The Public Switched Telephone Network (PSTN)

Importance of Telephony

- Official name: the Public Switched Telephone Network
- New technologies revolutionizing “plain old telephone service” (POTS)
- More options are bringing more complex elements
- WANs are based on telephone technology and regulation

The Main Elements of the PSTN

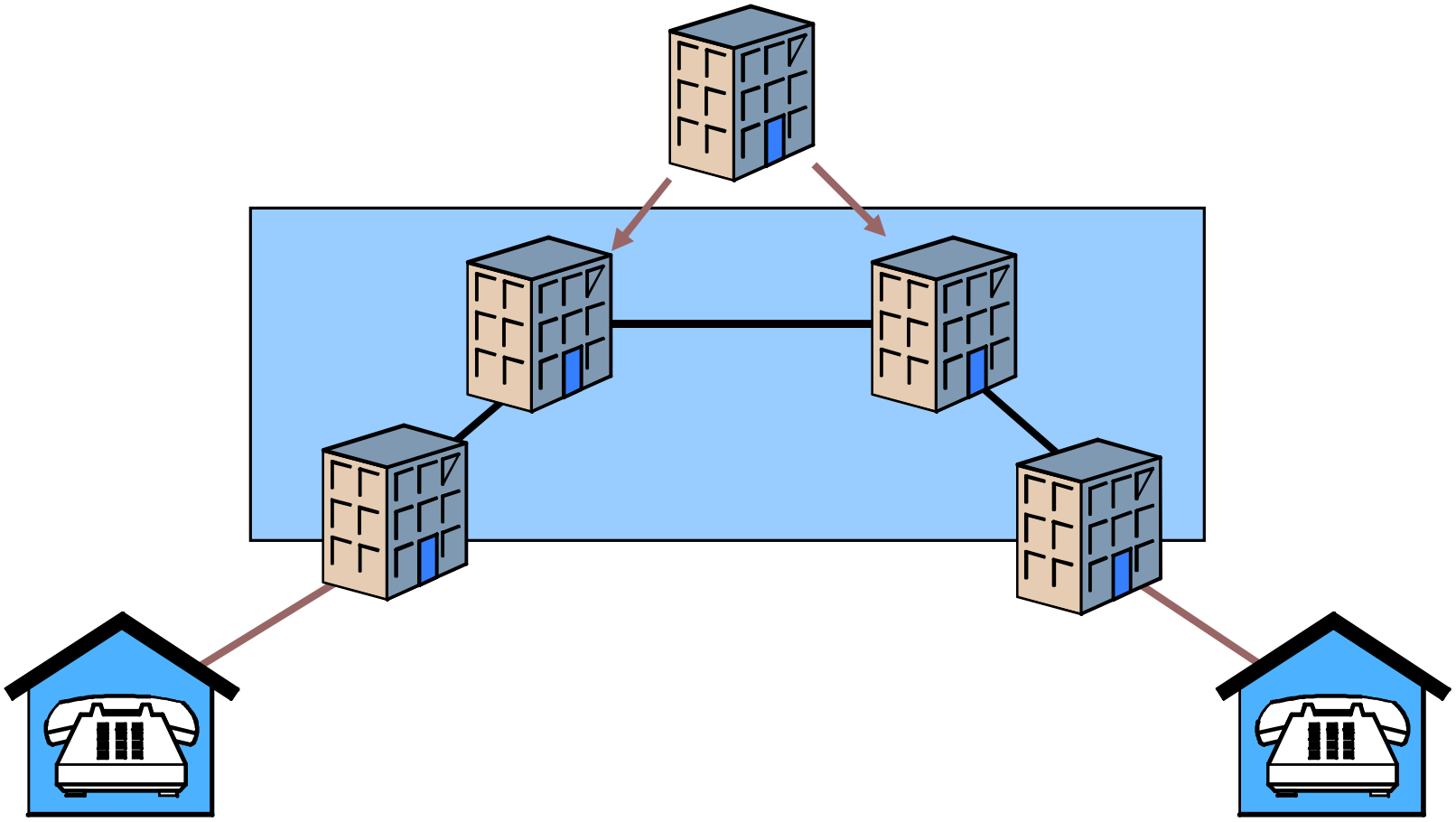
Customer Premises Equipment

Access System

Transport Core

Signaling

Figure 6-1: Elements of the Public Switched Telephone Network (PSTN)



