2

THE PHYSICAL LAYER

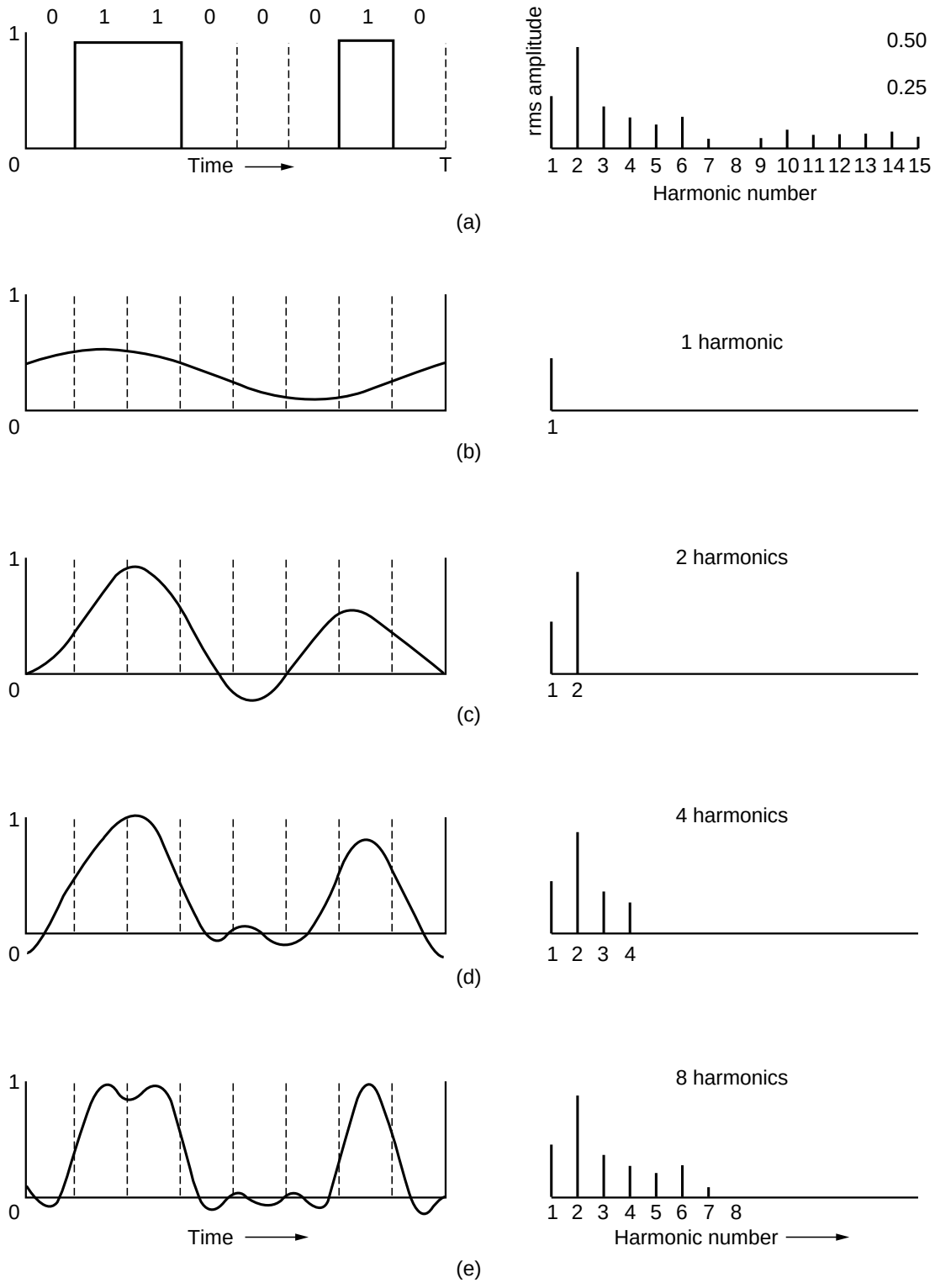

Fig. 2-1. (a) A binary signal and its root-mean-square Fourier amplitudes. (b)-(e) Successive approximations to the original signal.

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

Fig. 2-2. Relation between data rate and harmonics.

(a) (b)

Fig. 2-3. (a) Category 3 UTP. (b) Category 5 UTP.

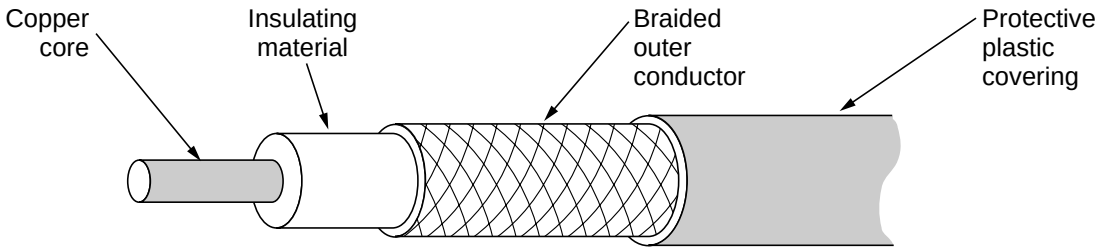

Fig. 2-4. A coaxial cable.

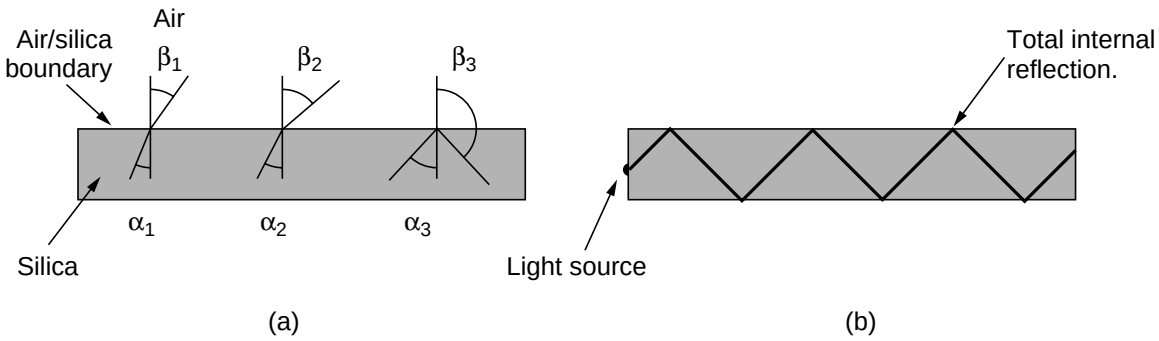

Fig. 2-5. (a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles. (b) Light trapped by total internal reflection.

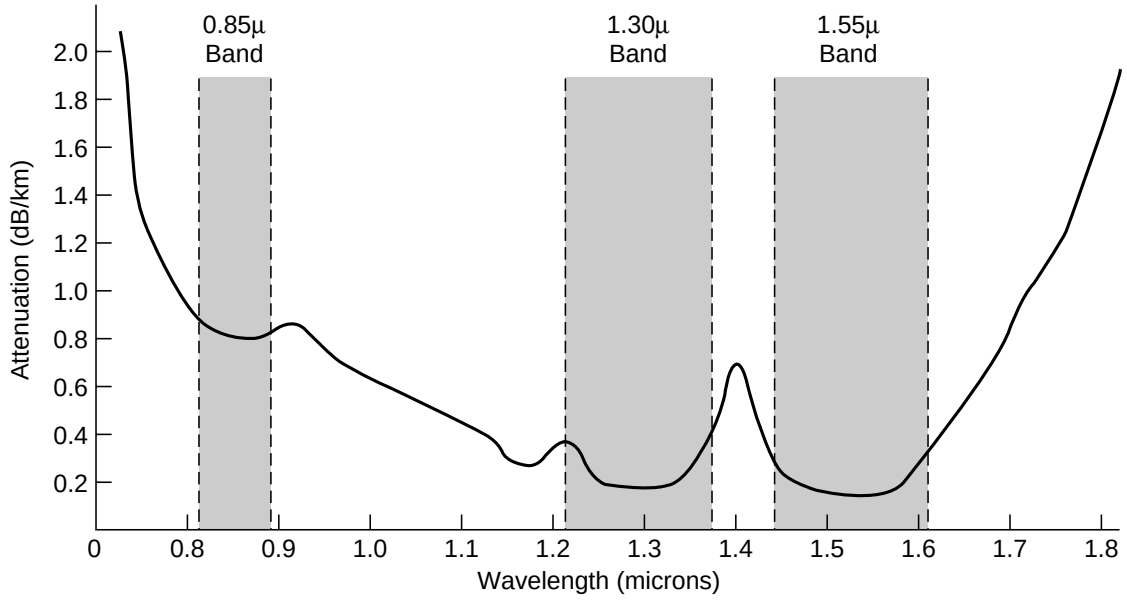

Fig. 2-6. Attenuation of light through fiber in the infrared region.

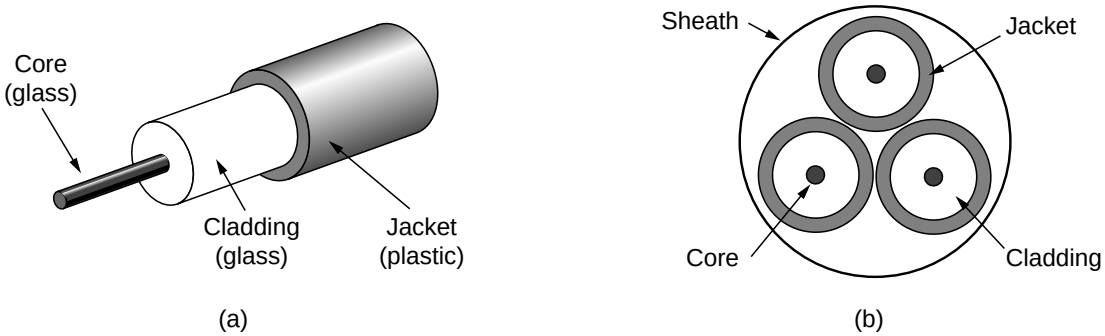

Fig. 2-7. (a) Side view of a single fiber. (b) End view of a sheath with three fibers.

Item	LED	Semiconductor laser
Data rate	Low	High
Fiber type	Multimode	Multimode or single mode
Distance	Short	Long
Lifetime	Long life	Short life
Temperature sensitivity	Minor	Substantial
Cost	Low cost	Expensive

Fig. 2-8. A comparison of semiconductor diodes and LEDs as light sources.

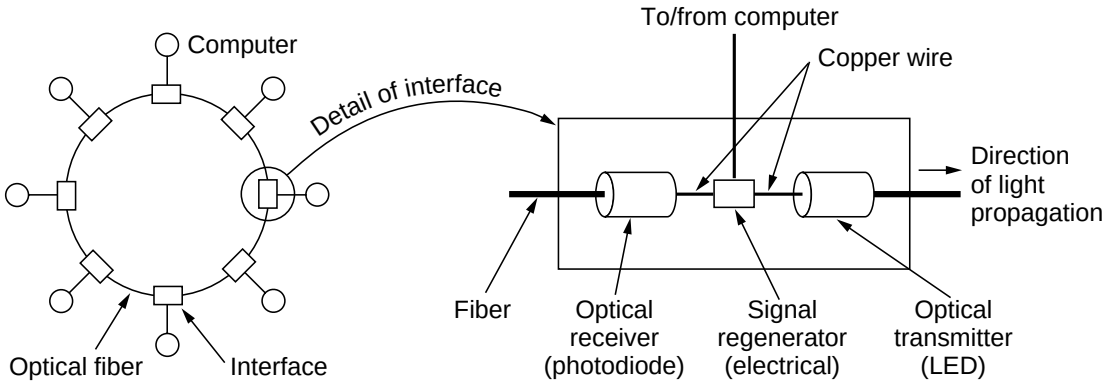

Fig. 2-9. A fiber optic ring with active repeaters.

