COMPUTER NETWORKS

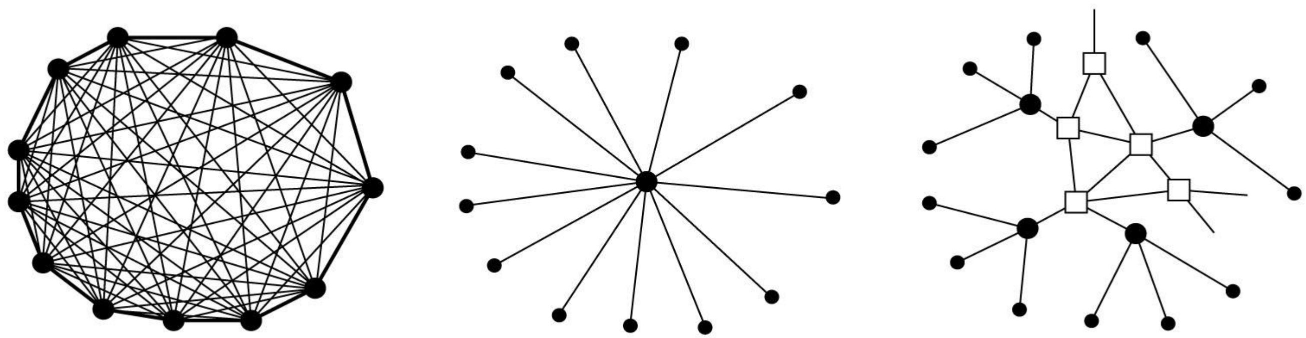
Chapter 02

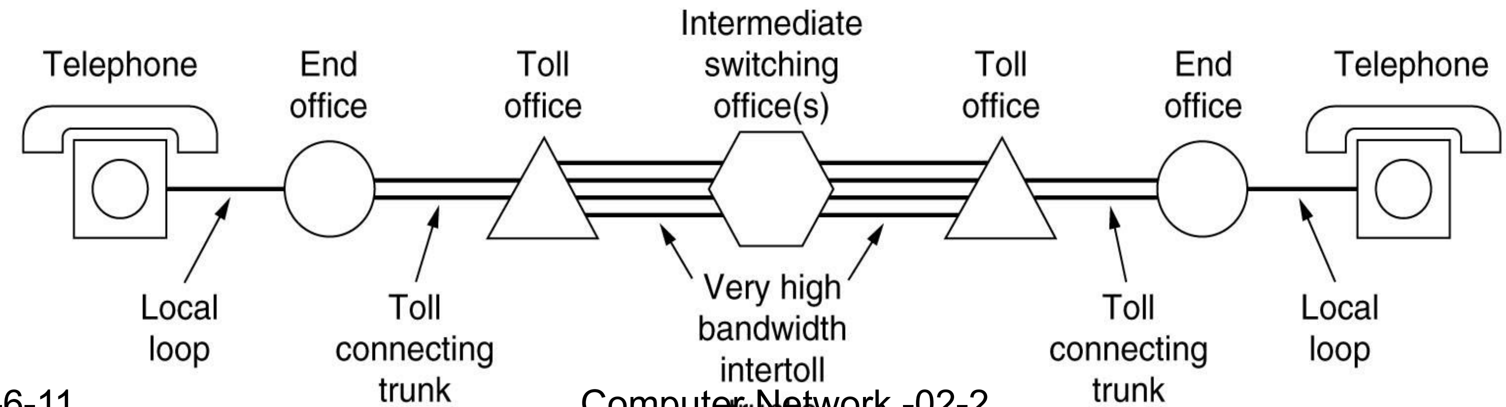
The Physical Layer Part 2

2.5 The Public Switched Telephone Network (PSTN)

2.5.1 Structure of the Telephone System

Local Loop, Trunks, Switching Office

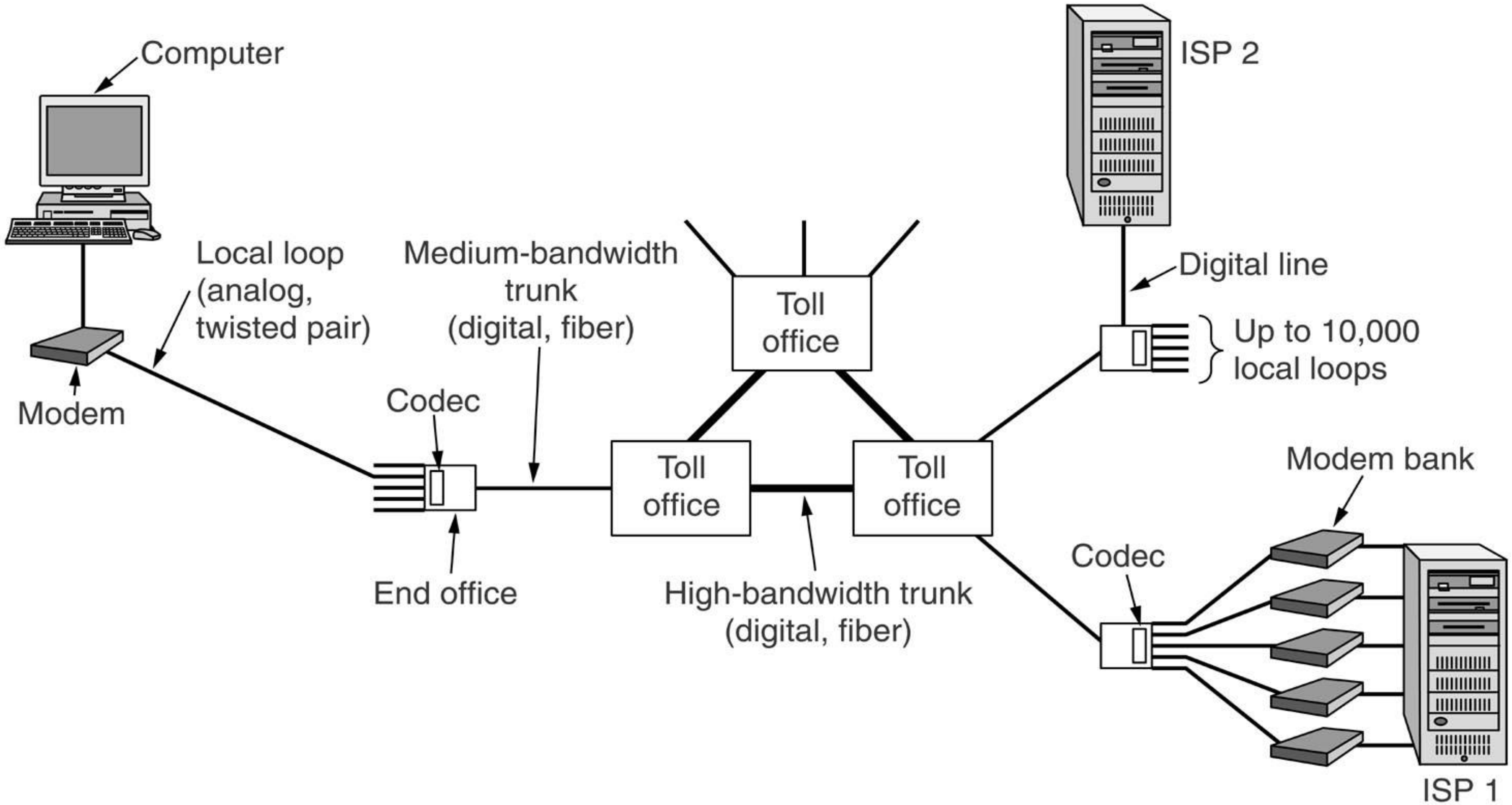




Major Components of the Telephone System

- 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

2.5.3 The Local Loop: Modems, ADSL, Wireless



The use of both analog and digital transmissions for a computer to computer call. Conversion is done by the modems (modulator and demodulator) and codecs (coder and decoder).

Modem: Modulator and Demodulator

- **Modulation Techniques**
  - **Problem:** How can we encode our signals when we can effectively use only a single frequency (or better: small frequency range)?
  - Answer: Apply modulation techniques
- Baseband(DC) signaling is unsuitable to be transmitted along a narrow band channel(e.g. a telephone line) due to attenuation, delay distortion, and noise.
- Modem is introduced to convert baseband (DC) signal into analog signal(AC) to be transmitted along a telephone line, convert analog signal back to digital at the destination.

Modem Techniques

- In order to avoid DC problems to transmit digital signals along a narrow band medium, sine wave carrier is introduced:

  $$A\sin(\omega t + \varphi)$$

  A: amplitude

  ω : frequency

  φ : phase

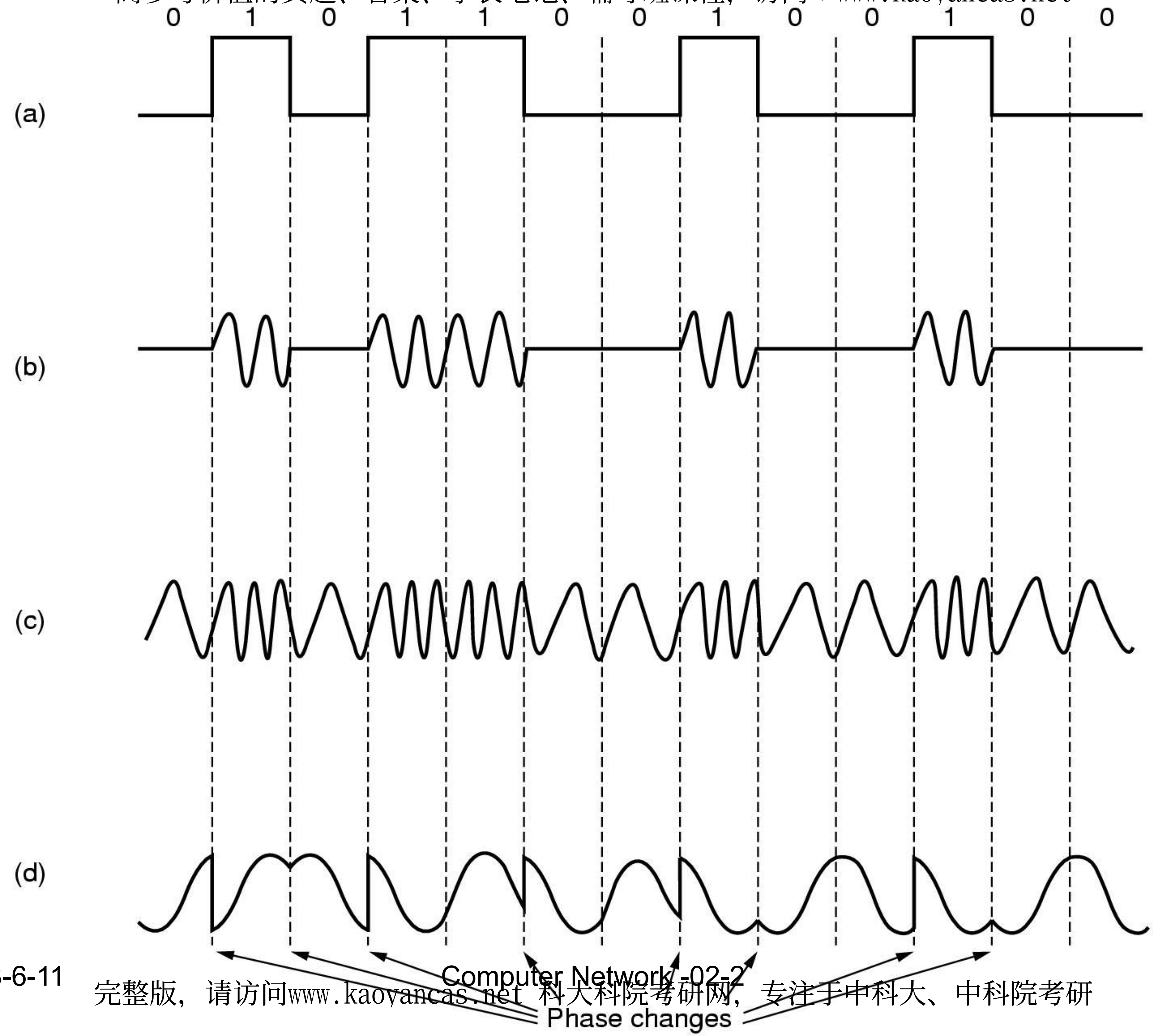
  - Continuous tone of analog signal
  - 1000-2000Hz

Three Modulation Methods

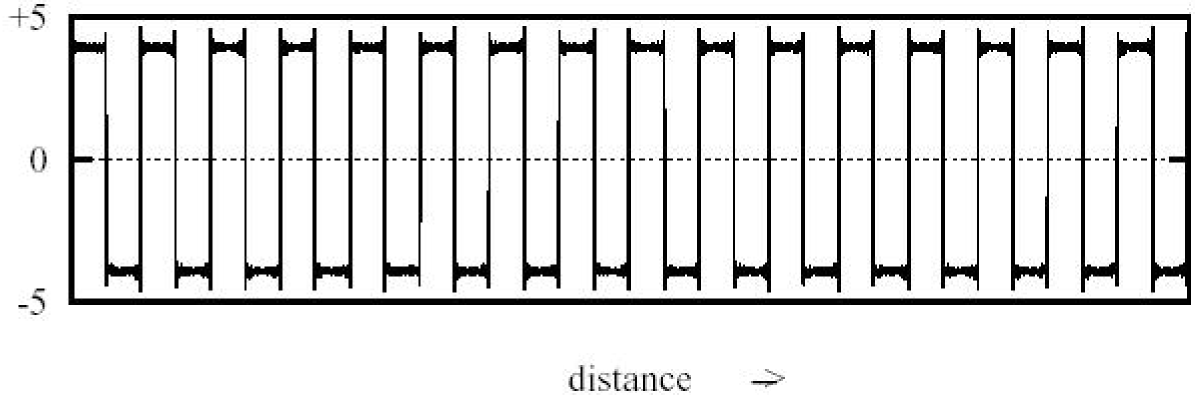
1. Change the amplitude (strength) of the signal: changing amplitude means a binary 1, constant amplitude a binary 0.