1. Customer Premises Equipment

1. Customer Premises Equipment

Figure 6-1: Elements of the Public Switched Telephone Network (PSTN), Continued

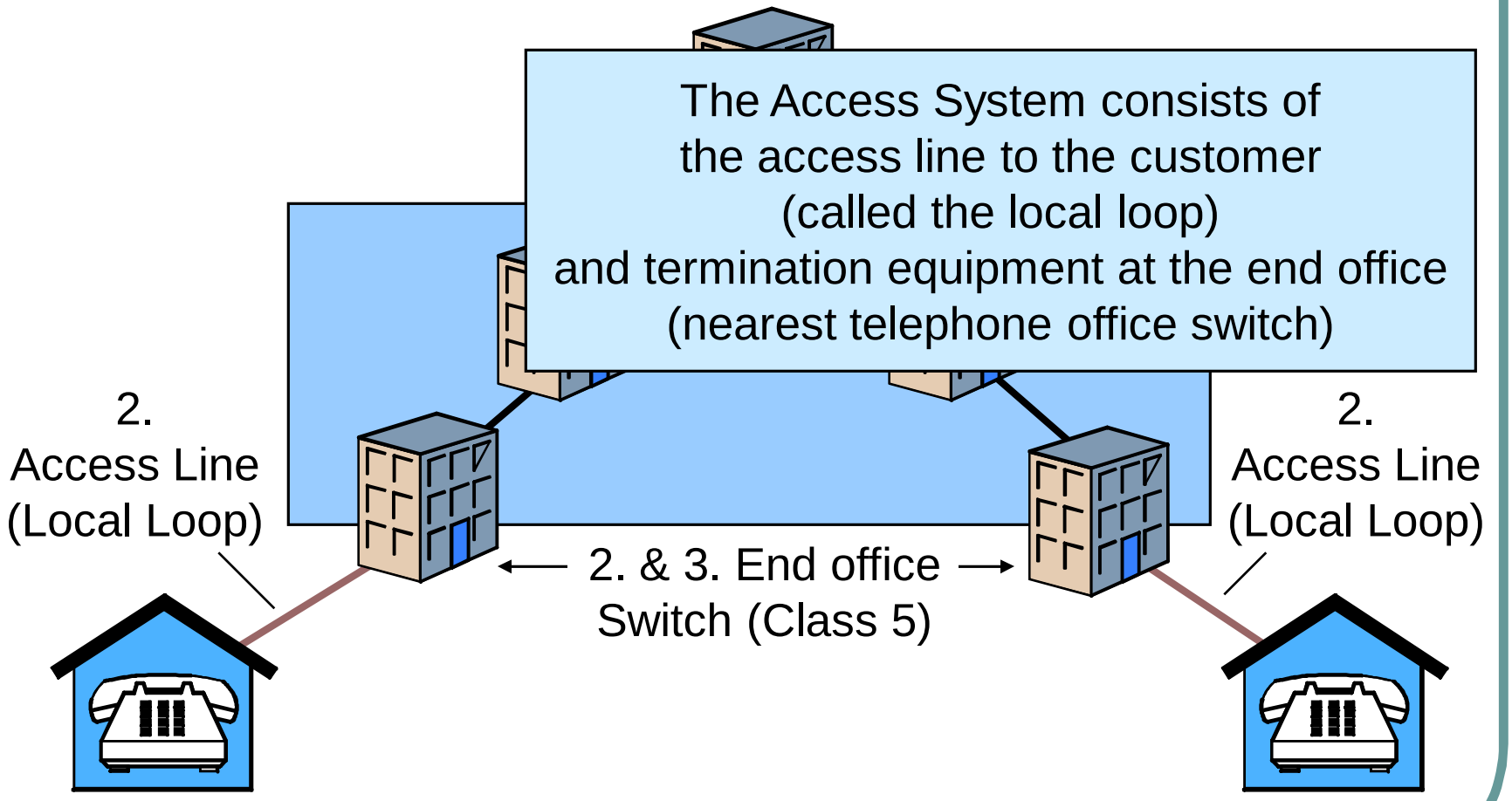


Figure 6-1: Elements of the Public Switched Telephone Network (PSTN), Continued

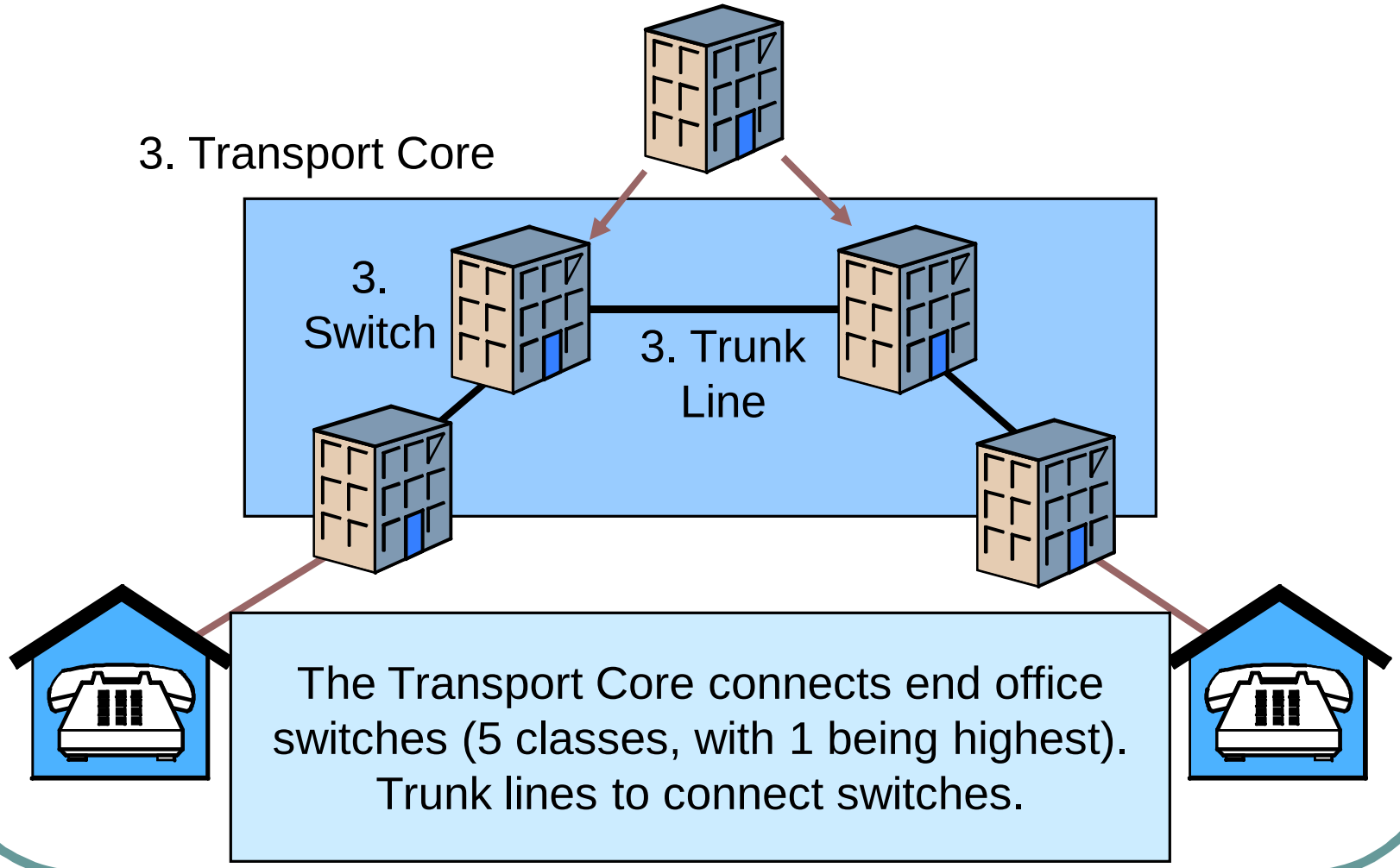


Figure 6-1: Elements of the Public Switched Telephone Network (PSTN), Continued

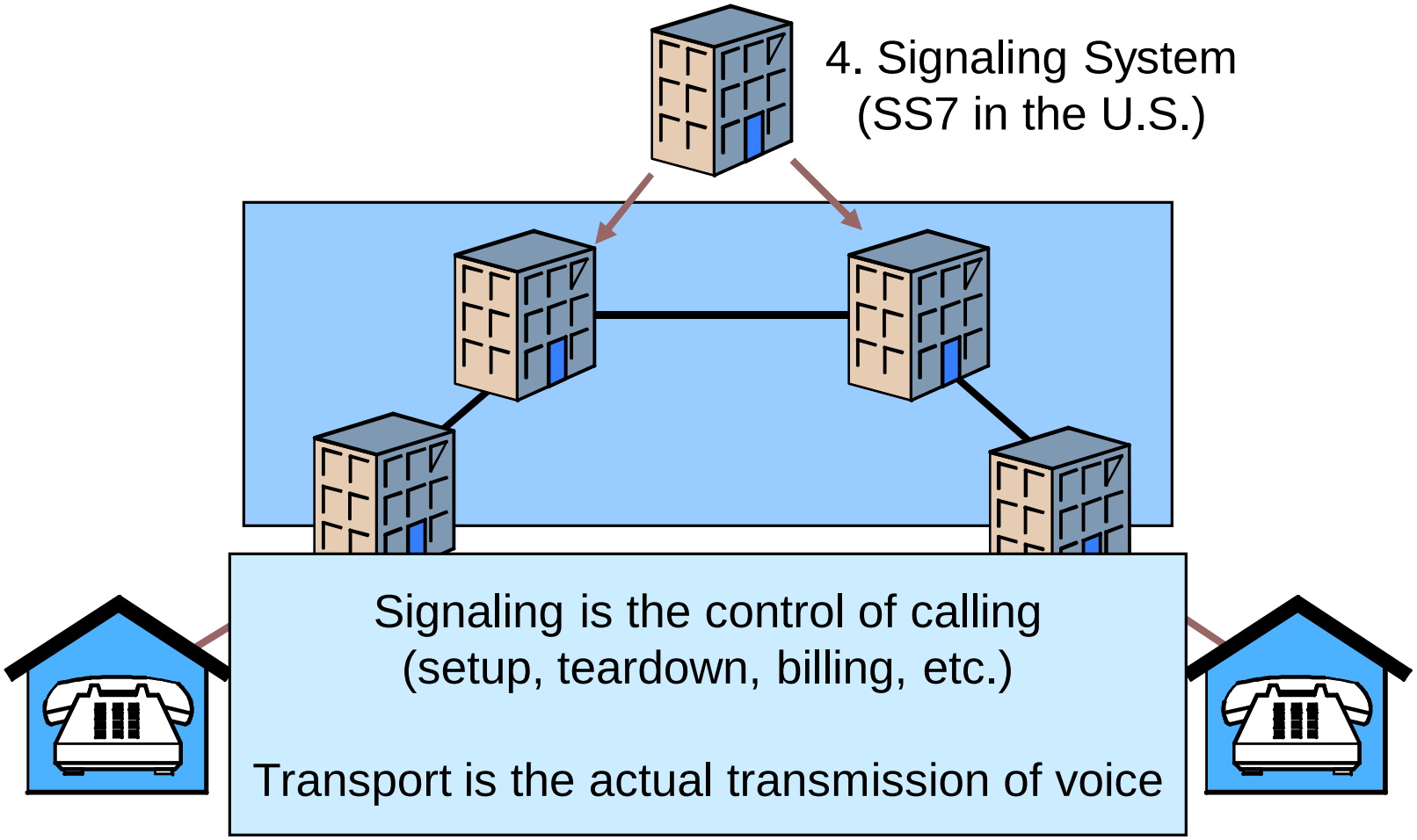


Figure 6-1: Elements of the Public Switched Telephone Network (PSTN), Continued

- Recap
  - Customer premises equipment
  - Access system
    - Local loop and termination equipment at the end office switch
  - Transport Core
    - Transport is the carriage of voice
  - Signaling
    - Signaling is the control of calling

Figure 6-2: Circuit Switching

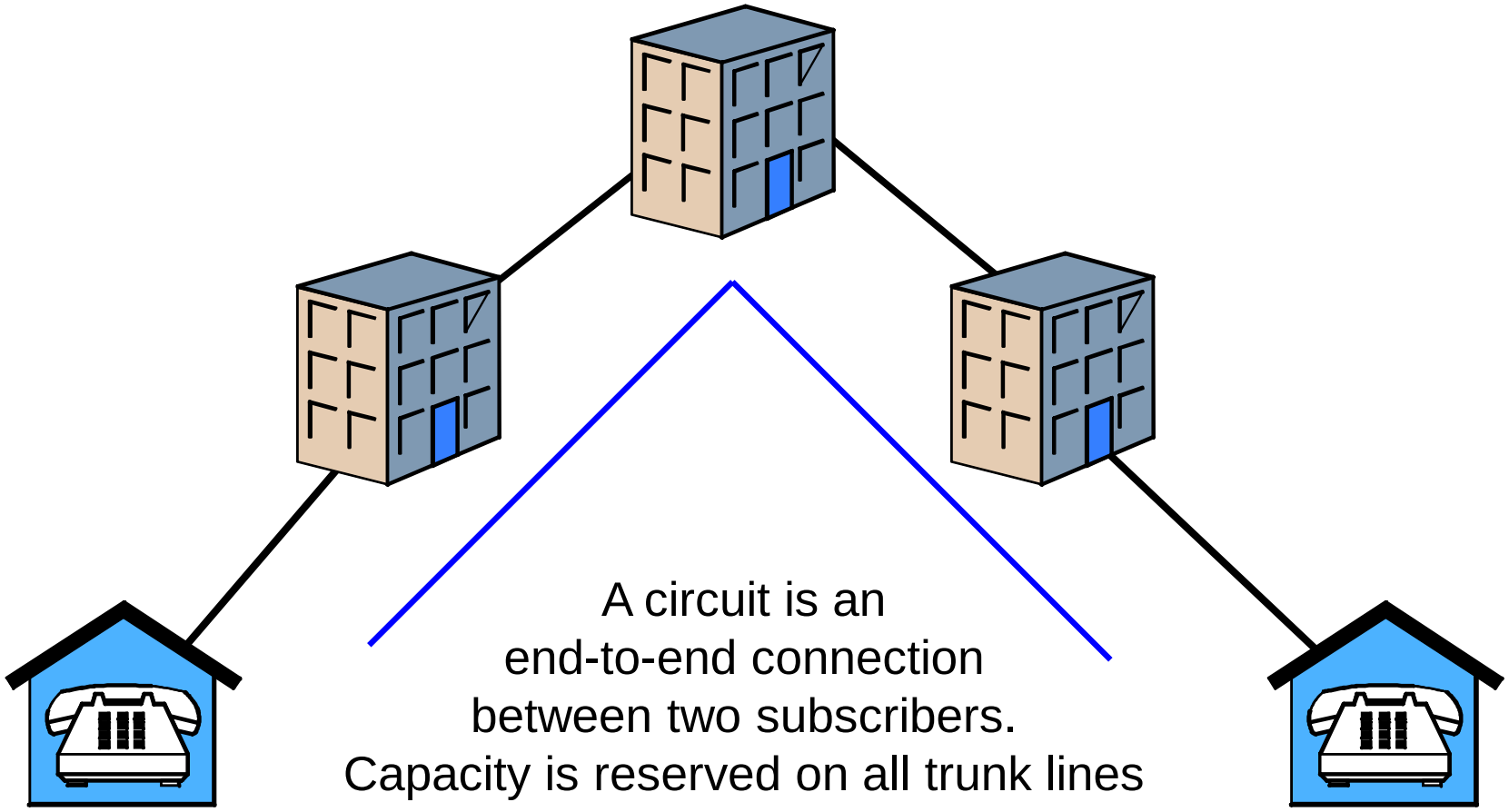


Figure 6-3: Time Division Multiplexing (TDM)

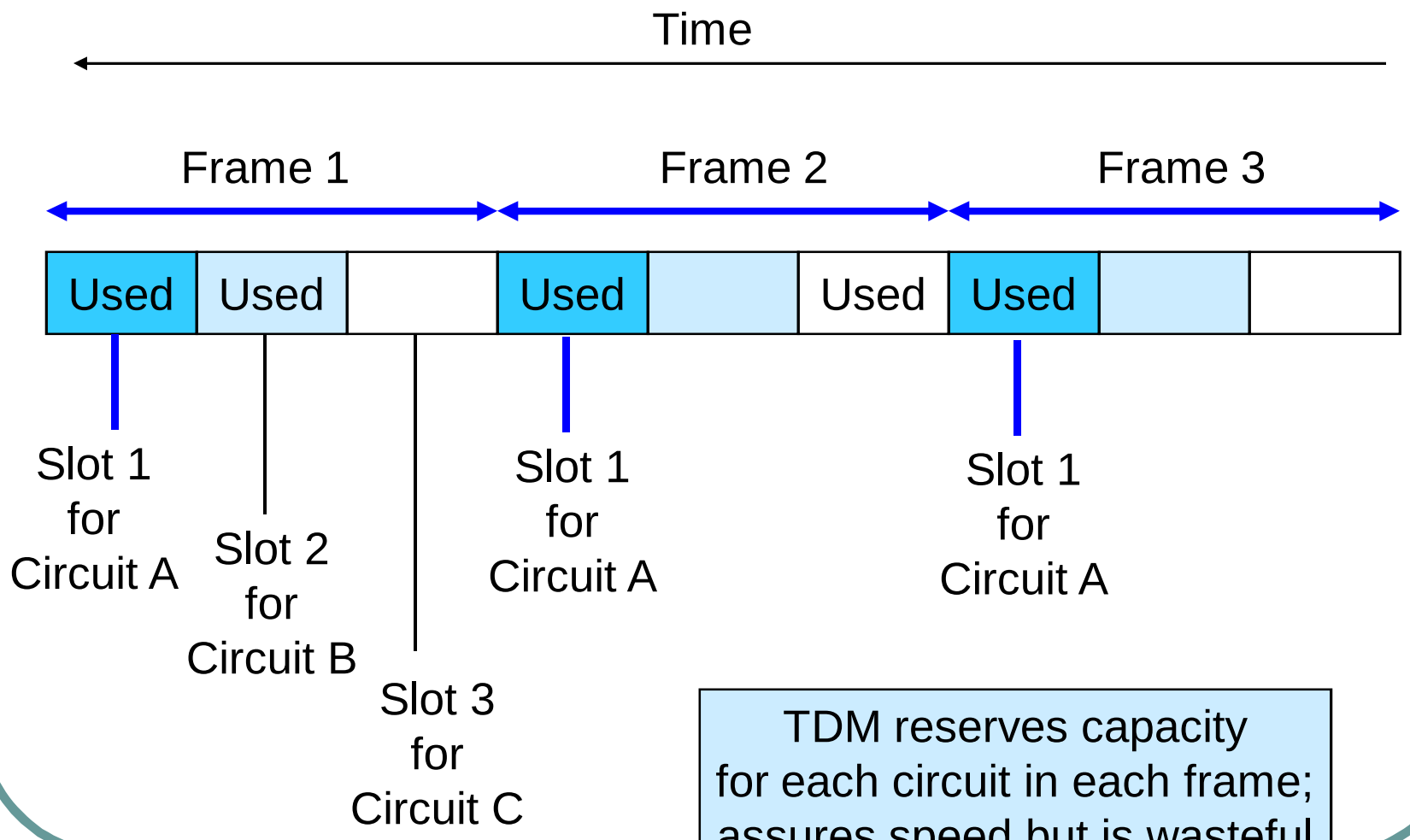
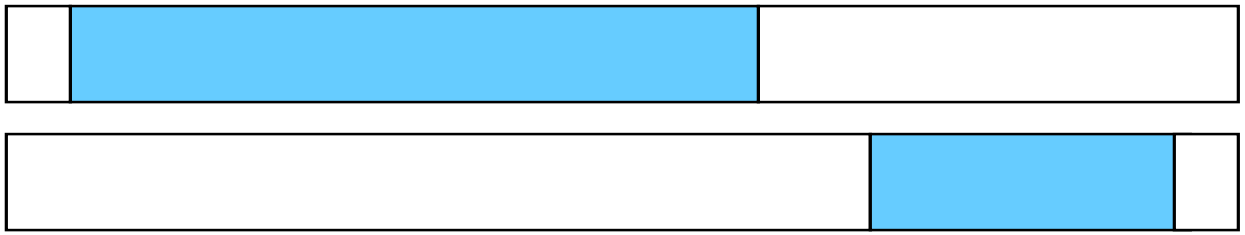


Figure 6-4: Voice and Data Traffic

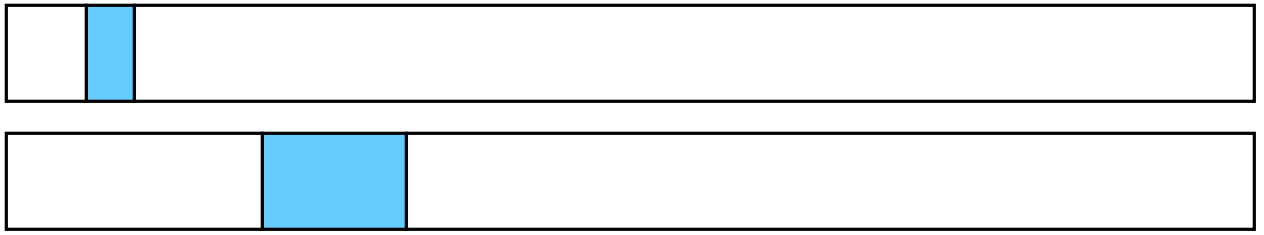
Full-Duplex (Two-Way) Circuit



Voice Traffic:
Fairly Constant Use of Capacity;
Circuit Switching is Fairly Efficient

Figure 6-4: Voice and Data Traffic, Continued

Full-Duplex (Two-Way) Circuit



Data Traffic:
Short Bursts, Long Silences;
Circuit Switching is Inefficient for Data Traffic

