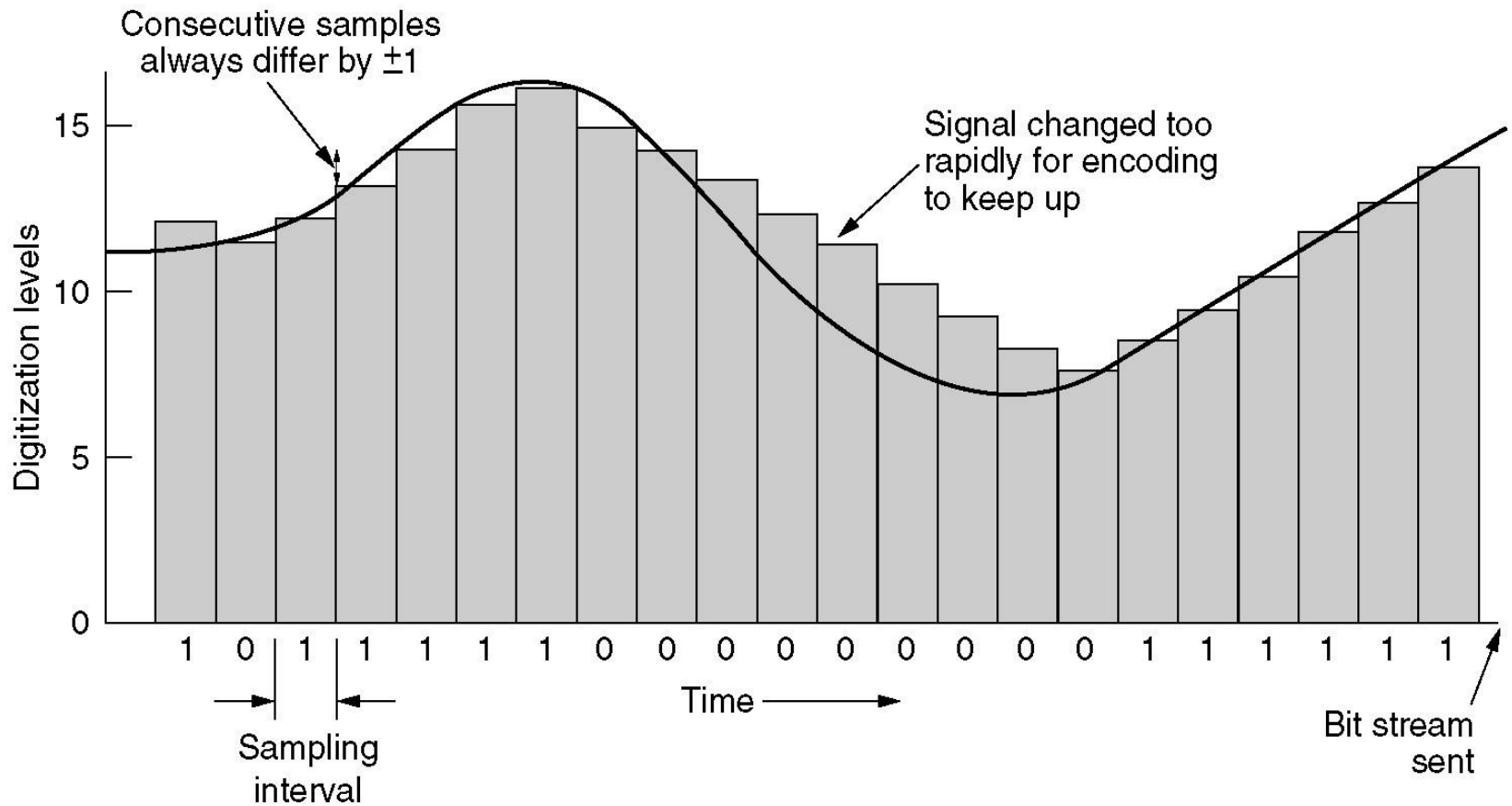
Time Division Multiplexing(2)



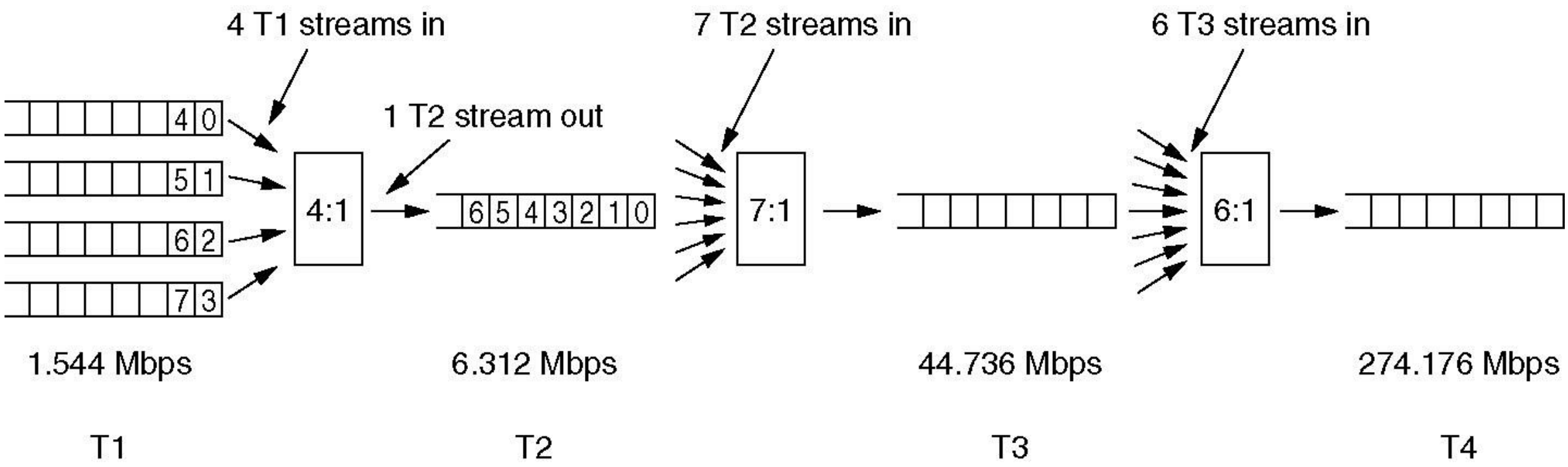
- Signaling and data
- Framing code
- The T1 carrier (24 channels,1.544 Mbps)
- The E1 carrier (32 channels,2.048Mbps)