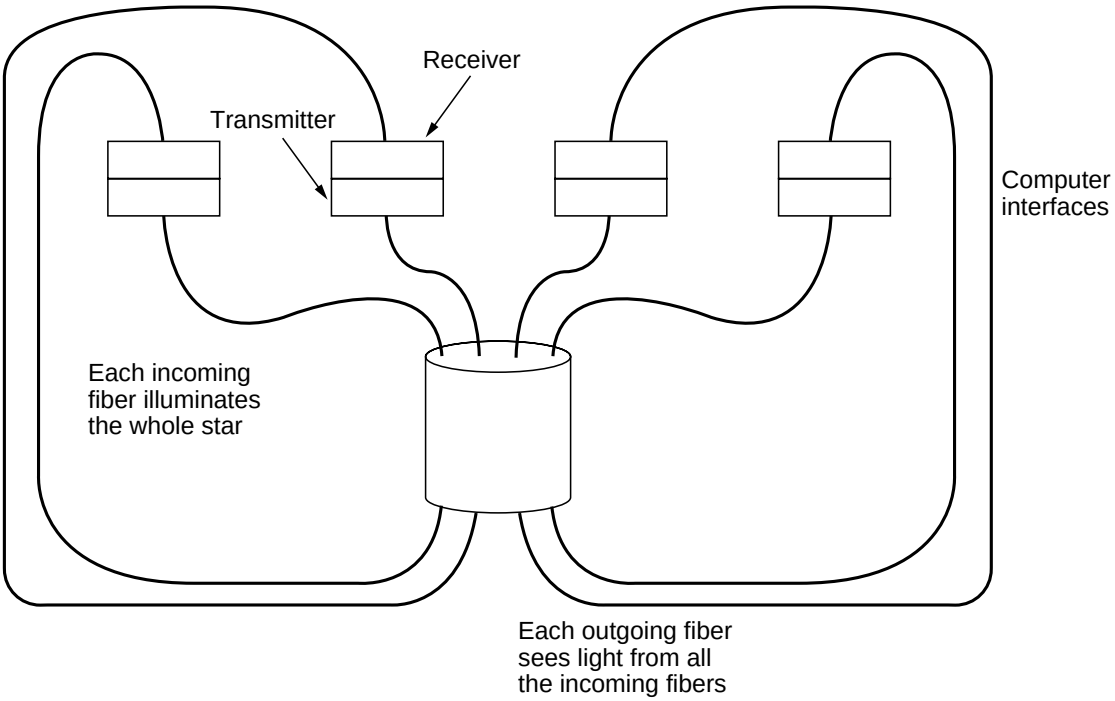

Fig. 2-10. A passive star connection in a fiber optics network.

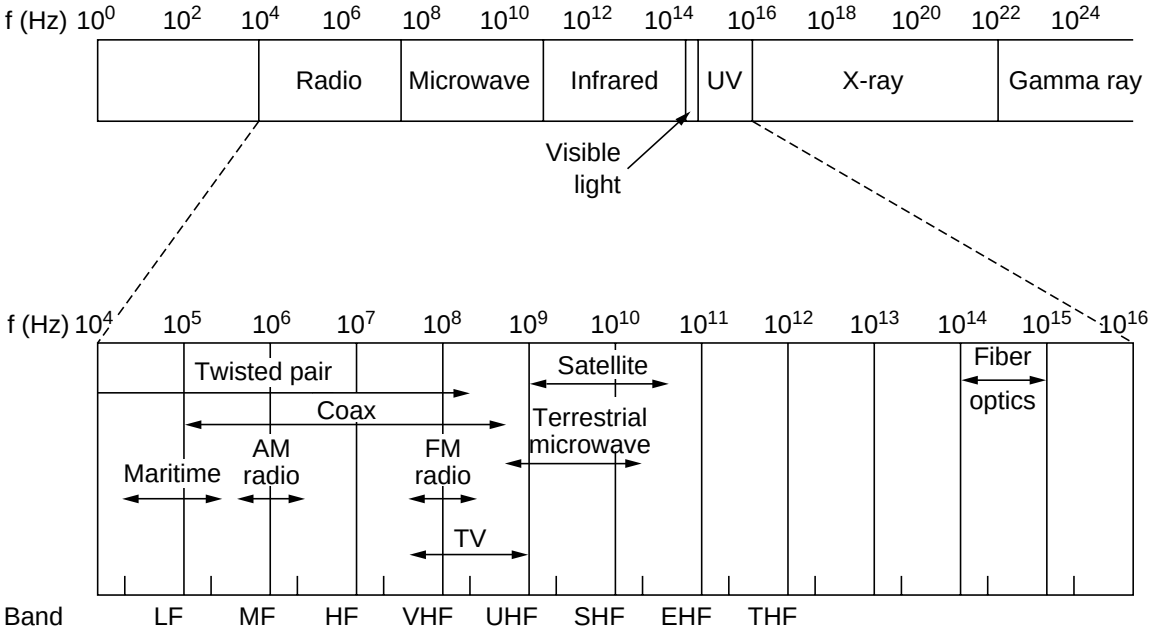

Fig. 2-11. The electromagnetic spectrum and its uses for communication.

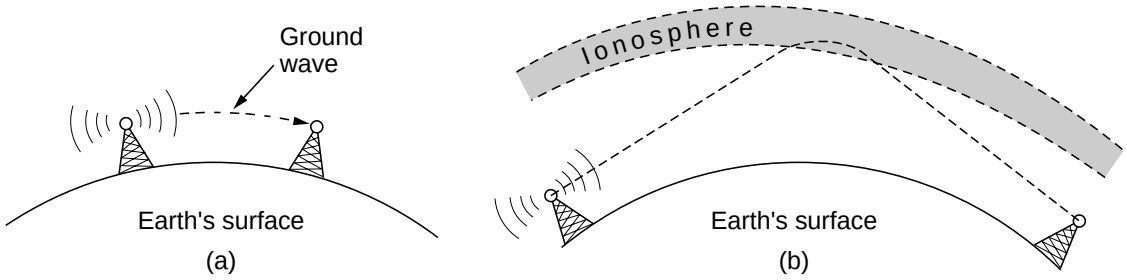

Fig. 2-12. (a) In the VLF, LF, and MF bands, radio waves follow the curvature of the earth. (b) In the HF band, they bounce off the ionosphere.

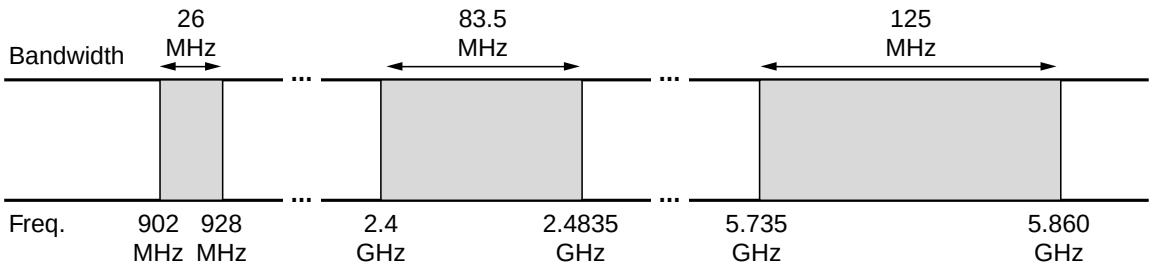

Fig. 2-13. The ISM bands in the United States.

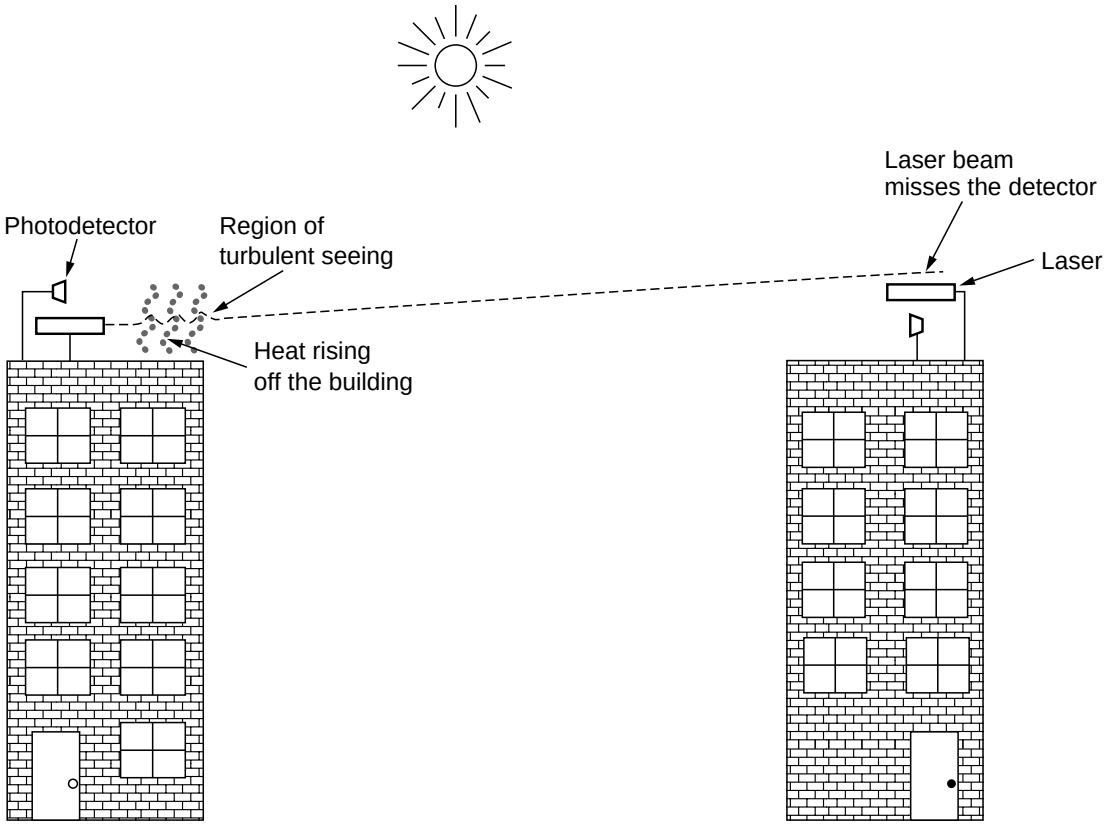

Fig. 2-14. Convection currents can interfere with laser communication systems. A bidirectional system with two lasers is pictured here.