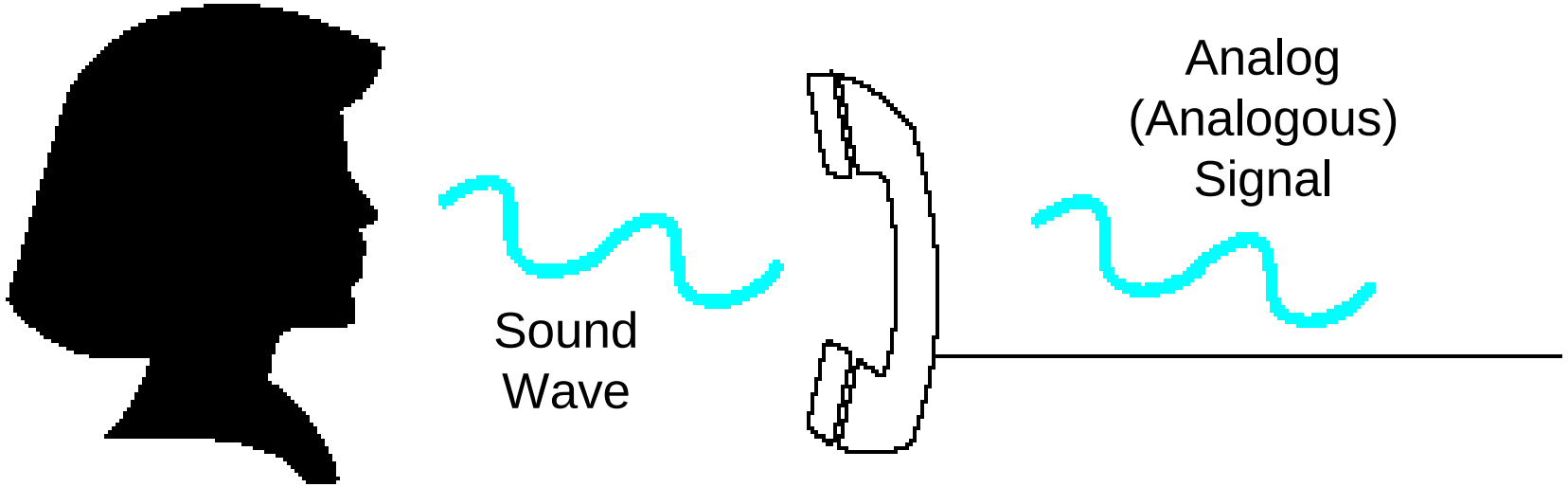
Figure 6-5: Dial-Up Circuits Versus Private Line Circuits

	Dial-Up Circuits	**Private Line Circuits**
Point to Point?	Yes	Yes
Operation	Dial-up. Circuit only lasts for duration of each call	Permanent circuit. Always on
Speed for Carrying Data	Up to 56 kbps	56 kbps to gigabit speeds
Number of Voice Calls per Circuit	One	Several due to Multiplexing

Figure 6-6: Local Loop Technologies

Technology	**Use**	**Status**
1-Pair Voice-Grade UTP	Residences	Already installed
2-Pair Data-Grade UTP	Businesses for high-Speed access lines	Must be pulled to the customer premises (this is expensive)
Optical Fiber	Businesses for high-Speed access lines	Must be pulled to the customer premises (this is expensive)

Figure 6-7: Analog Telephone Transmission



In digital transmission, state changes abruptly.

In analog transmission, state (loudness) changes smoothly over time, analogously to the way voice amplitude changes

Figure 6-8: The PSTN: Mostly Digital with Analog Local Loops

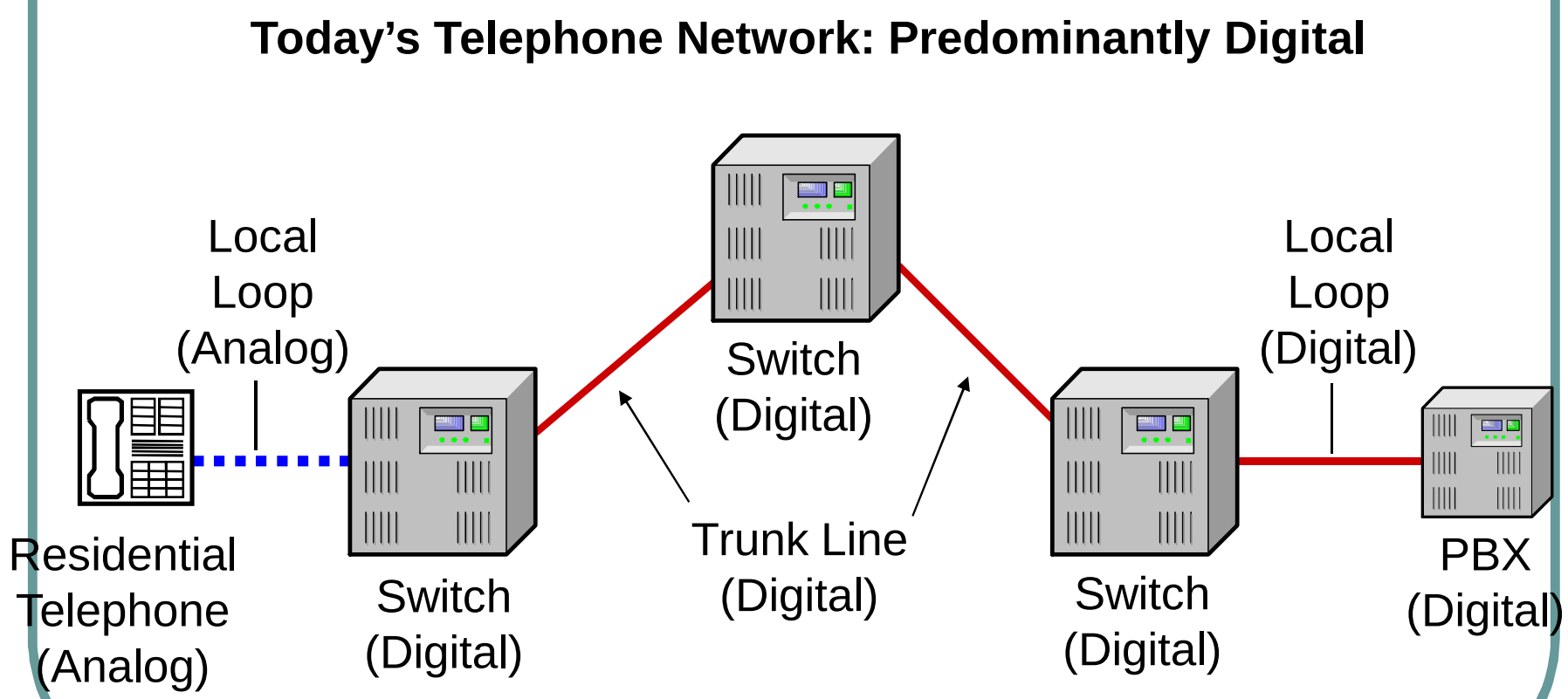
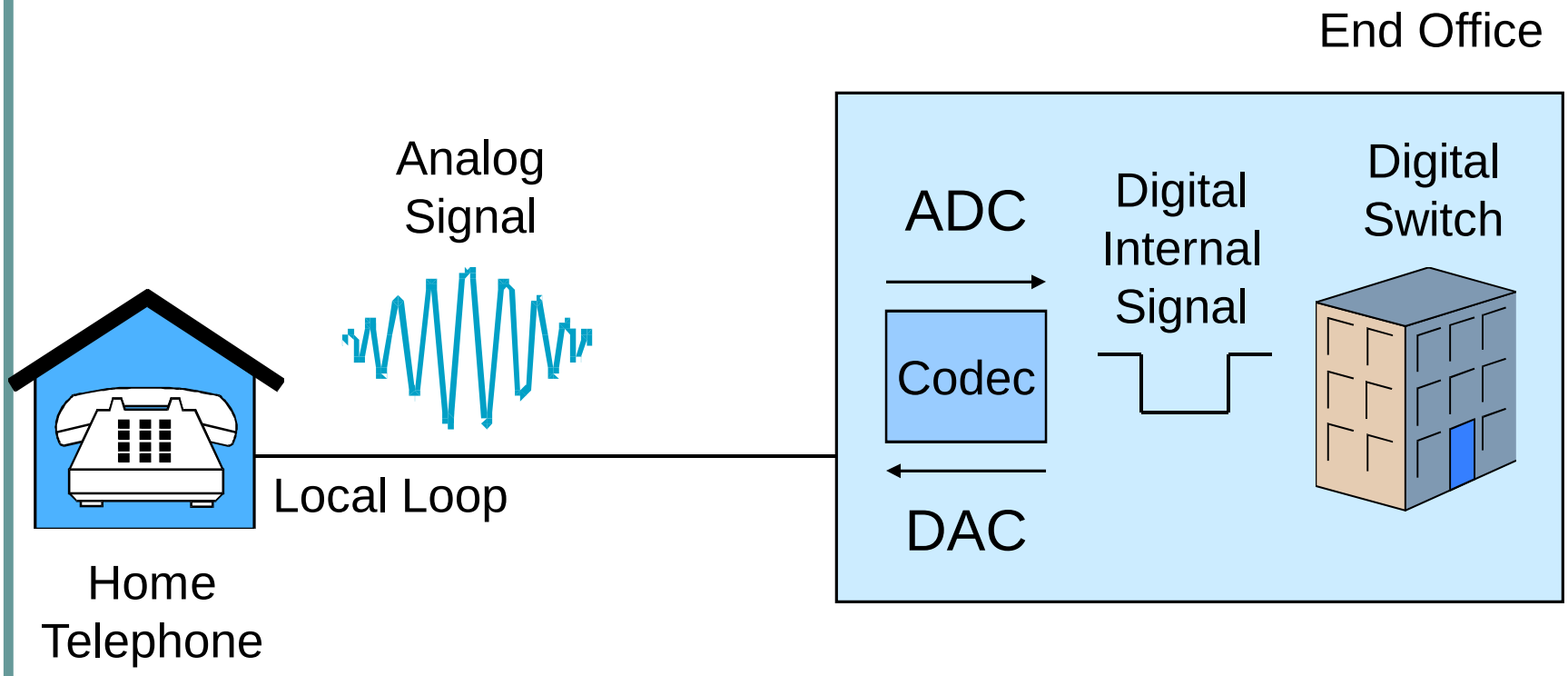
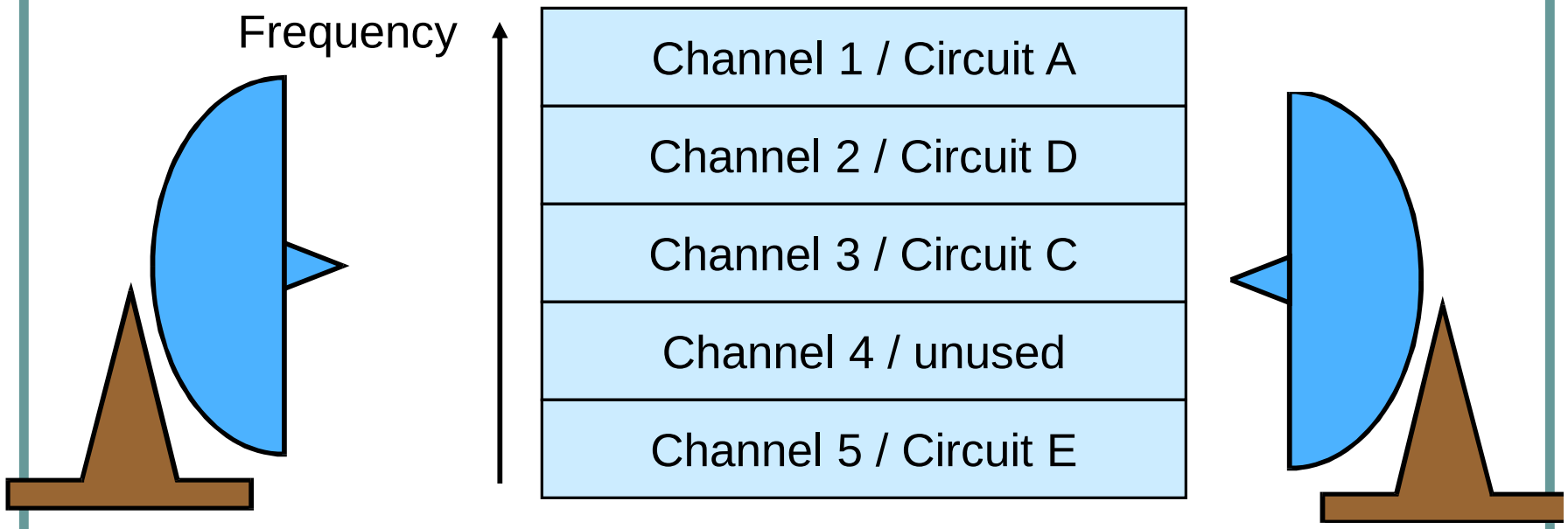


Figure 6-9: Codec at the End Office Switch



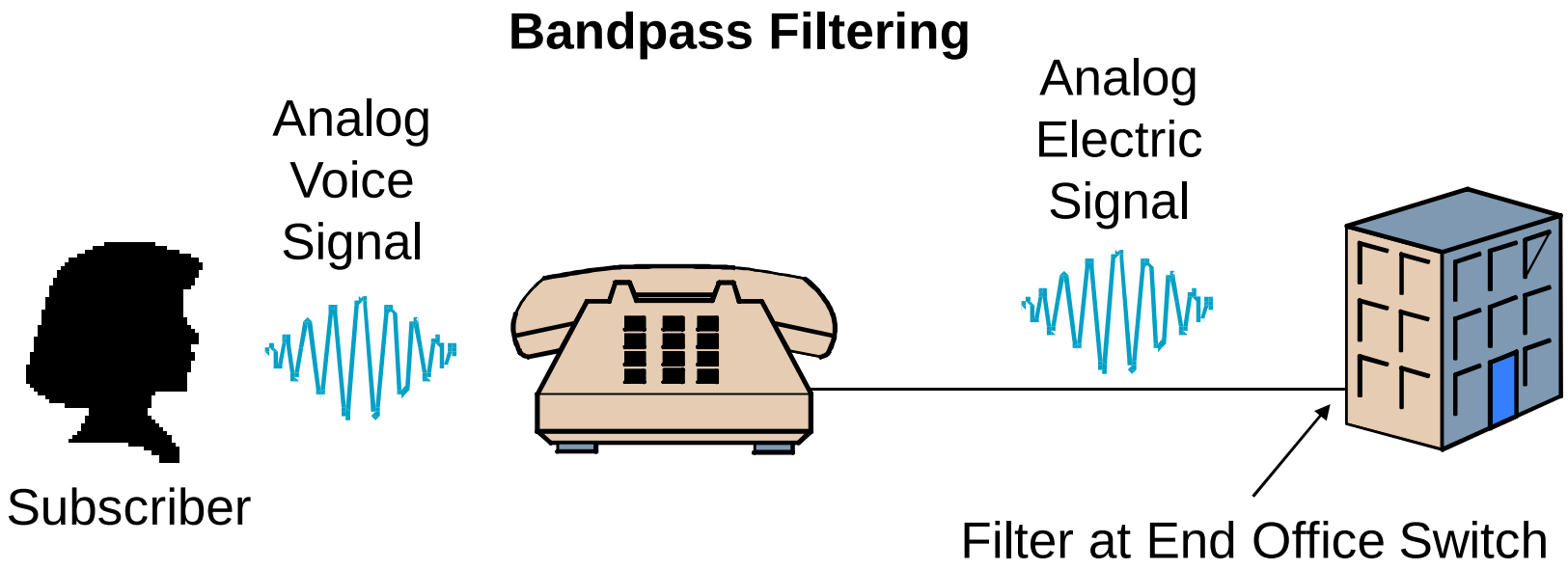
The codec at the end office translates between analog customer signals and digital internal signals