   Amplitude Shift Keying, ASK

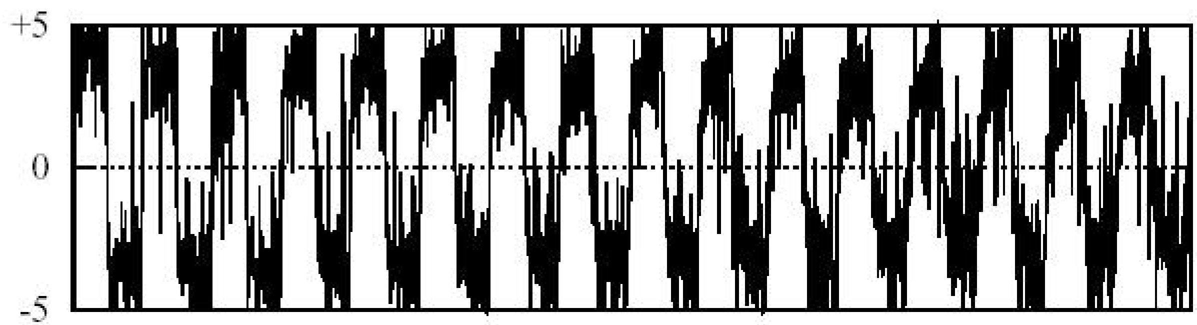
2. Use *two* frequencies to encode your bits (these frequencies can be put “on top” of your base frequency). FSK
3. Change the phase of the sine wave to do signal encoding. PSK


0 1 0 1 1 0 0 1 0 0 1 0 0
(a)
(b)
(c)
(d)
Phase changes

- **Observation:** Modulation is strongly related to not being able to set a (wide-frequency-ranges) DC signal value on the wire as direct encoding of binary signals:

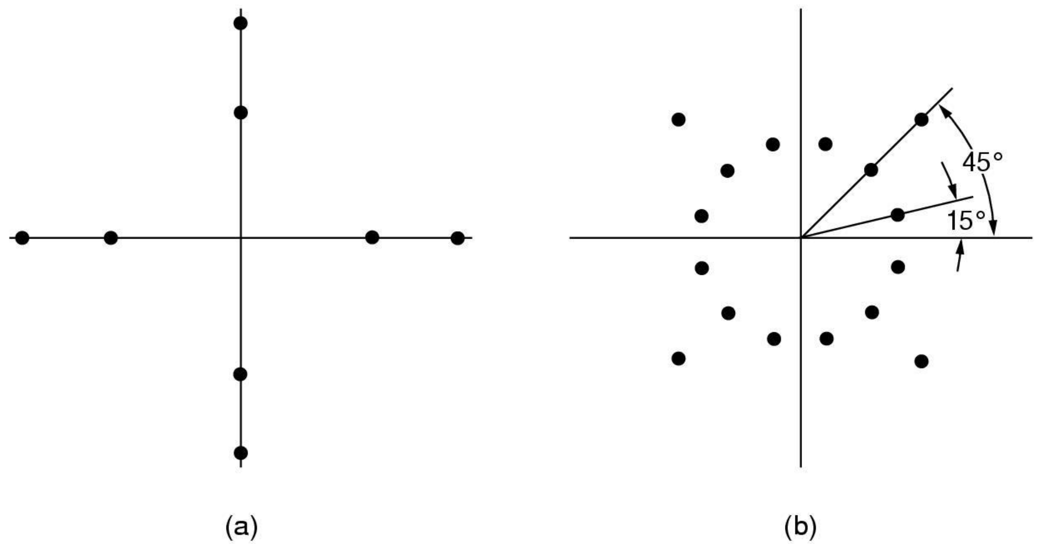


Becomes:



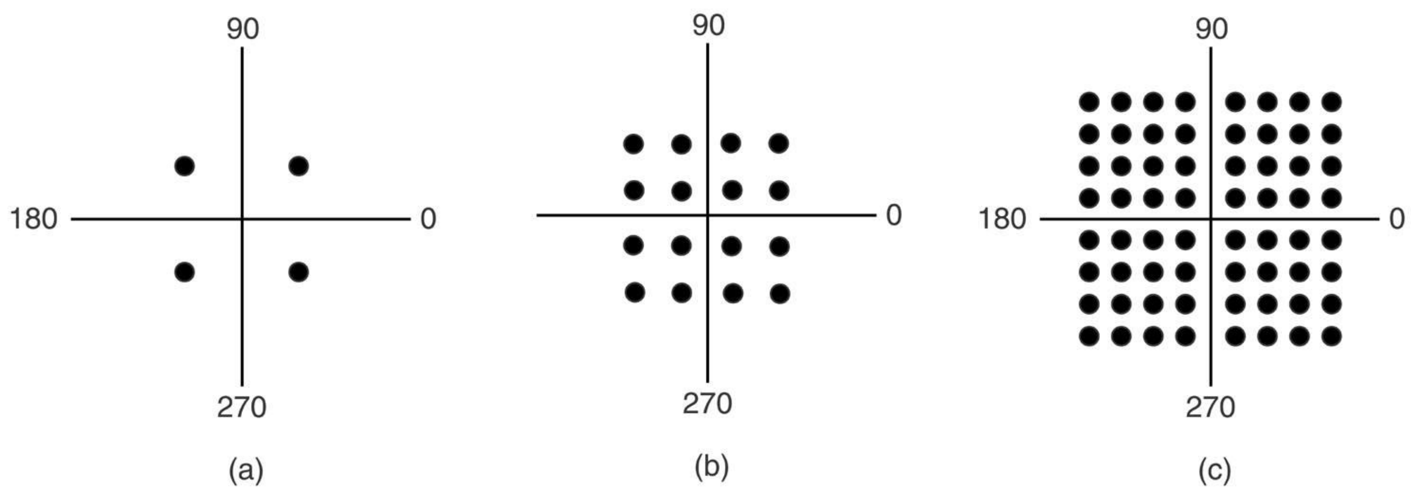
Increasing Transmission Rates

- **Observation:** An important issue is to use low-baud modems for high transmission rates, by increasing the number of signal values—according to Nyquist, $c=2H\log_2 V$. The key issue is how to present more bit information for each sample.



QAM (quadrature amplitude modulation)
3-bit/Baud 4-bit/Baud

Constellation Diagram and Modem Standards

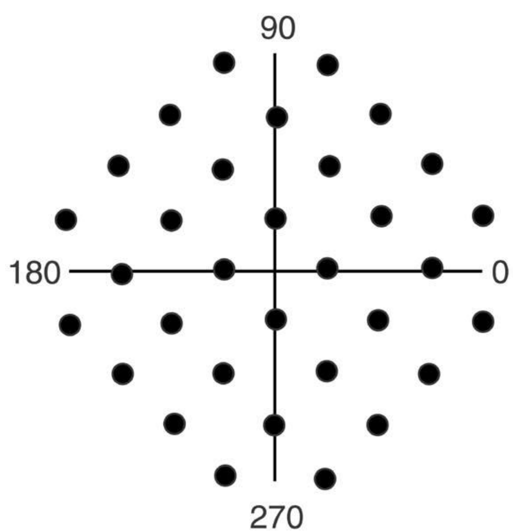


(a) QPSK (b) QAM-16 (c) QAM-64

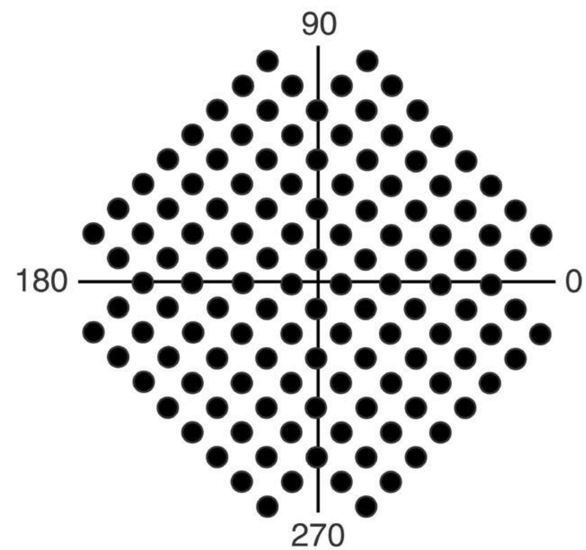
- Noise may lead to an error, which contains several error bits. So error correction is introduced, so called TCM (Trellis Code Modulation) by adding extra bit (s) for each sample (baud).
- v.32: uses phase-shifting combined with amplitude modulation, 32 constellation points, each baud encodes 4 bits plus 1 parity check, QAM-32. At 2400 baud, The date rate is 9600bps.

Constellation Diagram and Modem Standards

- v.32bis: each sample transmits 6 data bits, plus 1 parity check, 128 constellation points, QAM-128, At 2400 baud, date rate is 14.4kbps, such as fax/modem.
- v.34: each sample transmits 12 data bits, date rate is 28.8kbps
- v.34bis: each sample transmits 14 data bits, data rate is 33.6kbps
- Stop at 33.6kbps, because of Shannon's limitation.
- v.90: By Nyquest theorem, 8000 samples per second leads to 56kbps
- v.92: 56k+



(b)

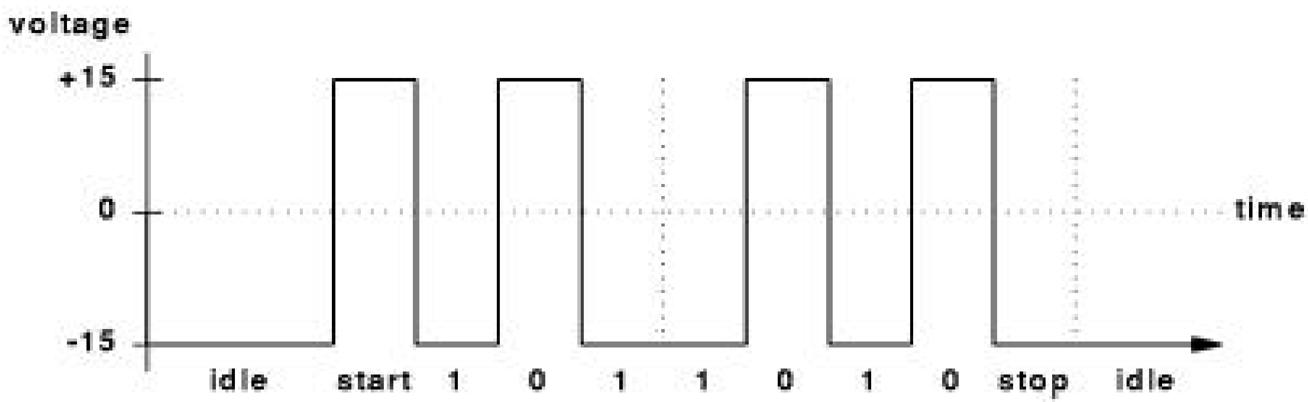


(c)

Modem specifications

- bit rate, baud rate, modulation method,
- data format, compression and its ratio,
- Standard: v.21, v.35, v.22, etc.
- Transmission: HDX/FDX, 2lines/4lines, dedicated lines.