Time Division Multiplexing(3)

- To reduce the number of bits needed per channel
  - Differential pulse code modulation, 5 bit is sufficient
  - Delta modulation, 1 bit is sufficient
  - Predictive encoding
- Influence when packet lost

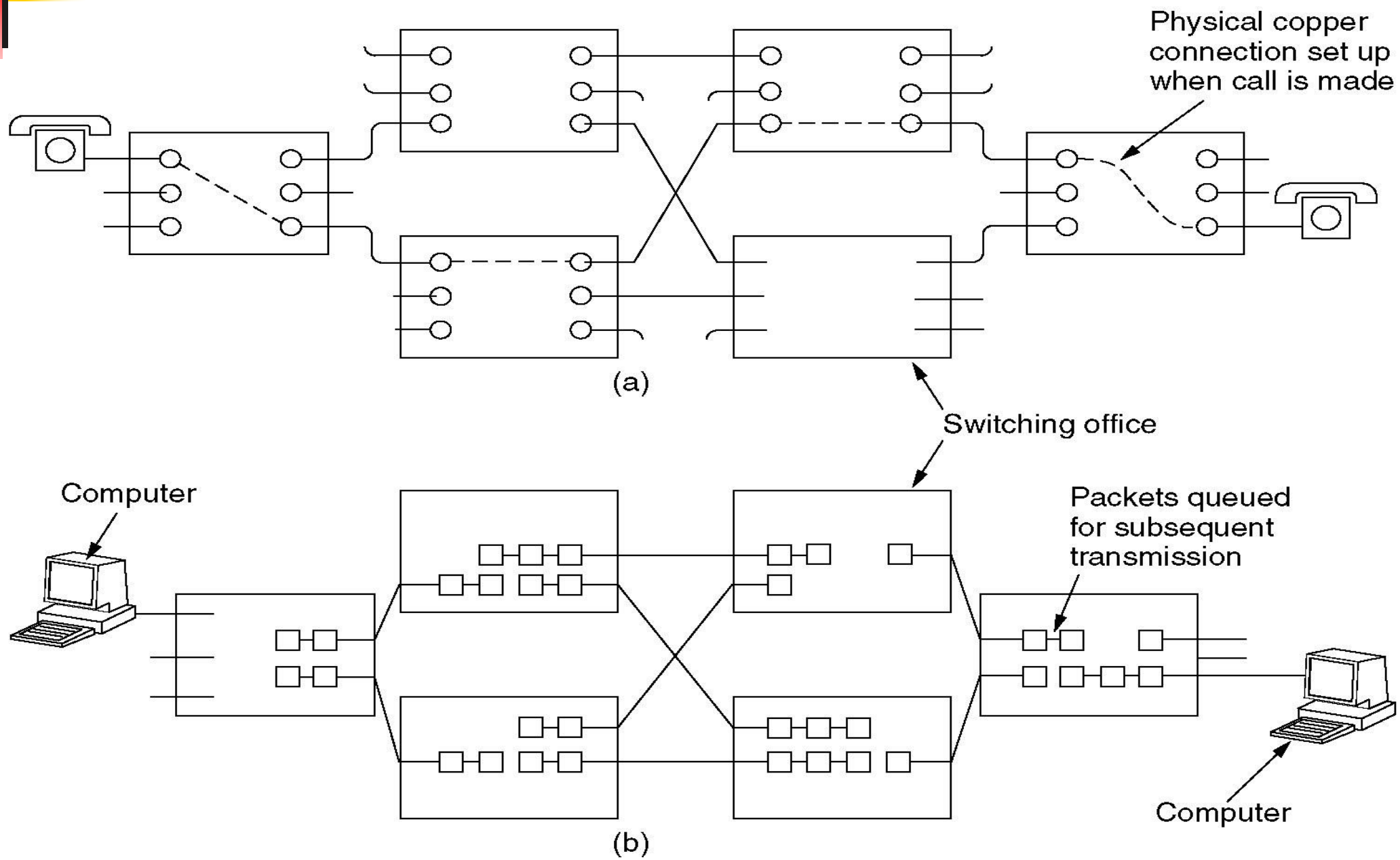


Time Division Multiplexing(4)