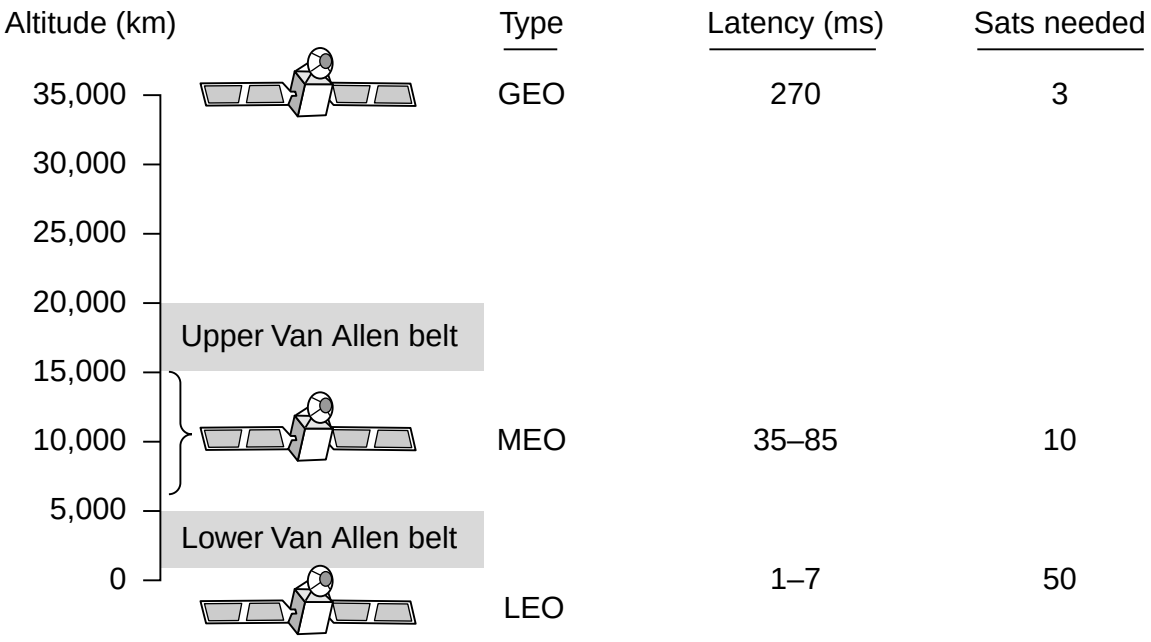

Fig. 2-15. Communication satellites and some of their properties, including altitude above the earth, round-trip delay time, and number of satellites needed for global coverage.

Band	Downlink	Uplink	Bandwidth	Problems
L	1.5 GHz	1.6 GHz	15 MHz	Low bandwidth; crowded
S	1.9 GHz	2.2 GHz	70 MHz	Low bandwidth; crowded
C	4.0 GHz	6.0 GHz	500 MHz	Terrestrial interference
Ku	11 GHz	14 GHz	500 MHz	Rain
Ka	20 GHz	30 GHz	3500 MHz	Rain, equipment cost

Fig. 2-16. The principal satellite bands.

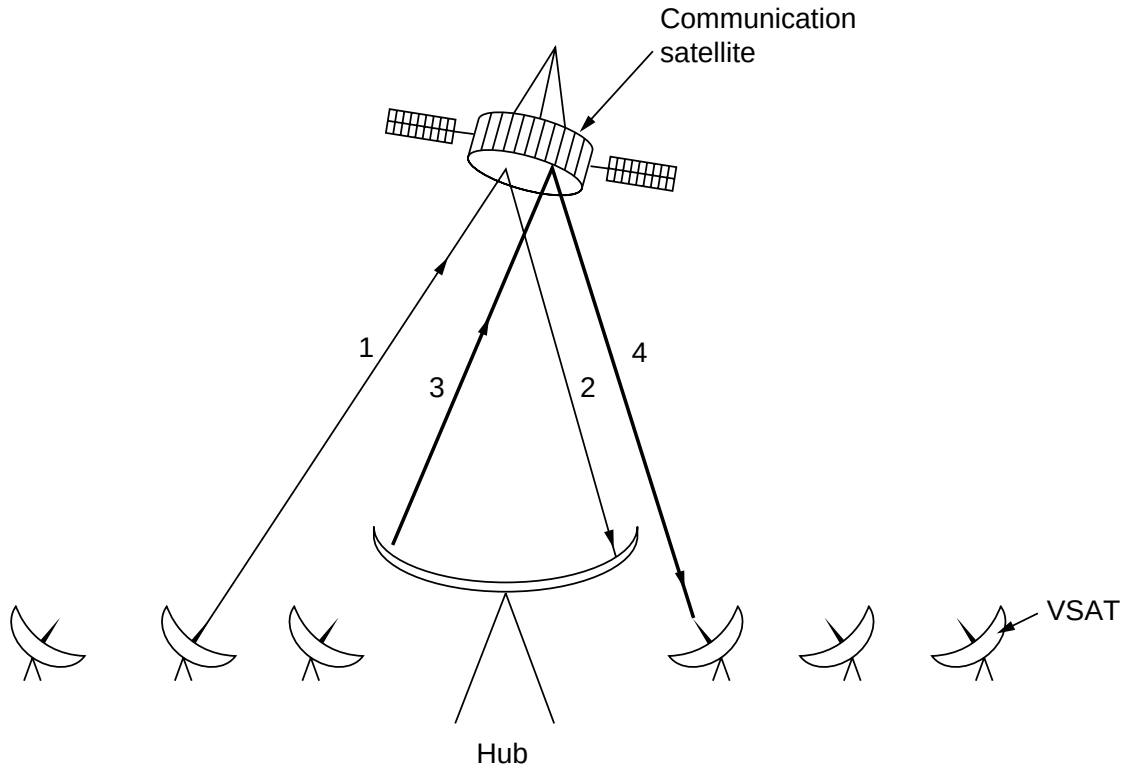

Fig. 2-17. VSATs using a hub.

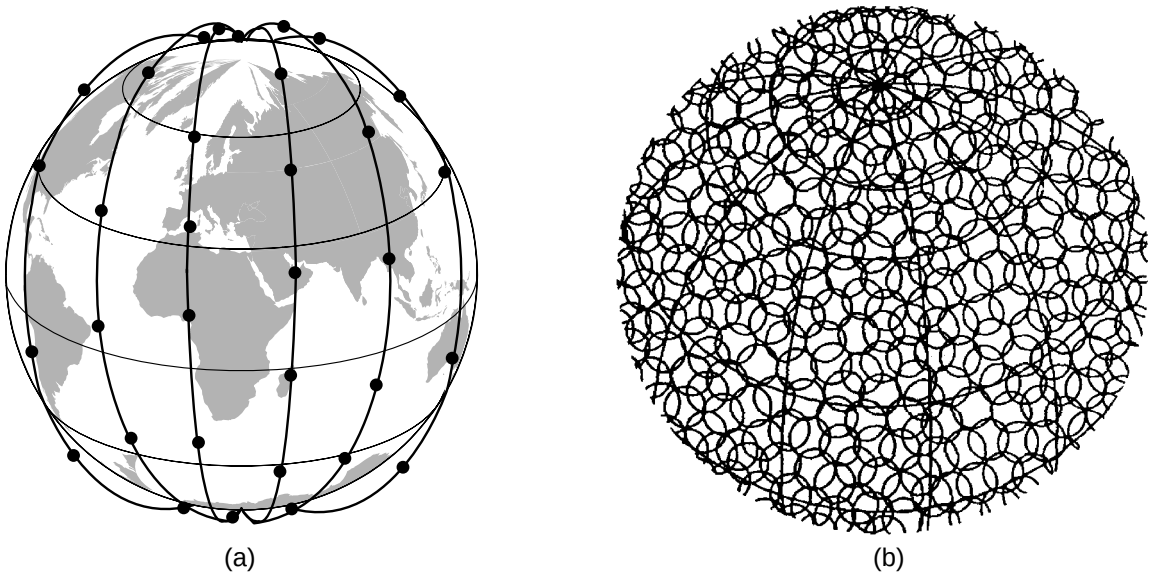

Fig. 2-18. (a) The Iridium satellites form six necklaces around the earth. (b) 1628 moving cells cover the earth.

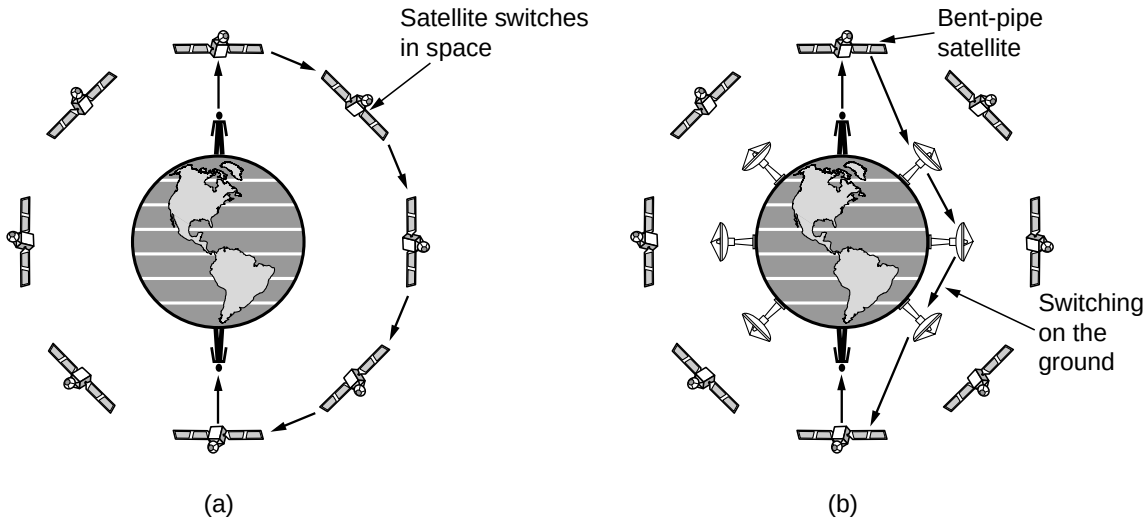

Fig. 2-19. (a) Relaying in space. (b) Relaying on the ground.

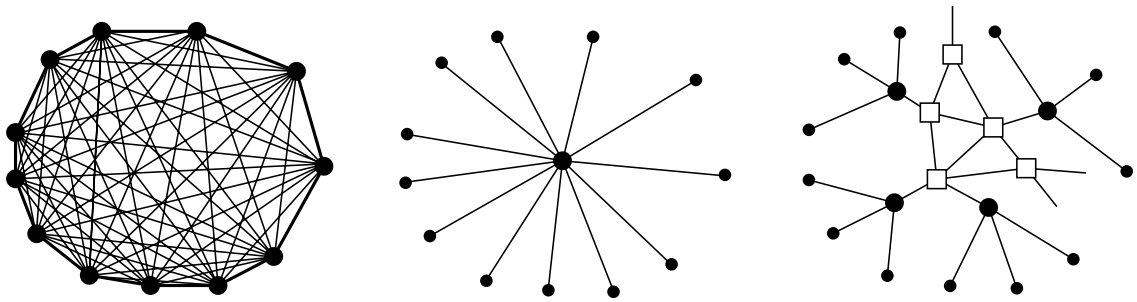

Fig. 2-20. (a) Fully-interconnected network. (b) Centralized switch. (c) Two-level hierarchy.

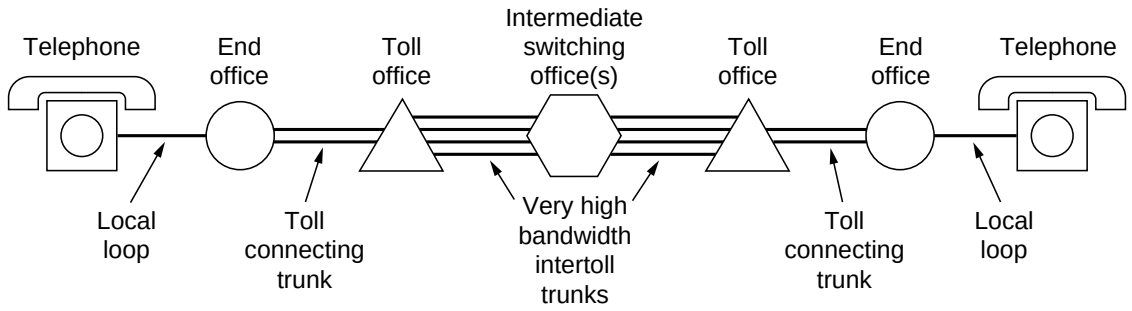

Fig. 2-21. A typical circuit route for a medium-distance call.

