Chapter 2

(Week 4)

The Physical Layer (continuation)

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COMPUTER NETWORKS
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PP. 118 - 177

Public Switched Telephone System (1/3)

- PSTN - Public Switched Telephone System
- PSTN was designed for transmitting the human voice in a more-or-less recognizable form.
- The network designers must rely on the existing telecommunication facilities.
- The use of PSTN in computer-computer communication is often marginal at best, but the situation is rapidly changing with the introduction of fiber optics and digital technology.

Public Switched Telephone System (2/3)

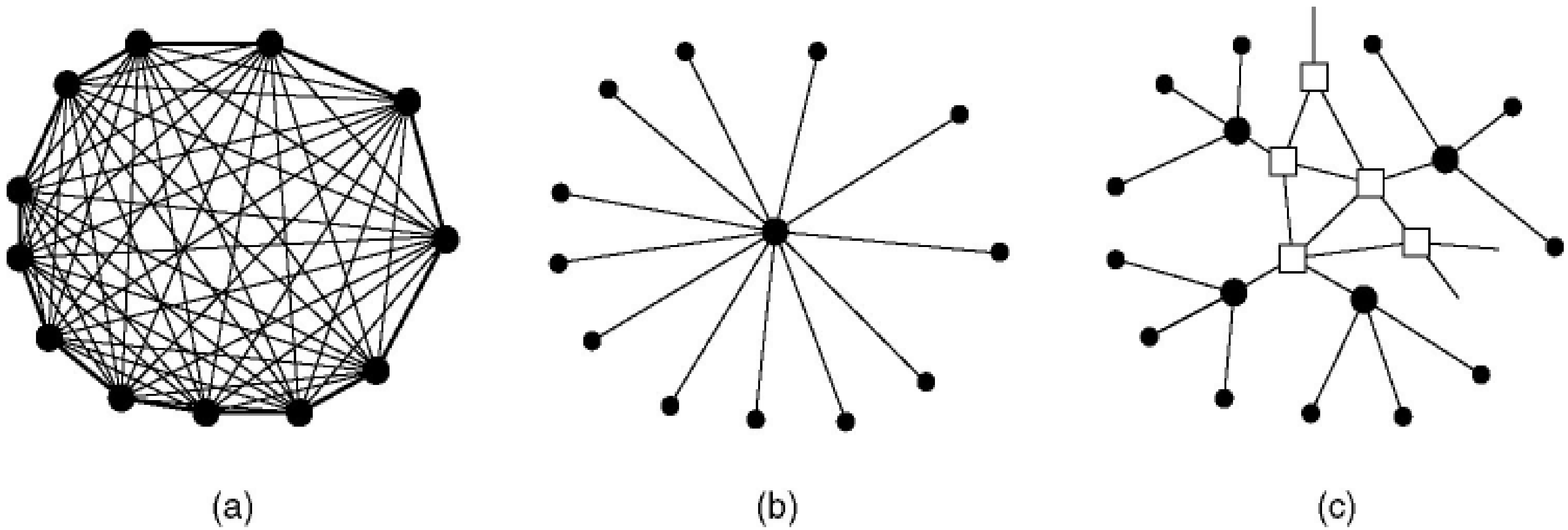
- Comparison of properties of a typical computer-computer connection via a local cable and via a dial-up telephone line:
- Cable running between two computers can transfer data at memory speeds, 10^8 to 10^9 bps. One error per day at these speeds is equivalent to one error per 10^{12} to 10^{13} bits sent.
- In contrast, a dial-up line has max. 10^4 bps and error rate of 1 bit per 10^5 bits sent.
- A difference of a factor of almost 20,000.
- With ADSL this is a factor of 1000-2000 difference

Public Switched Telephone System (3/3)

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

Structure of the Telephone System (1/5)

According to initial telephone architecture if a telephone owner wanted to talk to *n* other telephone owners, separate wires had to be strung to all *n* houses (a).

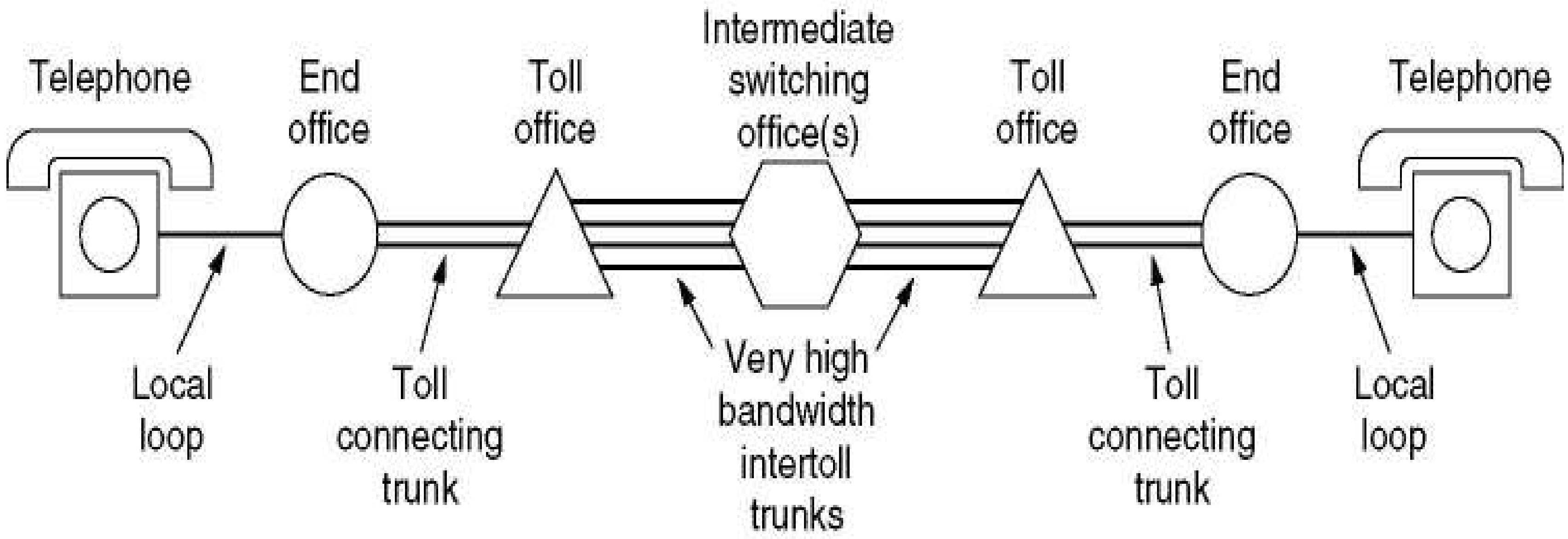


(a) Fully-interconnected network.

(b) Centralized switch.

(c) Two-level hierarchy.

Structure of the Telephone System (2/5)



A typical circuit route for a medium-distance call.

Structure of the Telephone System (3/5)

- Each telephone has two copper wires coming out of it that go directly to the telephone company's nearest end office (or local central office).
- The two-wire connections between each subscriber's telephone and the end office are known in the trade as the local loop.
- Each end office has a number of outgoing lines to one or more nearby switching centers, called toll offices (or if they are within the same local area, tandem office). These lines are called toll connecting trunks.

Structure of the Telephone System (4/5)

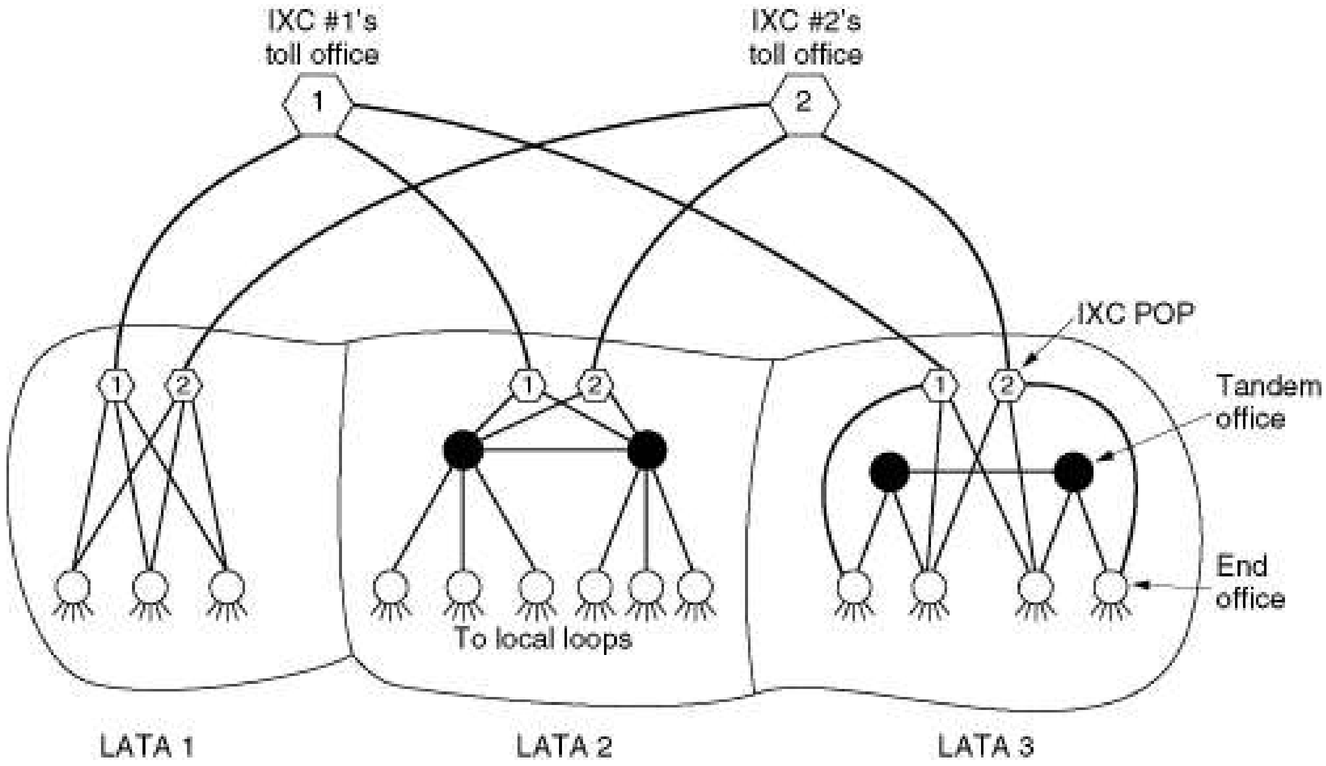
- If the caller and callee do not have a toll office in common, the path will have to be established somewhere higher up in the hierarchy.
- Primary, sectional, and regional offices form a network by which the toll offices are connected.
- The toll, primary, sectional, and regional exchanges communicate with each other via high-bandwidth intertoll trunks (also called interoffice trunks).

Structure of the Telephone System (5/5)

Major Components of the Telephone System

- Local loops
  - Analog twisted pairs going to houses and businesses
- Trunks
  - Digital fiber optics connecting the switching offices
- Switching offices
  - Where calls are moved from one trunk to another

The Politics of Telephones



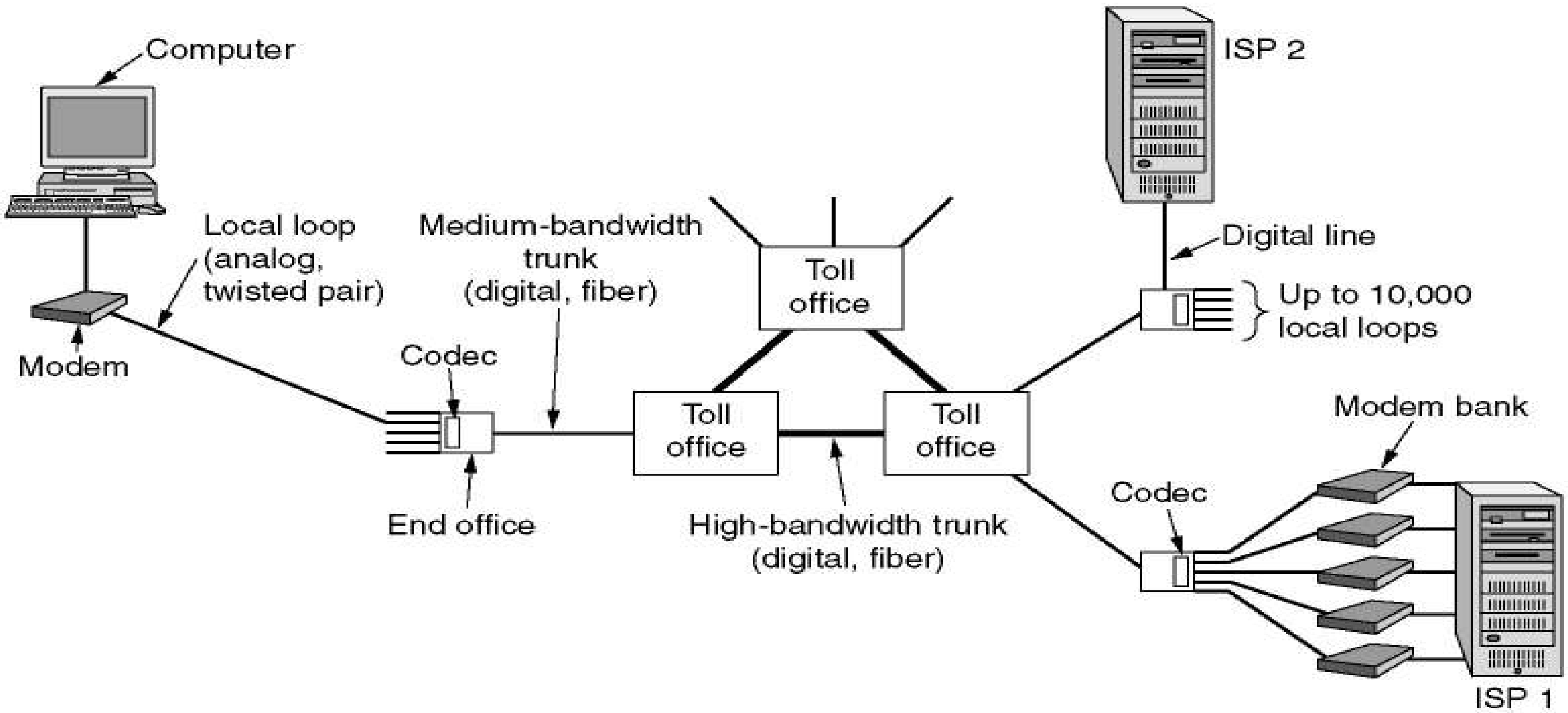
The relationship of LATAs (Local Access and Transport Areas), LECs (Local Exchange Carrier), and IXCs (IntereXchange C arrier). All the circles are LEC switching offices. Each hexagon belongs to the IXC whose number is on it. POP (Point of Presence)

The Local Loop: Modems, ADSL, and Wireless (1/4)

The working principle of the telephone system.