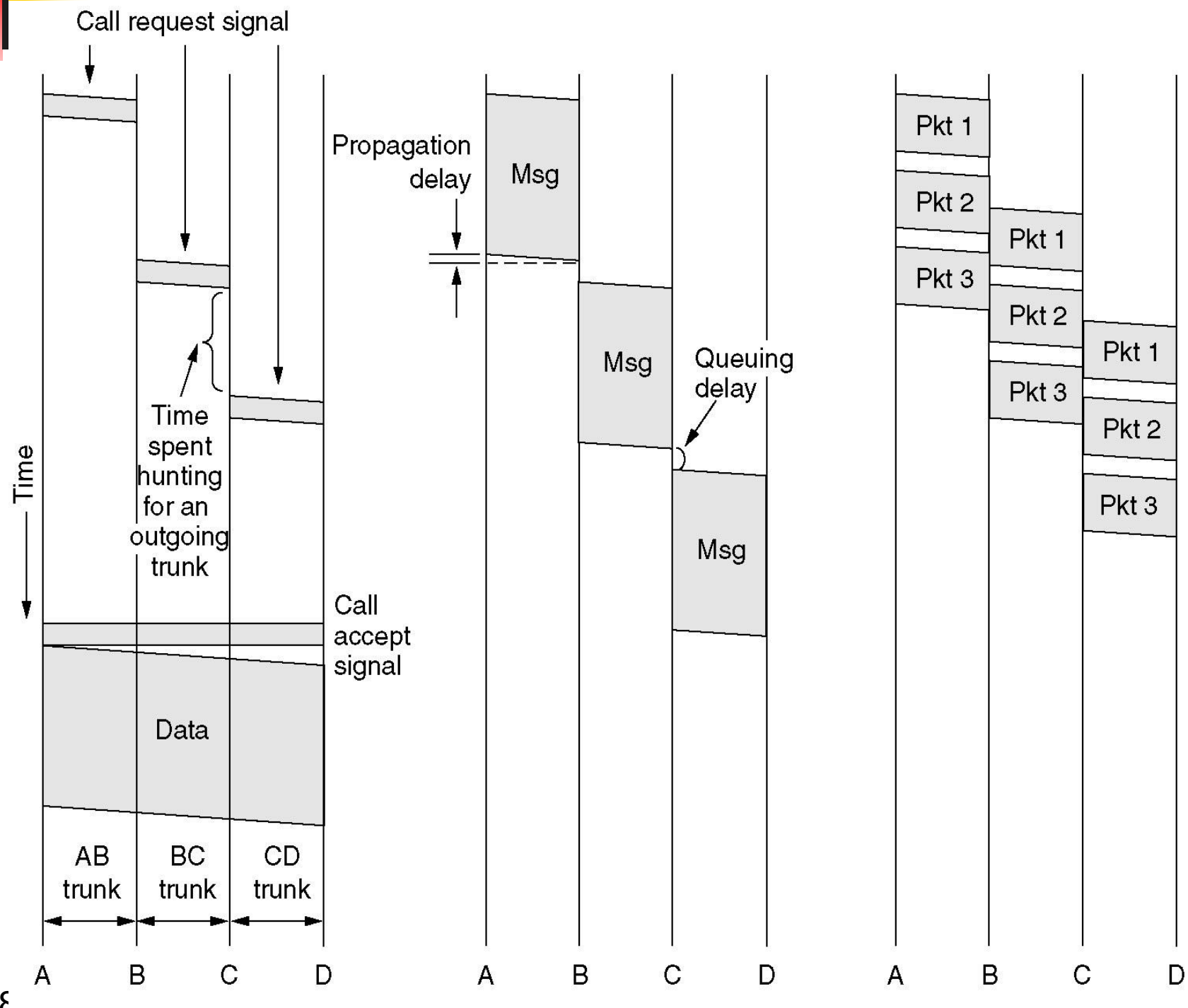
- Multiplexing T1 streams into higher-order carriers bit for bit

2.5.5 Switching



(a) Circuit switching. (b) Packet switching.

Timing of events



(a) Circuit switching

(b) Message switching

(c) Packet switching

Comparison

Item	Circuit-switched	Packet-switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
When can congestion occur	At setup time	On every packet
Potentially wasted bandwidth	Yes	No
Store-and-forward transmission	No	Yes
Transparency	Yes	No
Charging	Per minute	Per packet

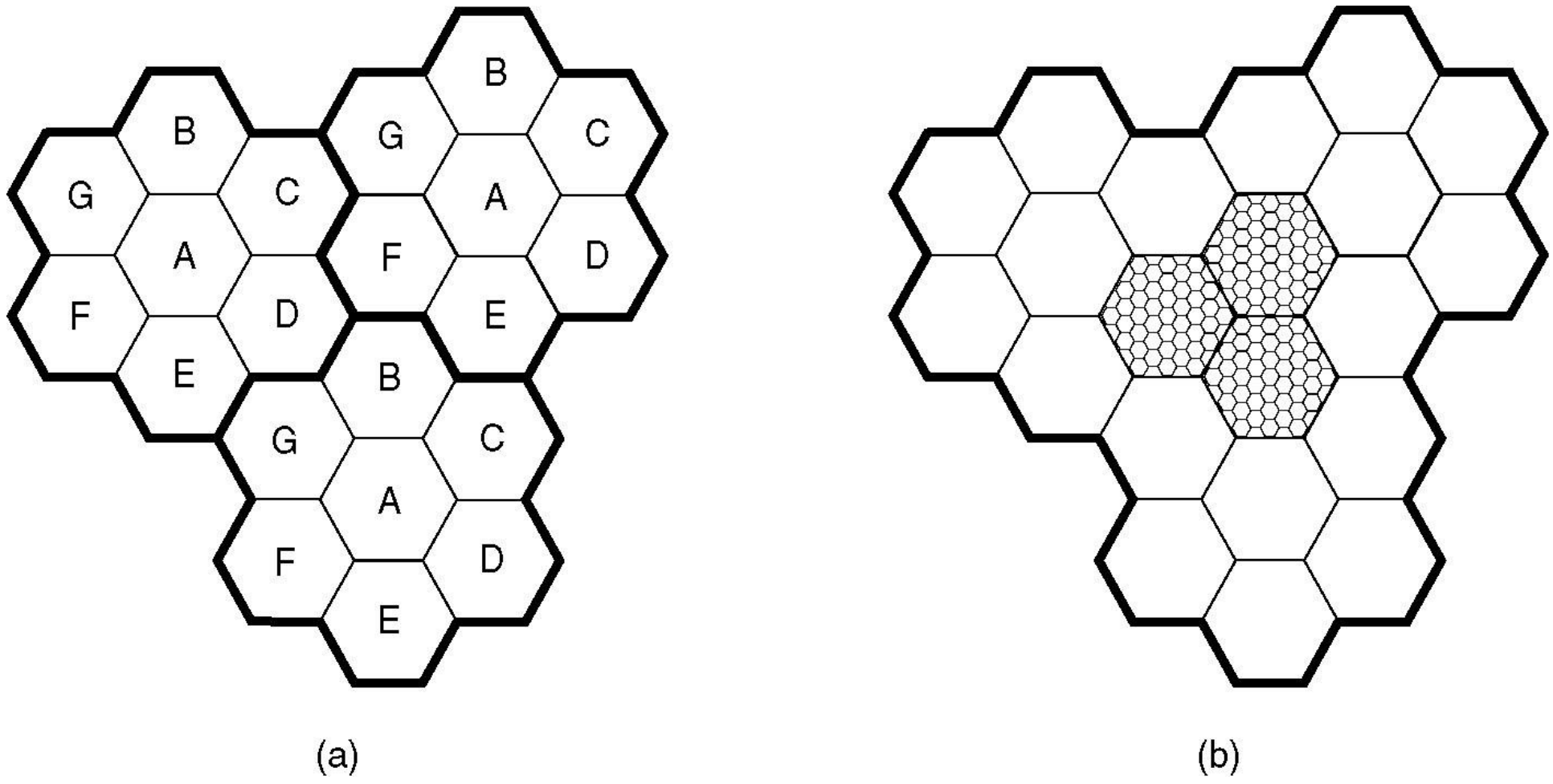
2.6 The Mobile Telephone System

- Cordless phone and mobile phone
- First-Generation Mobile Phones: Analog Voice
- Second-Generation Mobile Phones: Digital Voice
- Third-Generation Mobile Phones: Digital Voice and Data
- The Fourth-Generation ?