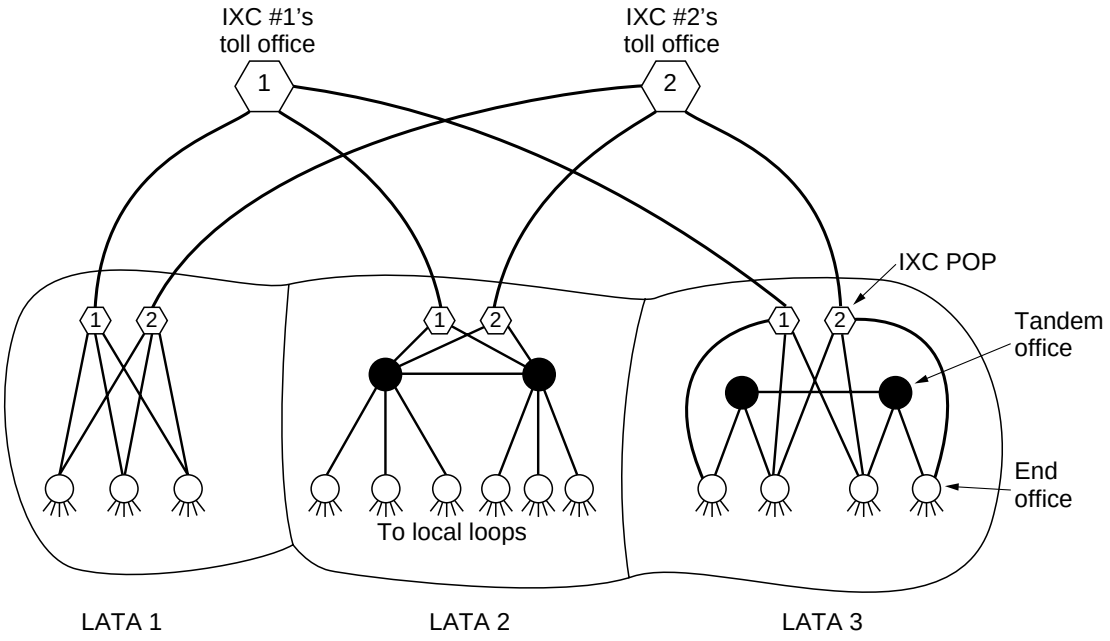

Fig. 2-22. The relationship of LATAs, LECs, and IXCs. All the circles are LEC switching offices. Each hexagon belongs to the IXC whose number is in it.

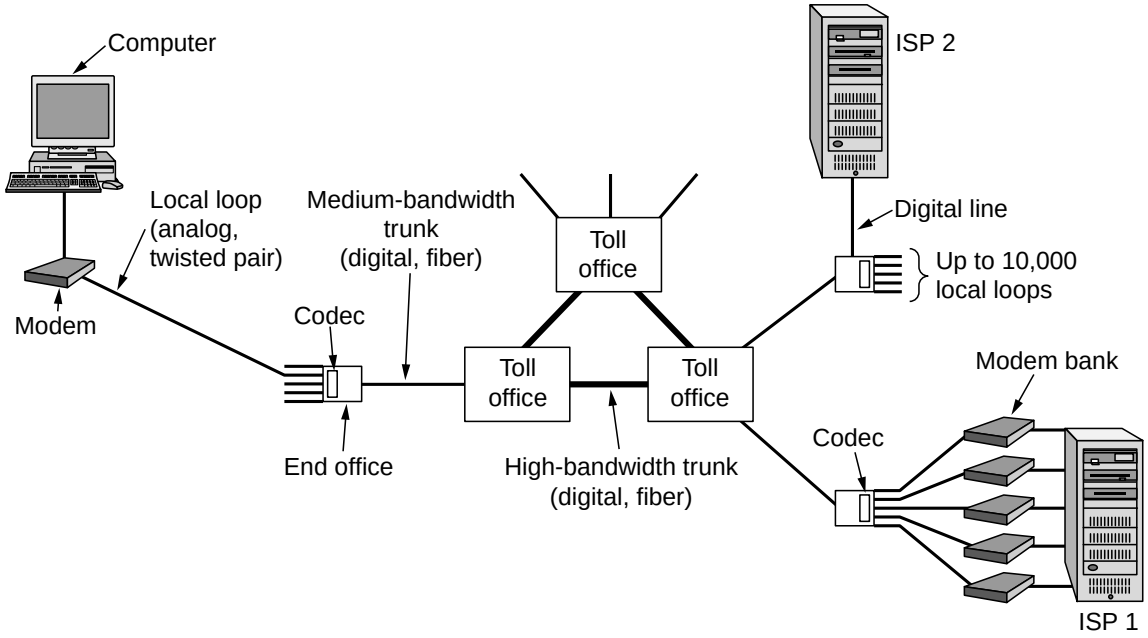

Fig. 2-23. The use of both analog and digital transmission for a computer to computer call. Conversion is done by the modems and codecs.

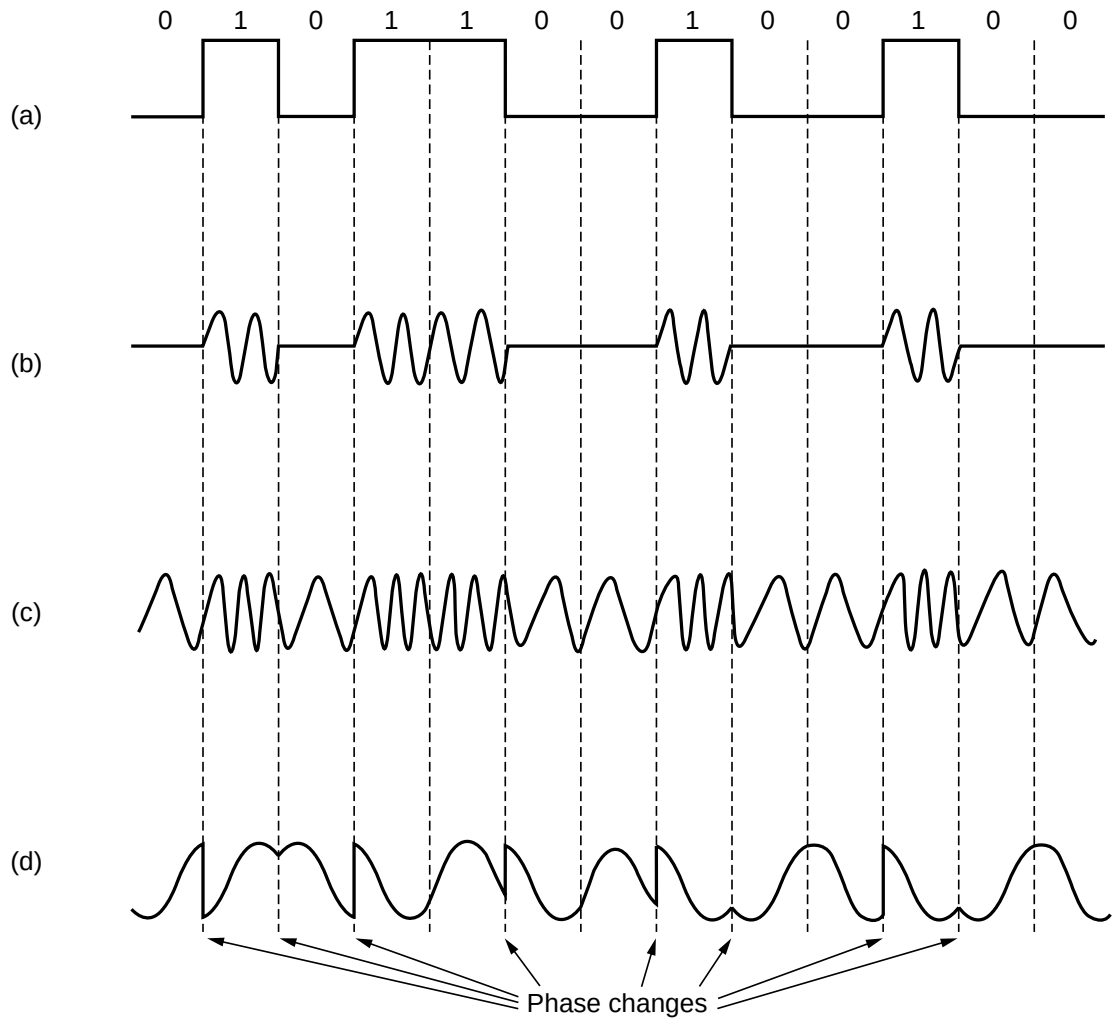

Fig. 2-24. (a) A binary signal. (b) Amplitude modulation. (c) Frequency modulation. (d) Phase modulation.

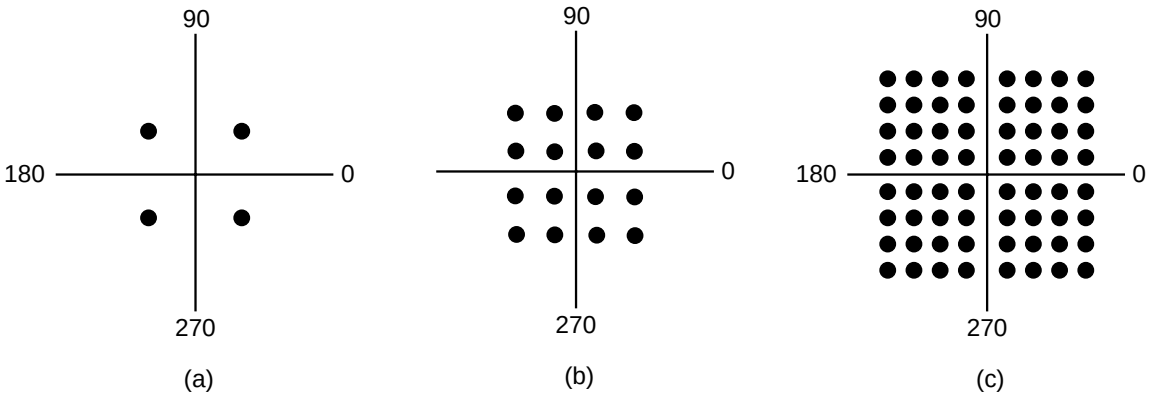

Fig. 2-25. (a) QPSK. (b) QAM-16. (c) QAM-64.