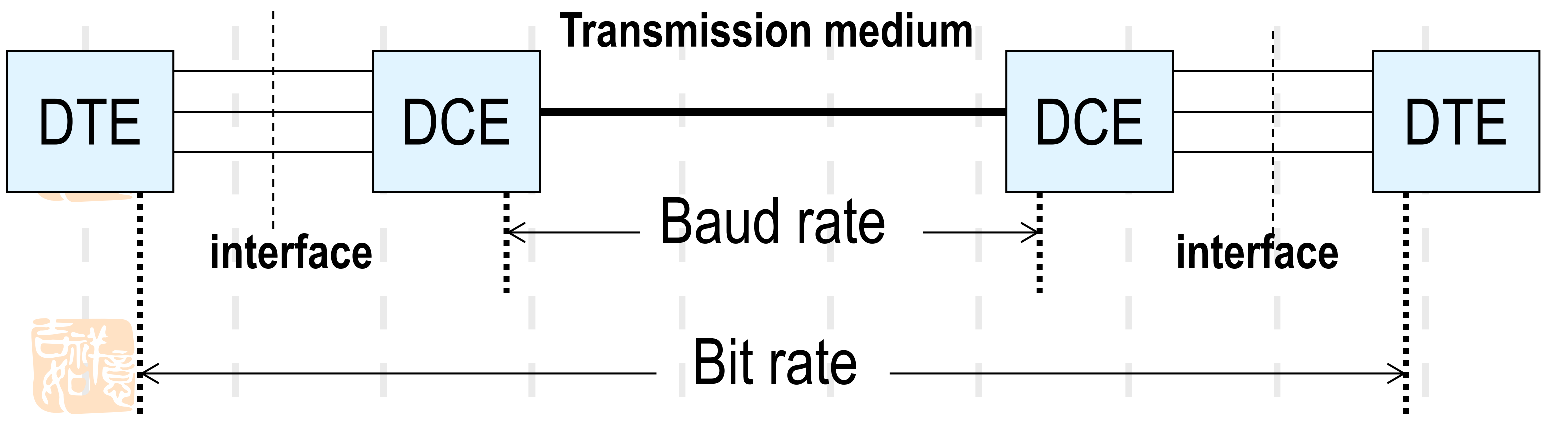
A character frame is as following:



RS-232-c: an Example Protocol of Physical Layer

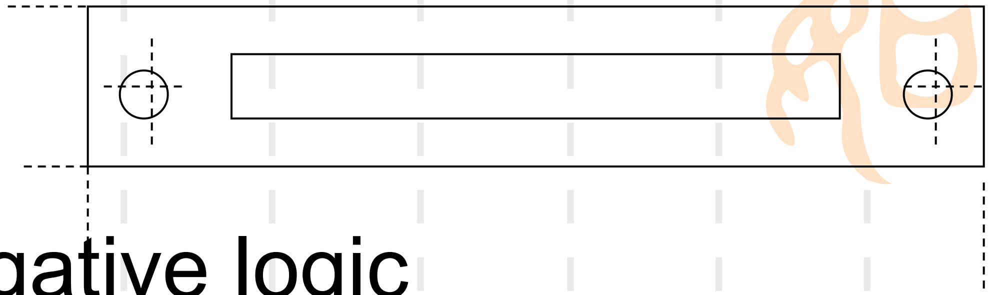
- Physical layer protocol specifies the mechanical, electrical, functional, and procedural interface between DTE/DCE

(Data Terminal Equipment/Data Circuit-Terminating Equipment)



RS-232-c

- Mechanical

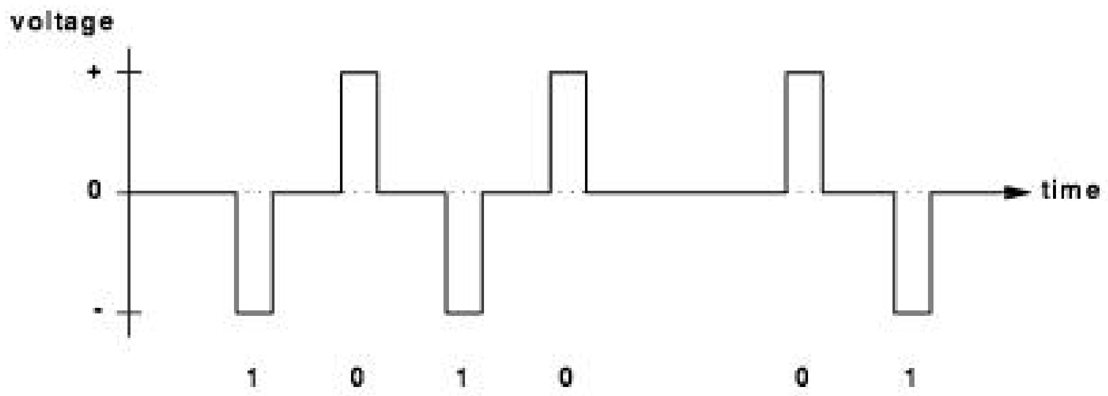


- Electrical: Negative logic

"0": +3v ~ +15v, we use +12v

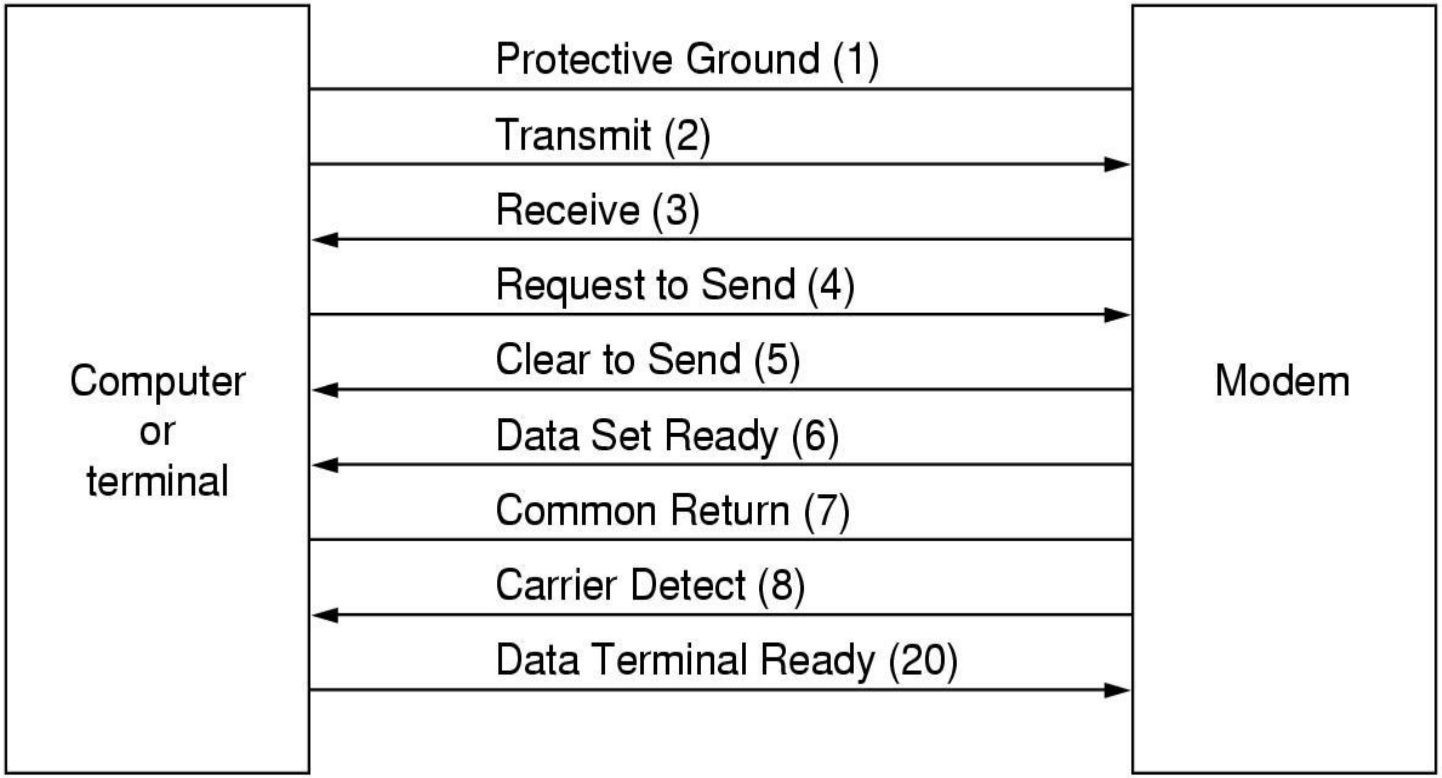
"1": -3v ~ -15v, we use -12v

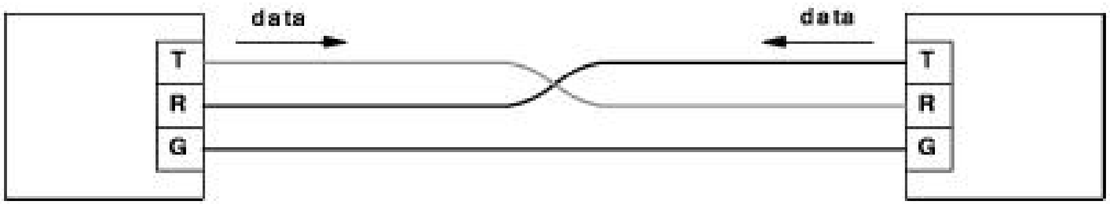
-3v ~ +3v: not defined, illegitimate



RS-232-c

- Functional





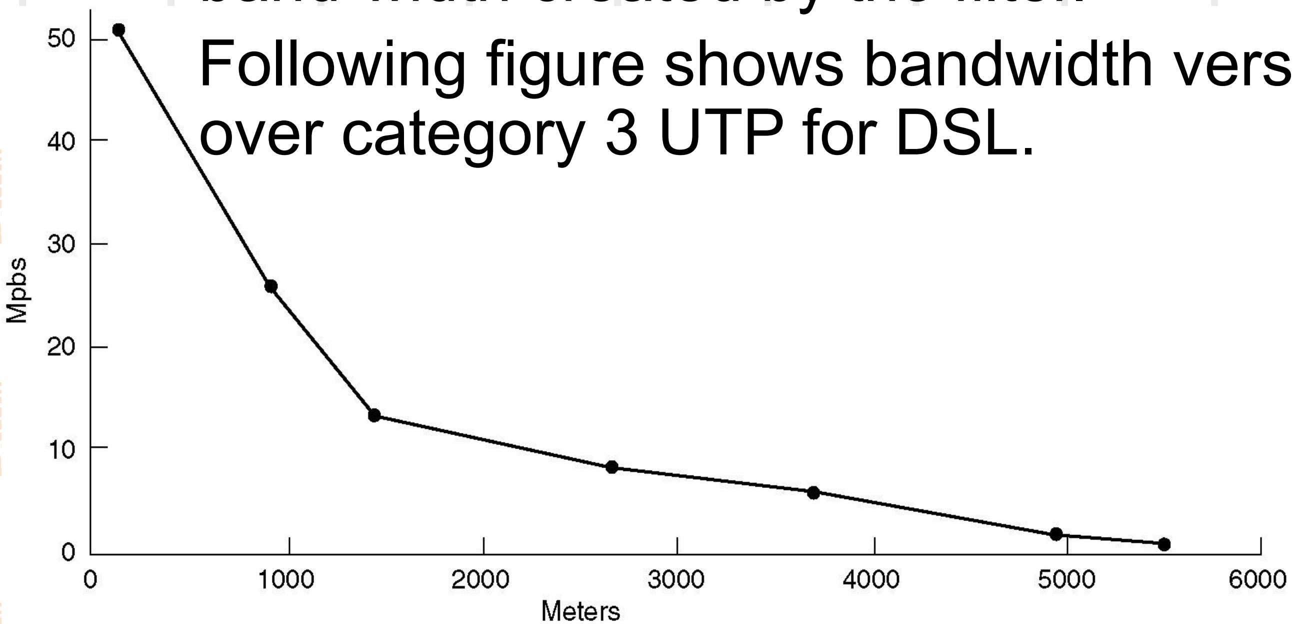
RS-232-c

- Procedural
- From 25 pin to 9 pin connector
- RS-449:
- Comparison of RS-232-c, v.24, RS-449
- Asynchronous communication with RS-232-c

Digital Subscriber Lines - DSL

The trick that makes xDSL work is that when a customer subscribes to it, the incoming line is connected to a different kind of switch, one that does not have filter, thus making the entire capacity of the local loop available. The limiting factor then becomes the physics of the local loop, not the artificial 3100Hz band-width created by the filter.