2.6.1 First-Generation: Advanced Mobile Phone System

- Push-to-Talk system: Single Channel
- IMTS: Improved Mobile Telephone System
  - Two frequency: Sending and Receiving
  - 23 Channels, spread out from 150Mhz to 450Mhz
- AMPS: Advanced Mobile Phone System
  - Cell, 10 to 20 km across
  - Base Station
  - Adjacent cells use different frequencies
  - Reuse of frequencies in nearby cells
  - MTSO: Mobile Telephone Switching Office
  - Handoff

Frequencies Reuse



(a) (b)

(a) Frequencies are not reused in adjacent cells.

(b) To add more users, smaller cells can be used

Channel Categories

- FDM
  - 824 to 849 MHz : 832 simplex transmission channels
  - 869 to 894 MHz : 832 simplex receive channels
  - Each channels is 30 kHz wide.
- The 832 channels are divided into four categories:
  - Control (base to mobile) to manage the system
  - Paging (base to mobile) to alert users to calls for them
  - Access (bidirectional) for call setup and channel assignment
  - Data (bidirectional) for voice, fax, or data

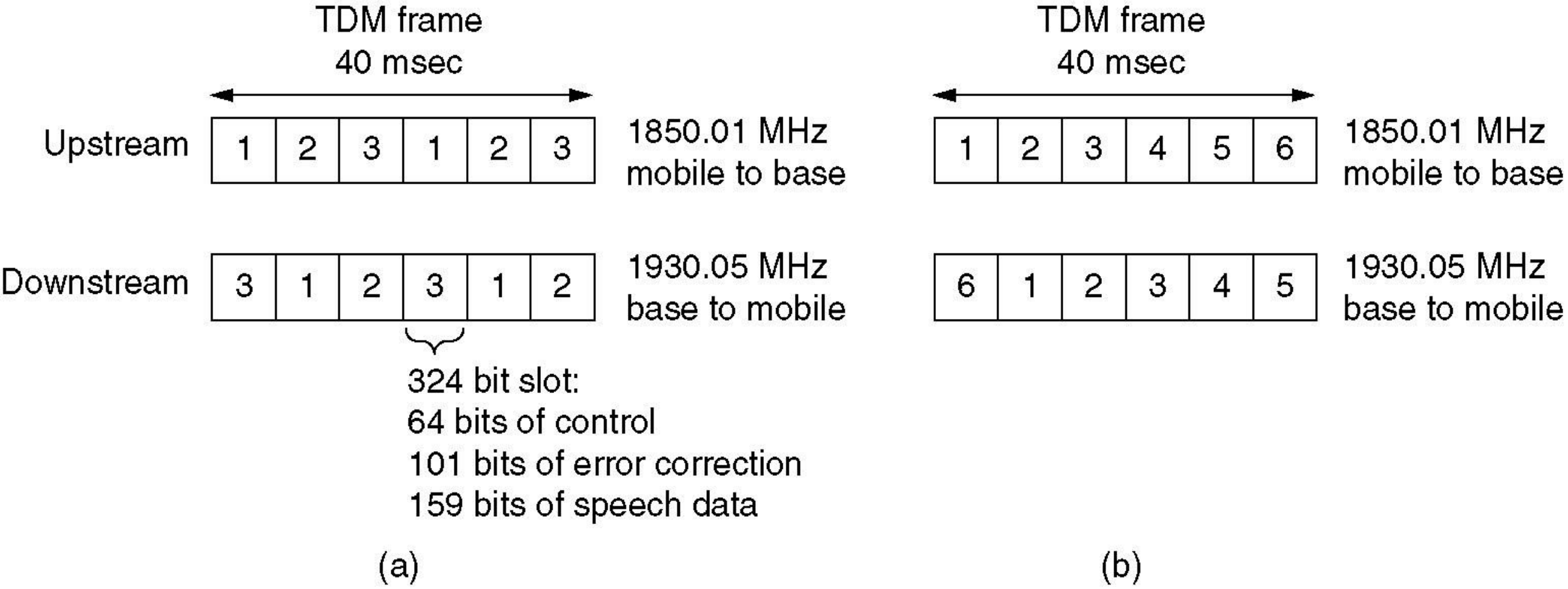
Call Management

- When a phone is switched on, it broadcasts its 32-bit serial number and 34-bit telephone number.
- BS heared the announcement tells the MTSO, and informs the customer's home MTSO of his current location.
- Idle phones listen to the paging channel to detect messages.
- Call: phone transmits the number to be called.
- MTSO looks for an idle voice channel for the call.
- The mobile phone switches to the selected voice channel and waits until the called party picks up the phone.
- MTSO to find out where the callee's home is and where the callee’s current cell is, sends a packet to the BS.
- BS sends a broadcast on the paging channel to check the exist of the called phone.
- The called phone responds on the access channel
- BS then informs the called phone to switches to a channel and starts making ringing sounds.