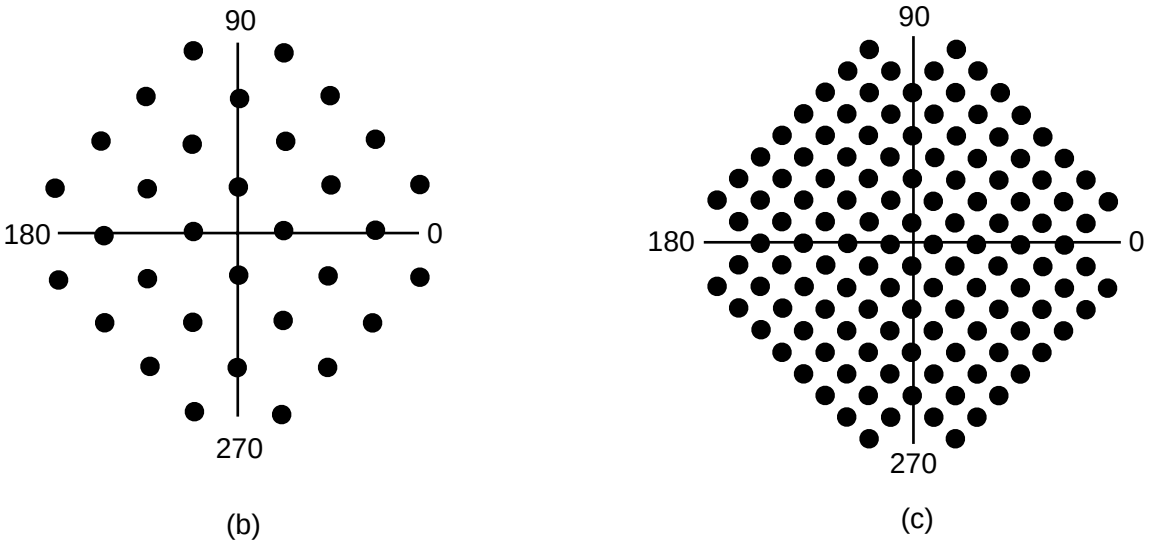

Fig. 2-26. (a) V.32 for 9600 bps. (b) V32 bis for 14,400 bps.

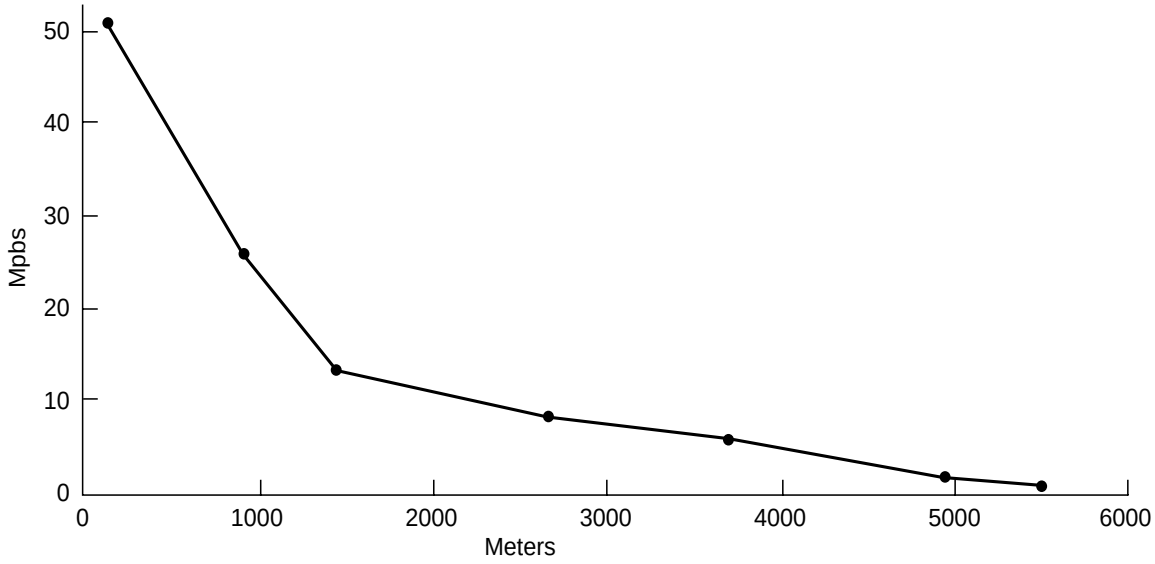

Fig. 2-27. Bandwidth versus distance over category 3 UTP for DSL.

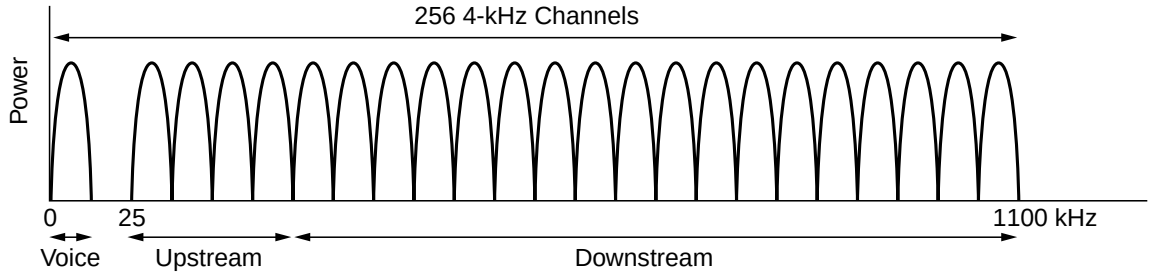

Fig. 2-28. Operation of ADSL using discrete multitone modulation.

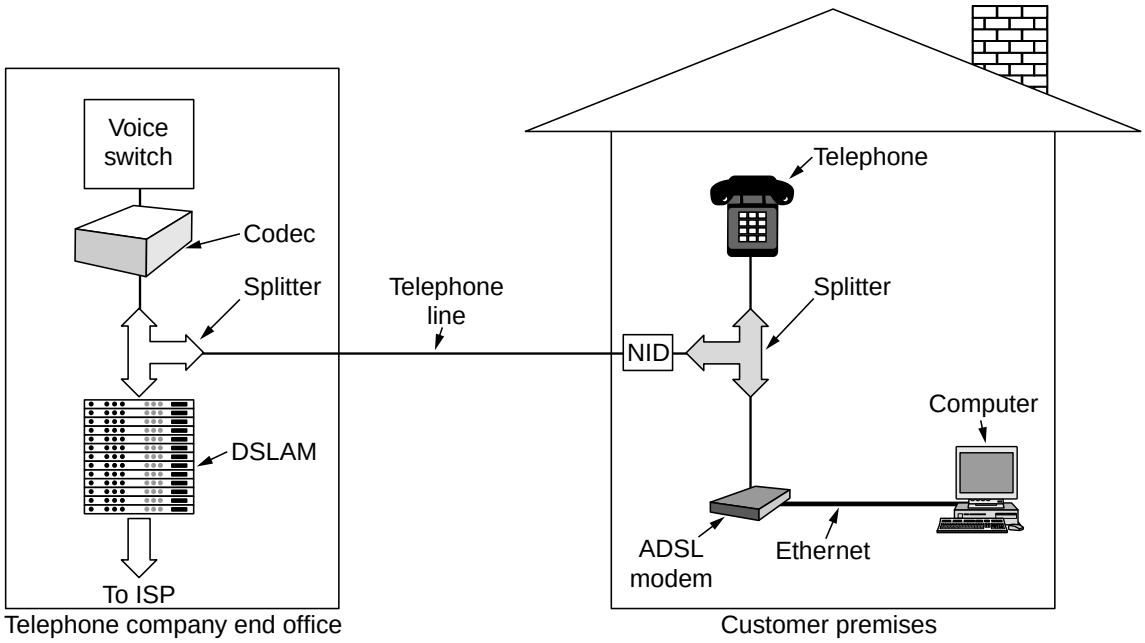

Fig. 2-29. A typical ADSL equipment configuration.

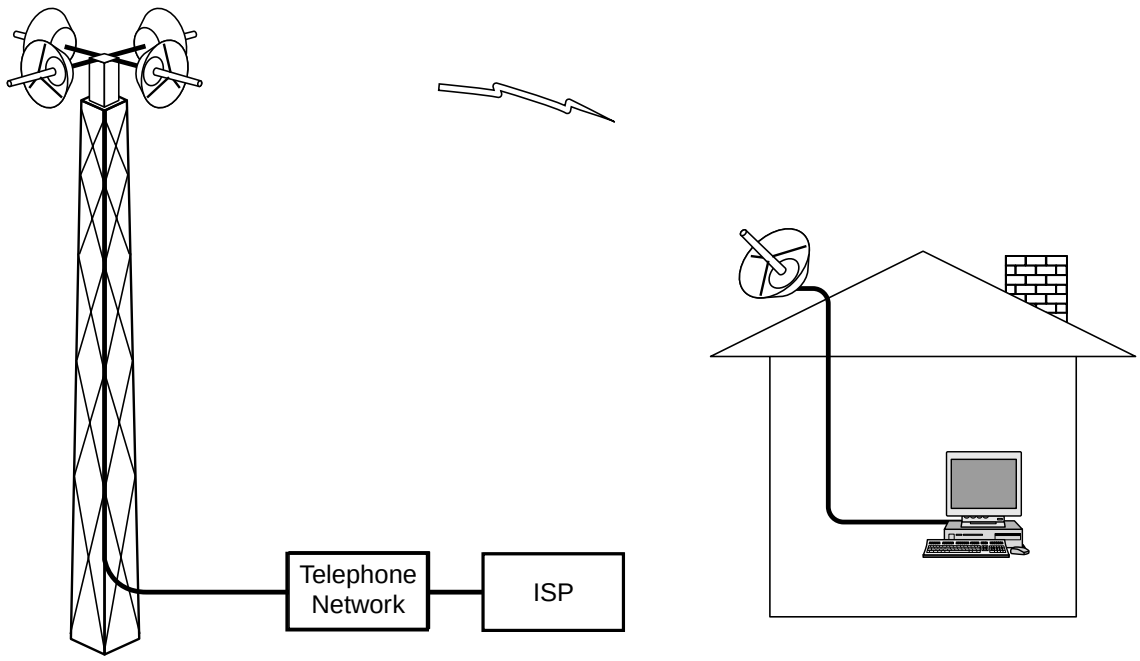

Fig. 2-30. Architecture of an LMDS system.

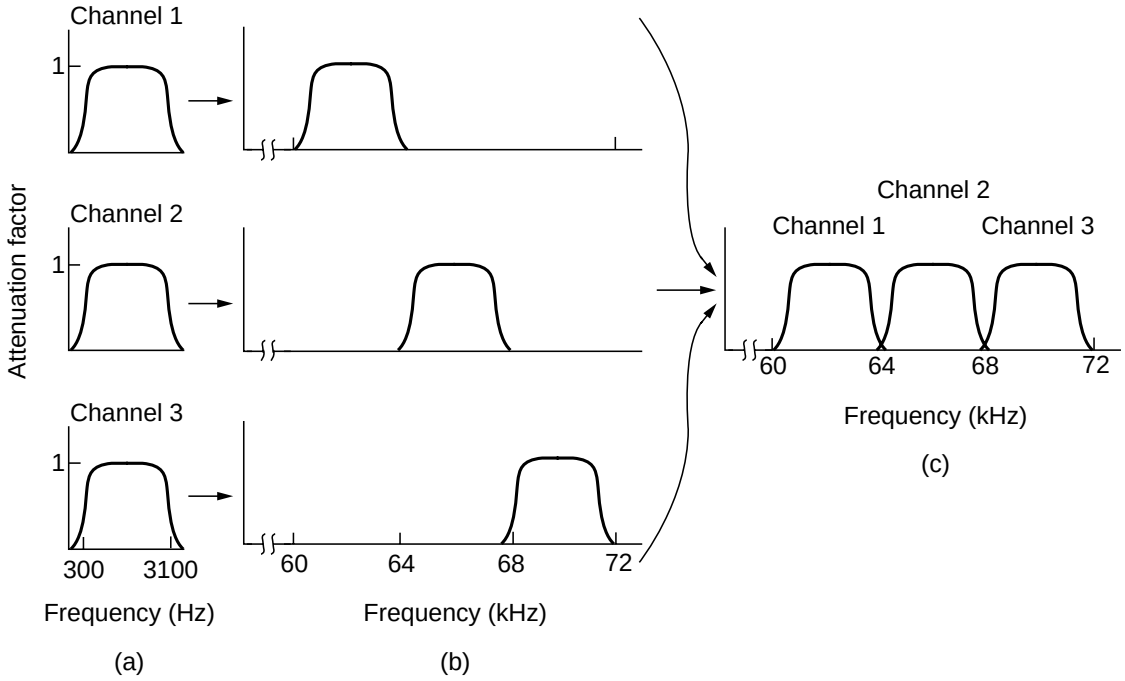

Fig. 2-31. Frequency division multiplexing. (a) The original bandwidths. (b) The bandwidths raised in frequency. (c) The multiplexed channel.