- When a computer wishes to send digital data over an analog dial-up line, the data must first be converted to analog form for transmission over the local loop by device called a modem.
- At the telephone company end office the data are converted to digital form for transmission over the long-haul trunks.

The Local Loop: Modems, ADSL, and Wireless (2/4)



The use of both analog and digital transmissions for a computer to computer call. Conversion is done by the modems and codecs.

The toll offices and end offices contain switching equipment that switches calls. An end office has up to 10,000 local loops.

The Local Loop: Modems, ADSL, and Wireless (3/4)

The working principle of the telephone system (cont.).

- If the other end is a computer with a modem, the reverse conversion – digital to analog - is needed to traverse the local loop at the destination.
- Analog signaling consists of varying a voltage with time to represent an information stream.
- Transmission lines suffer from three major problems: attenuation, delay distortion, and noise.

The Local Loop: Modems, ADSL, and Wireless (4/4)

- Attenuation is the loss of energy as the signal propagates outward. This loss is expressed in decibels per kilometer. The amount of energy lost depends on the frequency.
- The different Fourier components also propagate at different speeds in the wire. This speed difference leads to distortion of the signal received at the other end.
- Noise is unwanted energy from sources other than the transmitter (thermal noise, crosstalk noise, impulse noise).

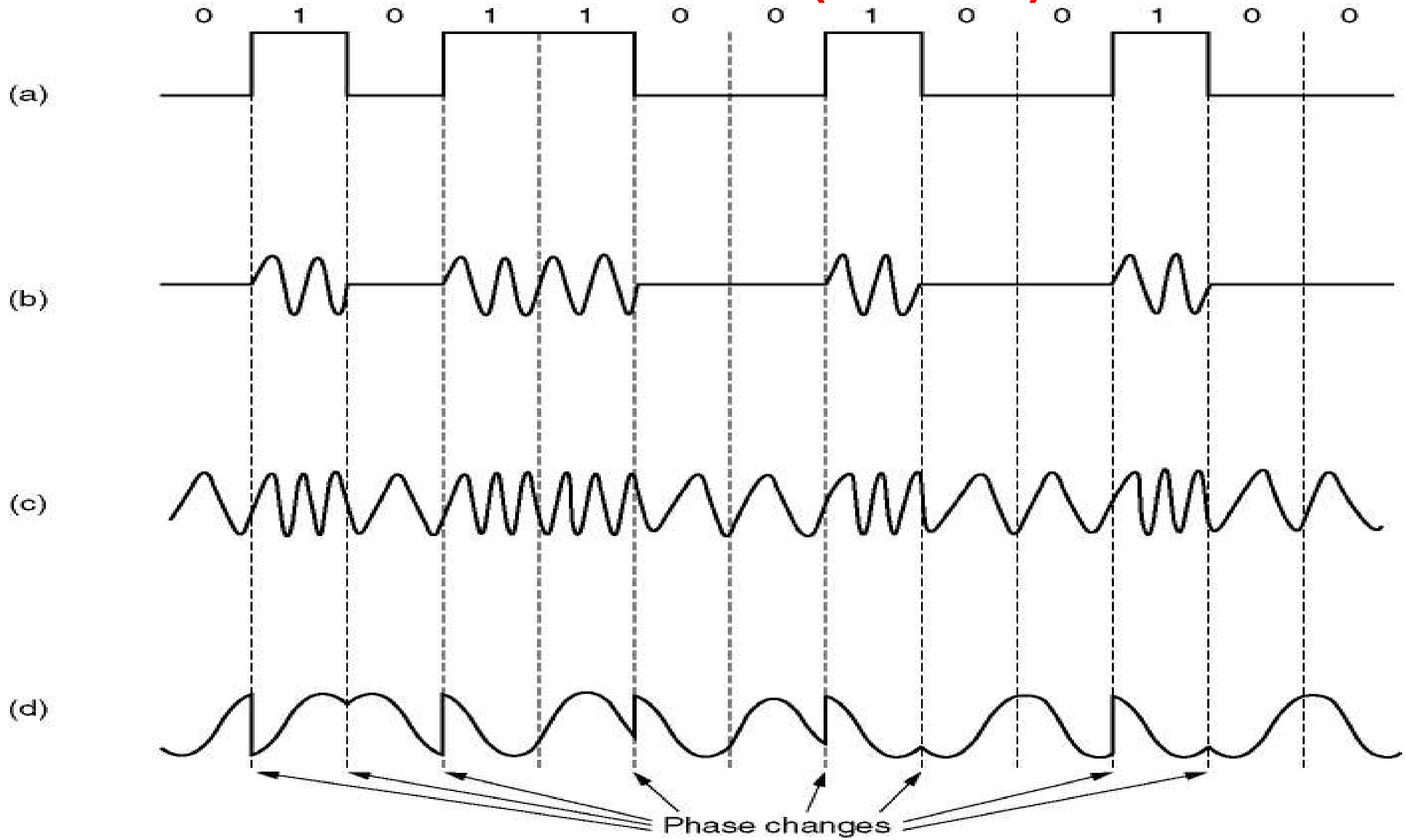
Modems (1/15)

- The fact that both attenuation and propagation speed are frequency dependent, it is undesirable to have a wide range of frequencies in the signal.
- Unfortunately, the square waves used in digital signals have a wide frequency spectrum and thus are subject to strong attenuation and delay distortion.
- To get around the problems associated with DC signaling, especially on telephone lines, AC signaling is used.

Modems (2/15)

- A continuous tone in the 1000 to 2000 Hz range, called a sine wave carrier, is introduced.
- Its amplitude, frequency, or phase can be modulated to transmit information.
- In amplitude modulation, two different amplitudes are used to represent 0 and 1, respectively.
- In frequency modulation, two or more different tones are used.
- In the simplest form of phase modulation, the carrier wave is systematically shifted 0 or 180 degrees at uniformly spaced intervals.

Modems (3/15)



(a) A binary signal

(b) Amplitude modulation

(c) Frequency modulation

(d) Phase modulation

Modems (4/15)

- A device that accepts a serial stream of bits as input and produces a carrier modulated by one (or more) of these methods (or vice versa) is called a modem (for modulator-demodulator).
- The modem is inserted between the (digital) computer and the (analog) telephone system.
- In practice, most modems sample 2400 times/sec and focus on getting more bits per sample.

Modems (5/15)

- Number of samples per second is measured in baud.
- During each baud, one symbol is sent. Thus, an *n*-baud line transmits *n* symbols / sec.
- For example, a 2400-baud line sends one symbol about every 416.667 μsec.
- If the symbol consists of 0 volts for a logical 0 and 1 volt for logical 1, the bit rate is 2400 bps.
- If however, the voltages 0,1,2,3 volts are used, every symbol consists of 2 bits, so a 2400-baud line can transmit 2400 symbols/sec. at 4800 bps.

Modems (6/15)

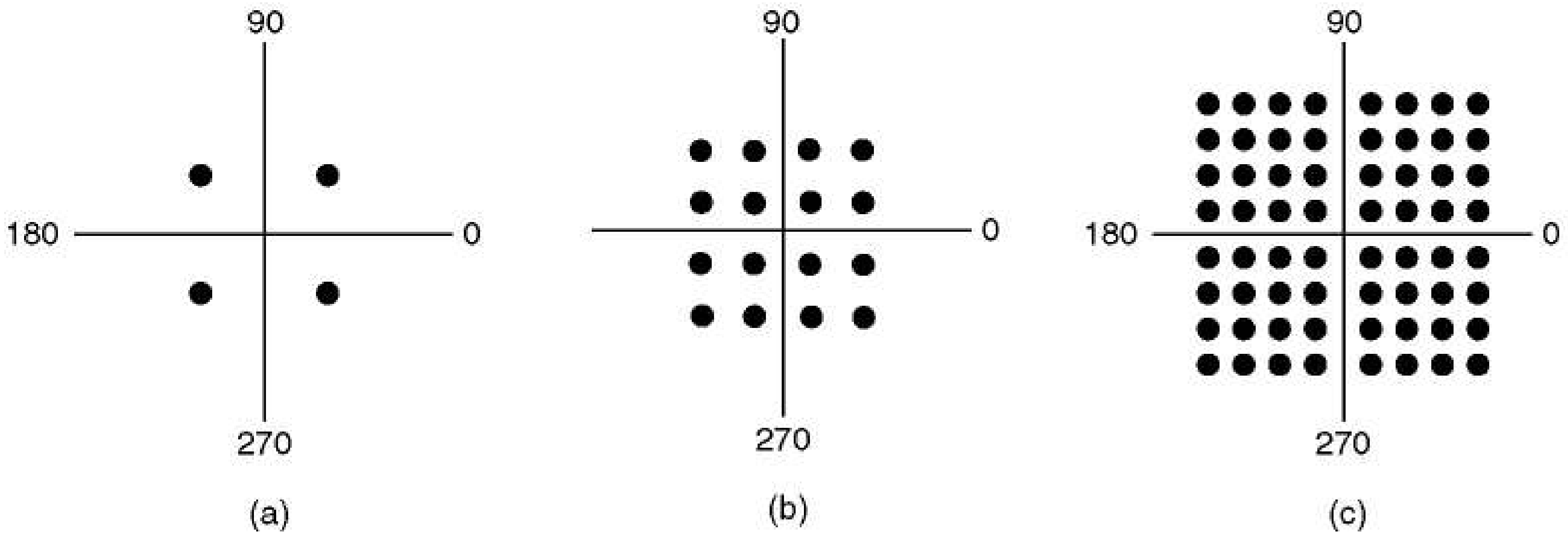
- QPSK (Quadrature Phase Shift Keying) is with four possible phase shifts, there are also 2 bits/symbol, so again here the bit rate is twice the baud rate.
- The concepts of bandwidth, baud, symbol, and bit rate are commonly confused.
- The bandwidth of a medium is the range of frequencies that pass through it with minimum attenuation. It is a physical property of the medium (usually from 0 to some maximum frequency) and measured in Hz.

Modems (7/15)

- The baud rate is the number of samples/sec made. Each sample sends one piece of information, that is, one symbol. The baud rate and symbol rate are thus the same. The modulation technique (e.g., QPSK) determines the number of bits/symbol.
- The bit rate is the amount of information sent over the channel and is equal to the number of symbols/sec times the number of bits/symbol.

Modems (8/15)

- All advanced modems use a combination of modulation techniques to transmit multiple bits per second.
- Often multiple amplitudes and multiple phase shifts are combined to transmit several bits/symbol.



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

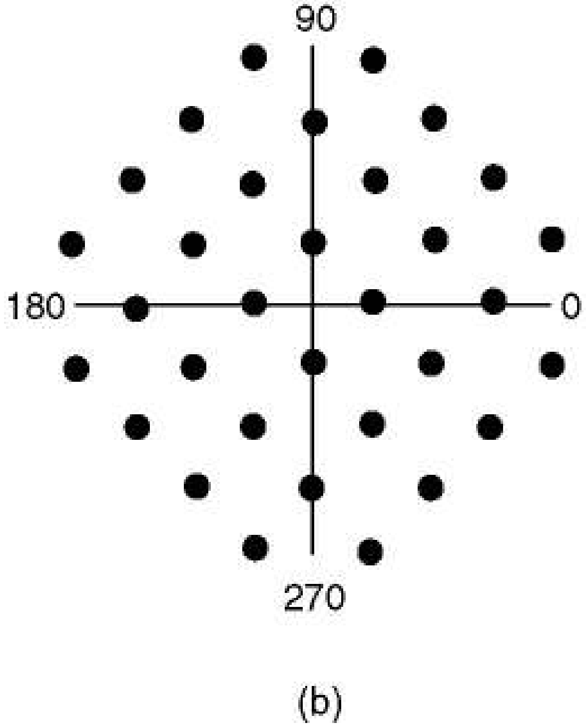
Modems (9/15)

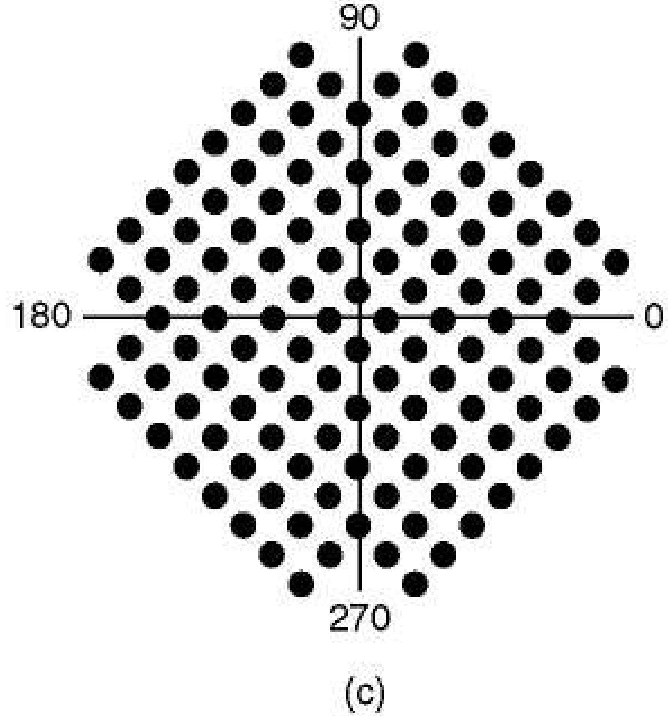
- QAM – Quadrature Amplitude Modulation
- QAM -16 can be used, for example, to transmit 9600 bps over a 2400-baud line.
- QAM -64 allows 64 different combinations, so 6 bits can be transmitted per symbol.
- Higher order QAMs also are used.