Figure 6-10: Frequency Division Multiplexing (FDM) in Microwave Transmission



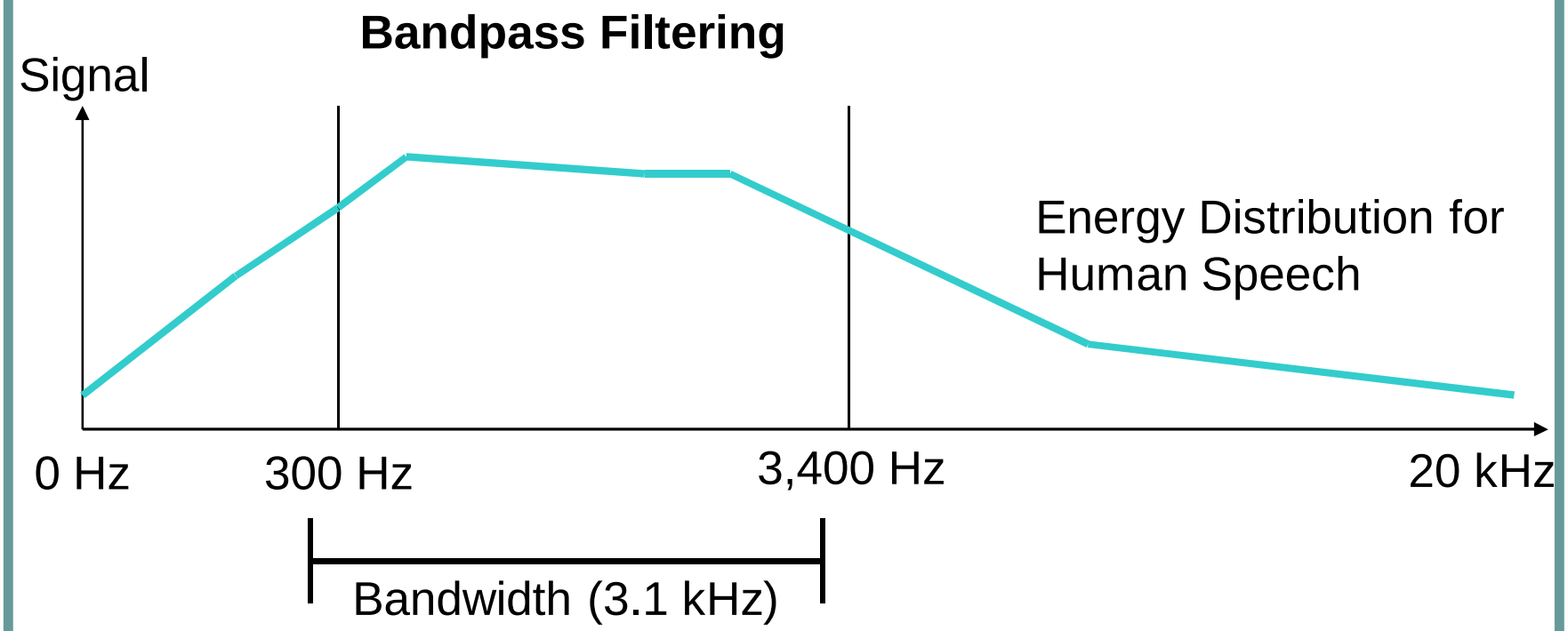
In FDM, each circuit is sent in a separate channel.
If channel bandwidth is large, there will be fewer channels.
Voice uses 4 kHz channels to allow more channels.

Figure 6-11: Analog-to-Digital Conversion (ADC): Bandpass Filtering and Pulse Code Modulation (PCM)



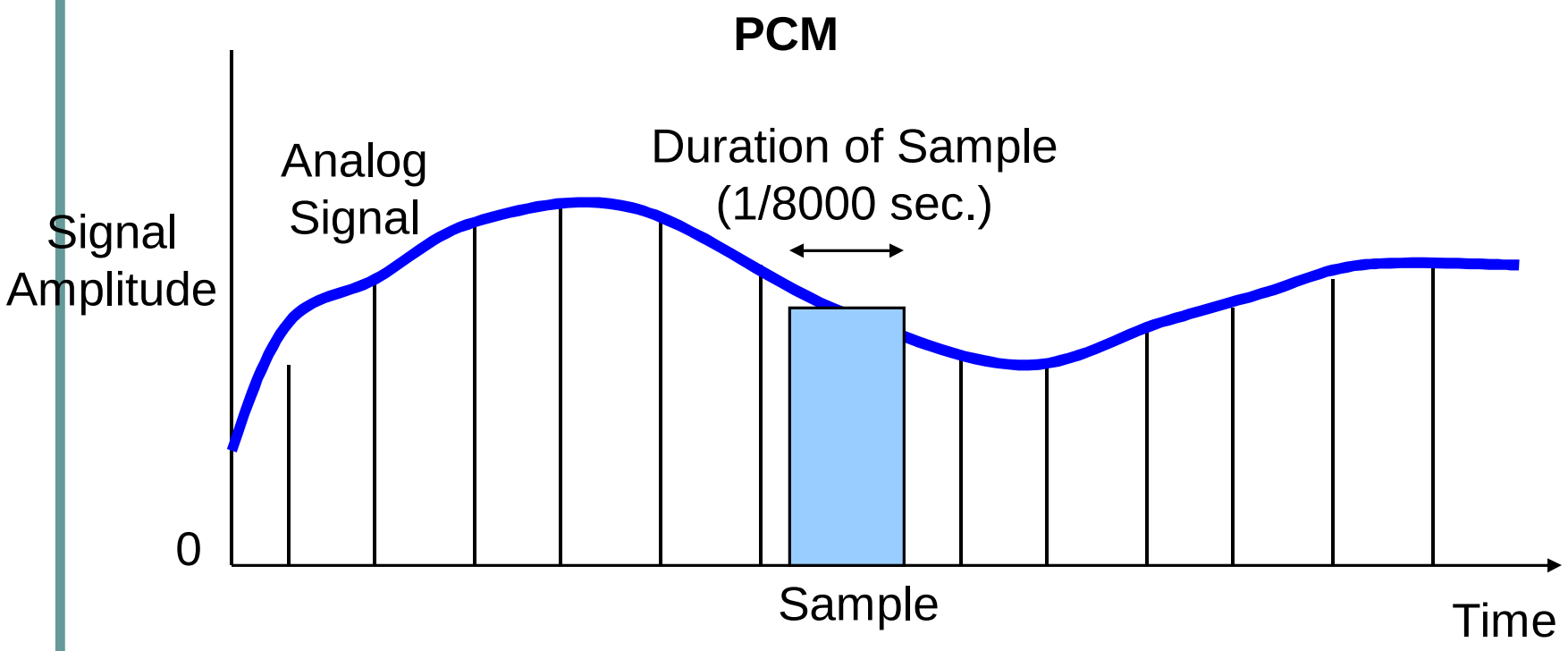
Bandpass filtering to limit voice to 4 kHz is carried out at the end office switch.

Figure 6-11: Analog-to-Digital Conversion (ADC): Bandpass Filtering and Pulse Code Modulation (PCM)



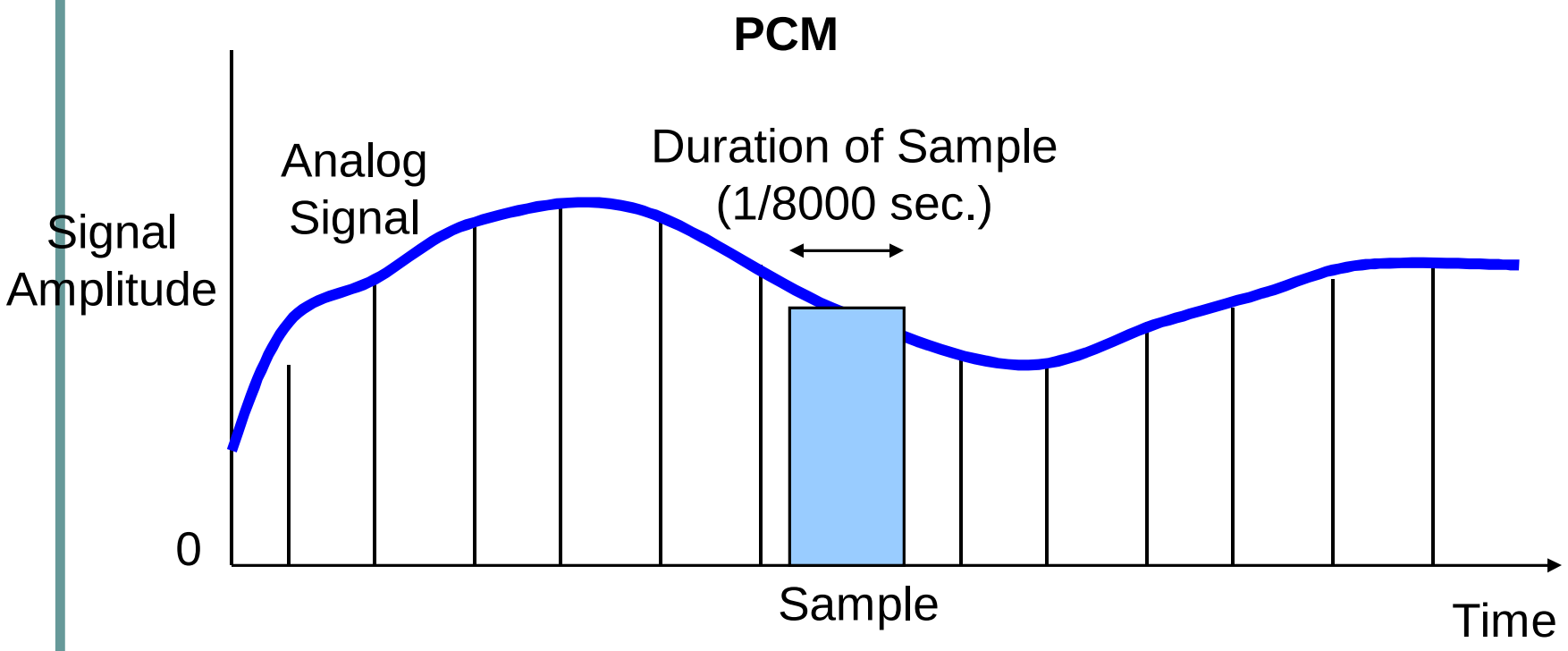
The human voice can produce sounds up to 20 kHz,
but most sound is between 300 Hz and 3.4 kHz.
The bandpass filter only passes this sound to reduce bandwidth.

Figure 6-11: Analog-to-Digital Conversion (ADC): Bandpass Filtering and Pulse Code Modulation (PCM)



In Pulse Code Modulation (PCM), the bandwidth is assumed to be 4 kHz. This adds “guard bands” to the actual 300 Hz - 3.1 kHz signal

Figure 6-11: Analog-to-Digital Conversion (ADC): Bandpass Filtering and Pulse Code Modulation (PCM)



A signal must be sampled at twice its highest frequency (4 kHz) for adequate quality. In PCM, there are 8,000 samples per second

Figure 6-11: Analog-to-Digital Conversion (ADC): Bandpass Filtering and Pulse Code Modulation (PCM)