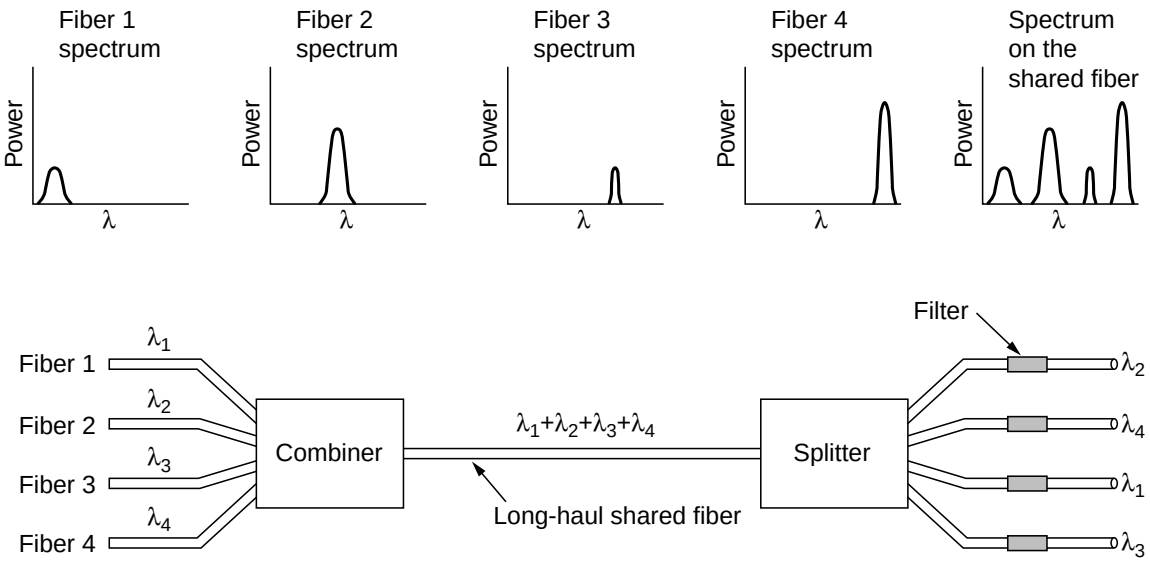

Fig. 2-32. Wavelength division multiplexing.

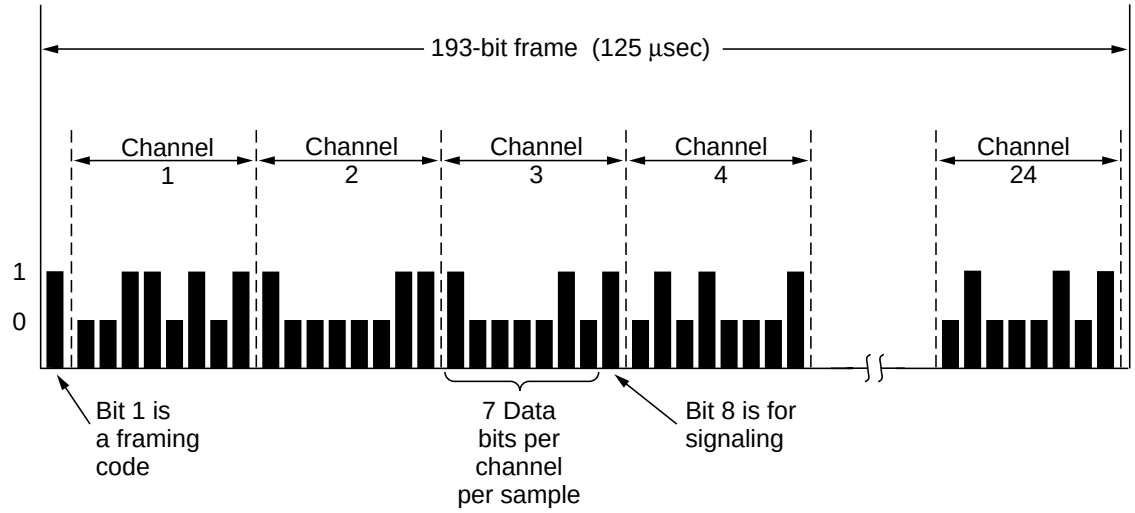

Fig. 2-33. The T1 carrier (1.544 Mbps).

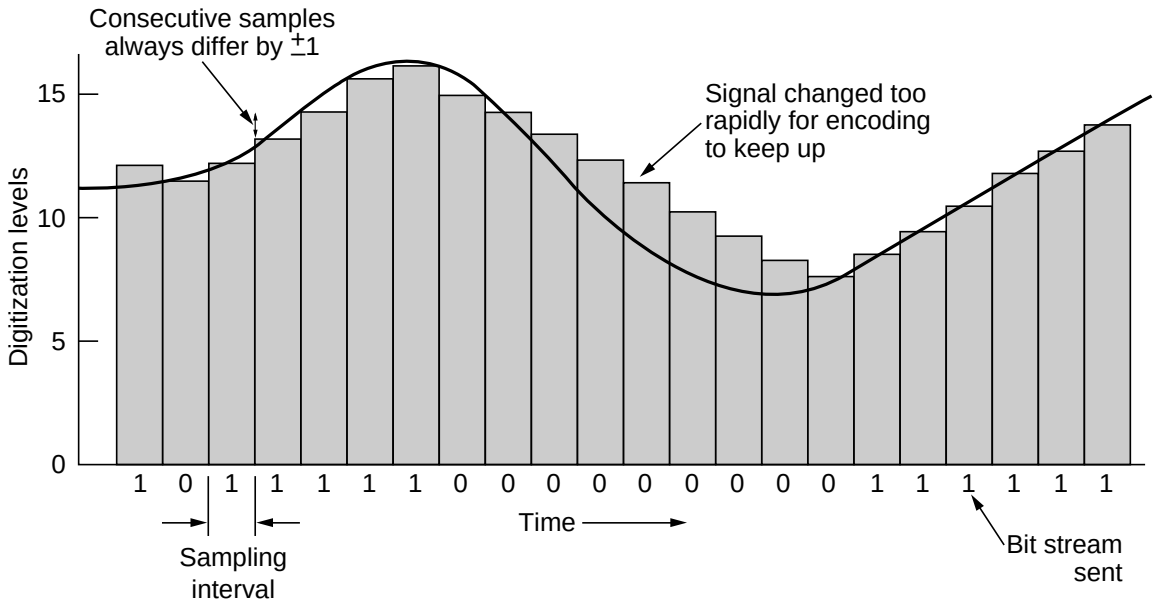

Fig. 2-34. Delta modulation.

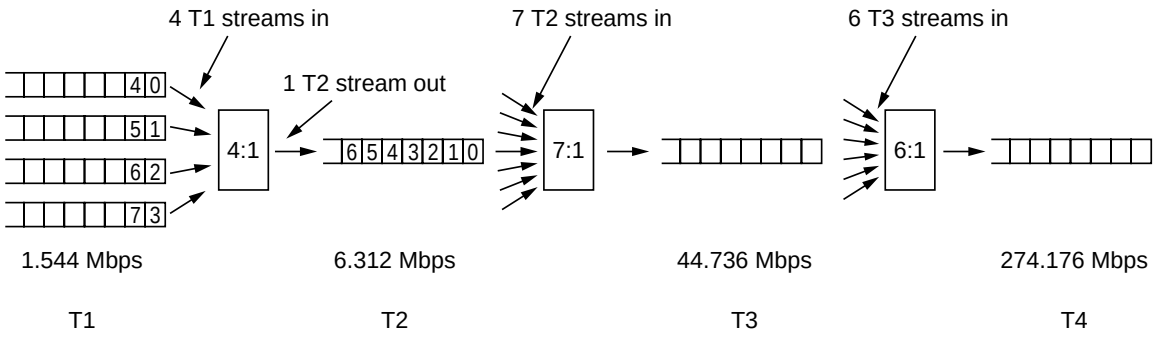

Fig. 2-35. Multiplexing T1 streams onto higher carriers.

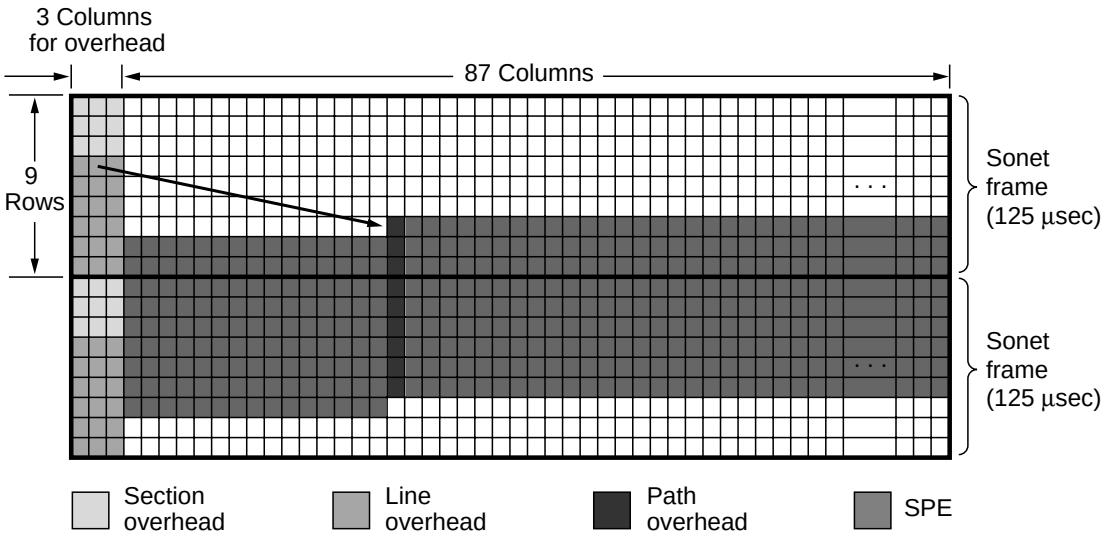

Fig. 2-36. Two back-to-back SONET frames.

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

Fig. 2-37. SONET and SDH multiplex rates.