Modems (10/15)

- Diagrams which show the legal combinations of amplitude and phase, are called constellation diagrams (see slide 22).
- With many points in the constellation pattern, even a small amount of noise in the detected amplitude or phase can result in an error and, potentially, many bad bits.
- TCM (Trellis Coded Modulation) schemes corrects errors by adding extra bits to each sample.

Modems (11/15)





(a) V.32 for 9600 bps

(b) V32 bis for 14,400 bps

Modems (12/15)

- V.32 for 9600 bps: this standard uses 32 constellation points to transmit 4 data bits and 1 parity bit per symbol at 2400 baud to achieve 9600 bps with error correction.
- V32 bis for 14,400 bps: this speed is achieved by transmitting 6 data bits and 1 parity bit per sample at 2400 baud. When QAM-128 is used the constellation pattern has 128 points.
- Fax modems use QAM-128 speed to transmit pages that have been scanned in as bit maps.

Modems (13/15)

- QAM-128 is not used in any standard telephone modems, but it is used on cable networks.
- V.34 runs at 28,800 bps at 2400 baud with 12 data bits/symbol.
- V.34 bis is final modem which uses 14 data bits/symbol at 2400 baud to achieve 33,600 bps.
- To increase the effective data rate further, many modems compress the data before transmitting it, to get an effective data rate higher than 33,600 bps.

Modems (14/15)

- All modern modems allow traffic in both directions at the same time (by using different frequences for different directions).
- A connection that allows traffic in both directions simultaneously is called full duplex.
- A connection that allows traffic either way, but only way at a time is called half duplex.
- A connection that allows traffic only one way is called simplex.

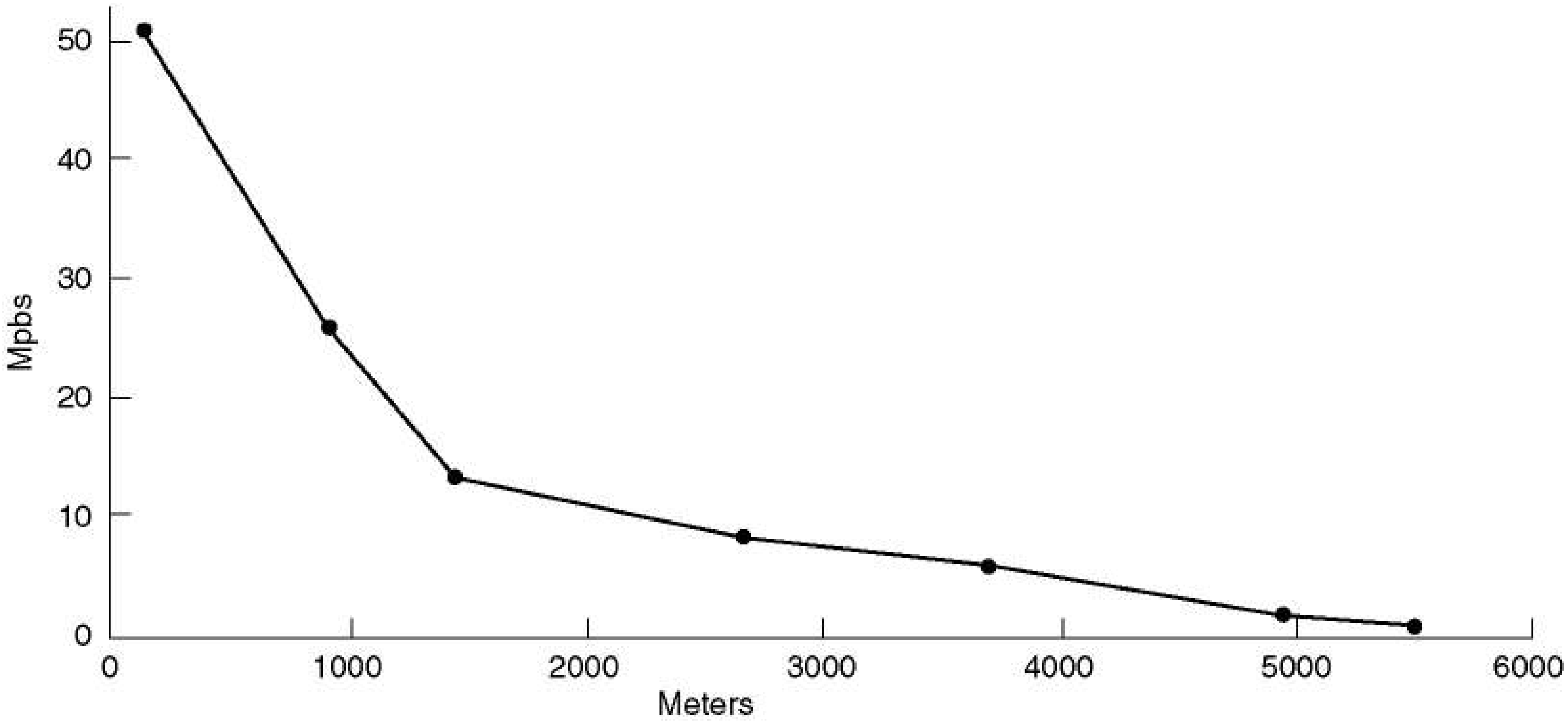
Modems (15/15)

- The modem standard V.90 provides for a 33.6 – kbps upstream channel (user to ISP), but a 56 kbps downstream channel (ISP to user).
- The modem standard V.92 provides a 48 kbps on the upstream channel if the line can handle it.
- Finally, they allow an incoming telephone call to interrupt an Internet session, provided that the line has call waiting service.

Digital Subscriber Lines (1/9)

- Services with more bandwidth than standard telephone service are sometimes called broadband.
- xDSL (Digital Subscriber Line) for various x is the services which provide broadband.
- ADSL (Asymmetric DSL).
- The capacity of the local loop depends on several factors, including its length, tickness, and general quality.

Digital Subscriber Lines (2/9)



Bandwidth versus distanced over category 3 UTP for DSL.

Digital Subscriber Lines (3/9)

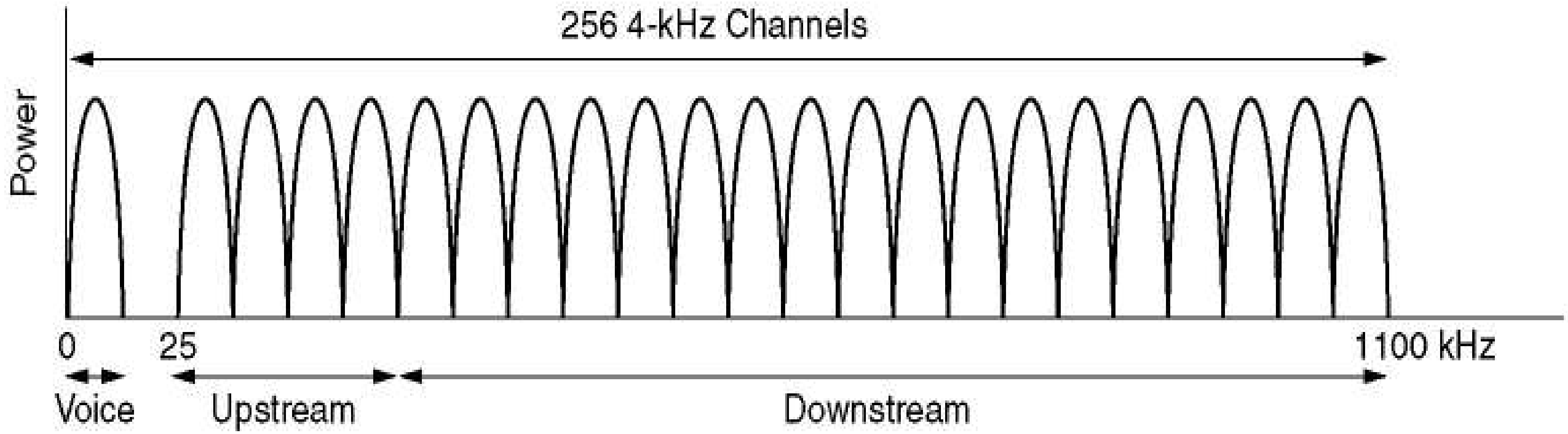
Goals of the xDSL services:

1. The services must work over the existing category 3 twisted pair local loops.
2. They must not affect customers' existing telephones and fax machines.
3. They must be much faster than 56 kbps.
4. They should be always on, with just a monthly charge but no per-minute charge.

Digital Subscriber Lines (4/9)

- The initial ADSL worked by dividing the spectrum available on the local loop, which is about 1.1 MHz, into three frequency bands: POTS (Plain Old Telephone Service) upstream (user to end office) and downstream (end office to user). The technique of having multiple frequency bands is called frequency division multiplexing.
- The alternative approach is called DMT (Discrete MultiTone).

Digital Subscriber Lines (5/9)



- Operation of ADSL using discrete multitone modulation.

Spectrum on the local loop is 1.1 MHz and is divided into 256 independent channels of 4312,5 Hz each.

- Channel 0 is used for POTS.
- Channels 1-5 are not used, to keep the voice signal and data signals from interfering with each other.

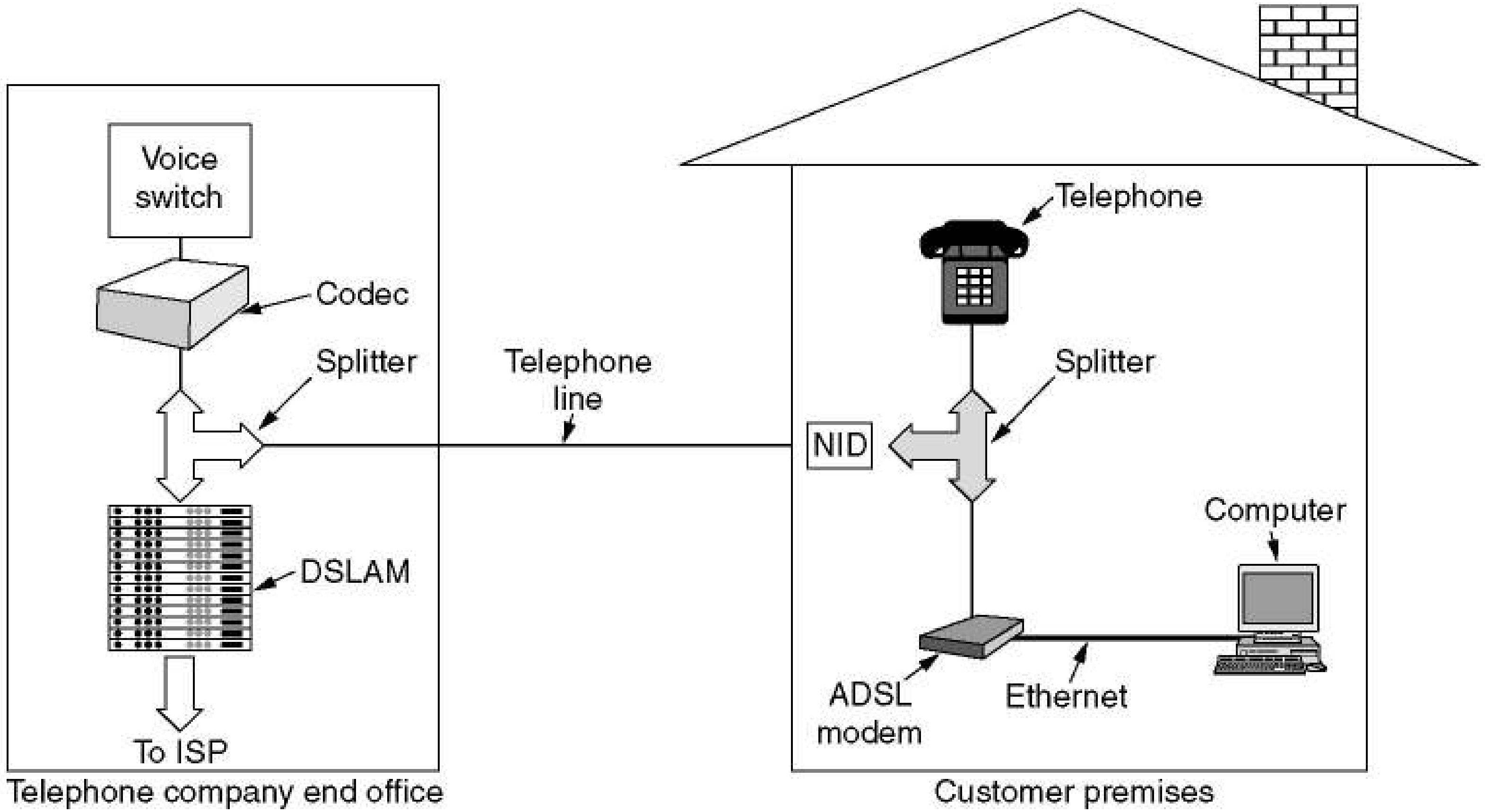
Digital Subscriber Lines (6/9)

- The ADSL standard allows speeds of as much as 8 Mbps downstream and 1 Mbps upstream. Few providers offer this speed.
- Typically, providers offer 512 kbps downstream and 64 kbps upstream (standard service) and 1 Mbps downstream and 256 kbps upstream (premium service).
- The actual data are sent with QAM modulation, with up to 15 bits per baud.