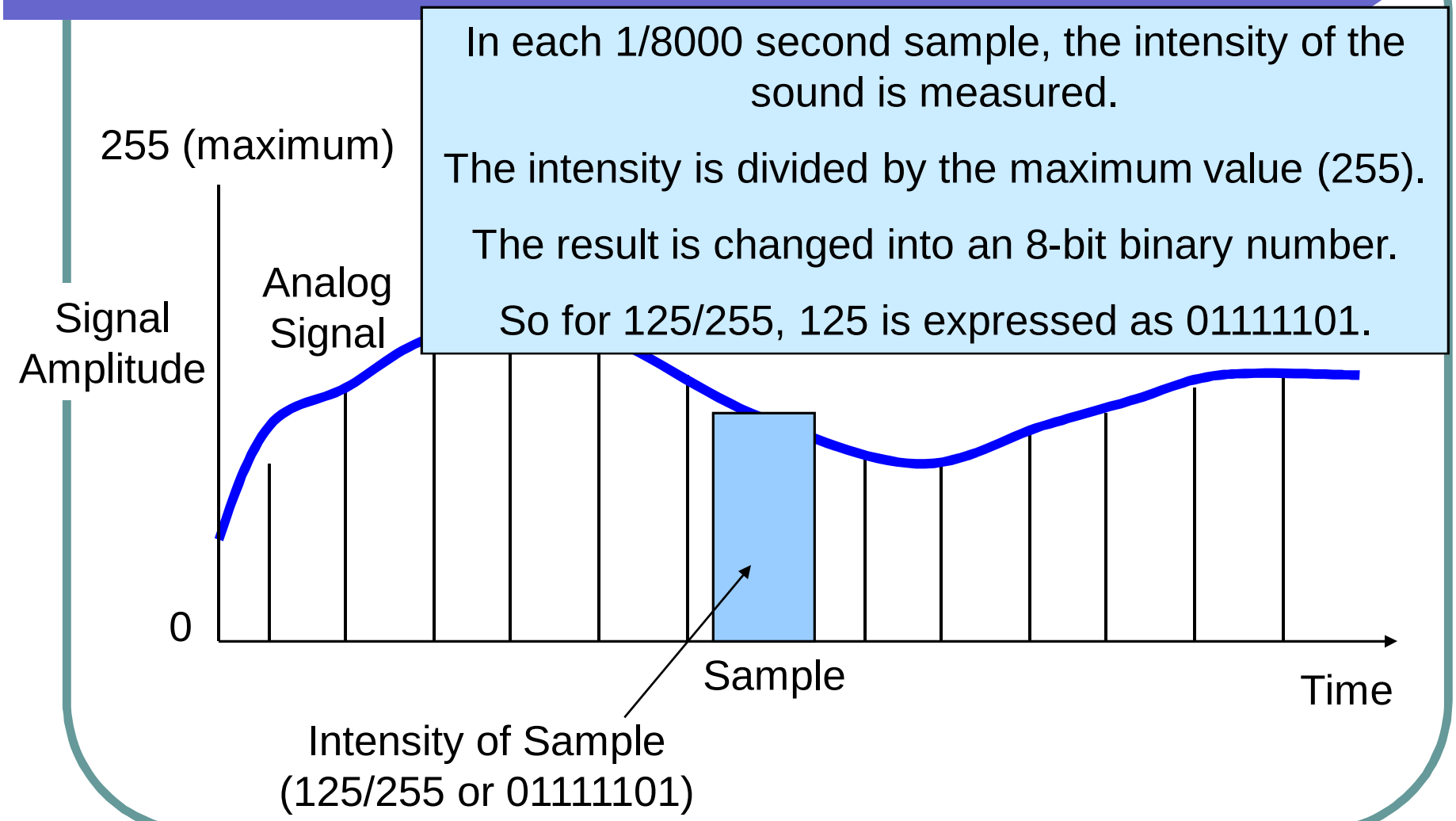
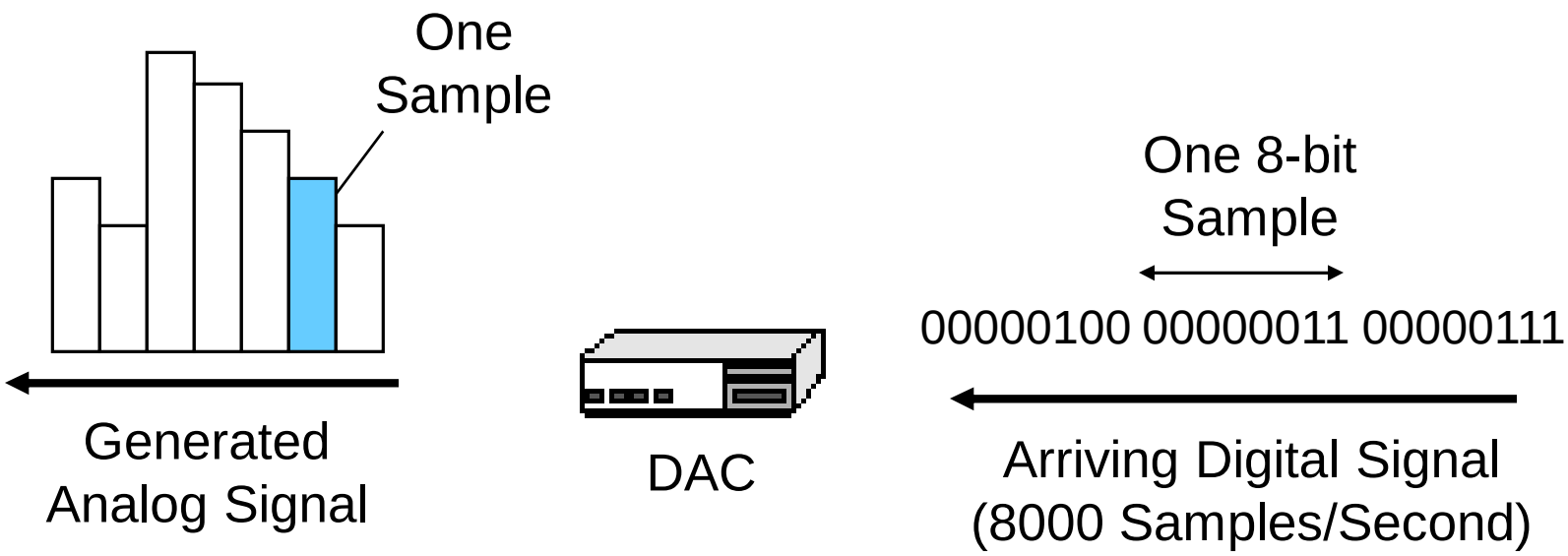


Figure 6-11: Analog-to-Digital Conversion (ADC): Bandpass Filtering and Pulse Code Modulation (PCM)

- The Math
  - The signal is assumed to be 0 Hz – 4 kHz
  - It must be sampled 8,000 times per second (2x4 kHz)
  - Each sample generates an 8-bit amplitude level
  - So voice codecs using PCM generate 64 kbps of data (8,000 x 8)

Figure 6-12: Digital-to-Analog Conversion (DAC)



For signals going to the customer,
sample bits are converted to amplitude levels for each sample.

With 8,000 samples per second, will sound smooth to the ear.