Following figure shows bandwidth versus distance over category 3 UTP for DSL.



xDSL Services

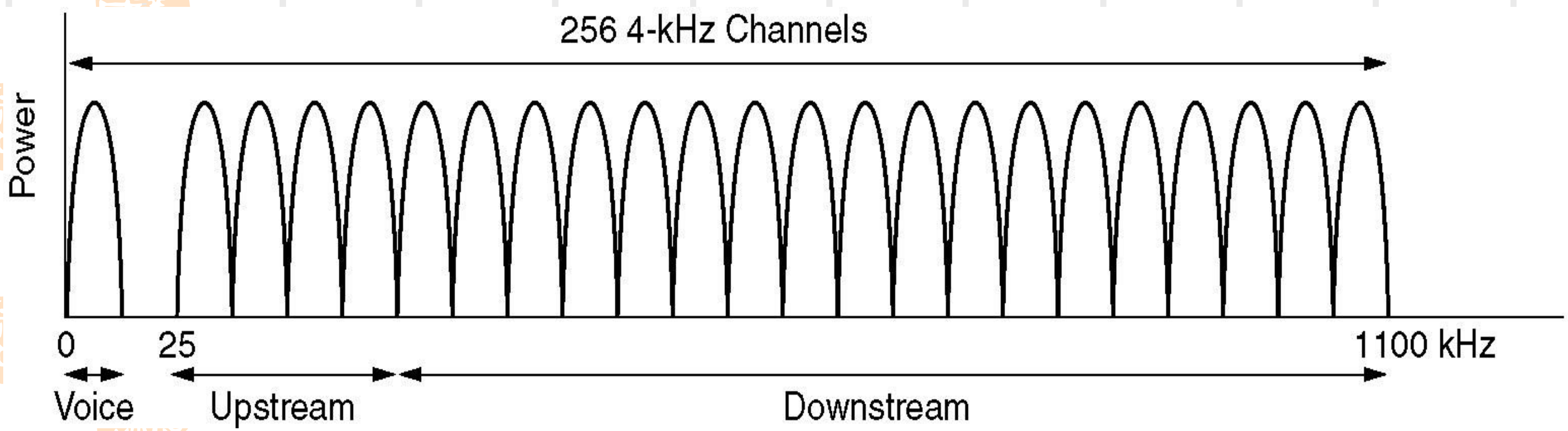
- The xDSL services have been designed with certain goals:
  - The services must work over the existing category 3 twisted pair local loops.
  - The must not affect customers' existing telephones and fax machine.
  - They must be much faster than 56kbps.
  - They should be always on, with just a monthly charge but no per-minute charge.

Asymmetric Digital Subscriber Line

- Currently, we're in **ADSL4**, which provides 6Mbps one-way (enough for good-quality TV) and 640 kbps two-way.
- **ADSL's background**
  - **Essence:** ADSL splits the bandwidth that can be transported across a simple copper wire into four different classes:
  - Higher-bandwidth simplex channel
  - Lower-bandwidth duplex channel
  - Duplex control channel
  - POTS (Plain Old Telephone Service)

How ADSL Works

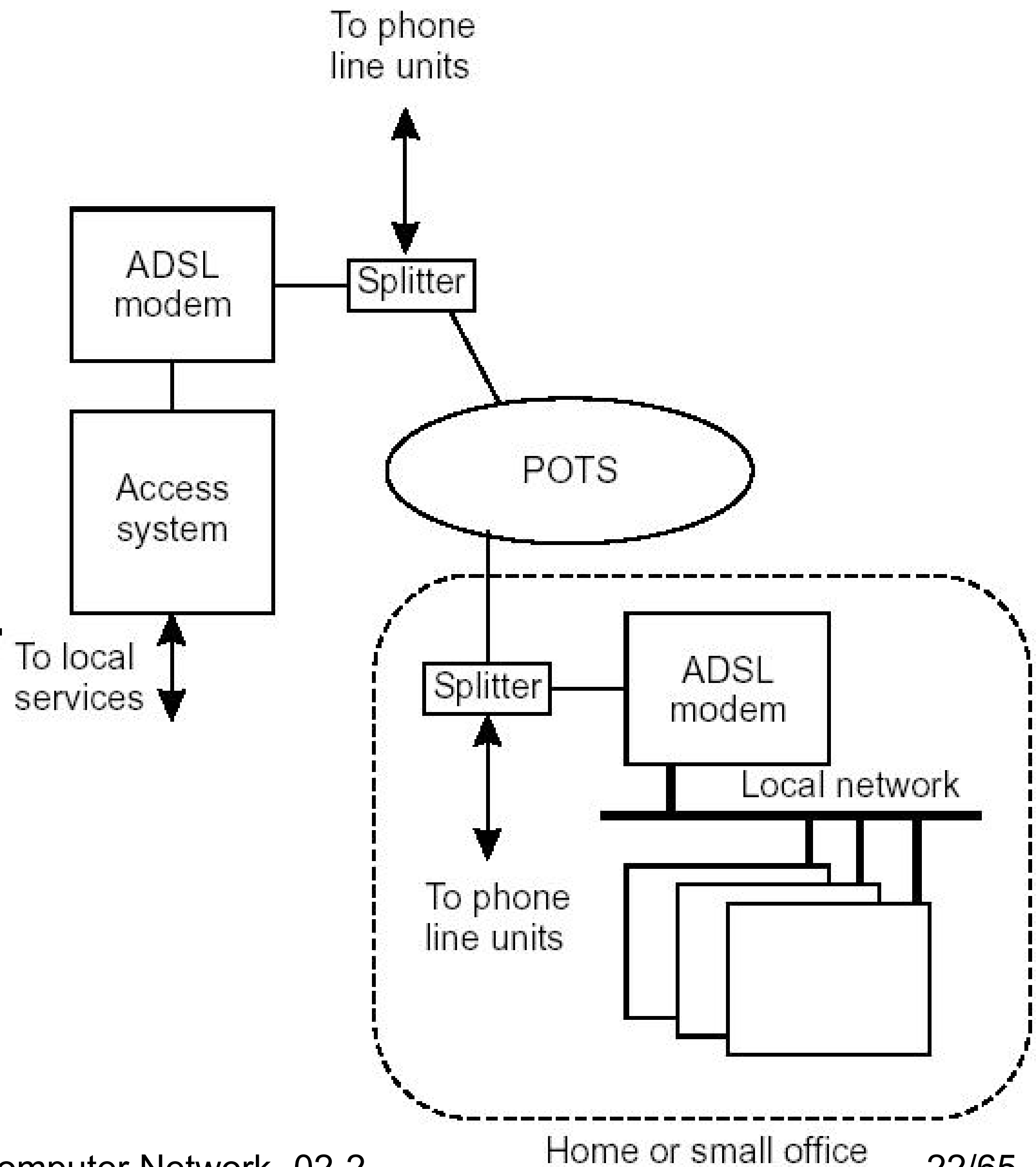
- Dividing the spectrum available on the local loop, which is about 1.1MHz, into three frequency bands: POTS (Plain Old Telephone Service) upstream (user to end office) and downstream (end office to user), frequency division multiplexing.



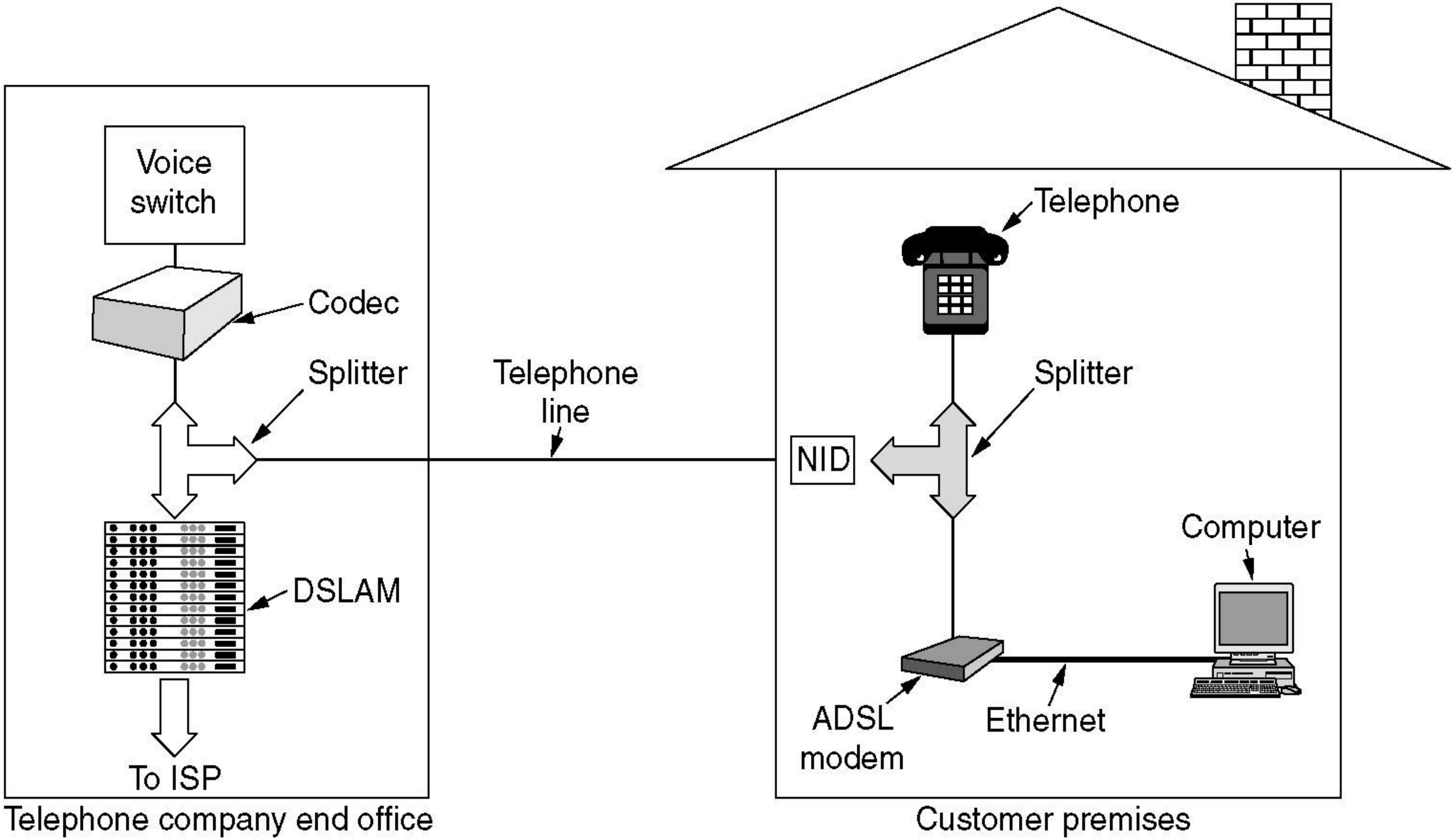
Operation of ADSL using discrete multitone modulation.

How ADSL Works

- **Important:** The real low-level bandwidth POTS channel can operate independent from the other channels. In other words, you can phone and transfer data at the same time.

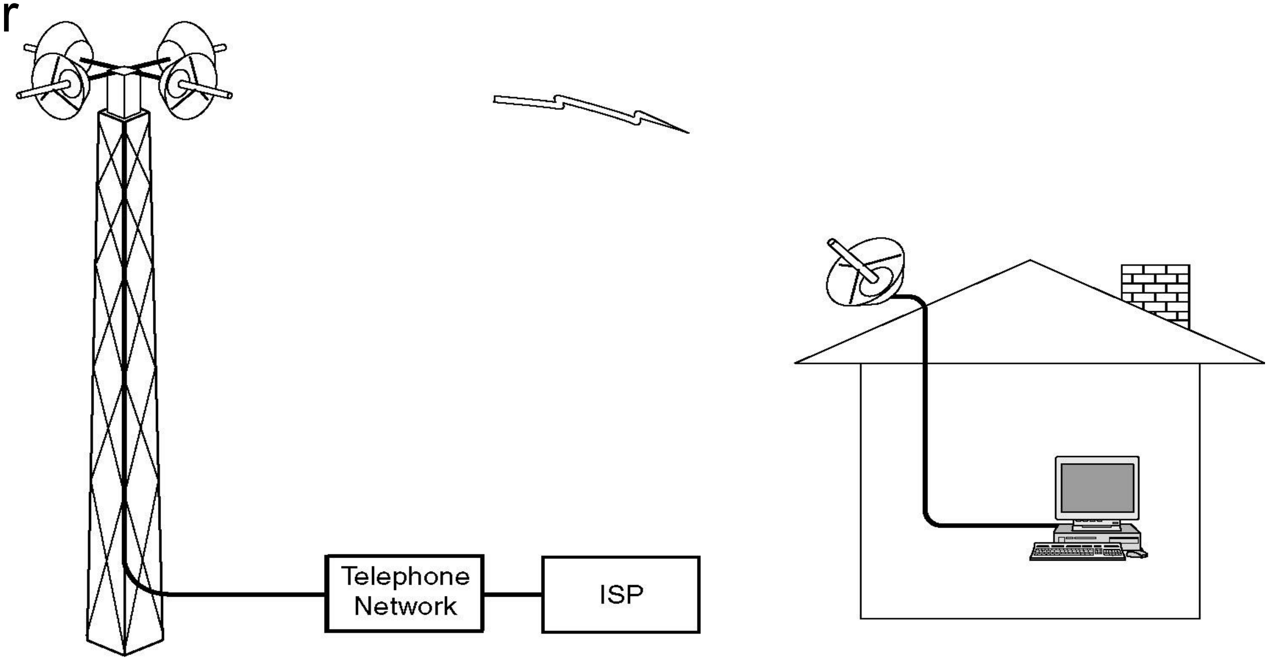


A typical ADSL equipment configuration.



Wireless Local Loops

- A fixed telephone using a wireless local loop is a bit like a mobile phone, but there a three crucial differences:
  - WLL user wants high speed Internet connectivity at least equal to ADSL
  - User does not mind to install a large directional antenna on his roof
  - User does not move, eliminating all the problems with mobility and cell handover



Architecture of an local multipoint distribution system.