Digital Subscriber Lines (7/9)

- NID (Network Interface Device) is a small plastic box which marks the end of the telephone company's property and the start of the customer's property.
- Splitter is an analog filter that separates the 0-4000 Hz band used by POTS from the data. The POTS signal is routed to the existing telephone or fax machine, and the data signal is routed to an ADSL modem.

Digital Subscriber Lines (8/9)



A typical ADSL equipment configuration.

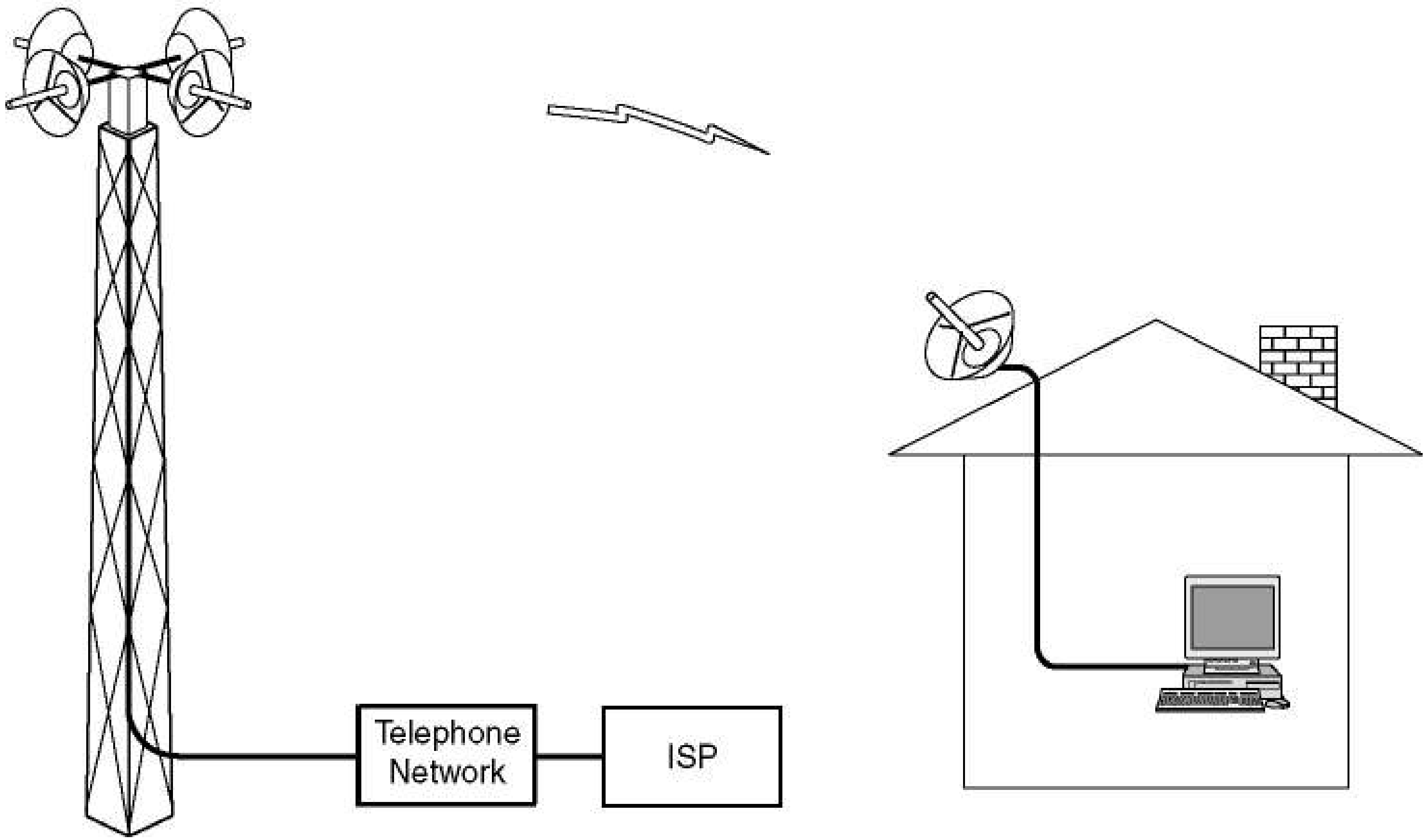
Digital Subscriber Lines (9/9)

- At the end office side the voice portion of the signal is filtered out and sent to the normal voice switch.
- The signal above 26 kHz is routed to a new kind of device called a DSLAM (Digital Subscriber Line Access Multiplexer), which contains the same kind of digital signal processor as the ADSL modem.
- ADSL is just a physical layer standard.

Wireless Local Loops (1/3)

- A cheaper alternative to the traditional twisted-pair local loop is the WLL (Wireless Local Loop).
- Fixed wireless local telephone and Internet service run by CLEC (Competitive LEC) over wireless local loops.
- MMDS (Multichannel Multipoint Distribution Service) is for WLL, spectrum is 198 MHz (low bandwidth), a range is about 50km, can penetrate vegetation and rain moderately well.
- LMDS (Local Multipoint Distribution Service), spectrum is 1,3 GHz, perspective is about 40 GHz.

Wireless Local Loops (2/3)



Architecture of an LMDS system.

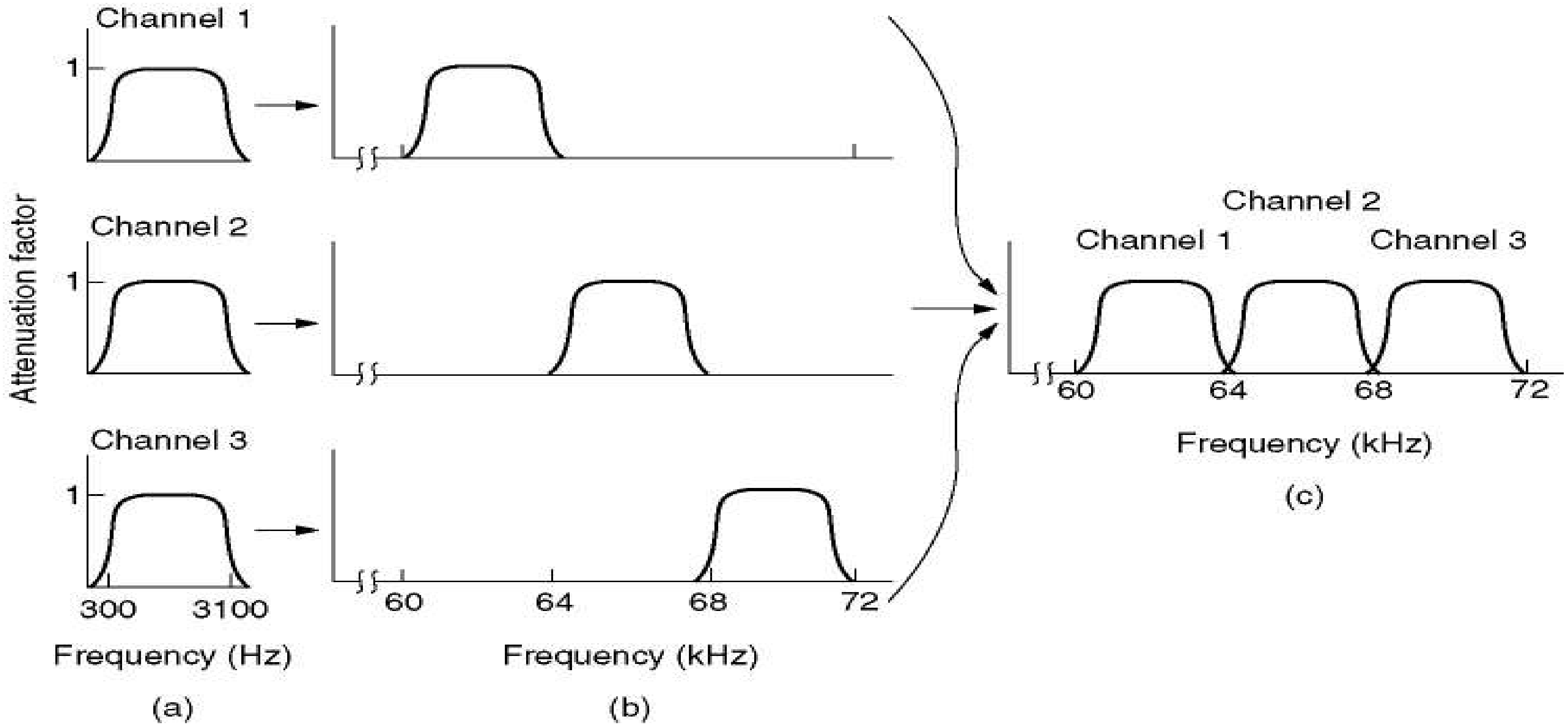
Wireless Local Loops (3/3)

- Like ADSL, LMDS uses an asymmetric bandwidth allocation favoring the downstream channel.
- With current technology, each sector can have 36 Gbps downstream and 1 Mbps upstream, shared among all the users in that sector.
- If each active user downloads three 5-KB pages per minute, the user is occupying an average of 2000bps of spectrum, which allows a maximum of 1800 active users per sector within a 5-km radius.

Trunks and Multiplexing

- Telephone companies have developed elaborate schemes for multiplexing many conversations over a single physical trunk.
- FDM (Frequency Division Multiplexing), with this technique the frequency spectrum is divided into frequency bands, with each user having exclusive possession of some band.
- TDM (Time Division Multiplexing), with this technique the users take turns (in a round-robin fashion), each one periodically getting the entire bandwidth for a little burst of time.

Frequency Division Multiplexing (1/2)



(a) The original bandwidths.

(b) The bandwidths raised in frequency.

(c) The multiplexed channel.

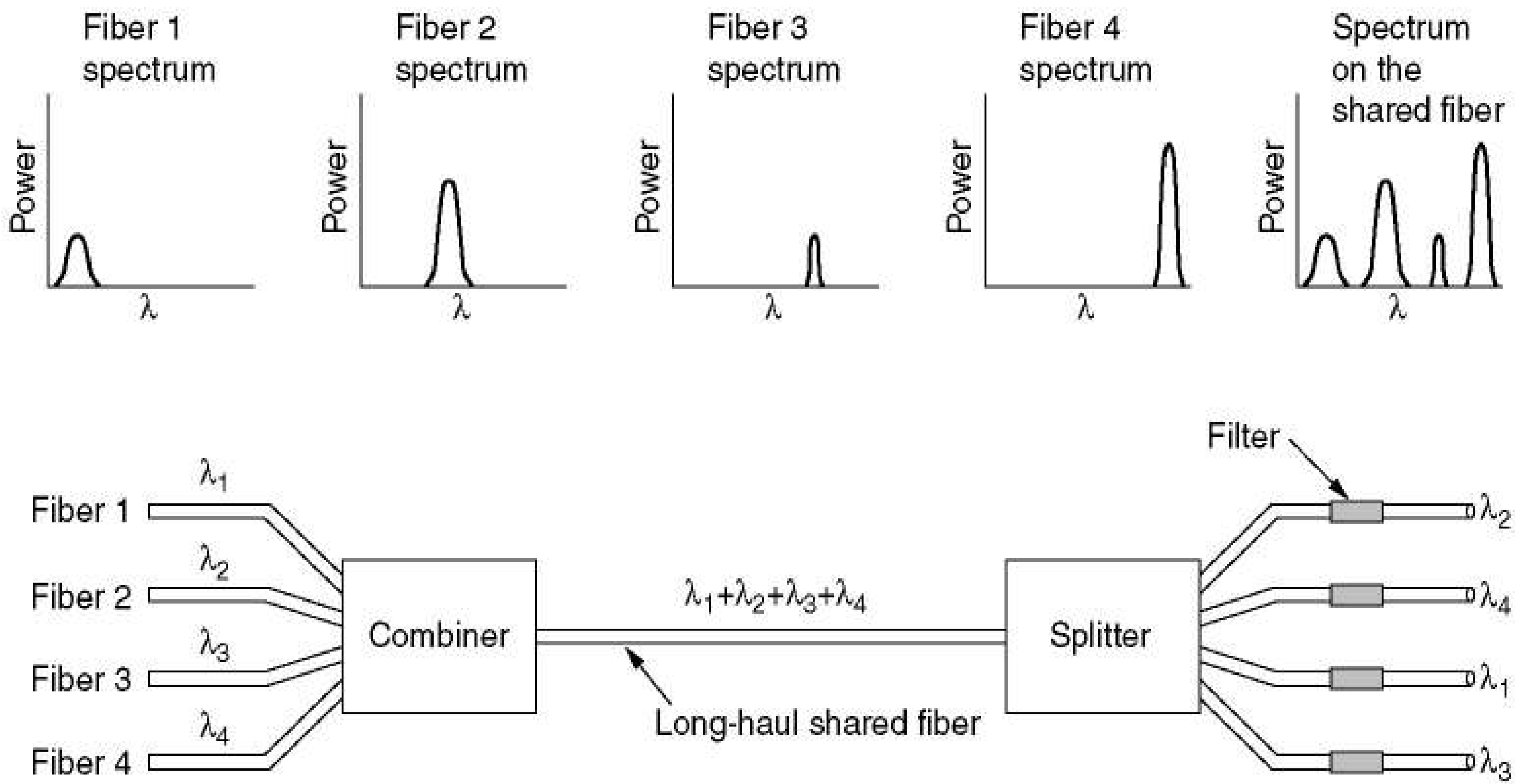
Trunks and Multiplexing (2/2)

- A widespread FDM standard is twelve 4000-Hz voice channels multiplexed into the 60 to 108 KHz band. This unit is called a group.
- Five groups (60 voice channel) can be multiplexed to form a supergroup.
- The next unit is the mastergroup, which is five supergroups (CCITT standard) or ten supergroups (Bell system).
- Other standards of up to 230,000 voice channels also exist.