Figure 6-13: TDM and ATM Switch Connections in the PSTN Transport Core

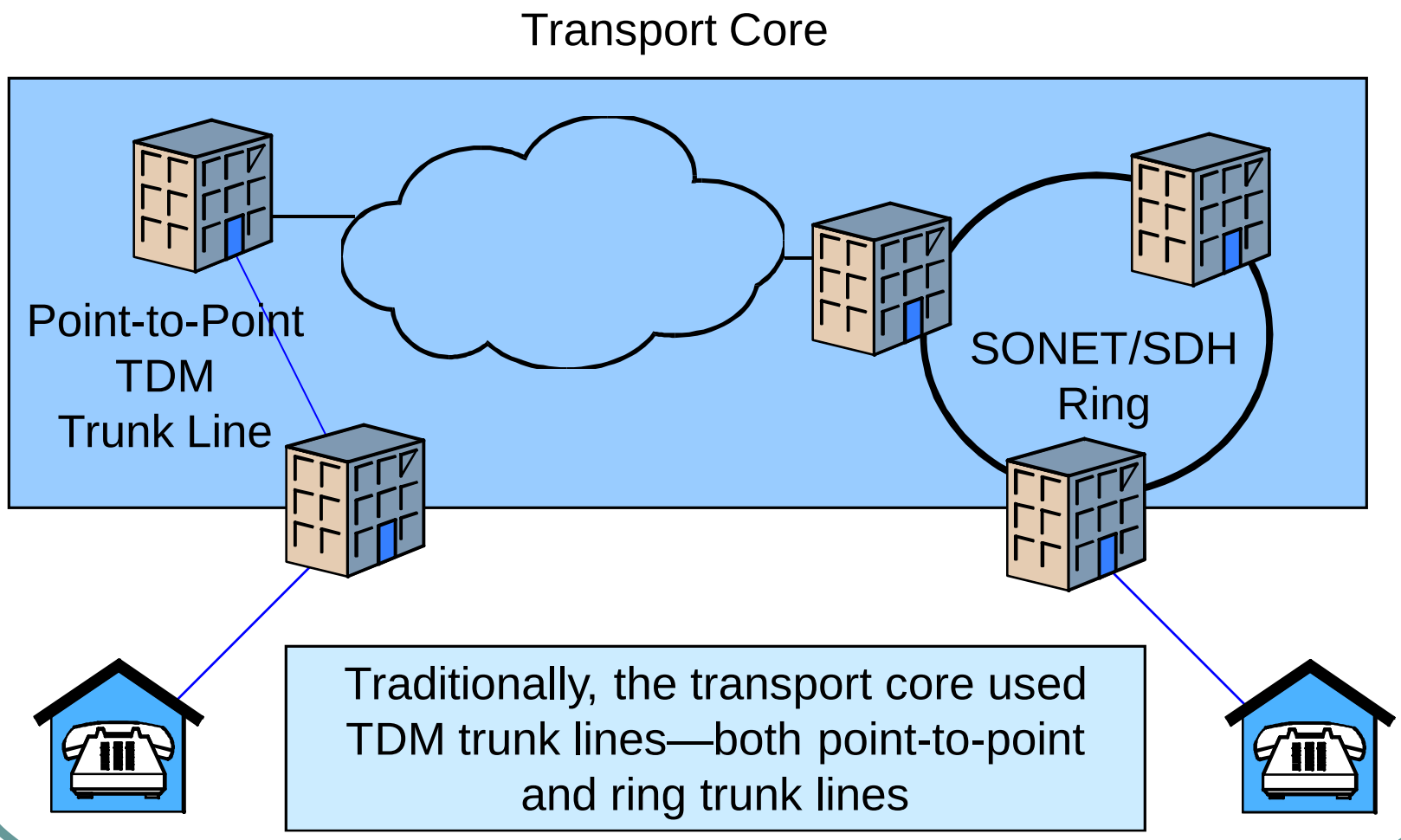


Figure 6-14: SONET/SDH Dual Ring

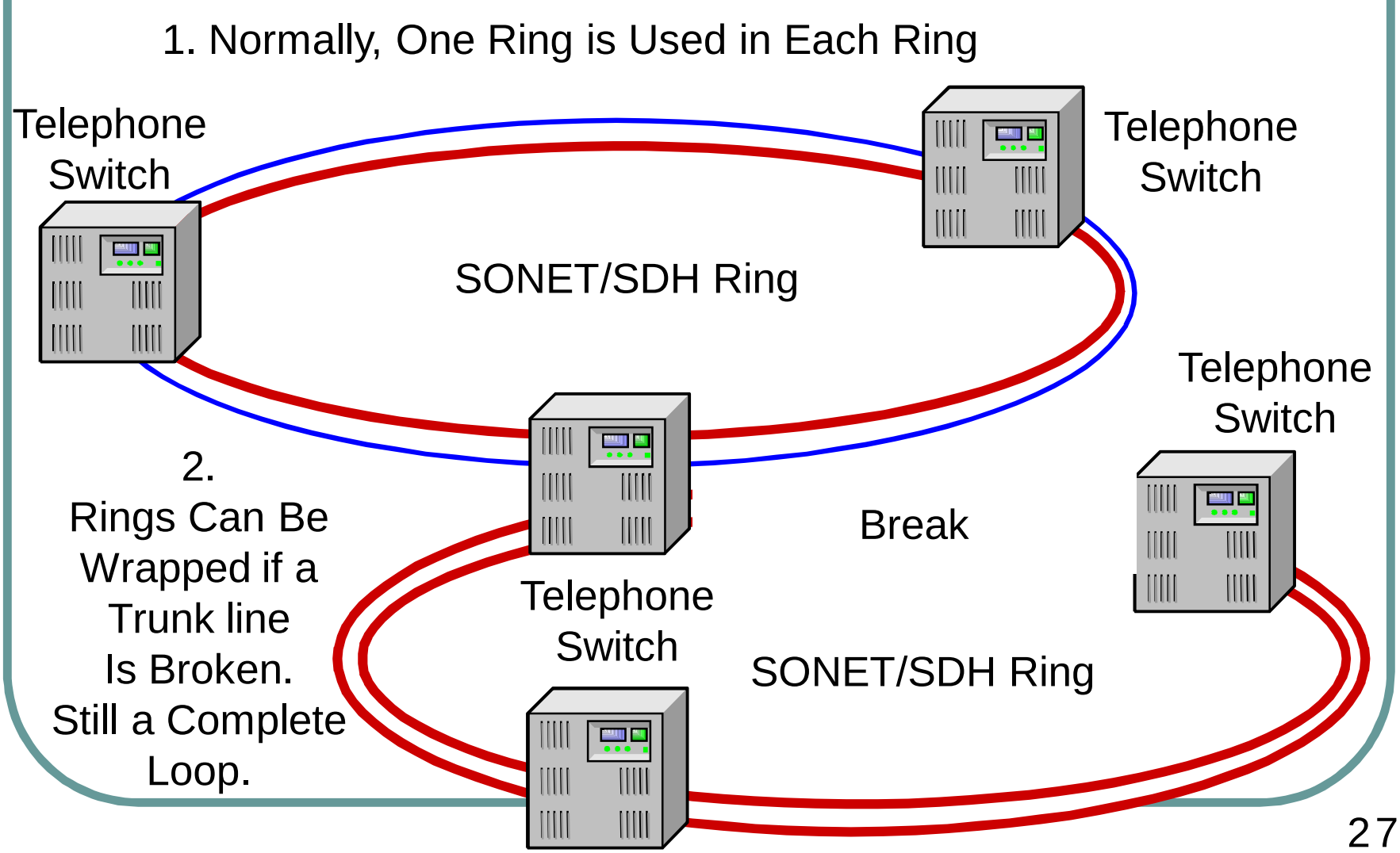


Figure 6-13: TDM and ATM Switch Connections in the PSTN Transport Core

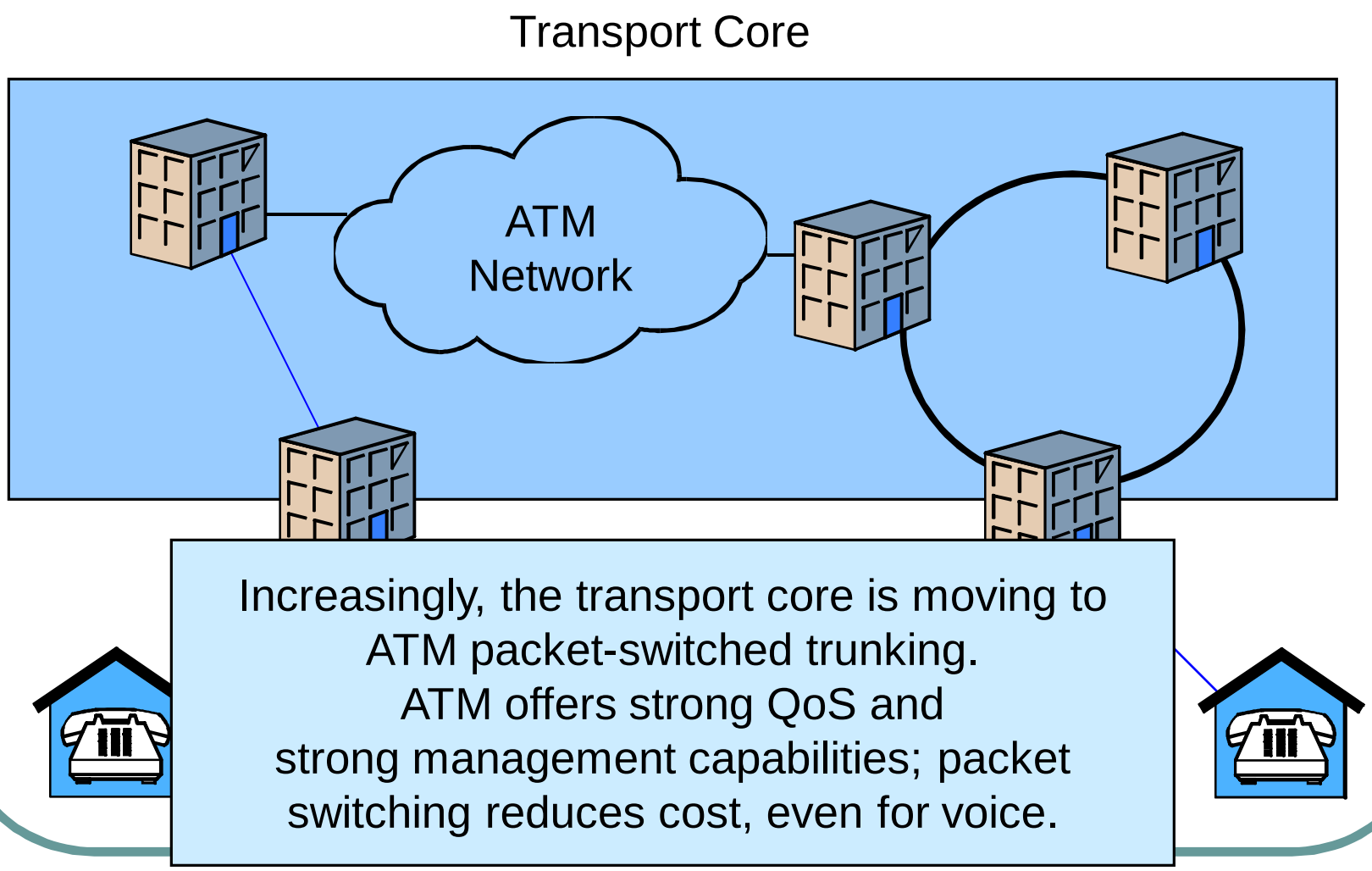


Figure 6-15: Cellular Telephony

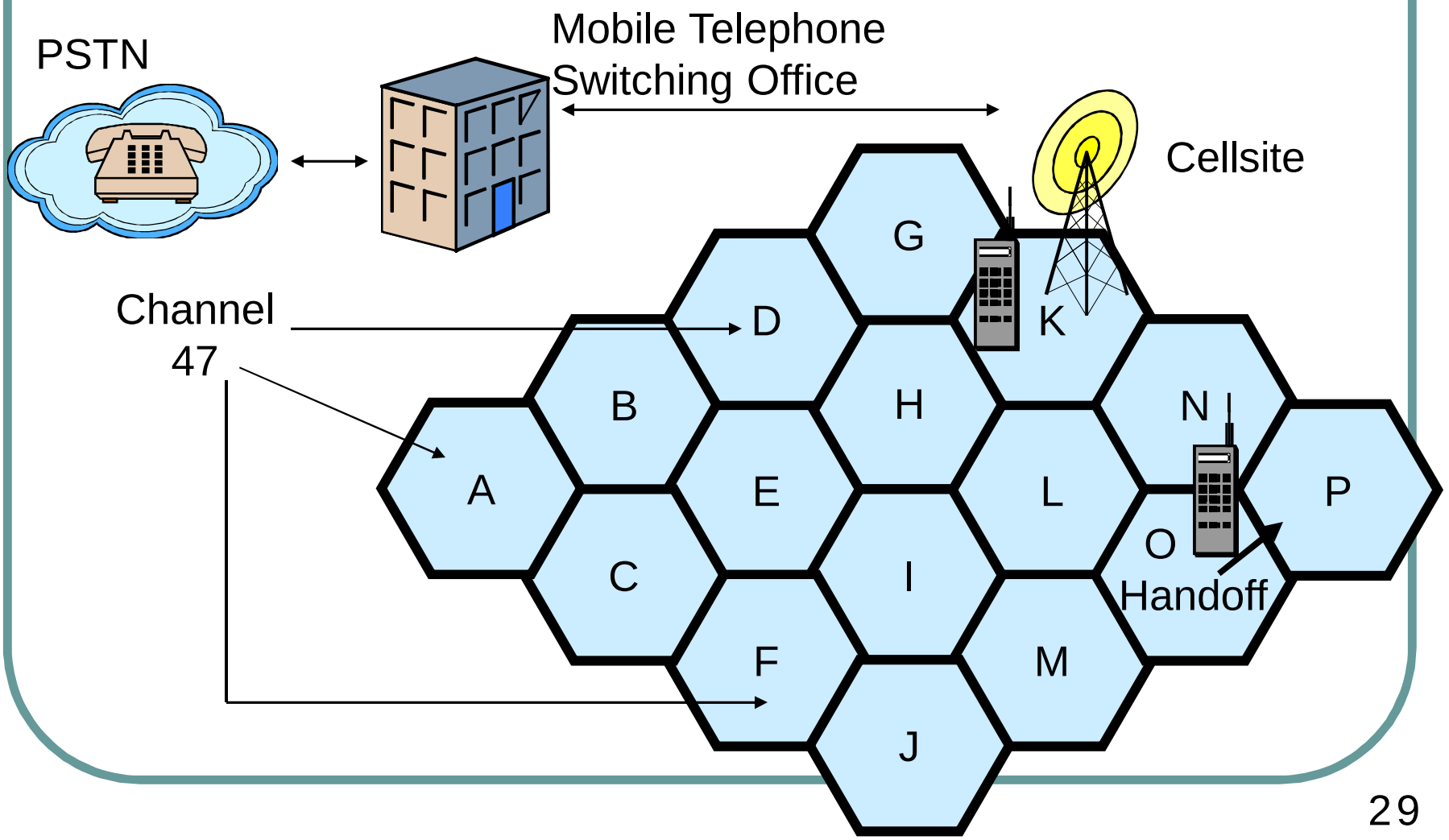
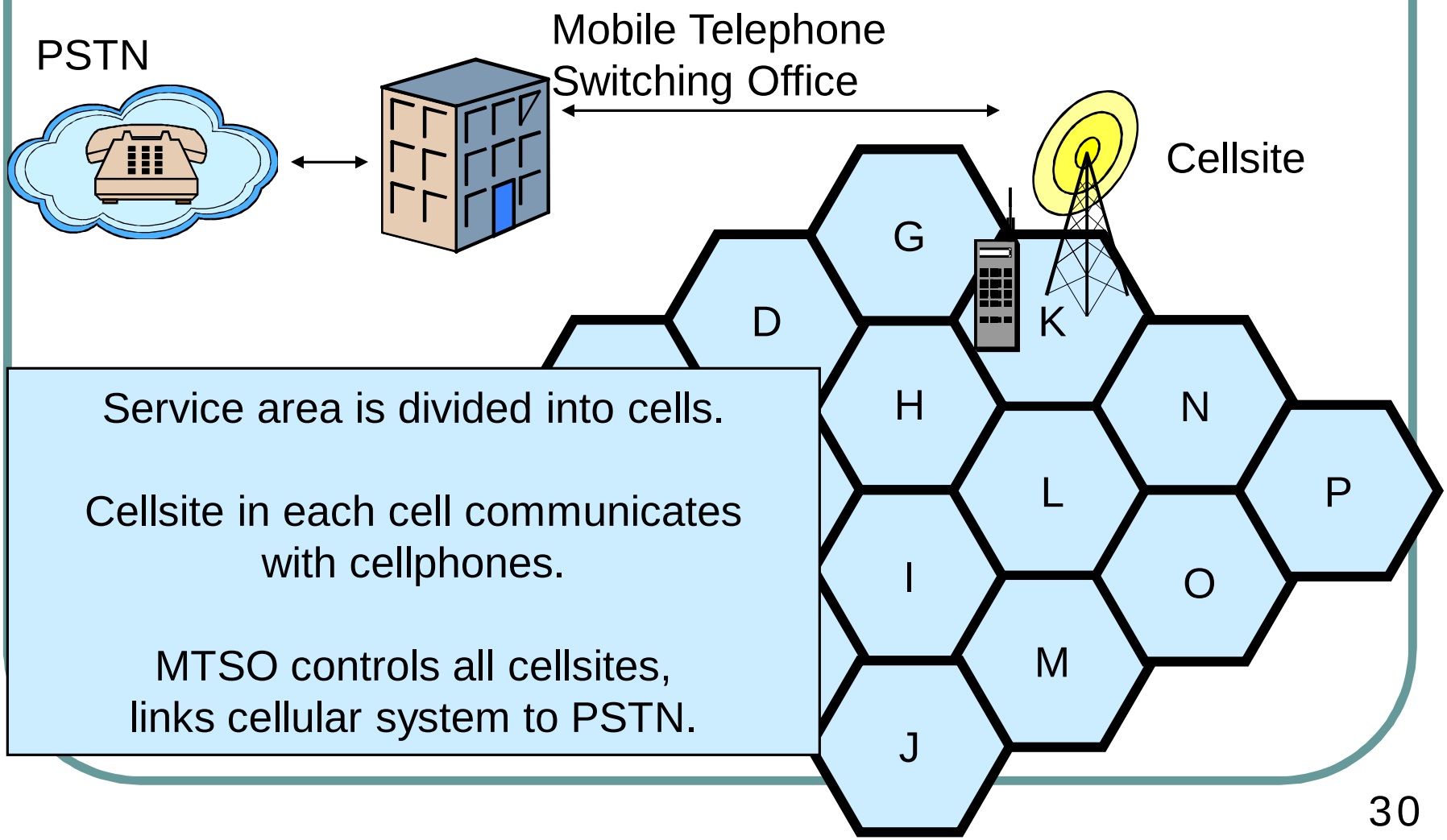


Figure 6-15: Cellular Telephony, Continued

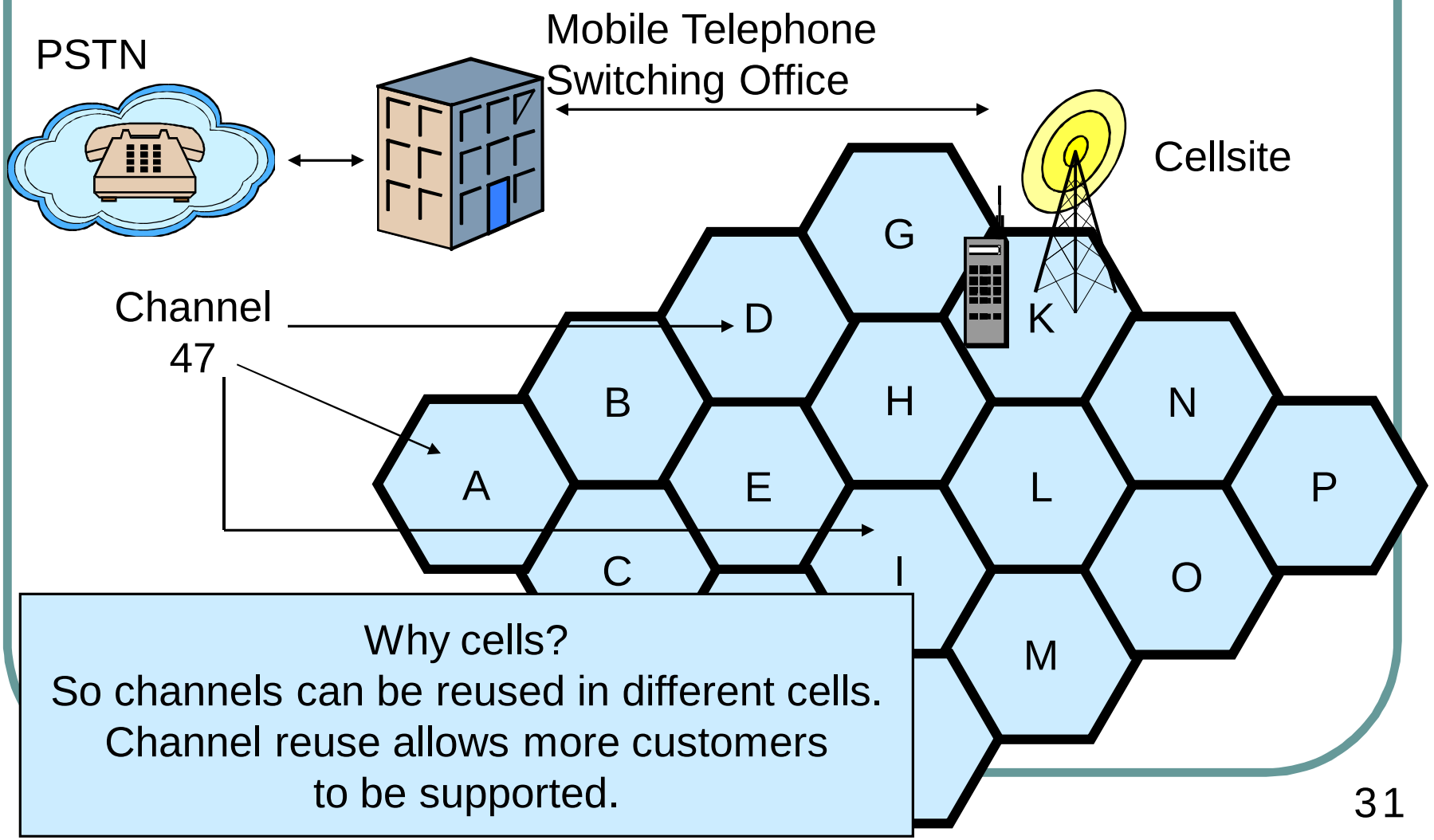


Service area is divided into cells.