2.5.4 Trunks and Multiplexing

- **What is multiplexing?**

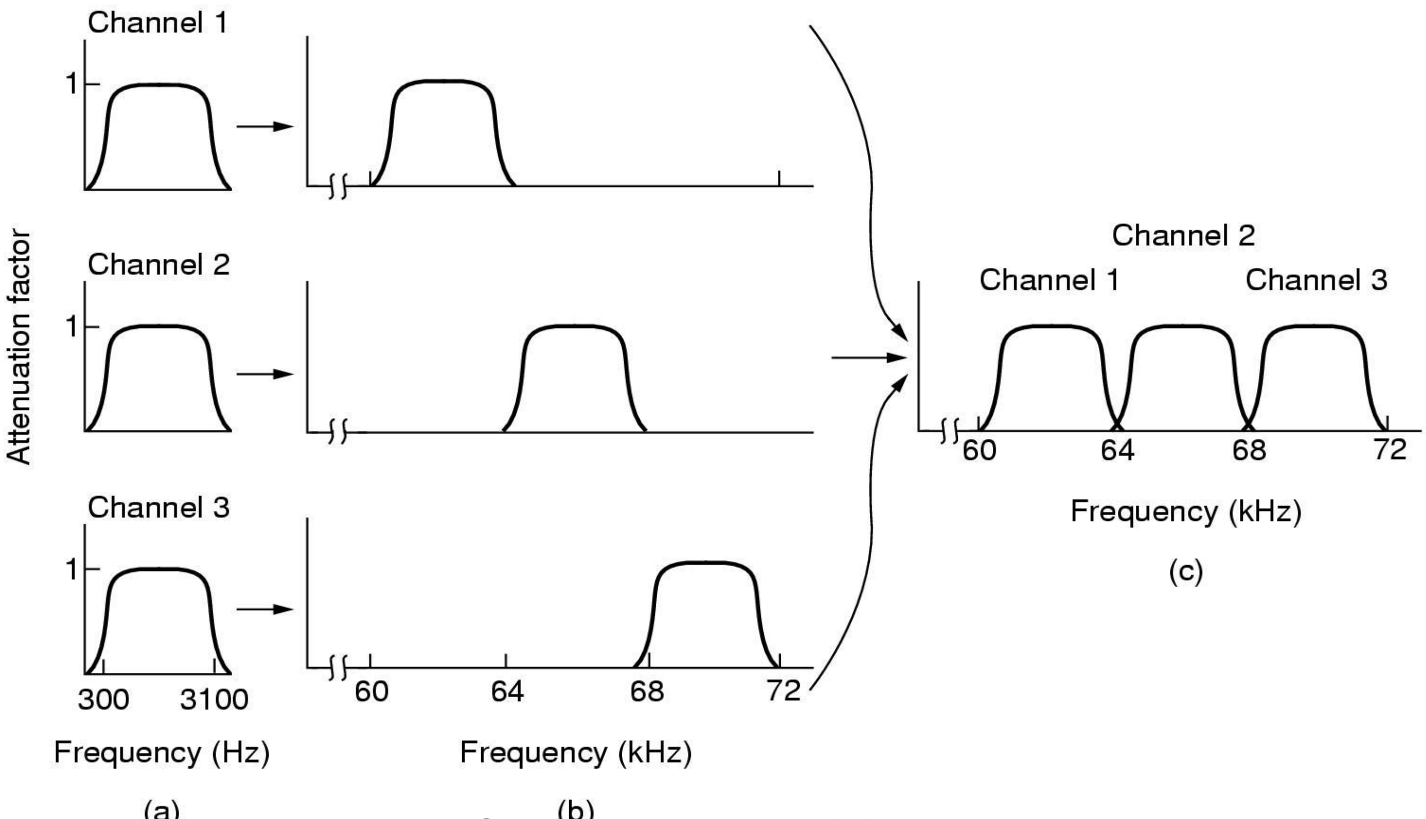
Problem: Considering that the bandwidth of a channel can be huge, wouldn't it be possible to *divide* the channel into sub-channels? And how?

Multiplexing: the technique of transport multiple data flow over a single channel

- FDM, TDM, WDM, DWDM, …

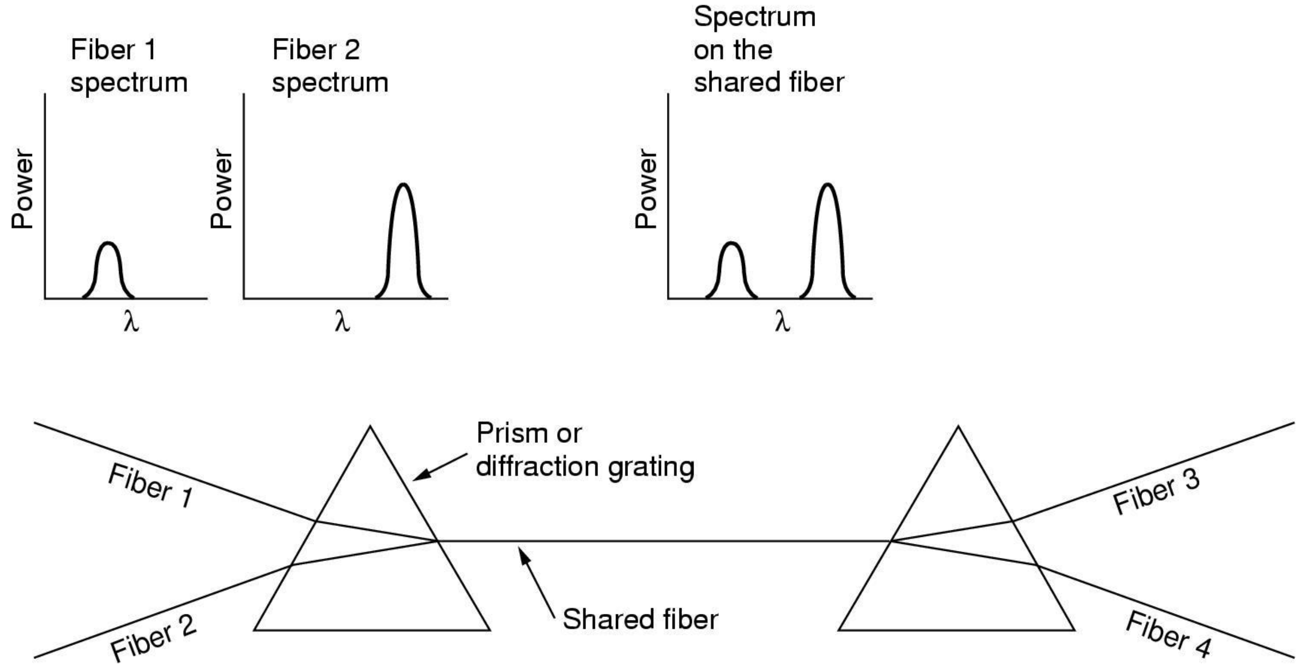
Frequency Division Multiplexing

- Divide the available bandwidth into channels through frequency filtering, and apply modulation techniques per channel:



Wavelength Division Multiplexing

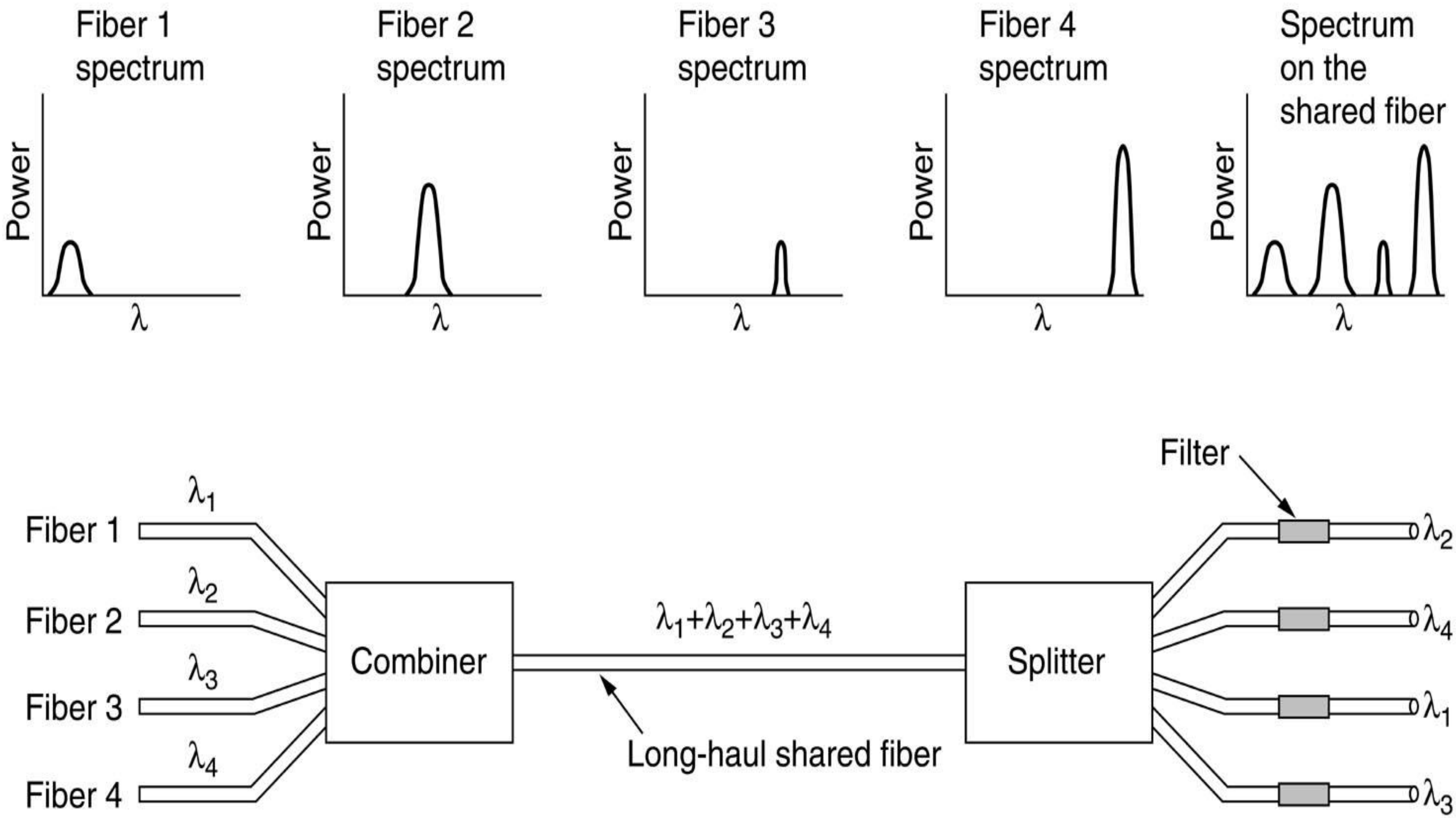
- Looks very much like FDM, but used for fiber optics.



Observation: Light waves have their own frequency range; they are simply combined and separated using standard (de)fraction properties

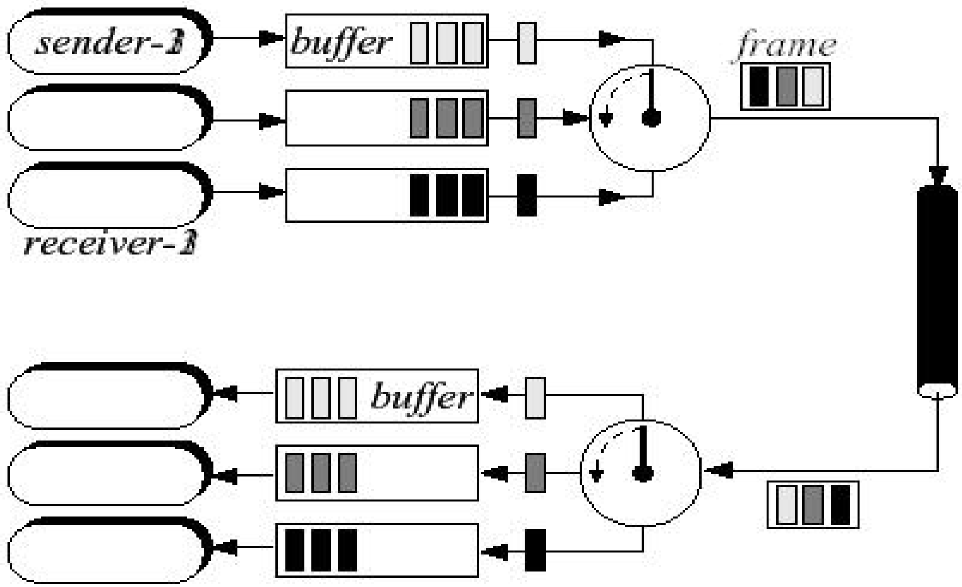
- DWDM, CWDM

Wavelength Division Multiplexing



Time Division Multiplexing

- Simply merge/split streams of digital data into a new stream. Data is handled in **frames** – a fixed series of consecutive bits:



This is full-digital solution in contrast to FDM and WDM

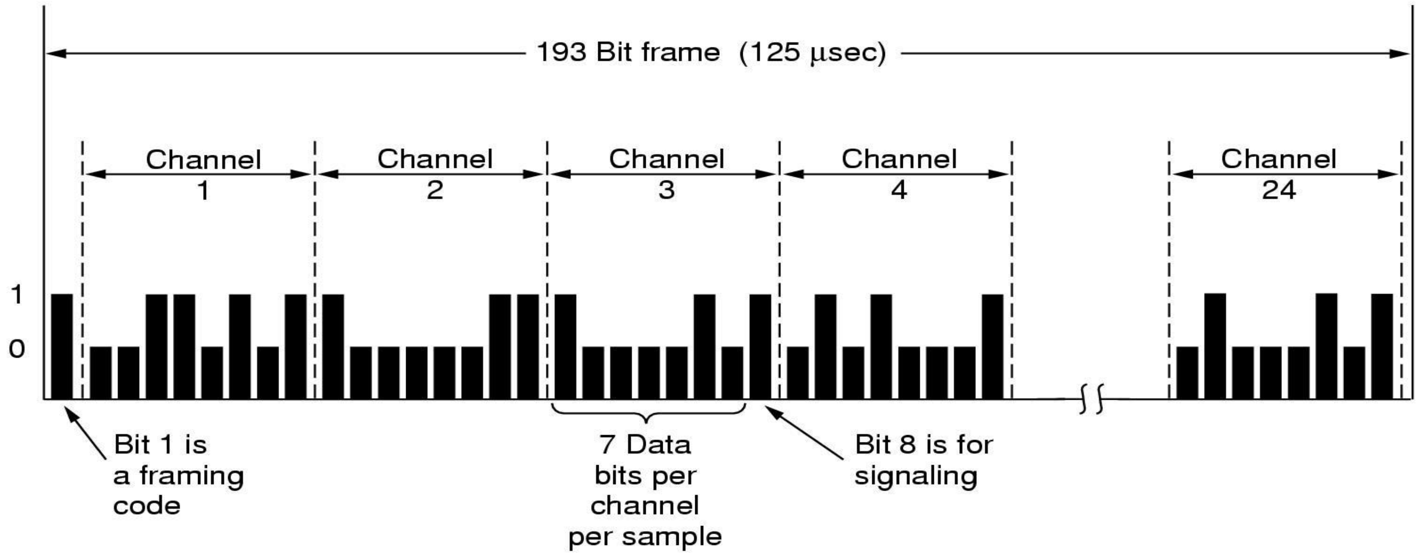
PCM: Pulse Code Modulation

- Digitize analog signal into digital signal, send over a digital transmission system, especially for voice transfer.
- Three steps for PCM :
  - Sampling: 8000 times/per second
    125 μsec/sample
  - Quantitizing: give definite value for each sample
  - Encoding: binary encoding of the value, say 7-bit or 8-bit

T1 system and others

- T1 system is a typical example of the combination with PCM and TDM

The T1 system samples at 8000 Hz, and encodes each sample as a 7-bit number (i.e. 128 different values). With some extra control bits, we merge samples into 193-bit frames, every 125 *μ*sec:



T1 system and others

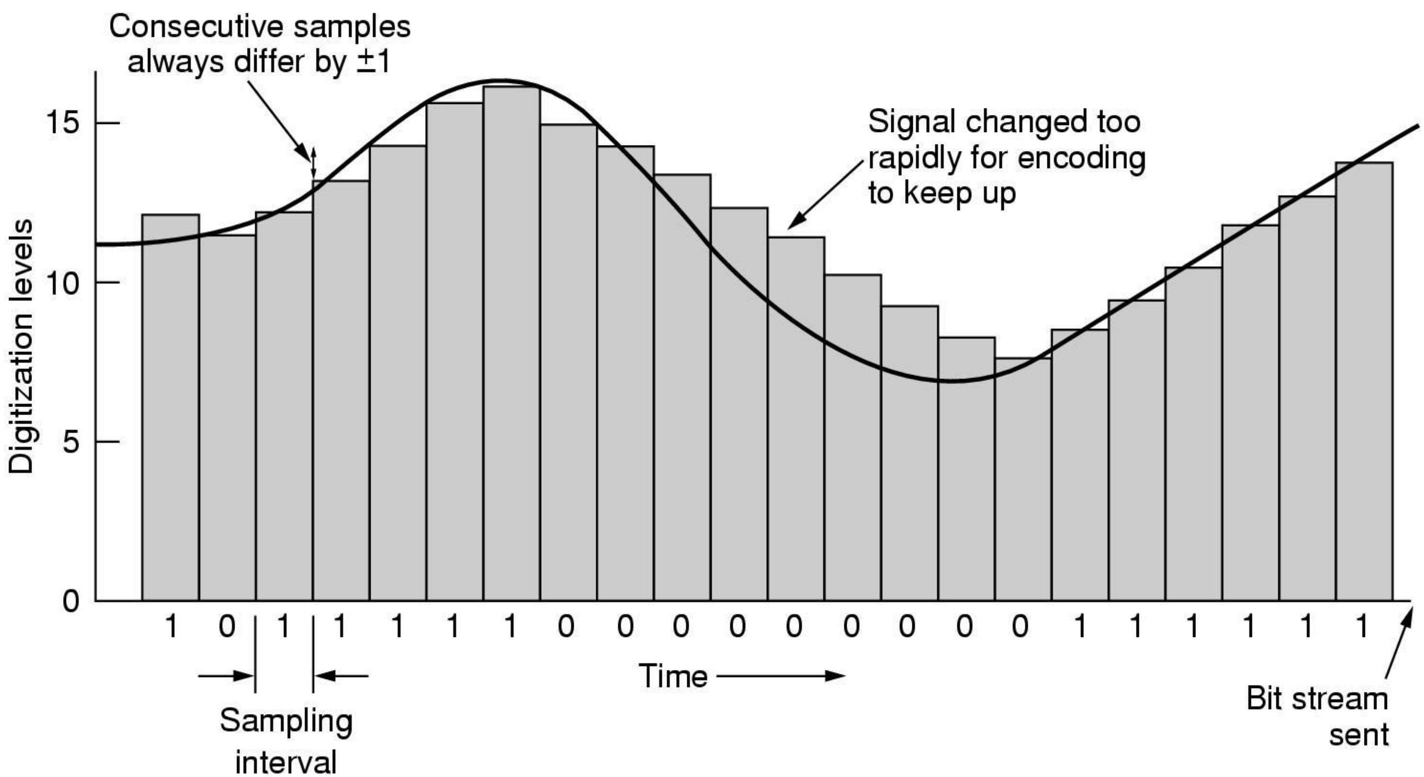
- T1 supports a total of
  $[(7+1) \times 24 + 1]$ bit x $1/125\ \mu s \times 10^6$
  $= 193$ bit x $1/125\ \mu s \times 10^6$
  = 1.544Mbit/sec or 1.544Mbps
- E1: 2.048Mbps
  $8 \times 32 \times 1/125 \times 10^6 = 2.048$Mbps
- T2: 6.312 Mbps
  T3: 44.736 Mbps
  T4: 274.176 Mbps
  E2: 8.848 Mbps
  E3: 34.304 Mbps
  E4: 139.264 Mbps

- DPCM(Differential PCM)

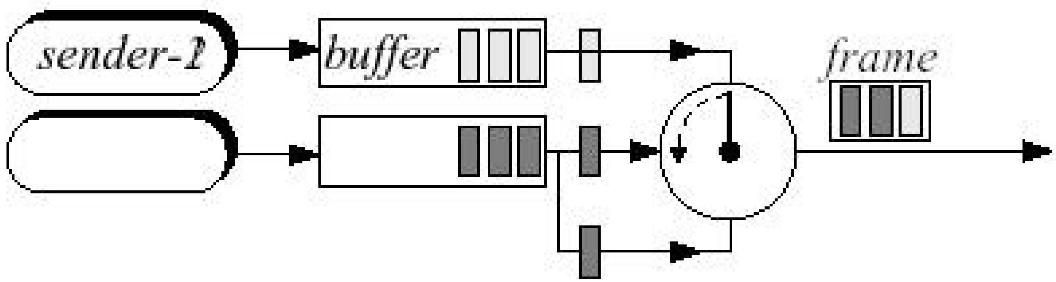
  [4 + 1(signaling)] x 8000 = 40 kbps

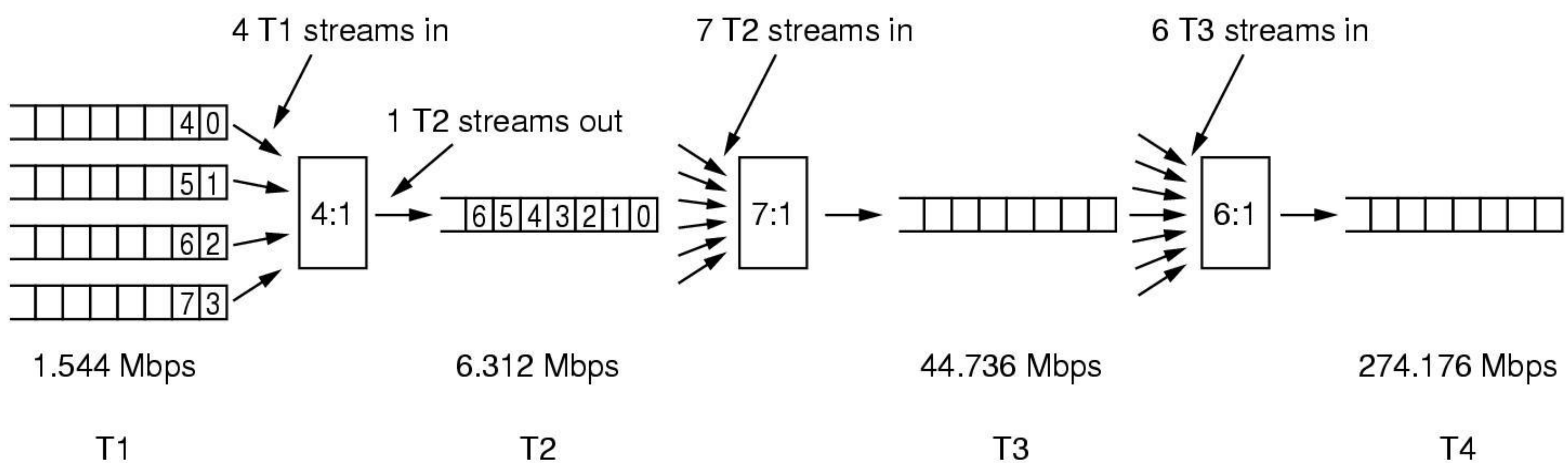
- Delta Modulation

  1 x 8000 = 8kbps



- TDM also makes it easy to offer individual senders higher bandwidth, by simply putting more data into a frame, or to combine several trunks into higher-bandwidth trunks:



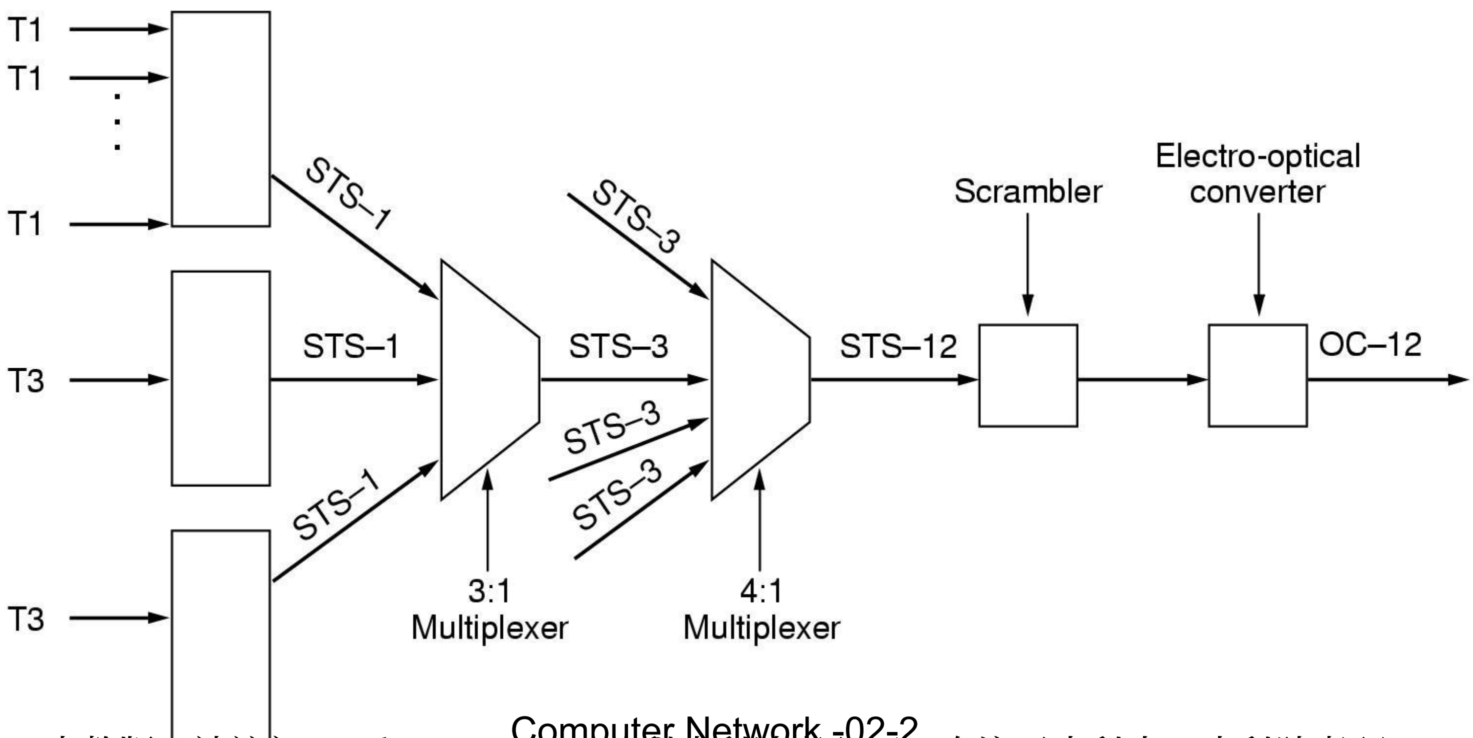


SONET/SDH

- Synchronous Optical Network (SONET)

  Synchronous Digital Hierarchy (SDH)

  Provides a way to multiplex multiple digital channels together.