Wavelength Division Multiplexing(1/2)

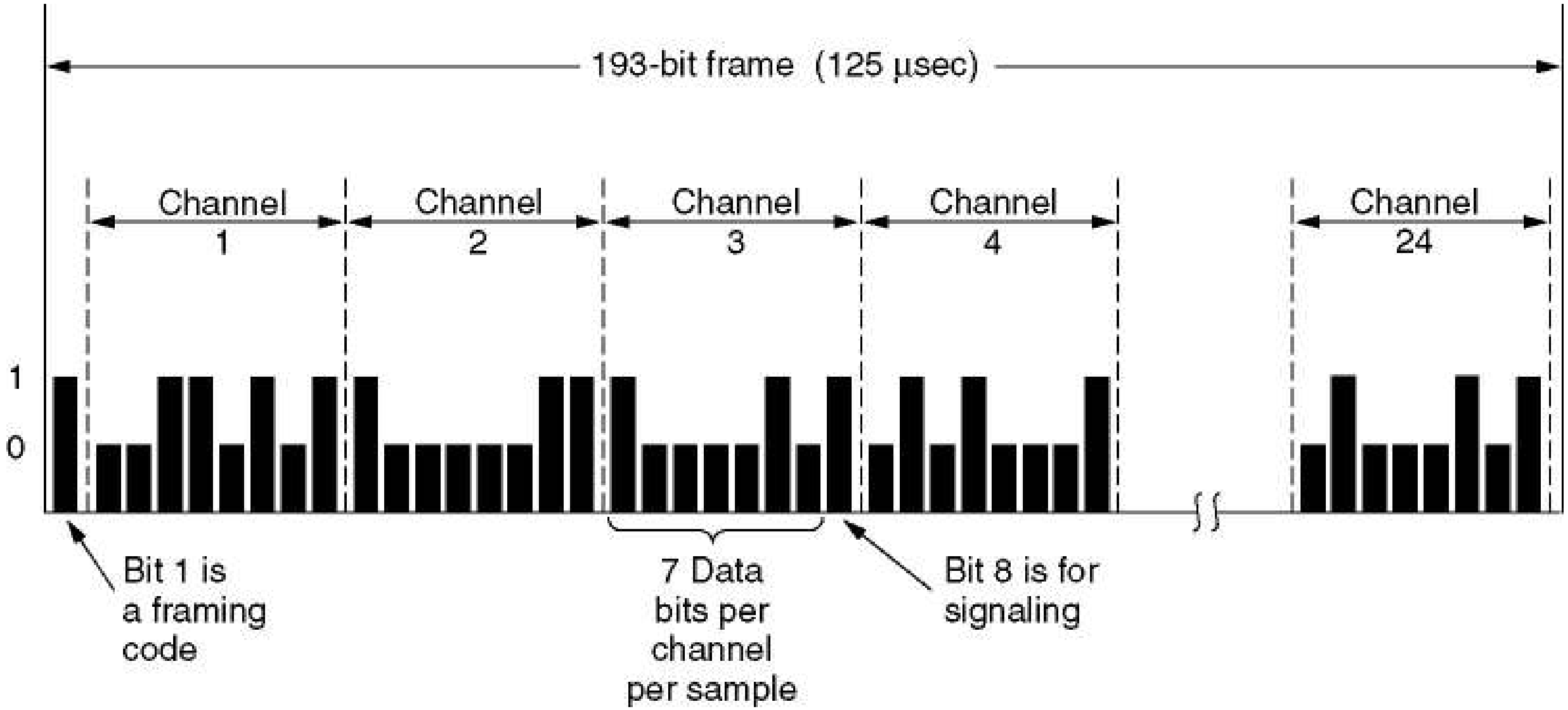
- For fiber optic channels, a variation of frequency division multiplexing is used.
- WDM (Wavelength Division Multiplexing)
- The difference with electrical FDM is that an optical system using a diffraction grating is completely passive and thus highly reliable.
- The first systems had 8 channels of 2.5 Gbps per channel
- In 1998 – 40 channels of 2.5 Gbps per channel
- By 2001, 96 channels of 10 Gbps per channel

Wavelength Division Multiplexing(2/2)



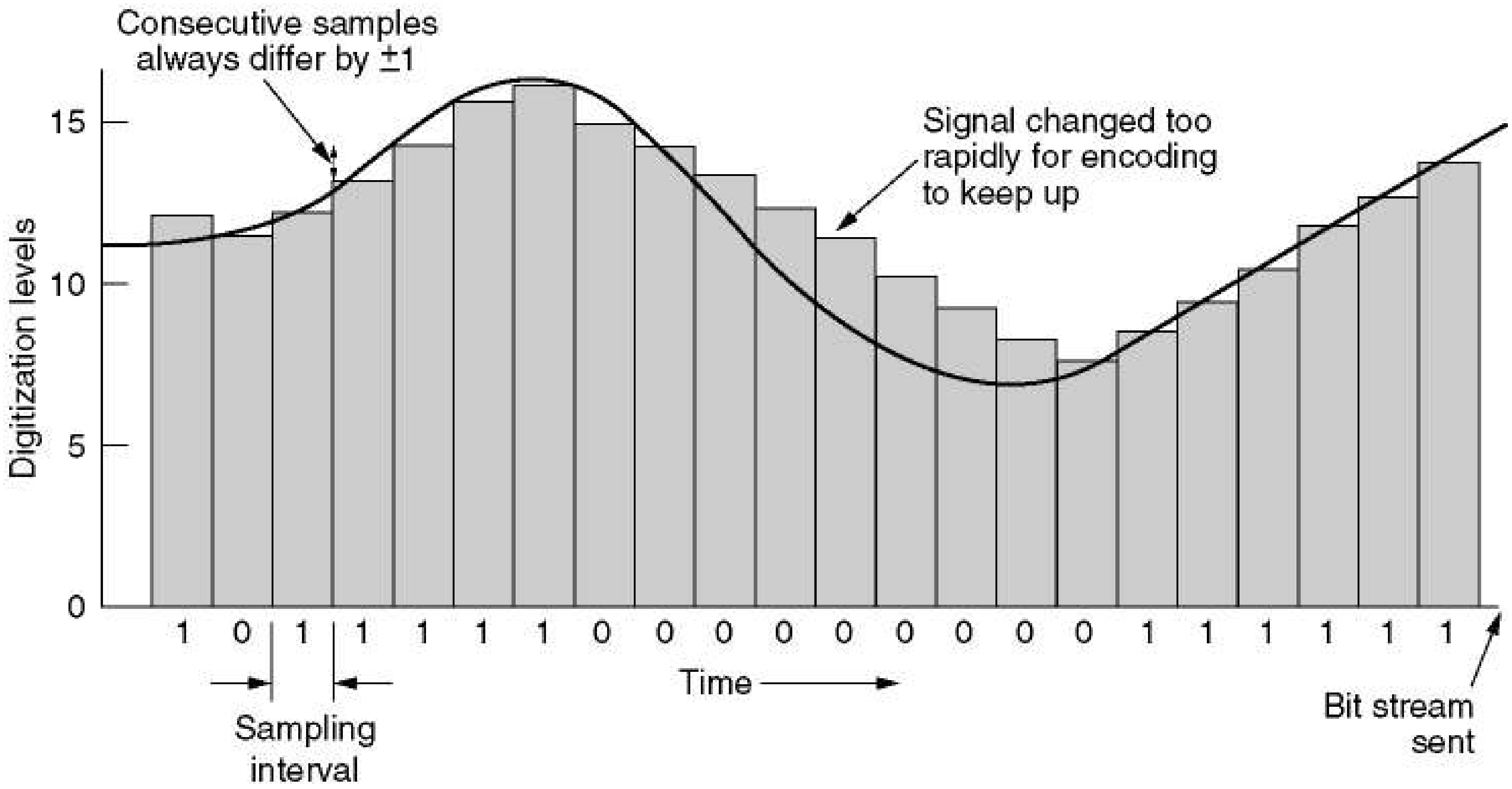
Wavelength division multiplexing.

Time Division Multiplexing



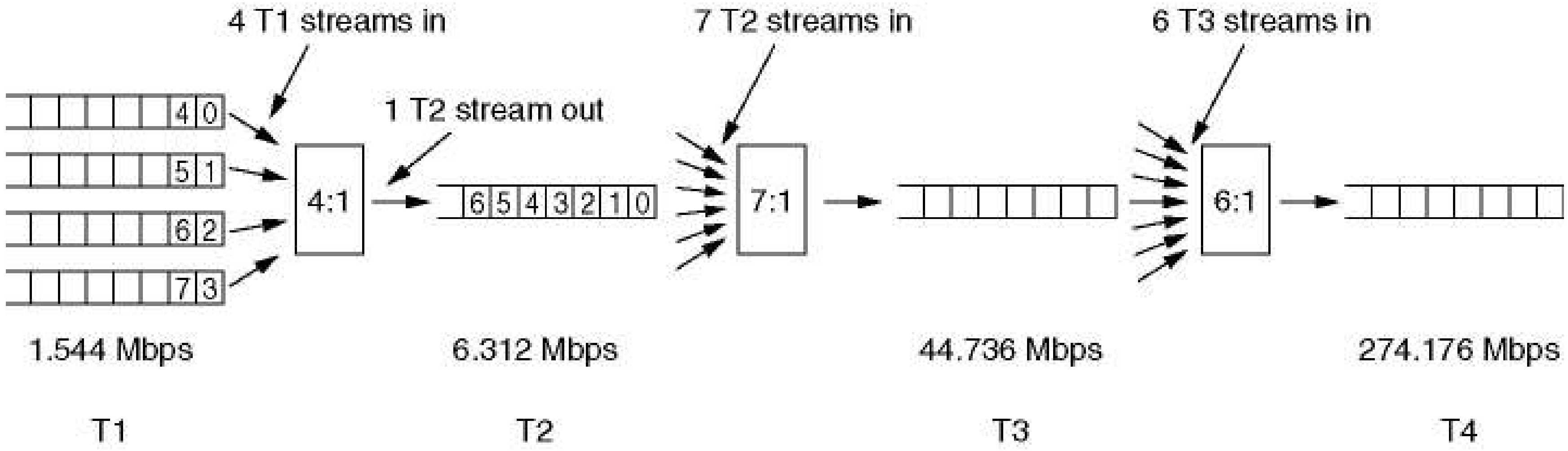
The T1 carrier (1.544 Mbps).

Time Division Multiplexing (2)



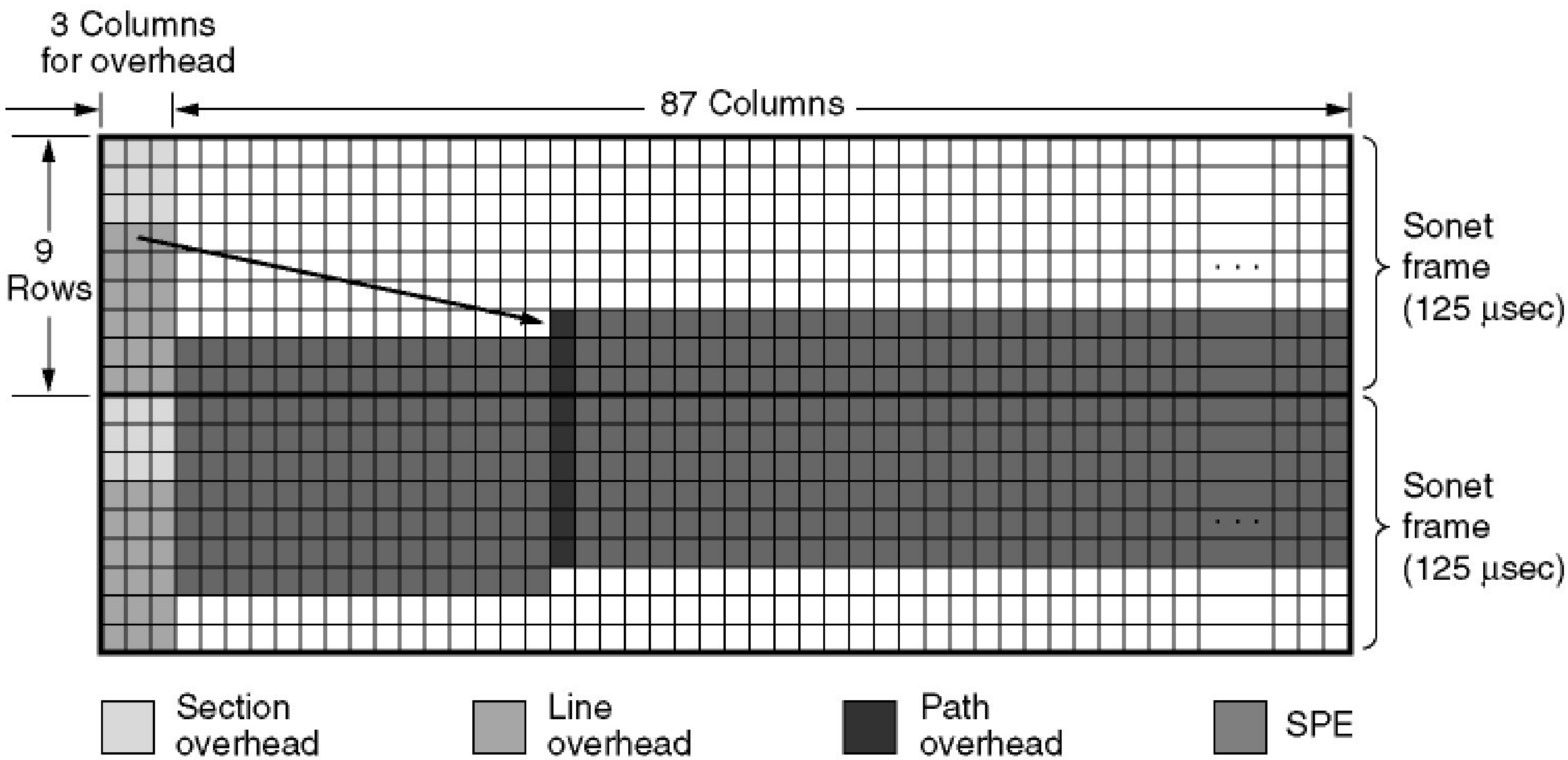
Delta modulation.