Cellsite in each cell communicates with cellphones.

MTSO controls all cellsites, links cellular system to PSTN.

Figure 6-15: Cellular Telephony, Continued



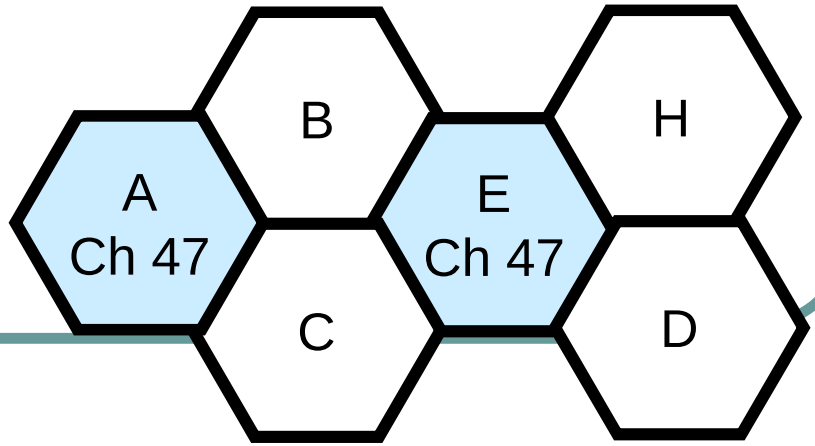
Why cells?
So channels can be reused in different cells.
Channel reuse allows more customers
to be supported.

Cellular Technology

- Handoff
  - Moving between cells in a system (city)
- Roaming
  - Moving between systems (cities)
  - Often restricted to avoid cellular fraud

Channel Reuse

- Traditional cellular technologies
  - Used FDMA, sometimes with TDMA within channels
  - Could not reuse channels in adjacent cells
  - Typically, a channel is reused roughly every seven cells
  - So if there are 25 cells, each channel will be reused about three times



Channel Reuse, Continued

- Newer cellular systems use CDMA
  - Code division multiple access
  - Type of spread spectrum transmission that allows multiple subscribers to transmit simultaneously in a single channel
  - Allows channel reuse in adjacent cells
  - If there are 25 cells, each channel can be reused 25 times
  - CDMA supports many more customers because of greater channel reuse

Figure 6-16: Generations of Cellular Technology

Generation	**1G**	**2nd**	**3G**
Year	1980	1990	2002
Technology	Analog	Digital	Digital
Data Transfer Rate	Data transfer is difficult; ~5 kbps	10 kbps	30 kbps to 500 kbps

Figure 6-16: Generations of Cellular Technology, Continued

Generation	1G	2nd	3G
Channels	~800	~800+2,500	Still being defined; using 2G channels in the interim
Cells / Channel Reuse	Large / Medium	Large / Medium and Small / High	Still being defined
Perspective	Being phased out	Dominates today	Just being implemented

Figure 6-16: Generations of Cellular Technology, Continued

- 1G was analog, fading away
- 2G dominates today. Digital but slow data transmission
- 3G will bring rapid data transmission over a metropolitan area

Figure 6-17: Cellular Standards Families (Study Figure)

- GSM Family
  - GSM (Global System for Mobile communications)
    - Dominates 2G service worldwide
    - 200 kHz channels shared by up to eight users via TDM
    - Data transmission speed of approximately 10 kbps

Figure 6-17: Cellular Standards Families (Study Figure), Continued

- GSM Family
  - General Packet Radio Service (GPRS)
    - Upgrade to GSM
    - Uses GSM channels
    - Provides several TDM time slots per user in each frame for greater throughput
    - 2.5G: Typical throughput of 20 kbps to 30 kbps
    - Comparable to telephone modems

Figure 6-17: Cellular Standards Families (Study Figure), Continued

- GSM Family
  - EDGE
    - Upgrade to GSM beyond GPRS
    - Also uses GSM channels with multiple time slots per user
    - 2.5G: Typical throughput of 80 kbps to 125 kbps

Figure 6-17: Cellular Standards Families (Study Figure), Continued

- GSM Family
  - W-CDMA
    - Wideband CDMA
    - Full 3G service
    - Throughput comparable to DSL and cable modems
    - Developed in Europe and Japan

Figure 6-17: Cellular Standards Families (Study Figure), Continued

- Qualcomm CDMA Family
  - CDMAone (IS-95)
    - 2G system used widely in the United States
      - Used by about 70% of cellphones in the U.S.
    - Uses CDMA
    - 125 MHz channel shared by multiple simultaneous users
    - 10 kbps data transmission

Figure 6-17: Cellular Standards Families (Study Figure), Continued

- Qualcomm CDMA Family
  - CDMA2000 (IS-2000) Upgrades
    - 1x: 30 kbps to 50 kbps throughput in a 1.25 MHz channel
      - Only modem throughput
      - Considered to be 3G because rated speed is 144 kbps
    - 1xEV-DO: 100 kbps to 300 kbps throughput
      - DSL/Cable modem throughput

Perspective

- 2G Service (Dominant Today)
  - Only 10 kbps data transfer
- Telephone Modem Throughput (2.5 G)
  - GPRS and Edge in GSM Family
  - 1x in Qualcomm CDMA Family
- DSL/Cable Modem Throughput
  - WCDMA in GSM Family
  - 1x EV-DO in Qualcomm CDMA Family

802.11 Hot Spots

- Hot Spots
  - Coffee houses, airport lounges, campus centers, etc.
  - Offer Internet access via 802.11 WLANs
  - Sometimes for free, sometimes for a fee
  - Growing in popularity and coverage
  - Hot spots are impeding demand for 3G services, which have wide coverage but that are both slower and more expensive

U.S. Cellular Telephony Lag

- The U.S. lags behind many other countries in cellular telephone use.
  - U.S. wired telephone charges are low, making the price gap to get a cellular phone high
  - In the U.S., when someone calls a cellular number, the receiver pays. In the rest of the world, the caller pays. This further makes cellular service expensive in the United States

IP Telephony (VoIP)

- IP telephony is the transmission of digitized voice over IP
  - Also called voice over IP (VoIP)
- Packet switching should reduce costs compared to traditional long-distance and international telephone calling
- Can integrate voice with data services, allowing new applications