2.6.2 Second-Generation Mobile phones

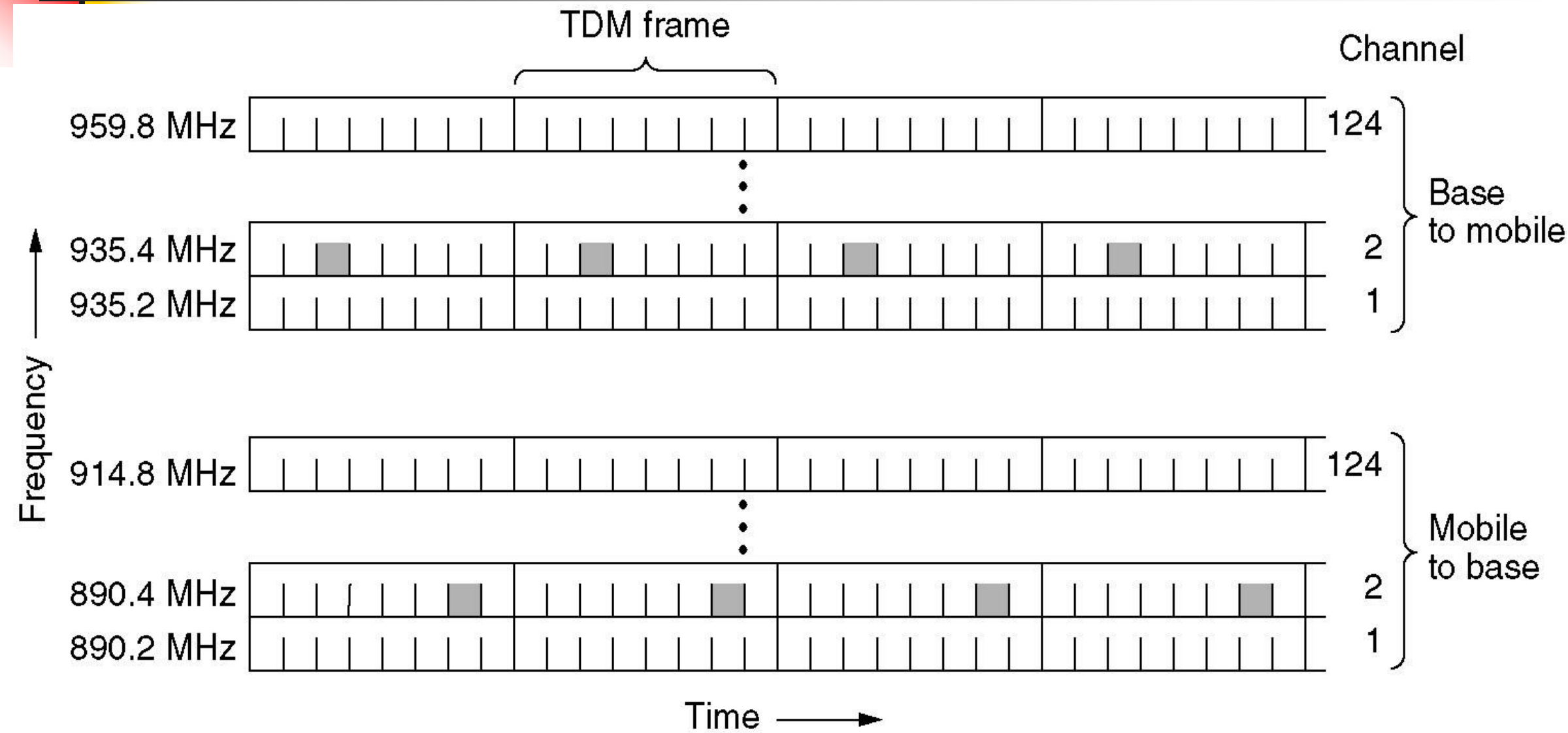
- D-AMPS
- GSM
- CDMA

D-AMPS
Digital Advanced Mobile Phone System



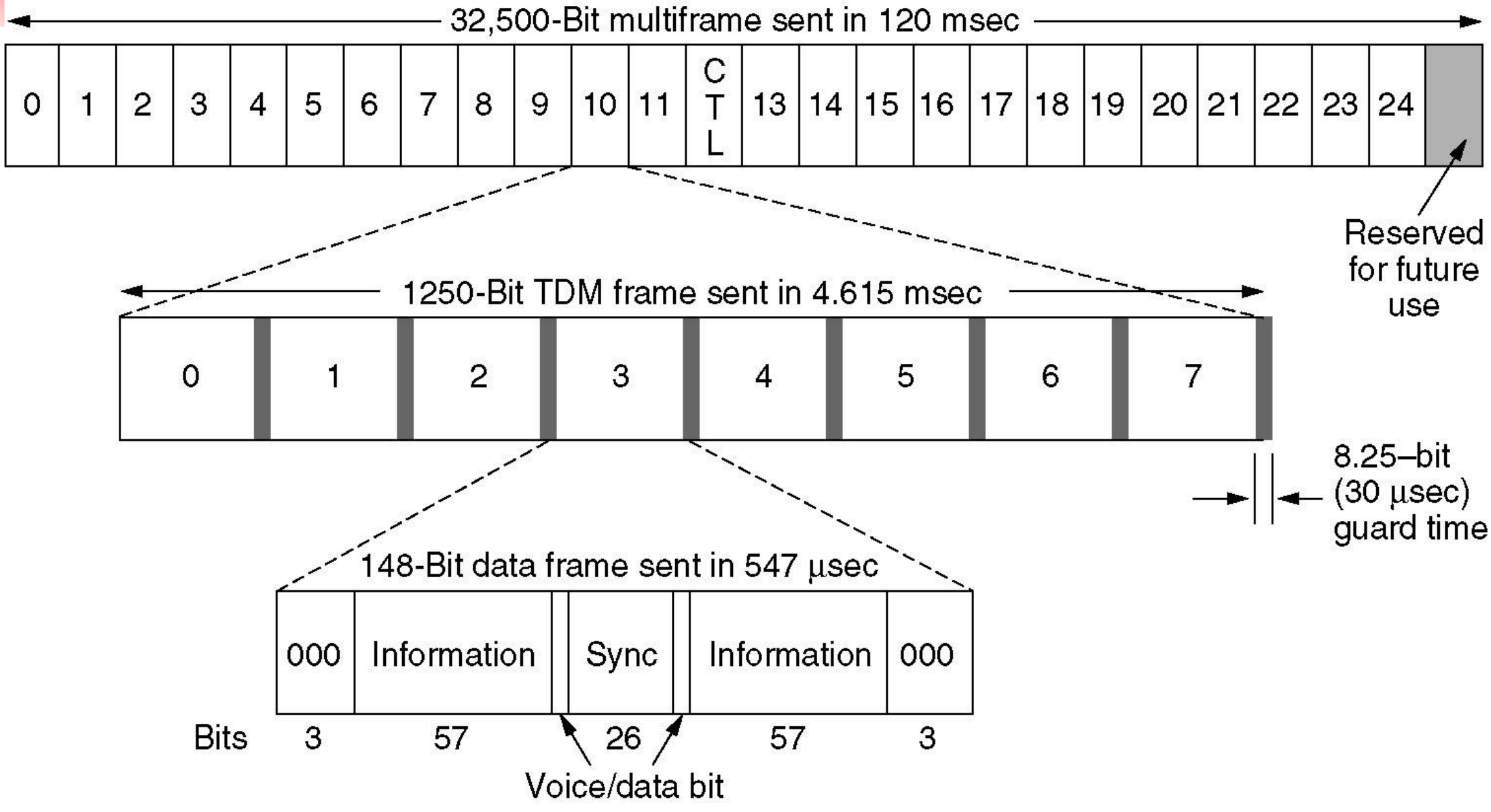
- Three users share a single frequency (30kHz)pair using time division multiplexing
- Each user has 8kbps for speech data