Time Division Multiplexing (3)



Multiplexing T1 streams into higher carriers.

Time Division Multiplexing (4)



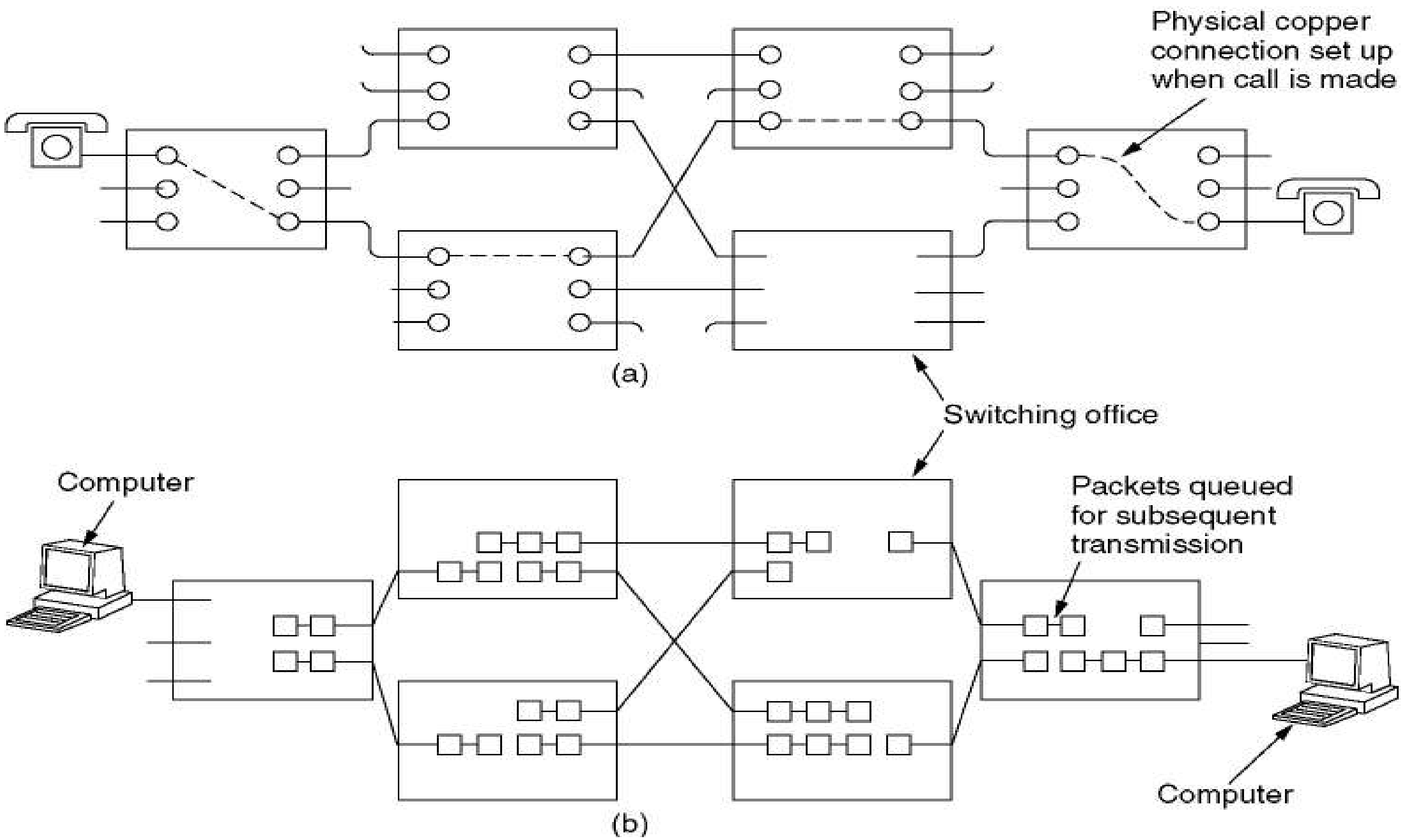
Two back-to-back SONET frames.

Time Division Multiplexing (5)

SONET		SDH	Data rate (Mbps)		
Electrical	Optical	Optical	Gross	SPE	User
STS-1	OC-1		51.84	50.112	49.536
STS-3	OC-3	STM-1	155.52	150.336	148.608
STS-9	OC-9	STM-3	466.56	451.008	445.824
STS-12	OC-12	STM-4	622.08	601.344	594.432
STS-18	OC-18	STM-6	933.12	902.016	891.648
STS-24	OC-24	STM-8	1244.16	1202.688	1188.864
STS-36	OC-36	STM-12	1866.24	1804.032	1783.296
STS-48	OC-48	STM-16	2488.32	2405.376	2377.728
STS-192	OC-192	STM-64	9953.28	9621.504	9510.912

SONET and SDH multiplex rates.

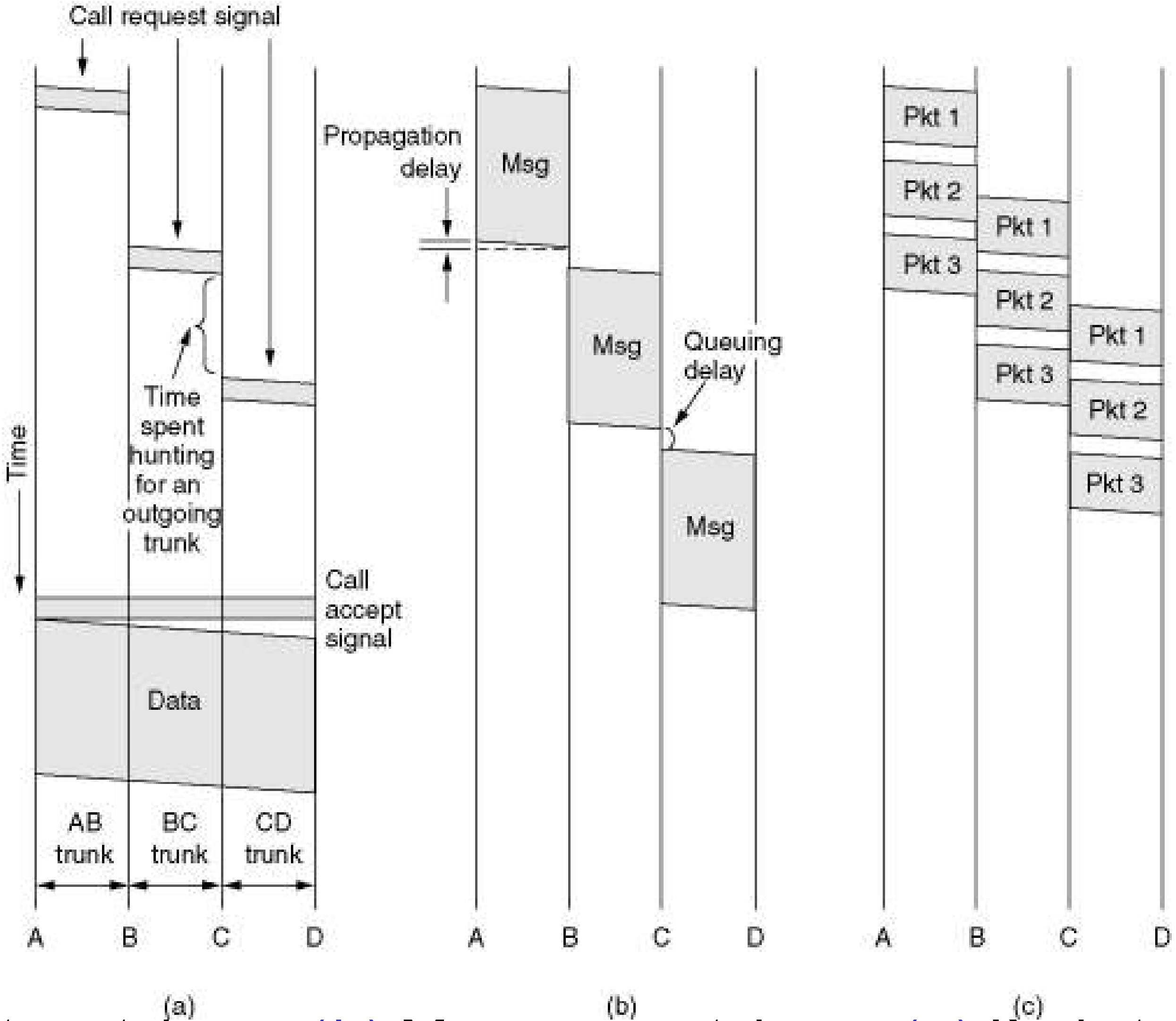
Circuit Switching



(a) Circuit switching.

(b) Packet switching.

Message Switching



(a) Circuit switching (b) Message switching (c) Packet switching

Packet Switching

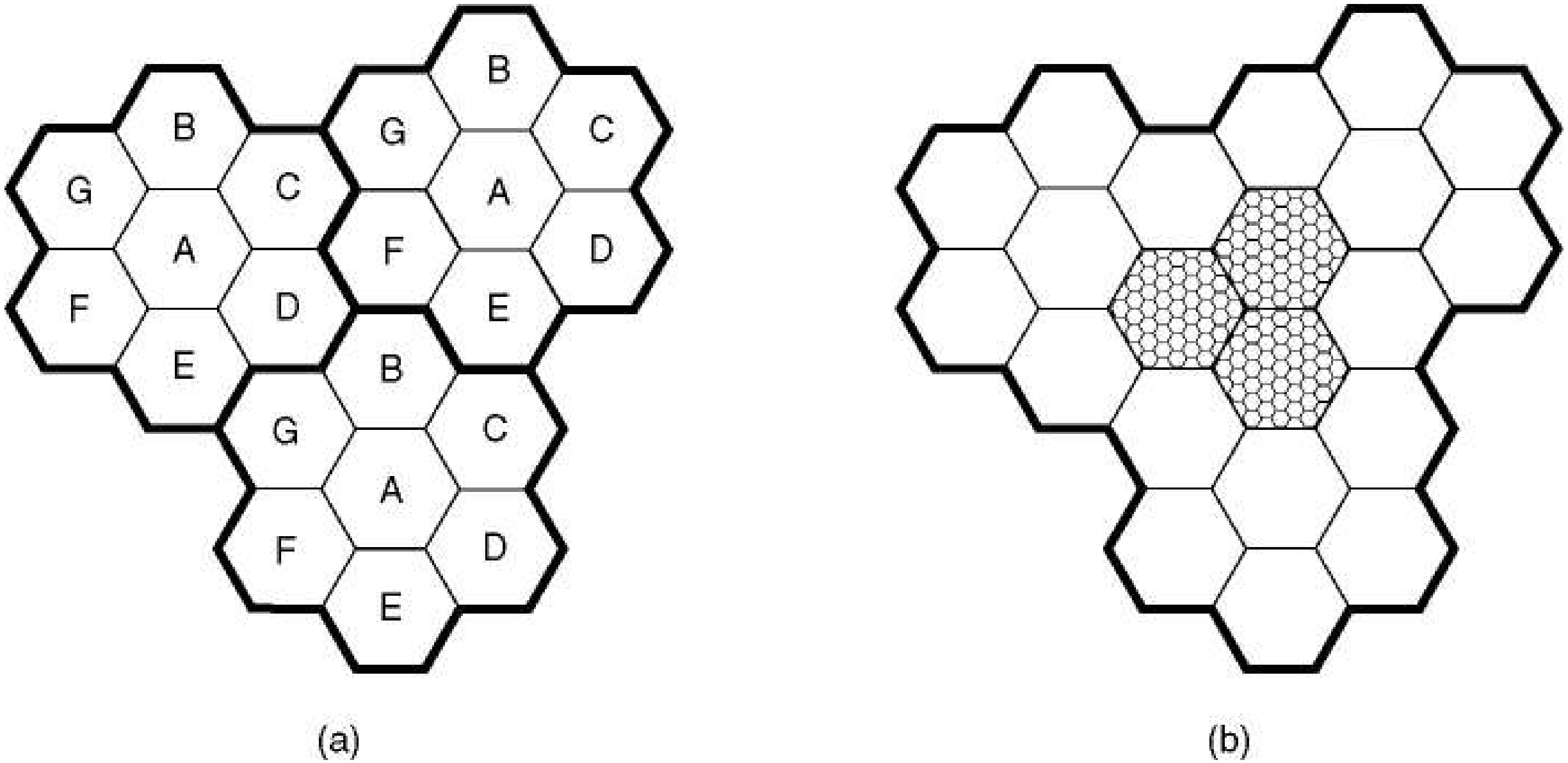
Item	Circuit-switched	Packet-switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
When can congestion occur	At setup time	On every packet
Potentially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

A comparison of circuit switched and packet-switched networks.

The Mobile Telephone System

- First-Generation Mobile Phones: Analog Voice (1G)
- Second-Generation Mobile Phones: Digital Voice (2G)
- Third-Generation Mobile Phones: Digital Voice and Data (3G)

Advanced Mobile Phone System



(a) Frequencies are not reused in adjacent cells.