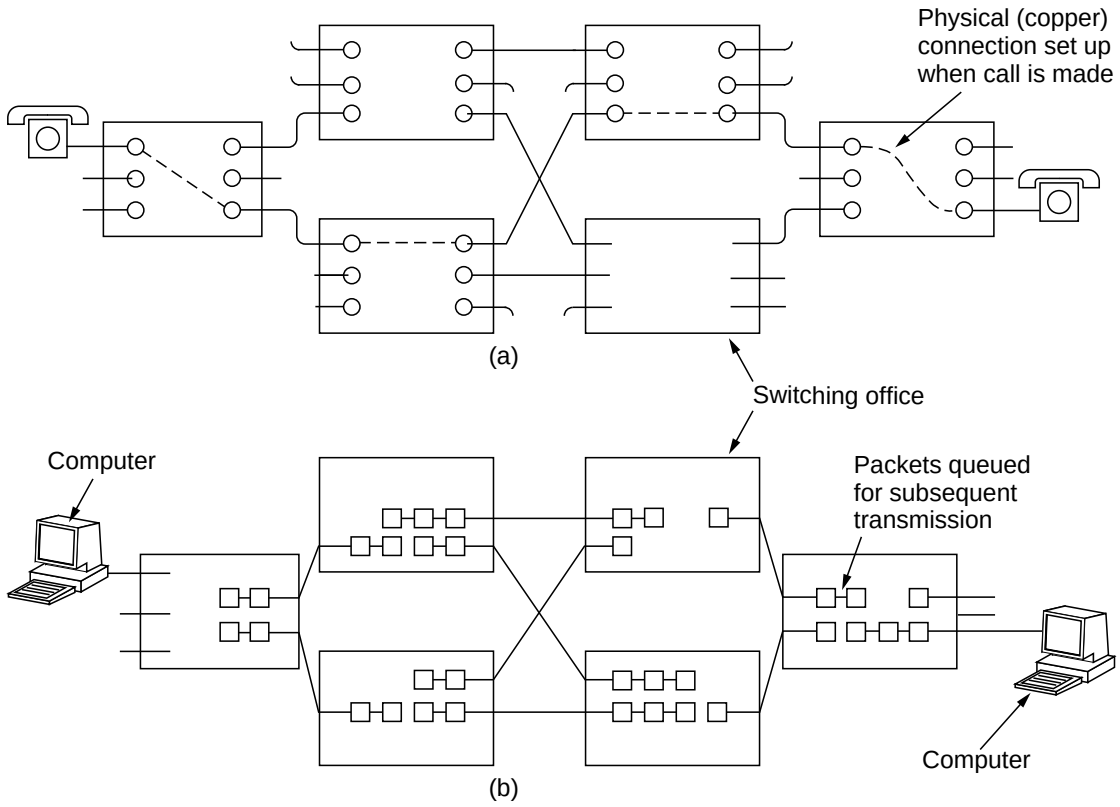

Fig. 2-38. (a) Circuit switching. (b) Packet switching.

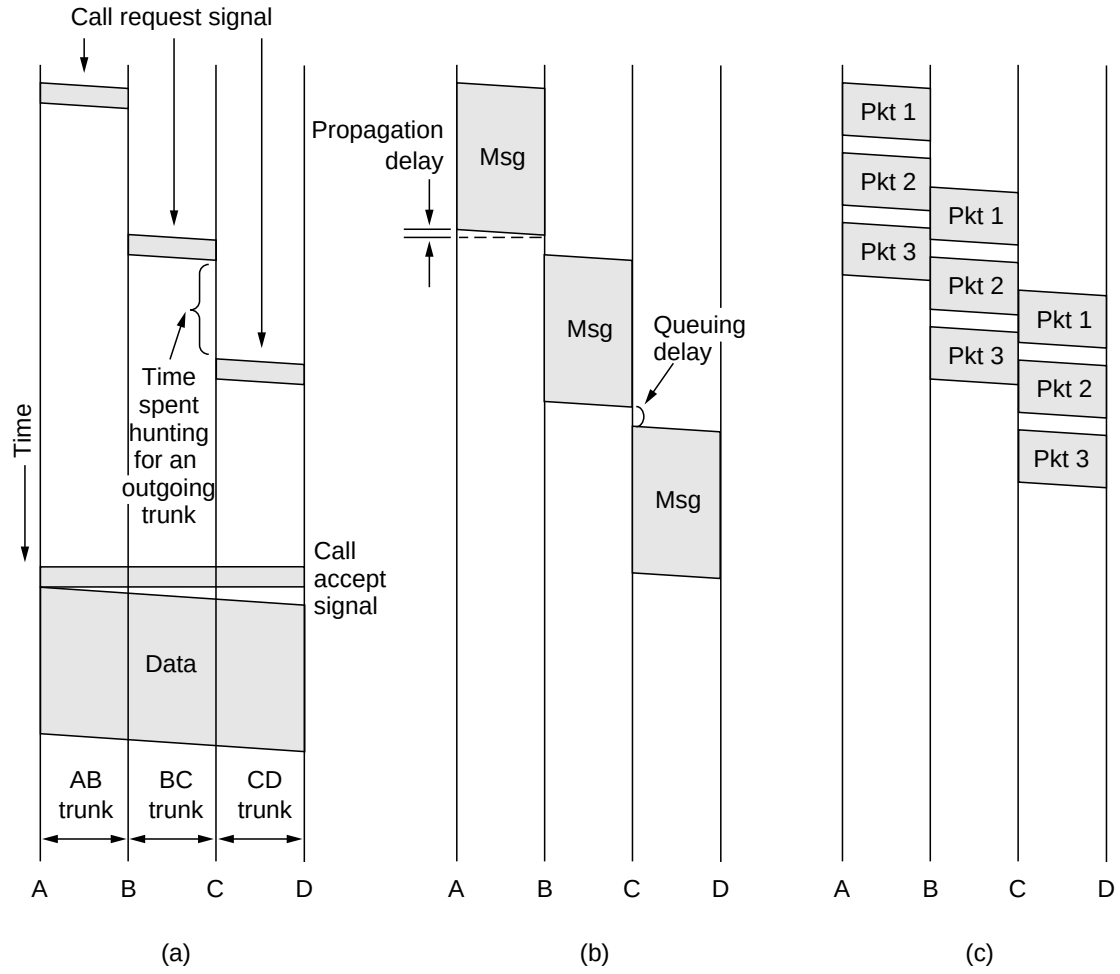

Fig. 2-39. Timing of events in (a) circuit switching, (b) message switching, (c) packet switching.

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
Time of possible congestion	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

Fig. 2-40. A comparison of circuit-switched and packet-switched networks.

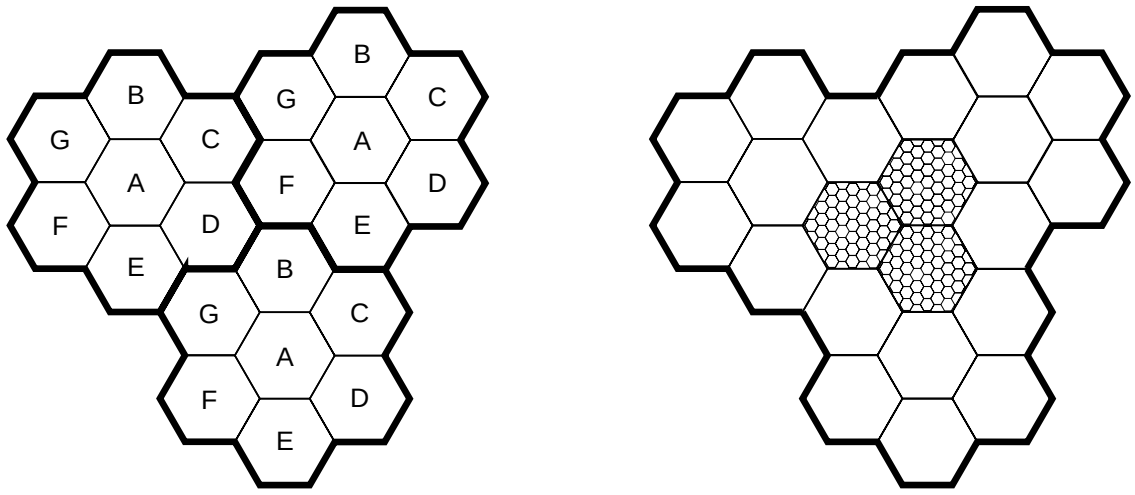

Fig. 2-41. (a) Frequencies are not reused in adjacent cells. (b) To add more users, smaller cells can be used.

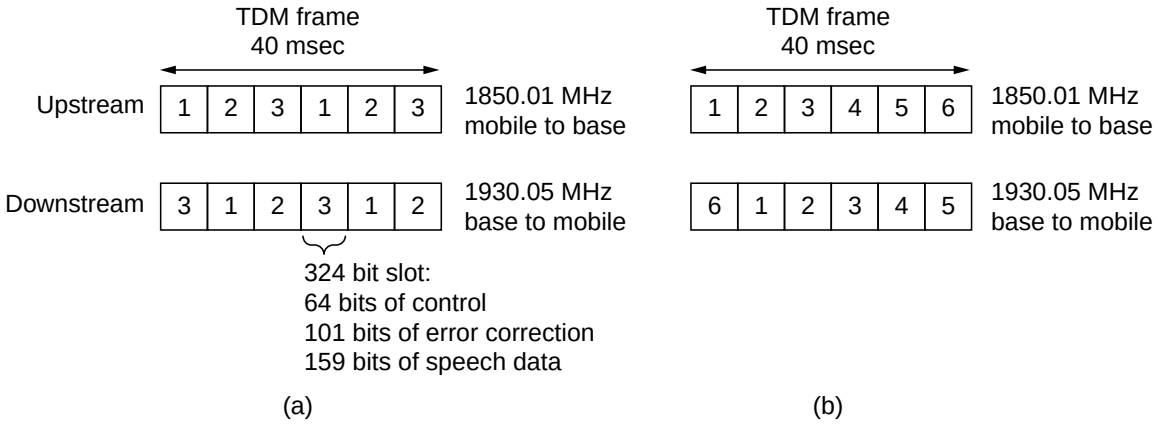

Fig. 2-42. (a) A D-AMPS channel with three users. (b) A D-AMPS channel with six users.

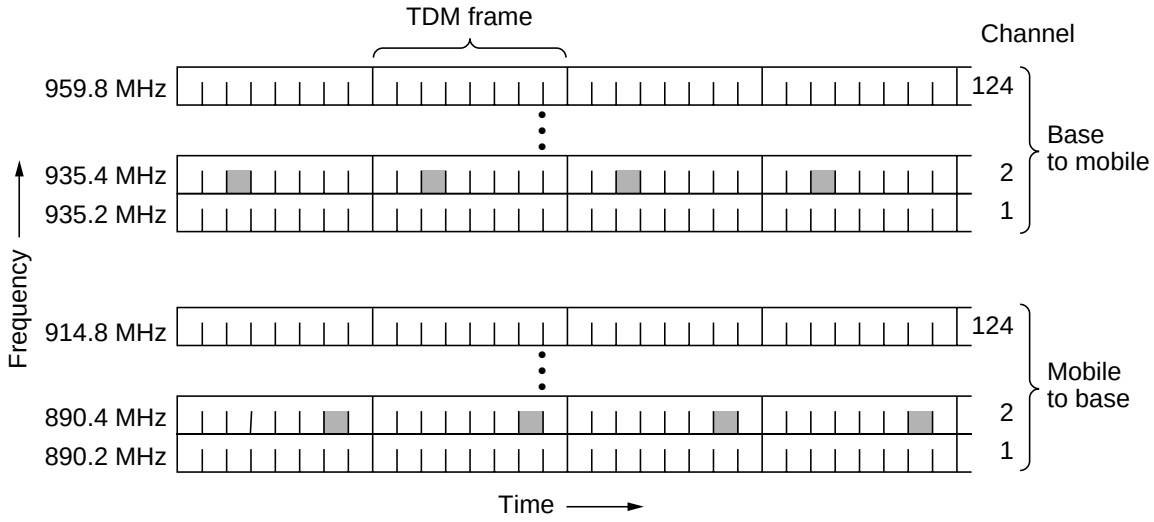

Fig. 2-43. GSM uses 124 frequency channels, each of which uses an eight-slot TDM system.