Global System for Mobile Communications --- GSM (1)



- GSM uses 124 frequency channels, each of which uses an eight-slot TDM system
- Transmission and receiving does not happen in the same time slot

GSM (2)



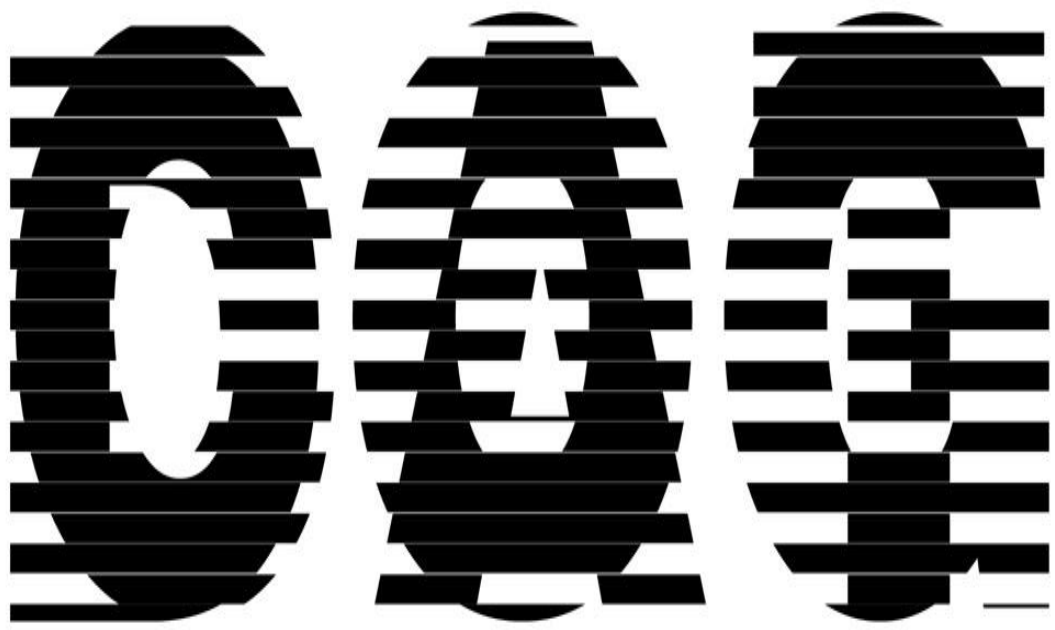
- A portion of the GSM framing structure.

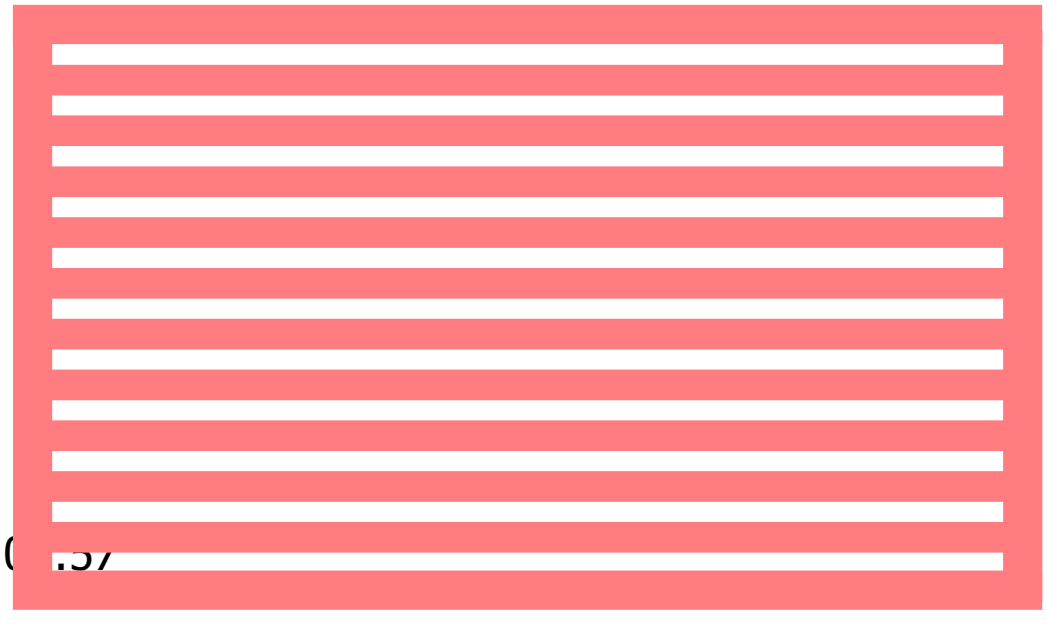
GSM (3)