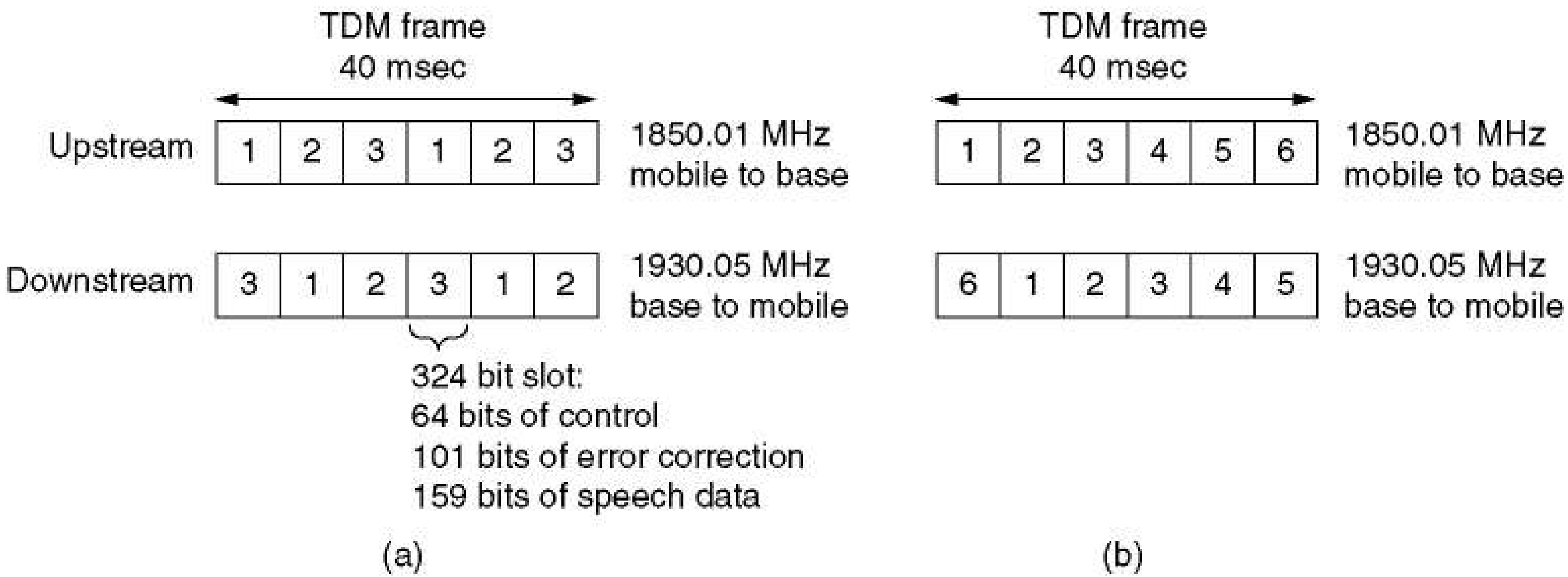
(b) To add more users, smaller cells can be used.

Channel Categories

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

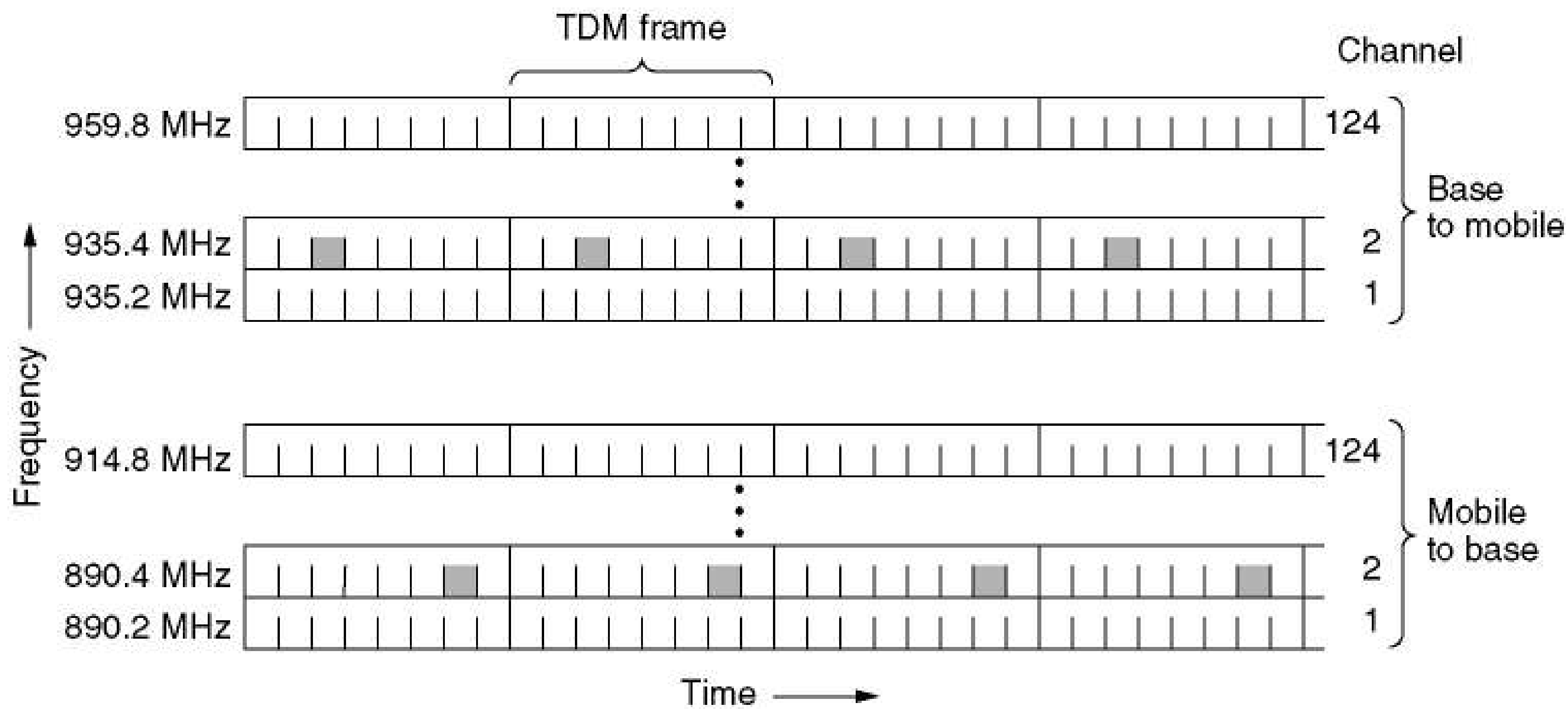
D-AMPS
Digital Advanced Mobile Phone System



(a) A D-AMPS channel with three users.

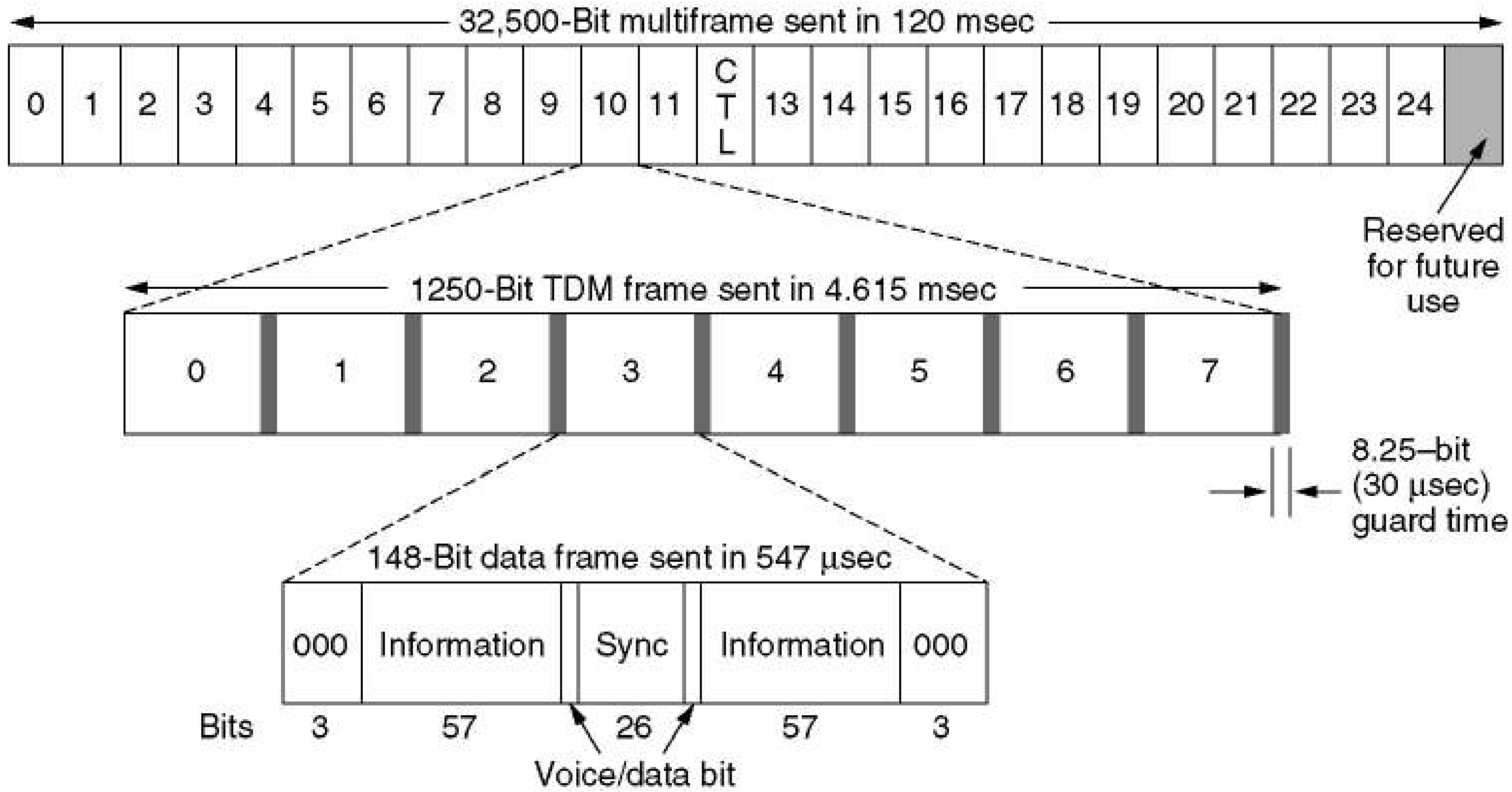
(b) A D-AMPS channel with six users.

GSM
Global System for Mobile Communications



GSM uses 124 frequency channels, each of which uses an eight-slot TDM system

GSM (2)



A portion of the GSM framing structure.

GSM
Global System for Mobile Communications

Gelecek Nesil: 4G GSM Hizmeti

Global System for Mobile Communications veya kısaca **GSM** (*Mobil İletişim İçin Küresel Sistem*), bir cep telefonu iletişim protokolüdür. En yaygın olan cep telefonu standardı olarak 212 ülkede 2 milyardan fazla insan tarafından kullanılmaktadır. En kullanışlı özelliklerinden birisi kullanıcıların aynı hat ile değişik ülkelerden görüşme (***roaming)*** yapabilmeleridir. Tüm GSM standartları, hücresel ağ kullanır ve dolaşım sırasında bile hücreler arası geçiş yapma kabiliyetine sahiptir.

CDMA – Code Division Multiple Access

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

(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)

(a) Binary chip sequences for four stations
(b) Bipolar chip sequences
(c) Six examples of transmissions
(d) Recovery of station C's signal

Third-Generation Mobile Phones: Digital Voice and Data

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, w/multimedia.)

Third-Generation Mobile Phones: Digital Voice and Data

3. Nesil GSM Hizmetleri (**3G** ya da **3N**) üçüncü nesil kablosuz telefon teknolojilerine verilen genel addır.

3G teknolojilerine örnek olarak ***U**niversal **M**obile **T**elecommunications **S**ystem* (yani *Evrensel Mobil İletişim Sistemi*) anlamına gelen UMTS verilebilir.

Bunun yanında Kuzey Amerika'da kullanılan CDMA2000 ve Japonya'da ***F**reedom **o**f Mobile **M**ultimedia **A**ccess* (*Mobil Çoklu Ortam Erişimine Özgürlük*) anlamına gelen FOMA standardları da bir 3G teknolojisidir.

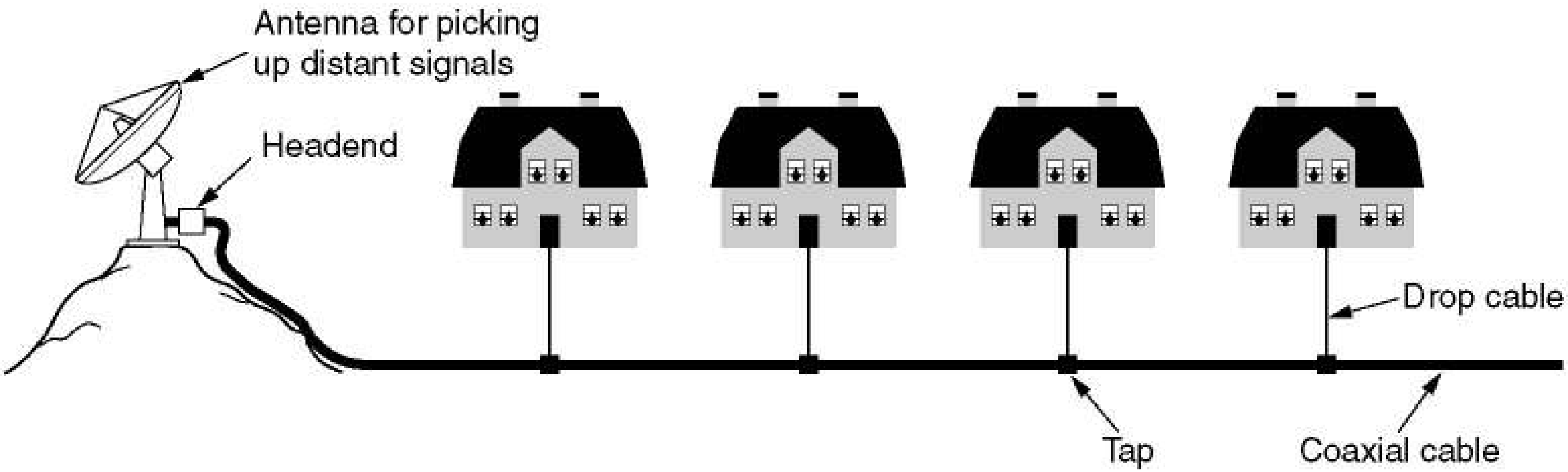
UMTS klasik frekans veya zaman çoklu iletişim (multiple access) tekniklerinden prensip olarak çok farklı olan kod çoklu iletişim CDMA (Code Division Multiple Access) teknolojisini kullanır.