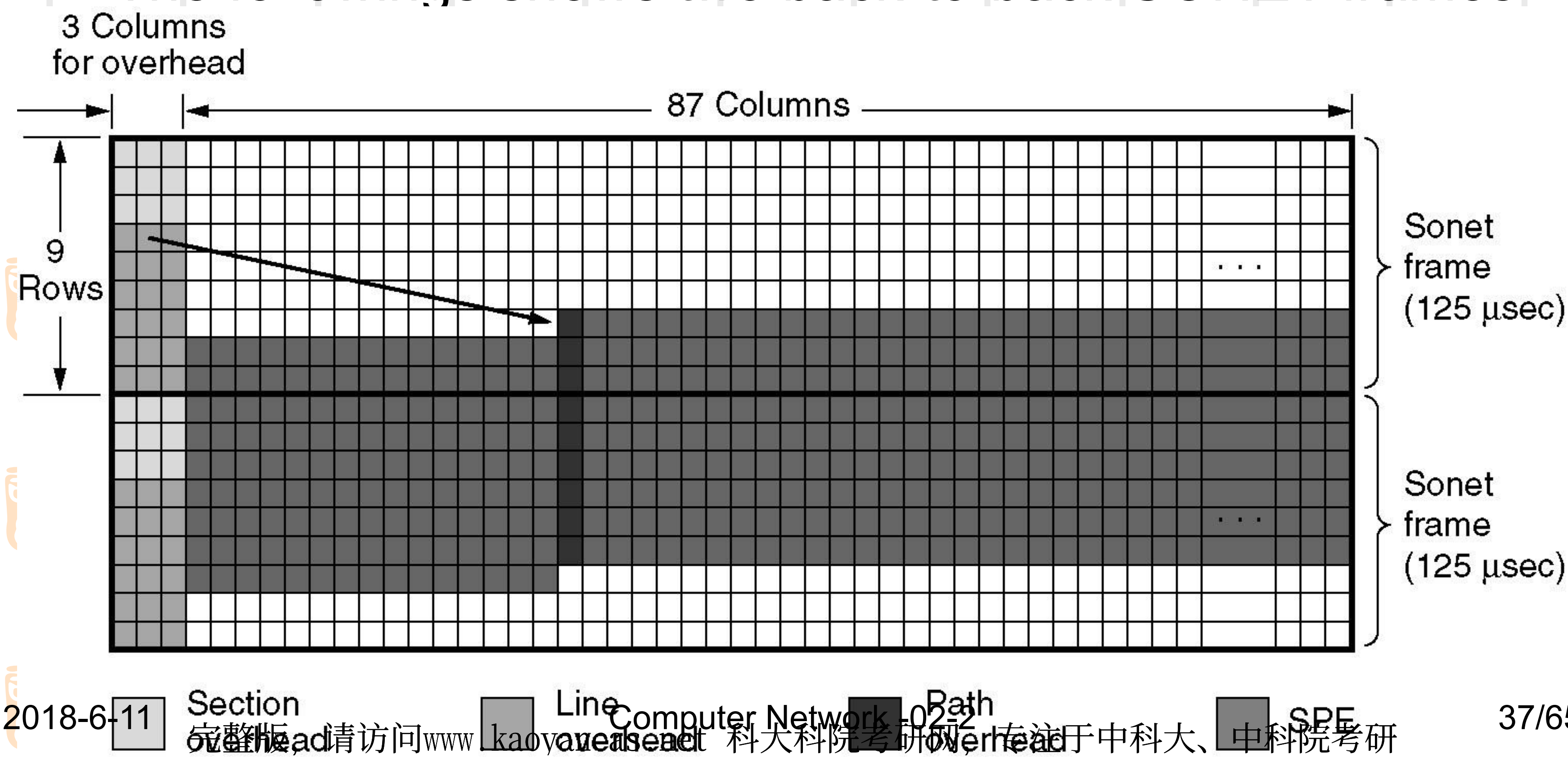


SONET Goals

- SONET had to make it possible for different carriers to work collaboratively
- Some means was needed to unify the U.S., European, and Japanese digital system, which are all based on 64-kbps PCM channels in different ways
- SONET had to provide a way to multiplex multiple digital channels
- SONET had to provide support for operations, administrations, and maintenance

Time Division Multiplexing

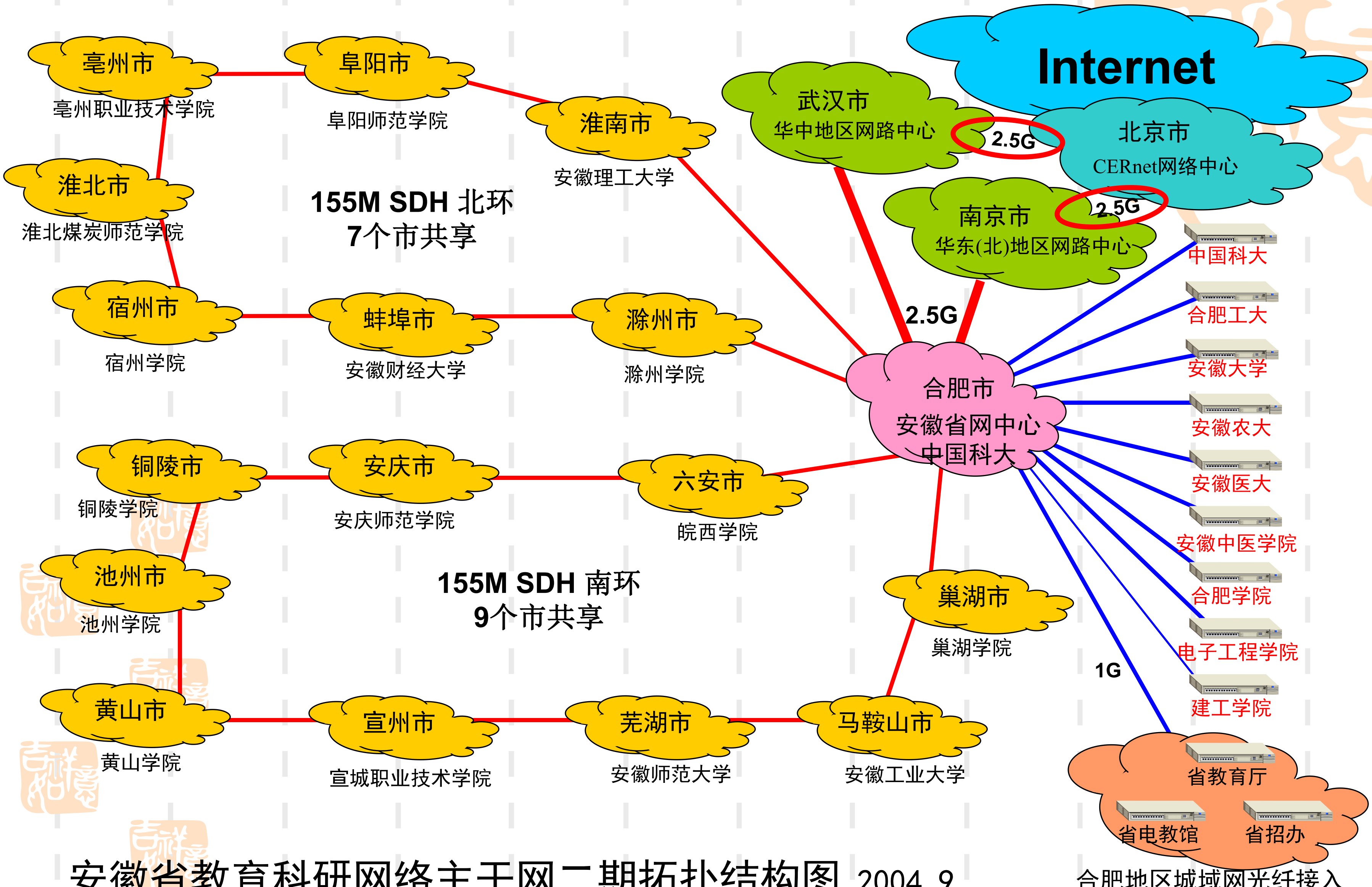
- A block of 810 bytes put out every 125μs
- 8X810=6480 bits are transmitted 8000 time per second for a gross data rate of 51.84Mbps, called STS-1 (Synchronous Transport Signal-1)
- The followings shows two back-to-back SONET frames.



SONET and SDH Multiplex Rates

- The followings shows SONET multiplexing hierarchy. The optical carrier corresponding to STS-n is called OC-n. SPE is for Synchronous Payload Envelope.