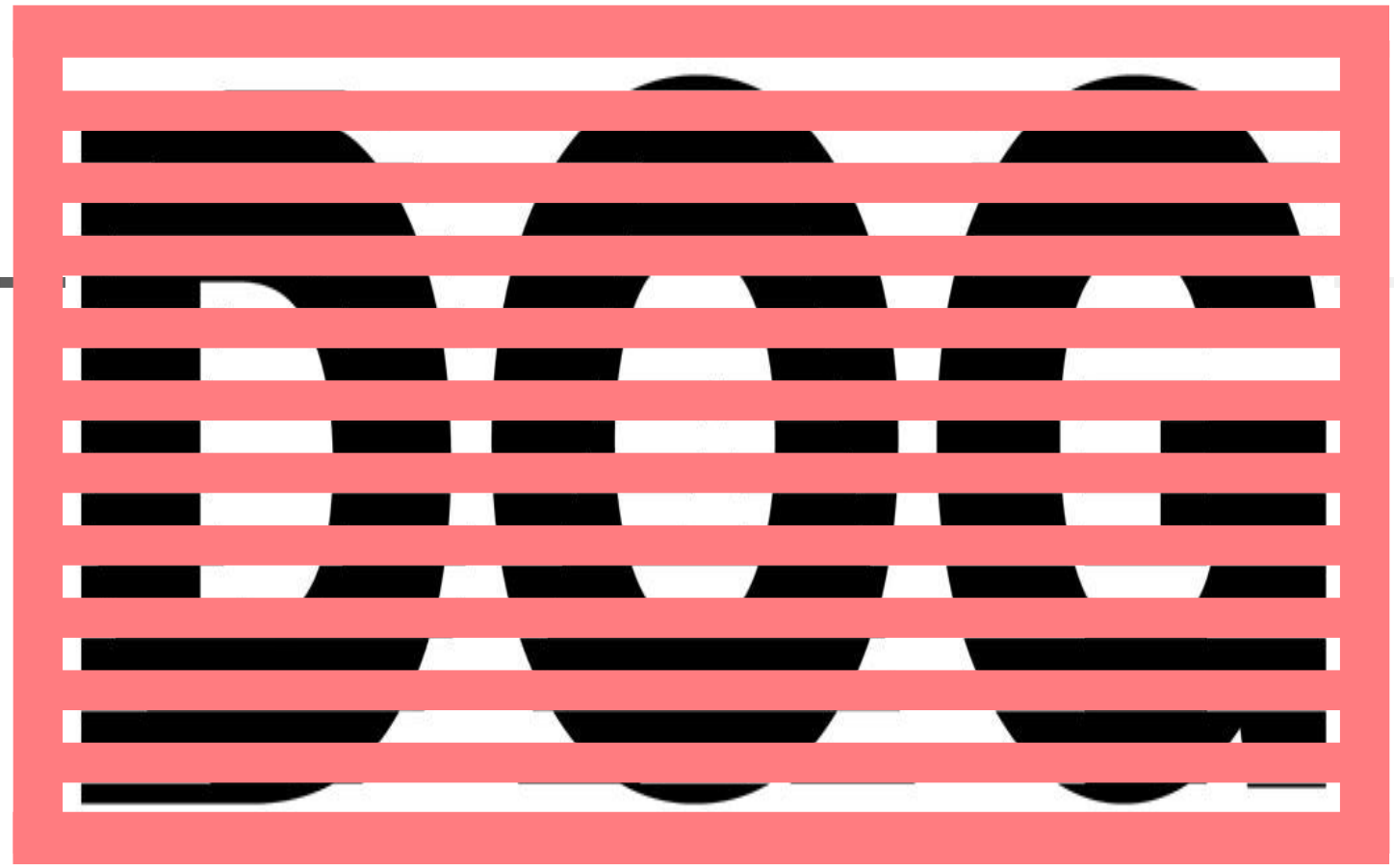
- Each TDM slot consists of a 148-bit data frame
- Eight data frame make up a **TDM frame**
- 26 TDM frames make up a 120-msec **multiframe**
- Several control channel
  - Broadcast control channel—BS ID. and channel status
  - Dedicated control channel— Location updating / Registration / Call setup
  - Common control channel— paging, user request, assigned slot announce