3G'nin 2G'ye göre getirmiş olduğu en büyük yenilik taban olarak alınan verinin ses değil sayısal veri olmasıdır. Buna ek olarak, 3G sisteminde cihazlar bant genişliğini sadece veri alışverişi sırasında işgal ederler. İlk örnekleri Japonya'da 1998 yılında kullanıma açılan bu teknoloji, 2003'ten itibaren Avrupa'ya da gelmiştir.

Cable Television

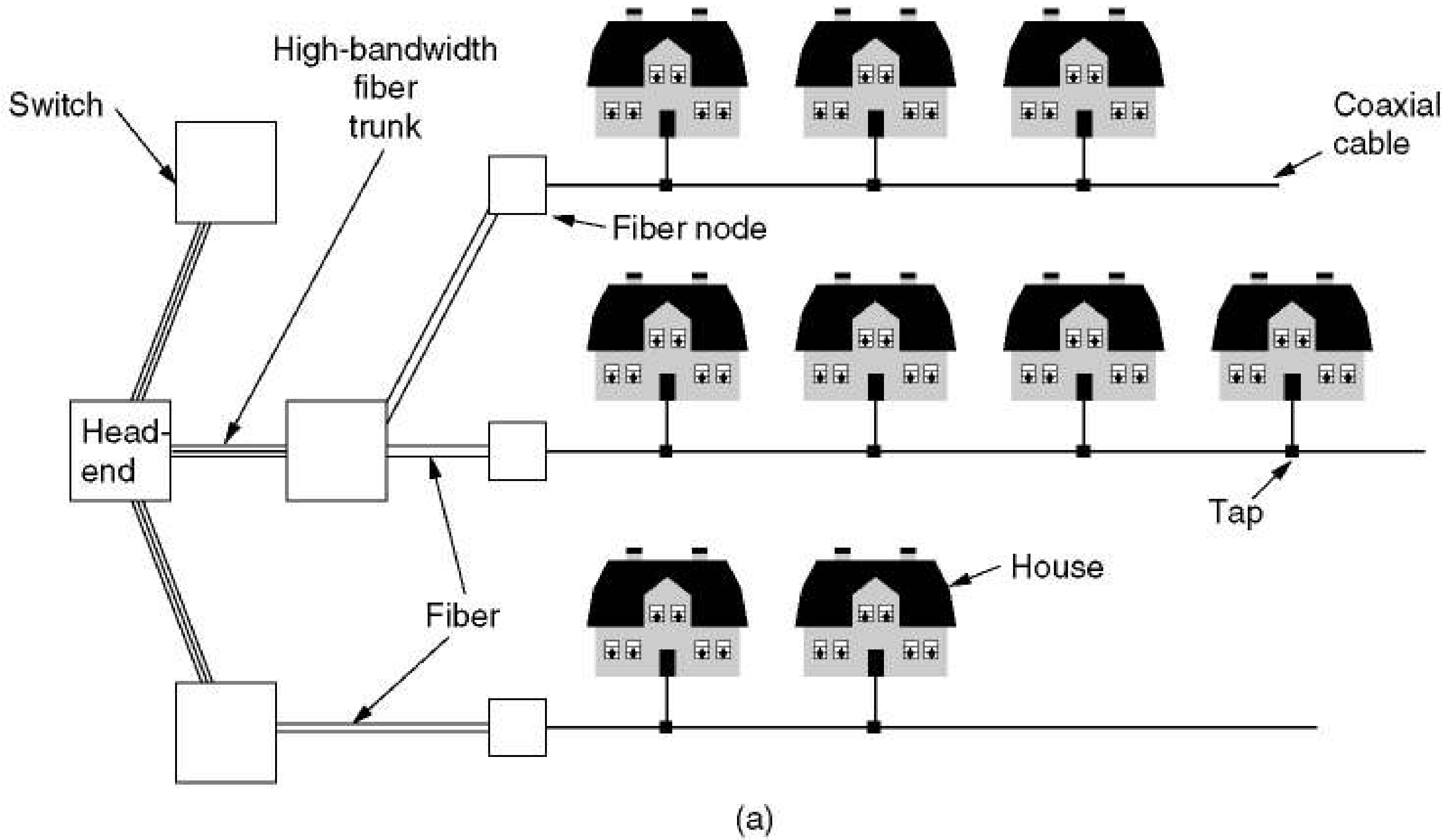
- Community Antenna Television
- Internet over Cable
- Spectrum Allocation
- Cable Modems
- ADSL versus Cable

Community Antenna Television



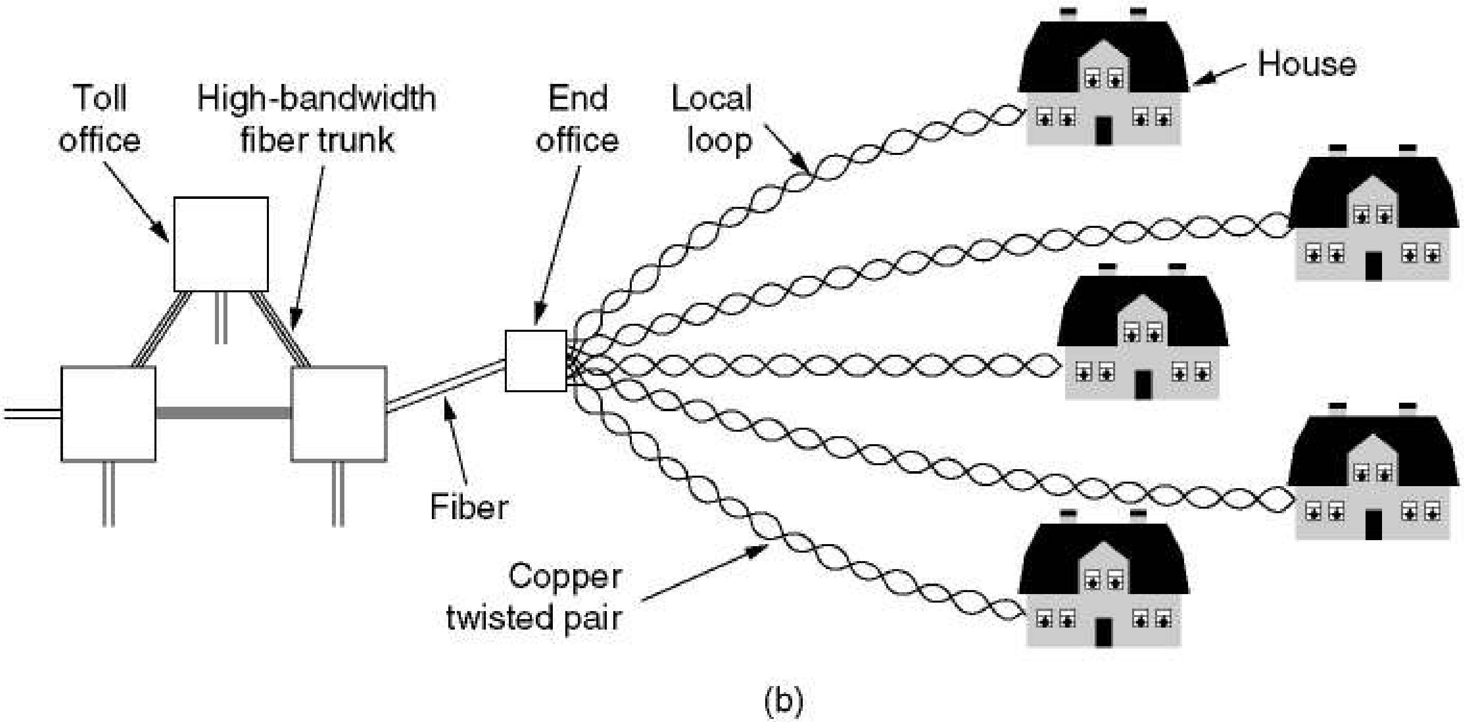
An early cable television system.

Internet over Cable



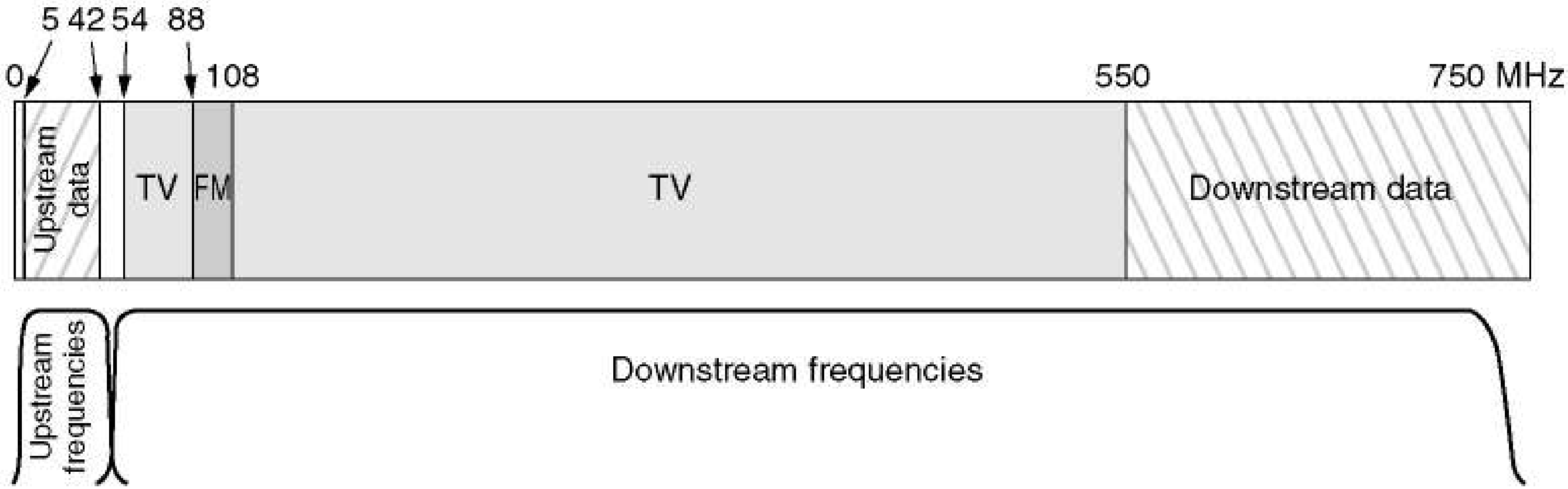
Cable television

Internet over Cable (2)



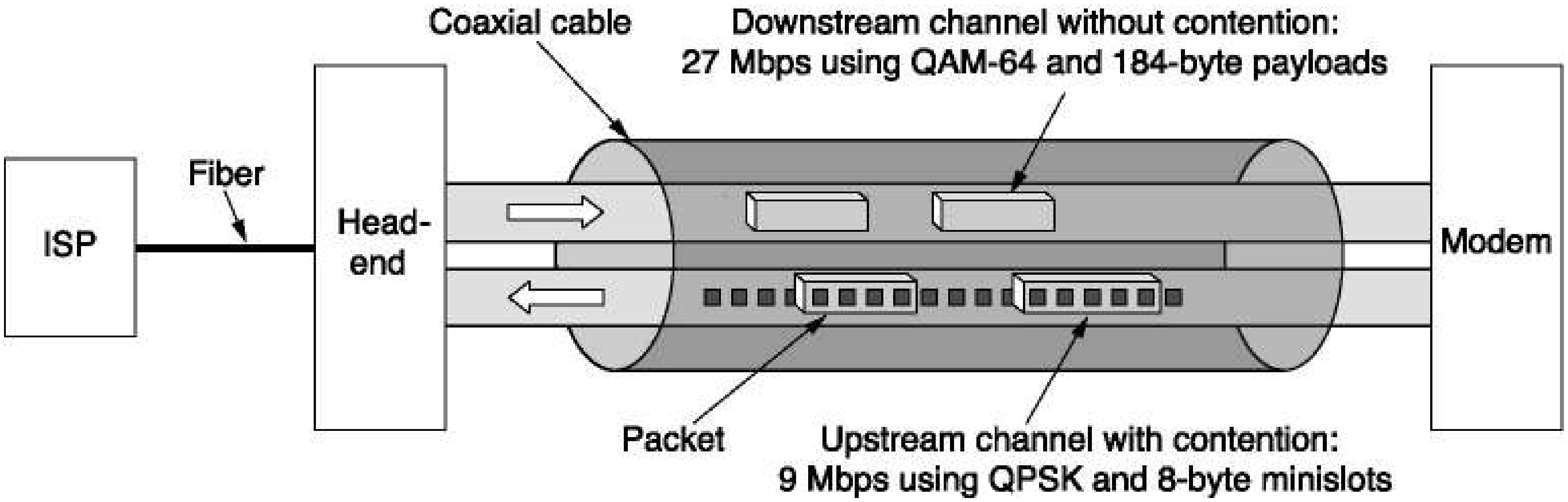
The fixed telephone system.

Spectrum Allocation



Frequency allocation in a typical cable TV system used for Internet access

Cable Modems



Typical details of the upstream and downstream channels in North America.