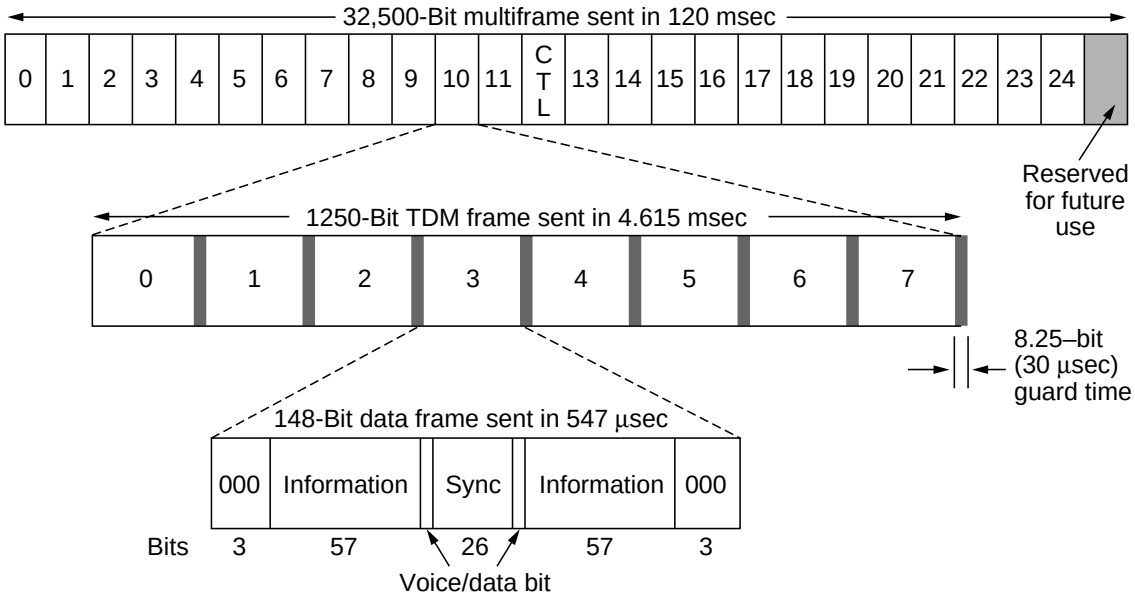

Fig. 2-44. A portion of the GSM framing structure.

A: 0 0 0 1 1 0 1 1	A: (–1 –1 –1 +1 +1 –1 +1 +1)
B: 0 0 1 0 1 1 1 0	B: (–1 –1 +1 –1 +1 +1 +1 –1)
C: 0 1 0 1 1 1 0 0	C: (–1 +1 –1 +1 +1 +1 –1 –1)
D: 0 1 0 0 0 0 1 0	D: (–1 +1 –1 –1 –1 –1 +1 –1)
(a)	(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)

Fig. 2-45. (a) Binary chip sequences for four stations. (b) Bipolar chip sequences. (c) Six examples of transmissions. (d) Recovery of station C's signal.

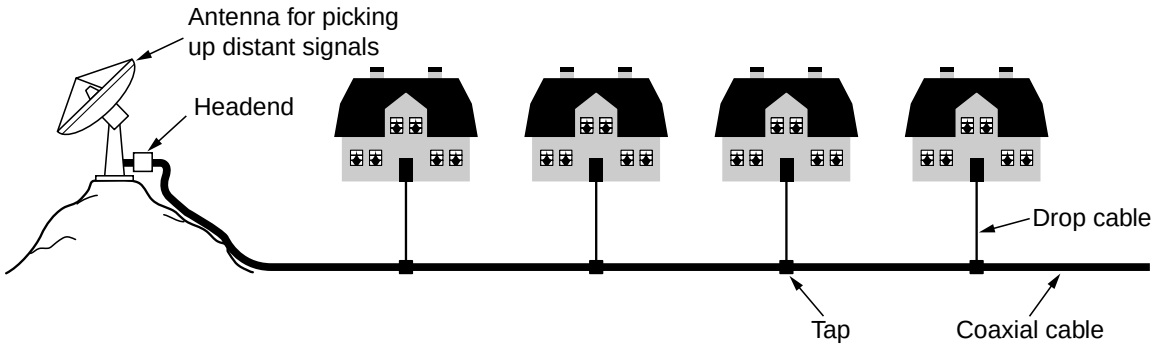

Fig. 2-46. An early cable television system.

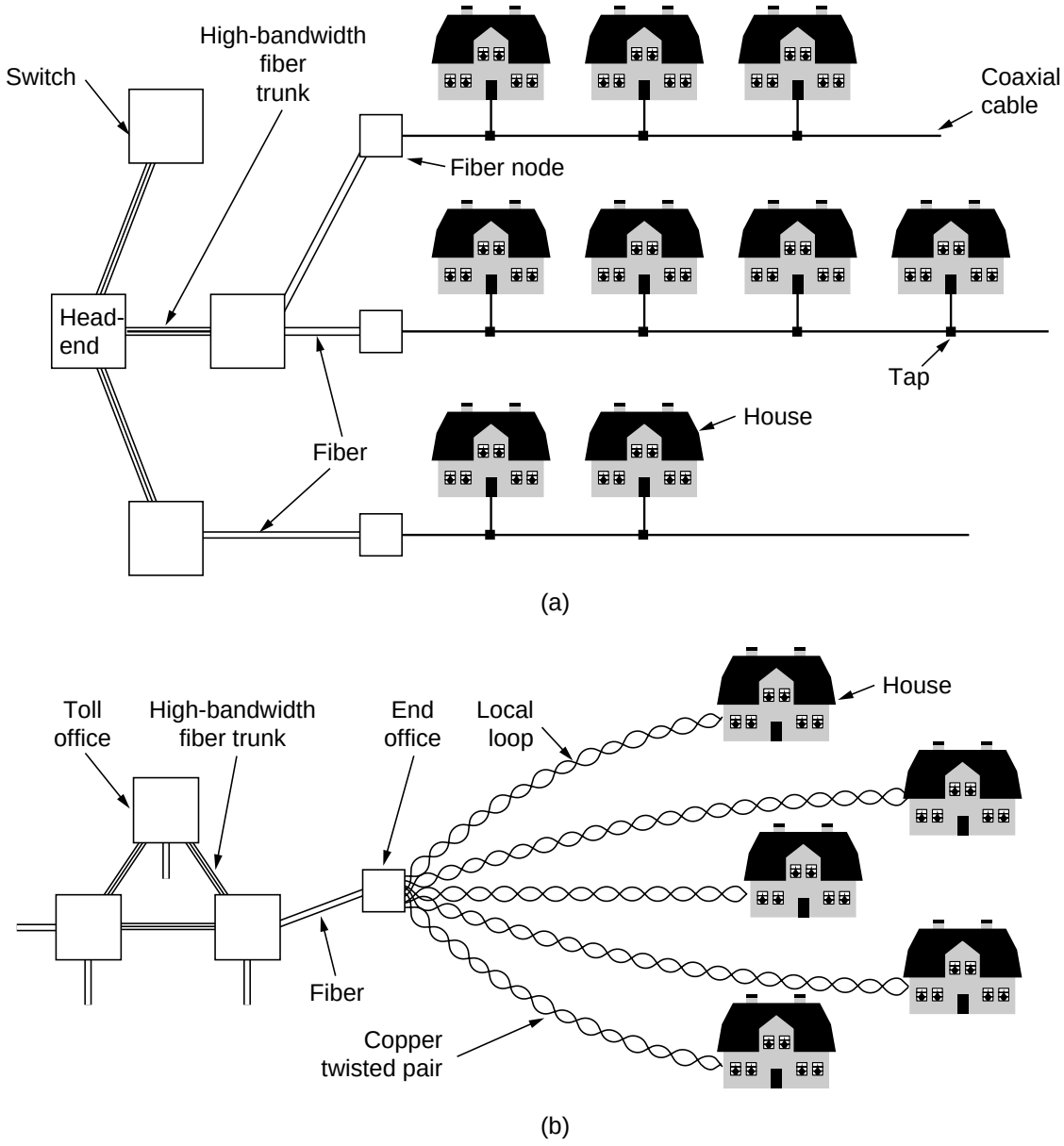

Fig. 2-47. (a) Cable television. (b) The fixed telephone system.

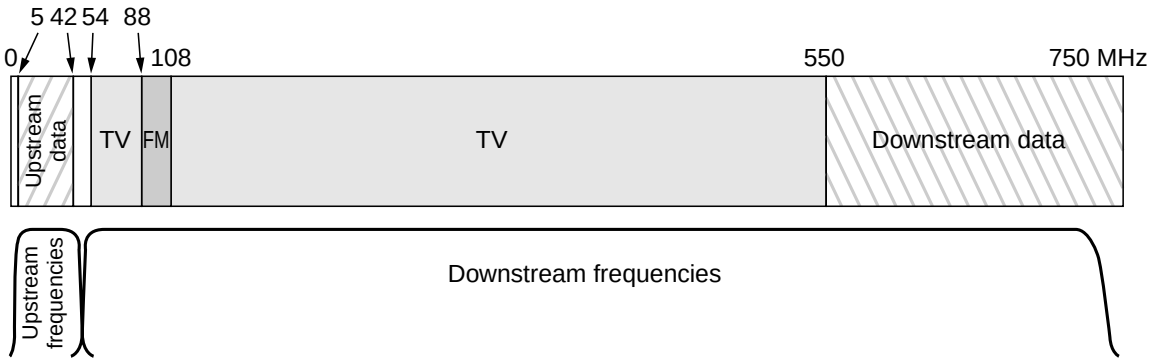

Fig. 2-48. Frequency allocation in a typical cable TV system used for Internet access.

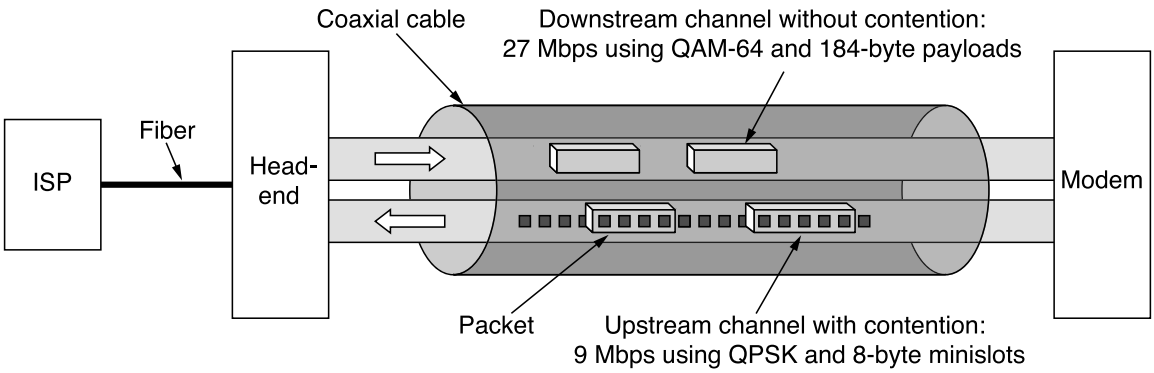

Fig. 2-49. Typical details of the upstream and downstream channels in North America.