Figure 6-18: IP Telephony

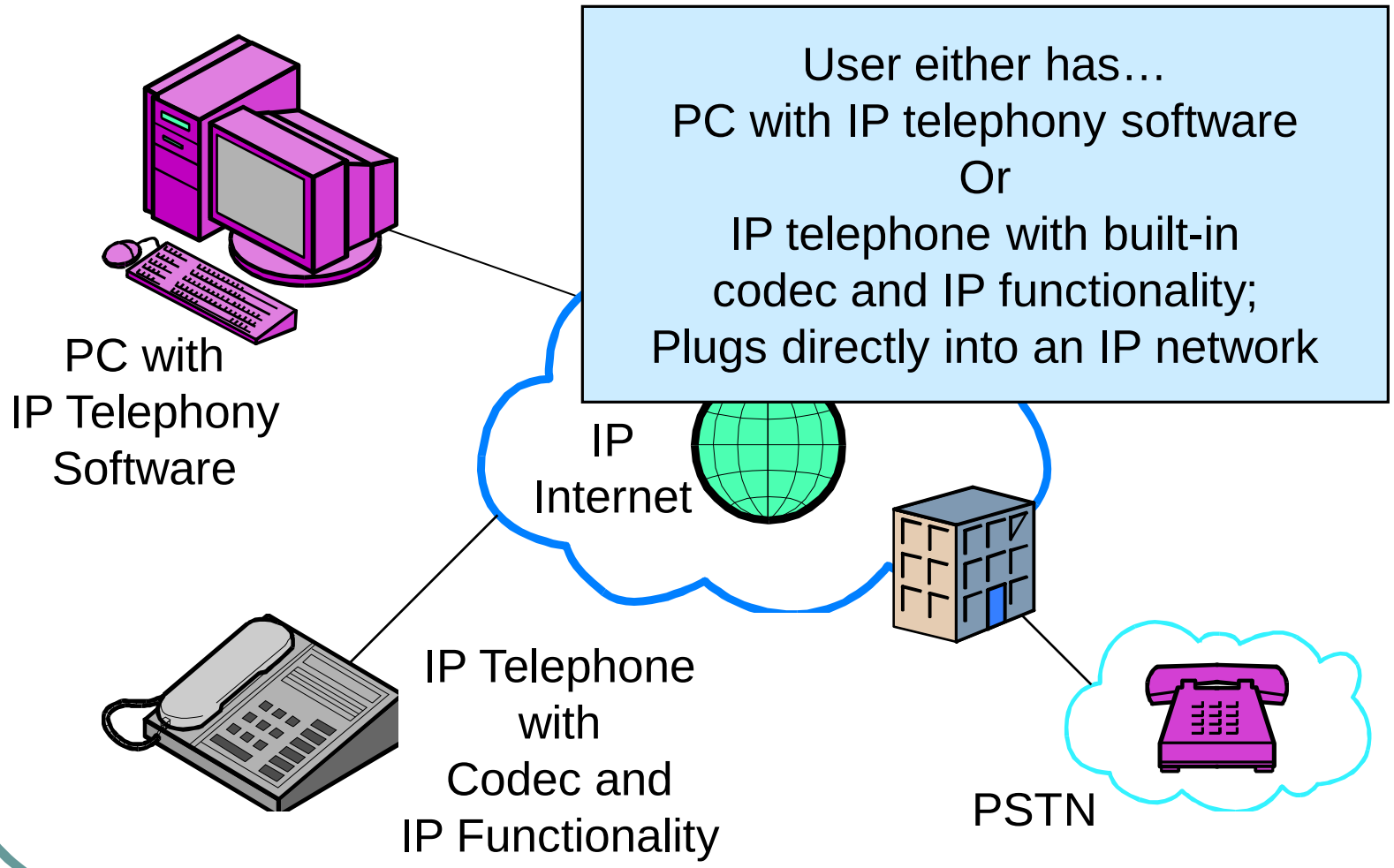


Figure 6-18: IP Telephony, Continued

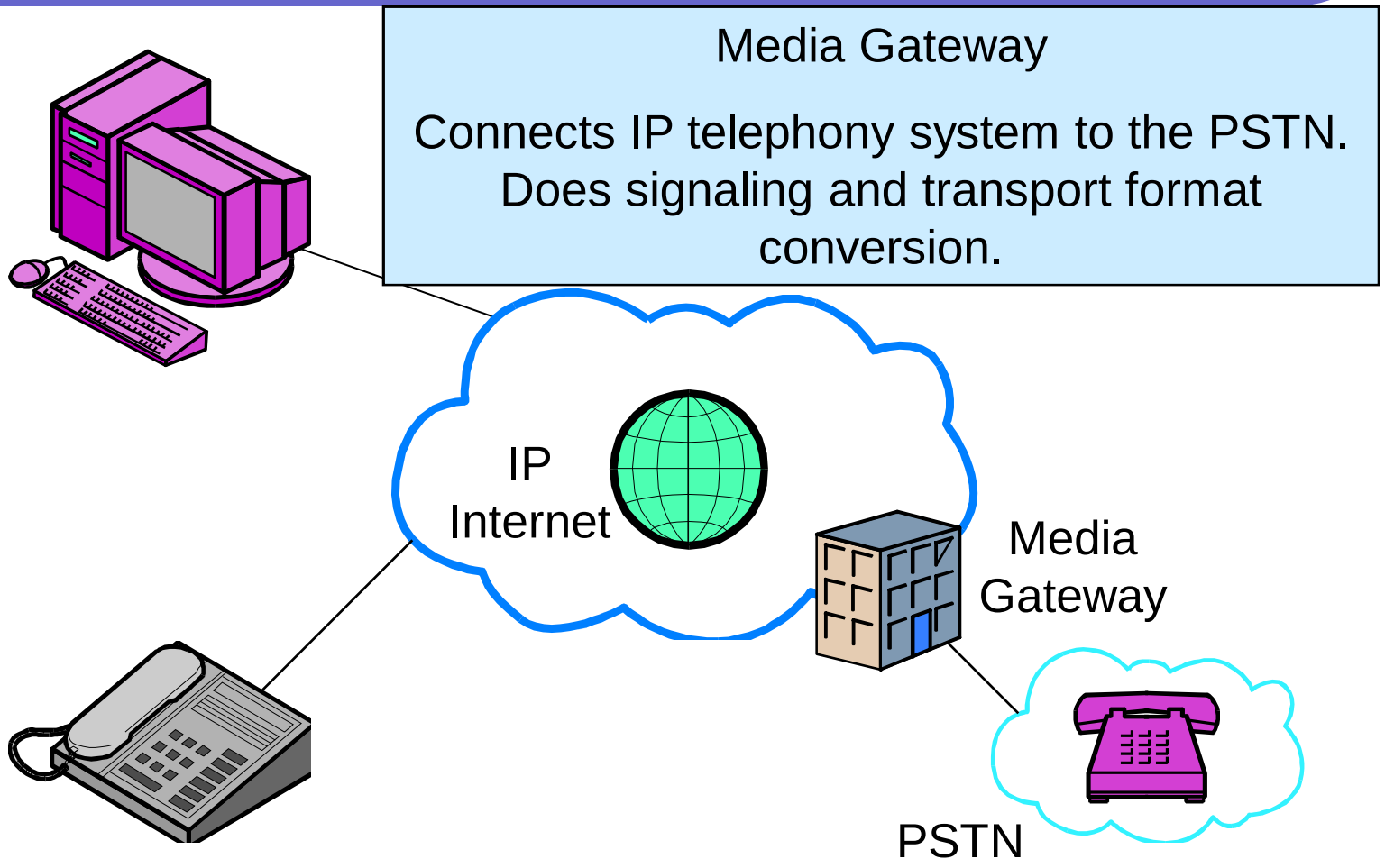


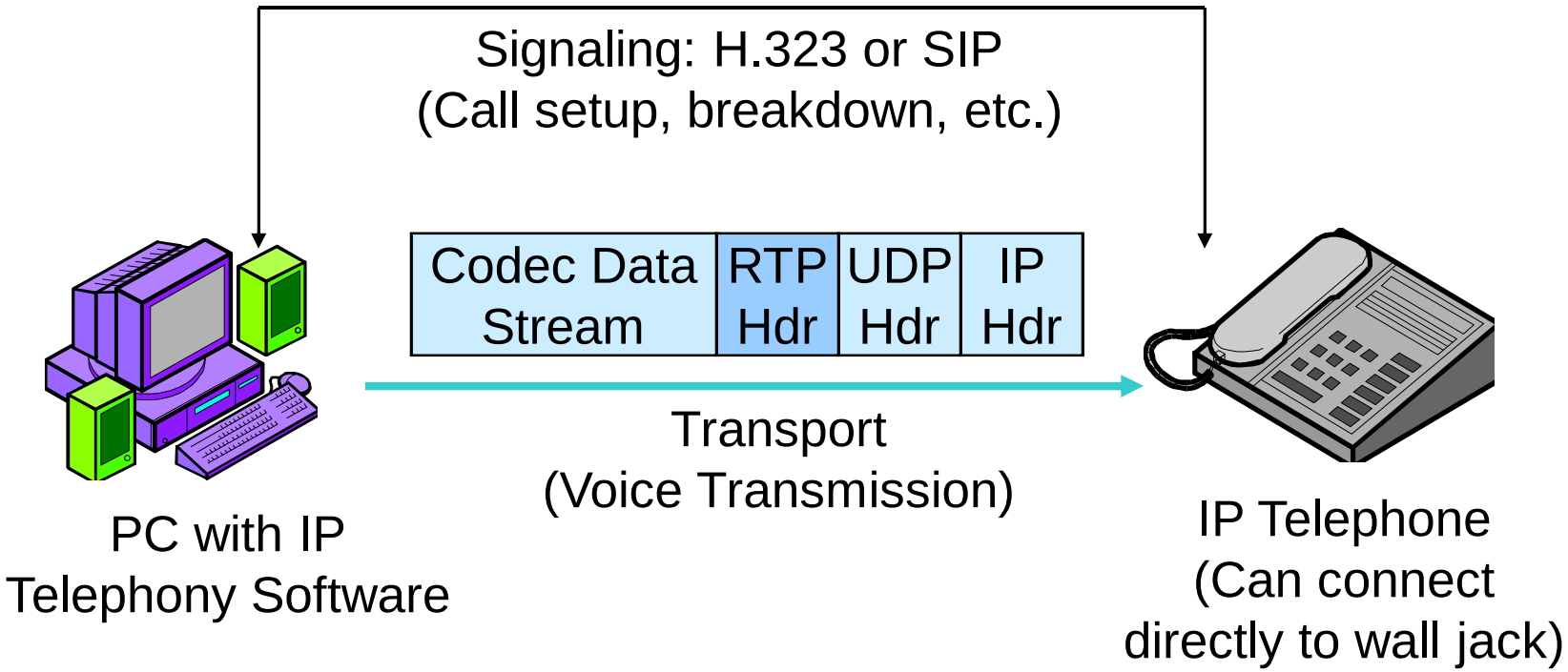
Figure 6-19: Speech Codecs

Codec	Transmission Rate
G.711	64 kbps
G.721	32 kbps
G.722	48, 56, 64 kbps
G.722.1	24, 32 kbps
G.723	5.33, 6.4 kbps
G.723.1A	5.3, 6.3 kbps
G.726	16, 24, 32, 40 kbps
G.728	16 kbps
G.729AB	8 kbps

Several different codecs can be used.

Vary in compression and sound Quality.

Figure 6-20: IP Telephony Protocols



IP Telephony Transport

- UDP (User Datagram Protocol)
  - Used at the transport layer instead of TCP
  - Efficient
    - No opens, closes, ACKs
    - So creates less delay, load on the network
  - Unreliable
    - No error correction
    - OK because there is no time to retransmit voice packets
    - Receiver “interpolates” between received packets

IP Telephony Transport, Continued

- RTP (Real Time Protocol)
  - RTP Header is used to improve voice signal
  - Contains a sequence number so that voice packets can be put in order even if unreliable IP and UDP deliver them out of order
  - Contains a time stamp so that the spacing of sounds in adjacent packets can be handled well
    - Reduces “jitter” (variability in latency)

Regulation and Carriers

- Regulation
  - Carriers: carry signals between customer premises
  - Rights of Way: government permission to lay wire
  - Monopoly: service was originally provided by a single telephone carrier
  - Regulation: This monopoly carrier was regulated to prevent abuse of the monopoly

Regulation and Carriers, Continued

- Deregulation
  - Deregulation: remove protections & restrictions
  - To increase competition, lowering prices
  - Varies by country
  - Varies by service within countries
    - Data, long-distance, and customer premises deregulation is high.
    - Local voice service deregulation is low.

Regulation and Carriers, Continued

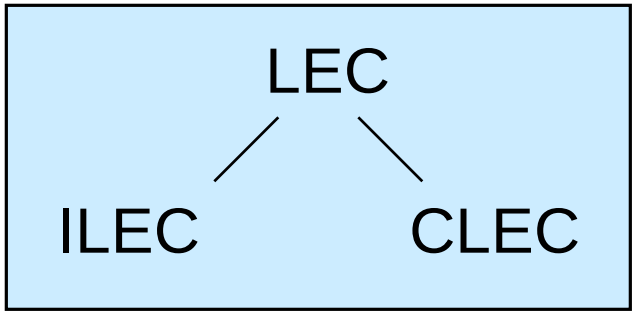
- Carriers
  - Public Telephone and Telegraph (PTT) authority is the traditional domestic monopoly carrier in most countries.
    - Domestic transmission: within a country
    - UK: British Telecoms
    - Japan: NTT
    - Ireland: Eircom

Figure 6-21: Telephone Carries in the United States, Continued

LATA

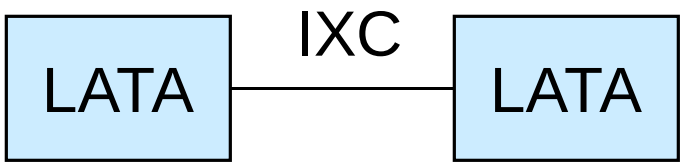
- Carriers
  - In the United States
    - U.S. is divided into regions called local access and transport areas (LATAs)
    - About 200 LATAs nationwide
    - Small states have just one LATA
    - Large states have 10 to 20 LATAs

Figure 6-21: Telephone Carries in the United States, Continued



- Carriers
  - In the United States
    - Local exchange carriers (LECs) provide service within a LATA
      - Incumbent LEC (ILEC) is the traditional monopoly carrier in the LATA
      - Competitive LEC (CLEC) is a new competitor

Figure 6-21: Telephone Carries in the United States, Continued



- Carriers
  - In the United States
    - Inter-exchange carriers (IXCs) provide service between LATAs
  - LEC versus IXC distinction is used by data carriers as well as voice carriers

Mix and Match Quiz

- A. Geographical Region
- B. Carrier within a region
- C. Carrier Between Regions

- 1. IXC
- 2. LEC
- 3. LATA
- 4. CLEC

Figure 6-21: Telephone Carries in the United States, Continued

- Carriers
  - In the United States
    - Point of Presence (POP) is a place in a LATA where all carriers interconnect to provide integrated service to all customers

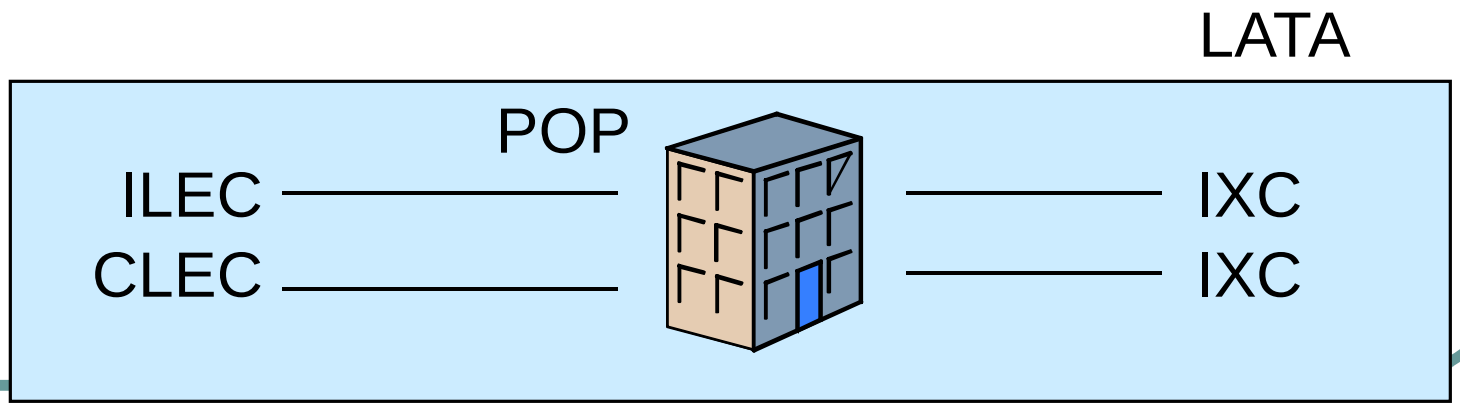


Figure 6-21: Telephone Carries in the United States, Continued

- International Service (Between Pairs of Countries)
  - Provided by international common carriers (ICCs)
  - Allowed carriers, prices, and conditions of service are settled through bilateral negotiation between each pair of countries

Figure 6-21: Telephone Carries in the United States, Continued

- U.S.
  - Intra-LATA
    - LECs
      - ILEC
      - CLECs
  - Inter-LATA
    - IXCs
- Most of the World
  - PTTs for domestic service
- ICCs for Service Between Countries

Main Elements of the PSTN

- Customer premises equipment
- Access system
  - Access line (local loop), termination equipment
- Transport core
- Signaling

Note:
Transport versus Signaling
Is Fundamental

Circuit Switching

- Reserved capacity all along the path between subscribers
- Typically implemented by TDM
- Wasteful for bursty data transmission
- Dial-up versus Private Line Circuits
  - Private line circuits are always on and fast

Analog-Digital Conversion

- Residential local loop is analog
- The rest of the PSTN is digital
- At the end office switch
  - Bandpass filtering to limit signal to 300 Hz to 3.1 kHz
  - Codec to convert analog signal into 64 kbps digital stream
  - Codec also converts digital telephone company signals into analog signals for local loop

Analog-Digital Conversion

- Pulse Code Modulation
  - Bandpass filtering to limit signal to 300 Hz to 3.1 kHz
  - Treated as 4 kHz signal (0 Hz – 4 kHz)
  - 8,000 samples per second
    - Twice highest frequency for good quality
  - 8 bits per sample
    - 256 loudness levels is good
  - 64 kbps data stream (8,000 x 8)

Transport Core and Signaling

- Transport Core
  - TDM: point-to-point and ring
  - SONET uses dual rings for reliability
    - If there is a break, the rings are wrapped
  - ATM uses packet switching
    - More efficient than TDM, replacing TDM
- Signaling
  - SS7 in the United States, C7 in Europe
  - Interoperable

Cellular Telephony

- Multiple cells for channel reuse
  - Supports more subscribers with limited bandwidth
  - The whole reason for cellular operation
  - Channel reuse better for CDMA
- Generations
  - 1G: analog, being phased out
  - 2G: dominates today; only 10 kbps for data
  - 3G: for faster data transmission (telephone modem or DSL/cable modem speed)

IP Telephony

- Send voice over IP
  - More efficient than TDM
  - Promises to lower long-distance and international calling charges
- Multiple codecs give choices
- Signaling uses SIP or H.323
- Transport uses UDP and RTP to carry data streams

Regulation and Carriers

- Carriers and rights of way
- Regulation and deregulation
- In most countries, PTTs provided monopoly domestic service
- In the U.S., LATAs, ILECs and CLECs for intra-LATA service, IXCs for inter-LATA service
- ICCs for international service