CDMA (1)
Code Division Multiple Access

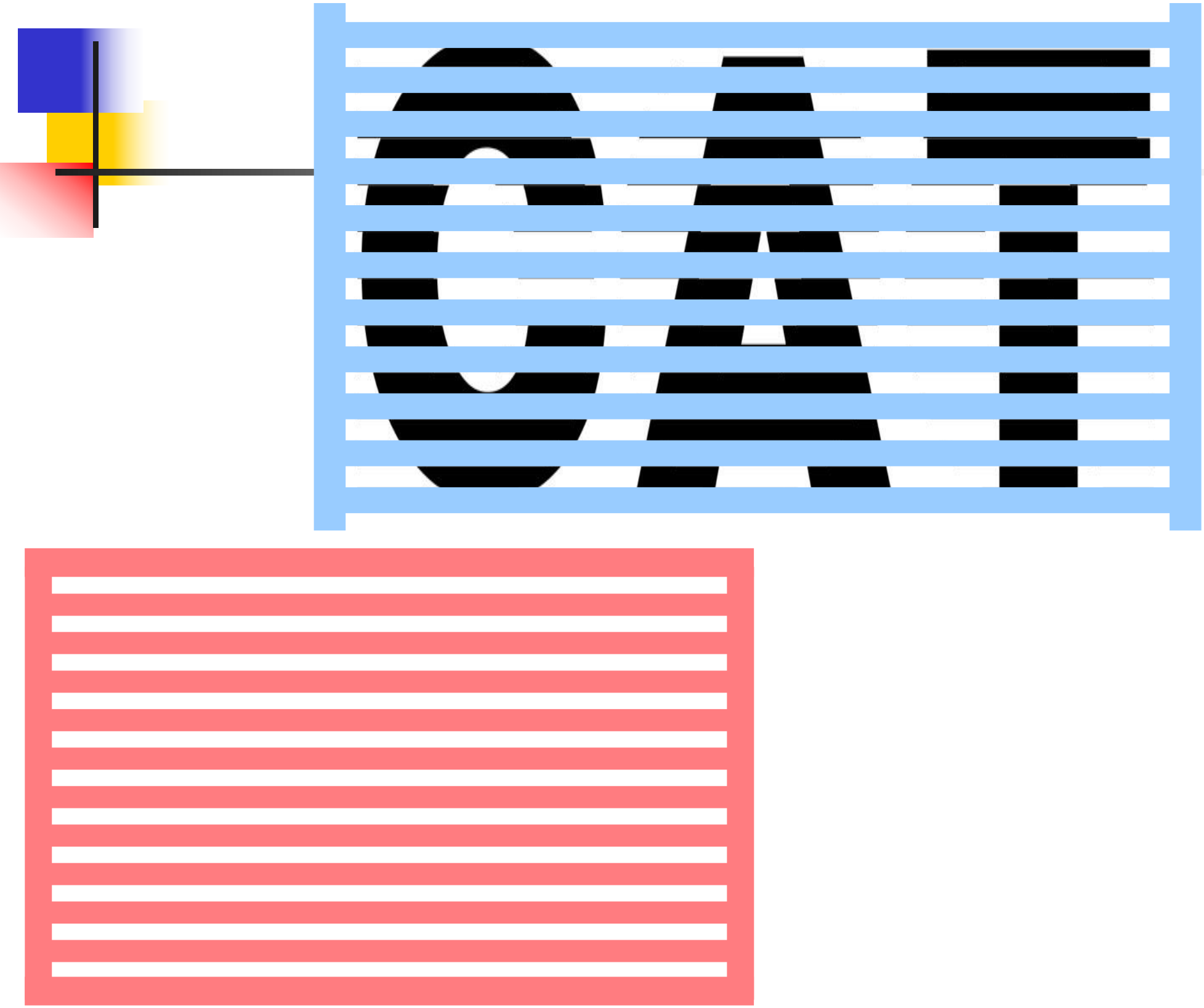
- Talking in a different language







Courtesy of Suresh Goyal & Rich Howard



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Courtesy of Suresh Goyal & Rich Howard

CDMA (2)
Code Division Multiple Access

- Concept
  - Chip, interval in each bit time
  - Chip sequence, a unique m-bit code assigned to each station
  - Chip sequence and complement, S and $\underline{S}$, express the value 1 or 0
  - Orthogonal
    - If S and T are two distinct chip sequence, then

      $\mathbf{S \cdot S = 1}$, $\mathbf{S \cdot \underline{S} = 0}$, $\mathbf{S \cdot T = 0}$, $\mathbf{S \cdot \underline{T} = 0}$

CDMA (3)

A: 0 0 0 1 1 0 1 1
B: 0 0 1 0 1 1 1 0
C: 0 1 0 1 1 1 0 0
D: 0 1 0 0 0 0 1 0

(a)

A: (–1 –1 –1 +1 +1 –1 +1 +1)
B: (–1 –1 +1 –1 +1 +1 +1 –1)
C: (–1 +1 –1 +1 +1 +1 –1 –1)
D: (–1 +1 –1 –1 –1 –1 +1 –1)

(b)

Six examples:

– – 1 –	**C**	$S_1 = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$
– 1 1 –	**B** + $\overline{\mathbf{C}}$	$S_2 = (-2\ \ 0\ \ 0\ \ 0\ +2\ +2\ \ 0\ -2)$
1 0 – –	**A** + $\overline{\mathbf{B}}$	$S_3 = (\ 0\ \ 0\ -2\ +2\ \ 0\ -2\ \ 0\ +2)$
1 0 1 –	**A** + **B** + **C**	$S_4 = (-1\ +1\ -3\ +3\ +1\ -1\ -1\ +1)$
1 1 1 1	**A** + **B** + **C** + **D**	$S_5 = (-4\ \ 0\ -2\ \ 0\ +2\ \ 0\ +2\ -2)$
1 1 0 1	**A** + **B** + $\overline{\mathbf{C}}$ + **D**	$S_6 = (-2\ -2\ \ 0\ -2\ \ 0\ -2\ +4\ \ 0)$

(c)

$S_1 \bullet C = (1 +1 +1 +1 +1 +1 +1 +1)/8 = 1$
$S_2 \bullet C = (2 +0 +0 +0 +2 +2 +0 +2)/8 = 1$
$S_3 \bullet C = (0 +0 +2 +2 +0 -2 +0 -2)/8 = 0$
$S_4 \bullet C = (1 +1 +3 +3 +1 -1 +1 -1)/8 = 1$
$S_5 \bullet C = (4 +0 +2 +0 +2 +0 -2 +2)/8 = 1$
$S_6 \bullet C = (2 -2 +0 -2 +0 -2 -4 +0)/8 = -1$

(d)

- Binary chip sequences for four stations
- Bipolar chip sequences
- Six examples of transmissions
- Recovery of station C's signal

CDMA(4)

- physical limitations reduce the capacity considerably.
  - Synchronize procedure will introduce random noise to other transmissions.
  - Power levels of all stations shall be same as perceived by the receiver.
  - Complicate , receiver listens to all the senders at once

2.6.3 Third-Generation Mobile Phones

- GPRS (General Packet Radio Service)
  - an overlay packet network on top of D-AMPS or GSM
  - allows stations to send and receive IP packets.
- Basic services an IMT-2000 network should provide
  - High-quality voice transmission
  - Messaging (replace e-mail, fax, SMS, chat, etc.)
  - Multimedia (music, videos, films, TV, etc.)
  - Internet access (web surfing, pages with multimedia.)
- W-CDMA
- CDMA2000
- TDS-CDMA

2.6.4 IMT-Advanced

- 定义：具有超过IMT-2000能力的新能力的移动系统。该系统能够提供广泛的电信业务：由移动和固定网络支持的日益增加的基于包传输的先进的移动业务
- 关键特性
  - 在保持成本效率的条件下，在支持灵活广泛的服务和应用的基础上，达到世界范围内的高度通用性；
  - 支持IMT业务和固定网络业务的能力；
  - 高质量的移动服务；
  - 用户终端适合全球使用；
  - 友好的应用、服务和设备；世界范围内的漫游能力；
  - 增强的峰值速率以支持新的业务和应用，例如多媒体（高移动性下支持100Mbps，低移动性下支持1Gbps）