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



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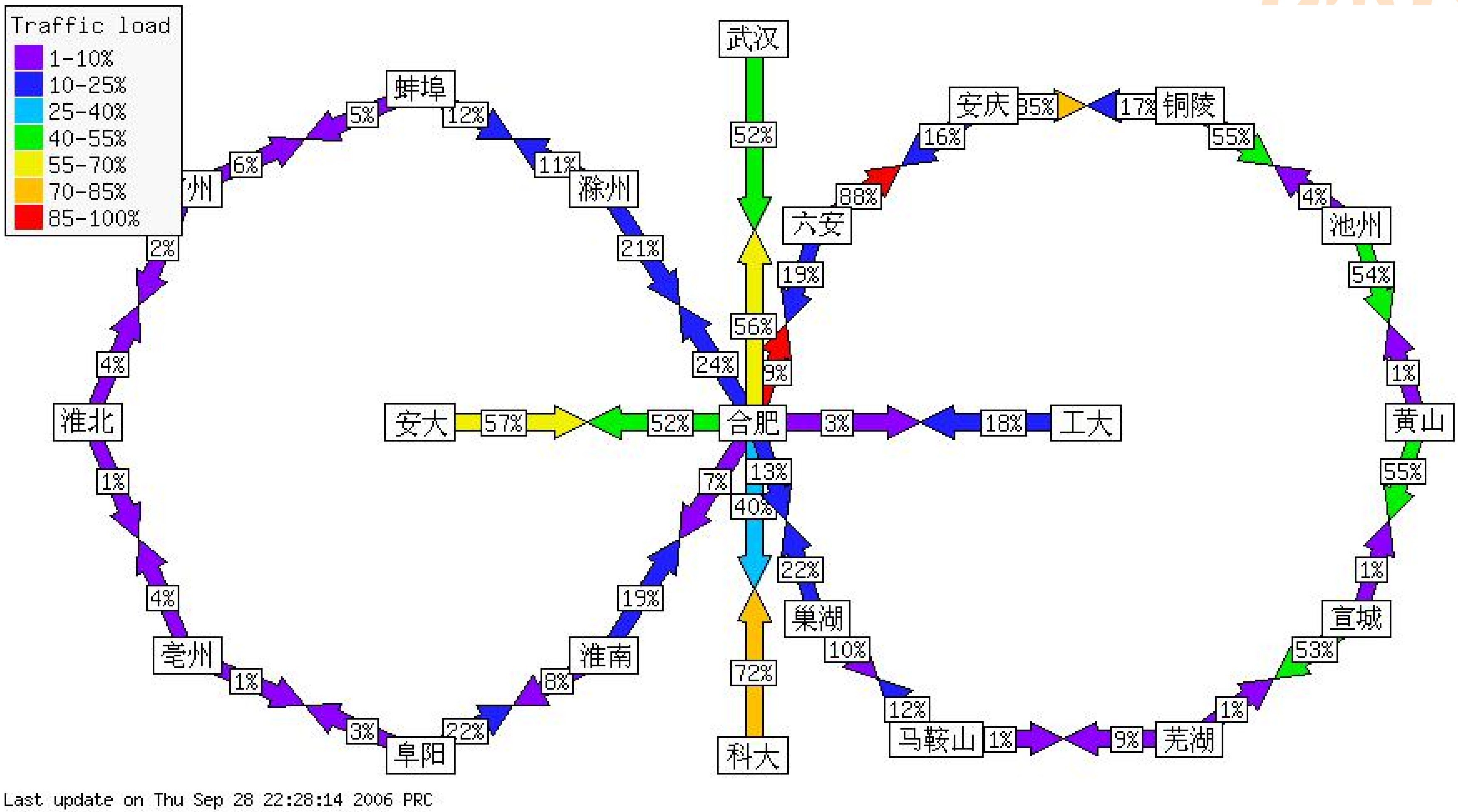
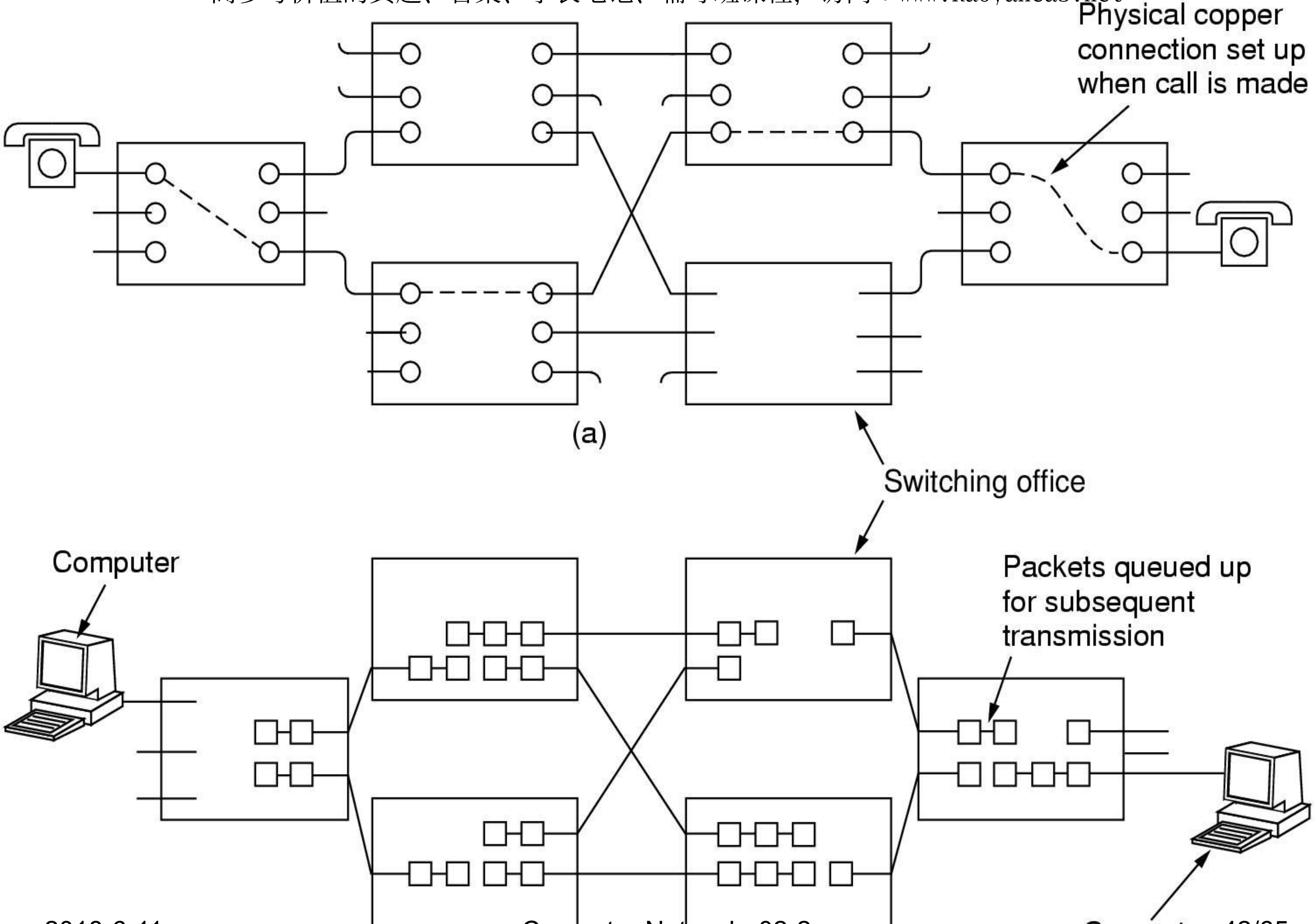
Weathercast Map



安徽省教育和科研网主干网网络天气图

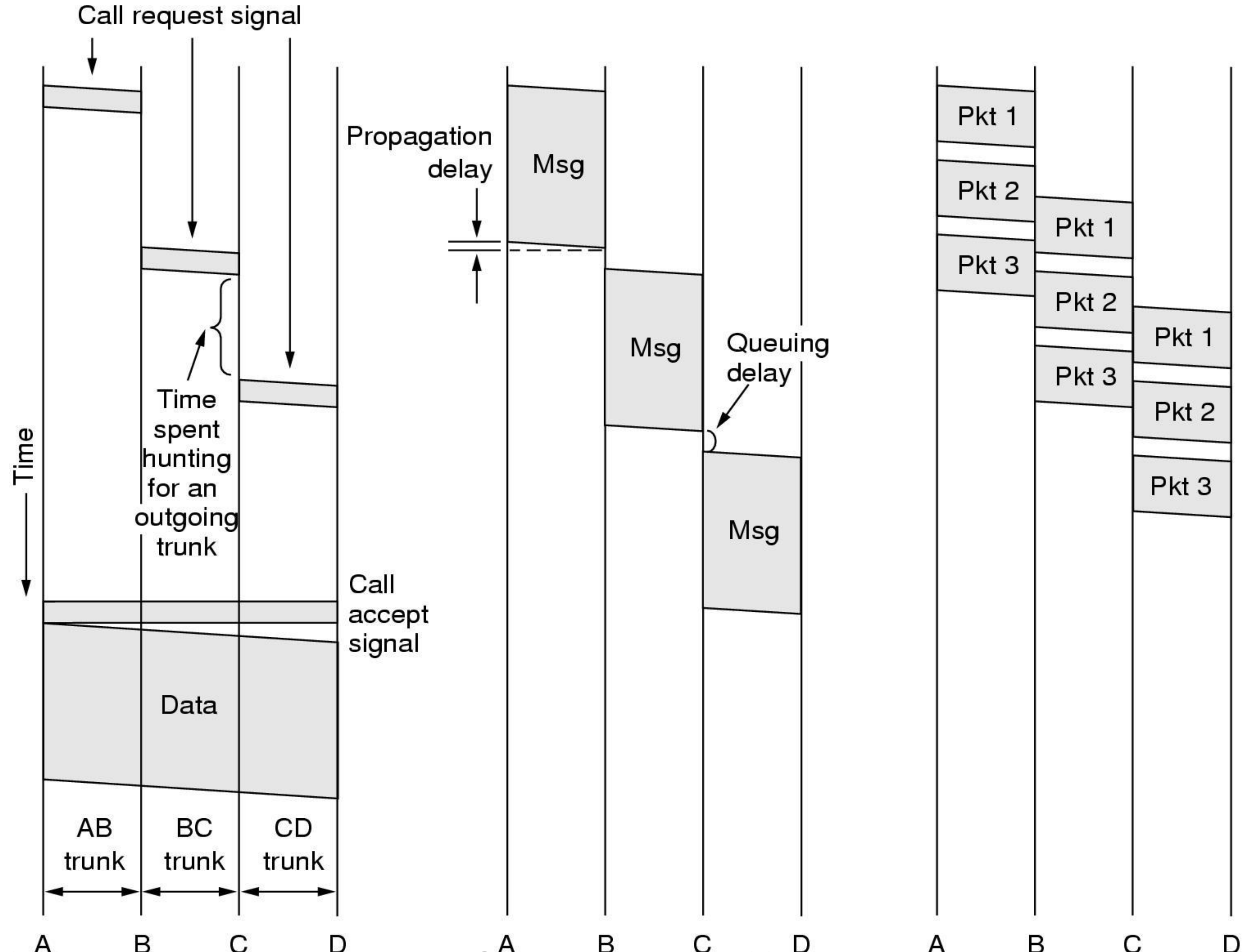
Switching

- **Switching:** A measure provided by telecom subnet to determine how to send message from source to destination.
- **Circuit switching:** Make a true **physical** connection from sender to receiver. This is what happens in traditional telephone systems.
- **Packet switching:** store-and-forward,(1) Split any data (i.e. message) into small **packets**, (2) route those packets separately from sender to receiver, and (3) assemble them again.
- **Message switching:** store-and-forward, a message is completely received at a router, stored, and then put into an outgoing queue for further routing.


Physical copper
connection set up
when call is made
(a)
Switching office
Computer
Packets queued up
for subsequent
transmission
Computer

(b)

Circuit switching, message switching, and packet switching



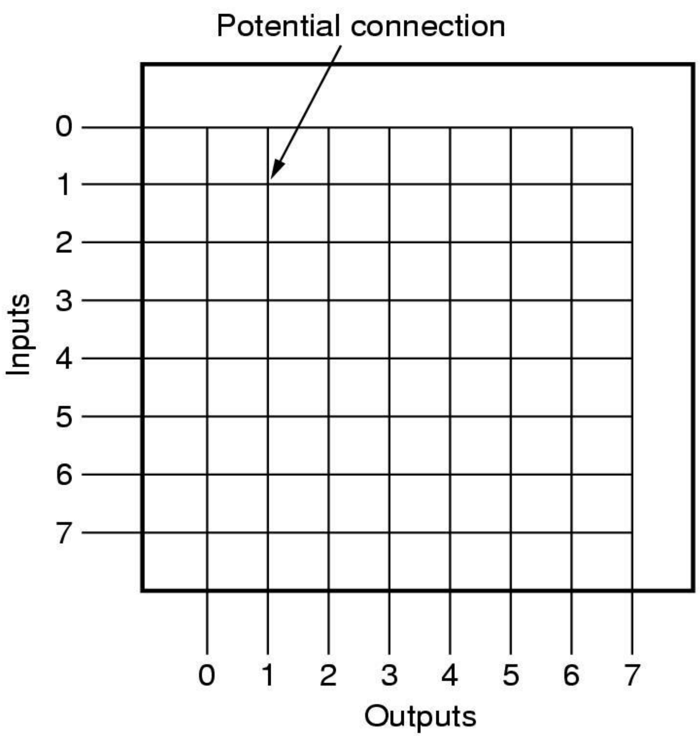
(a) (b) (c)

Switching: Comparison

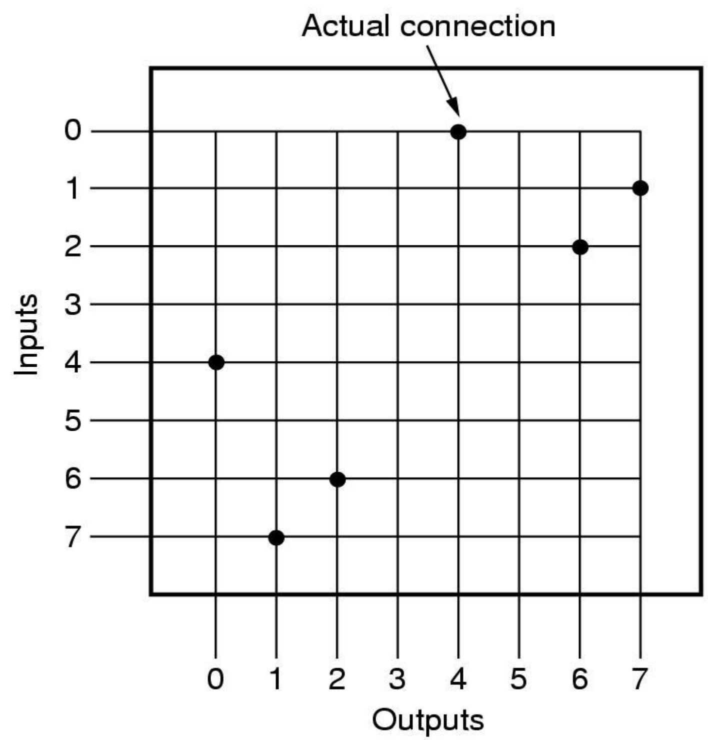
Item	Circuit switched	Packet switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
Time of possible congestion	At setup time	On every packet
Potentially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

Crossbar Switch

- **Crossbar Switch, crosspoint switch**
- **Essence:** Construct a matrix with input lines (rows)and output lines (columns); each entry represents a switch, implements circuit switching by making a direct electronic connection. Expensive and no scalability.



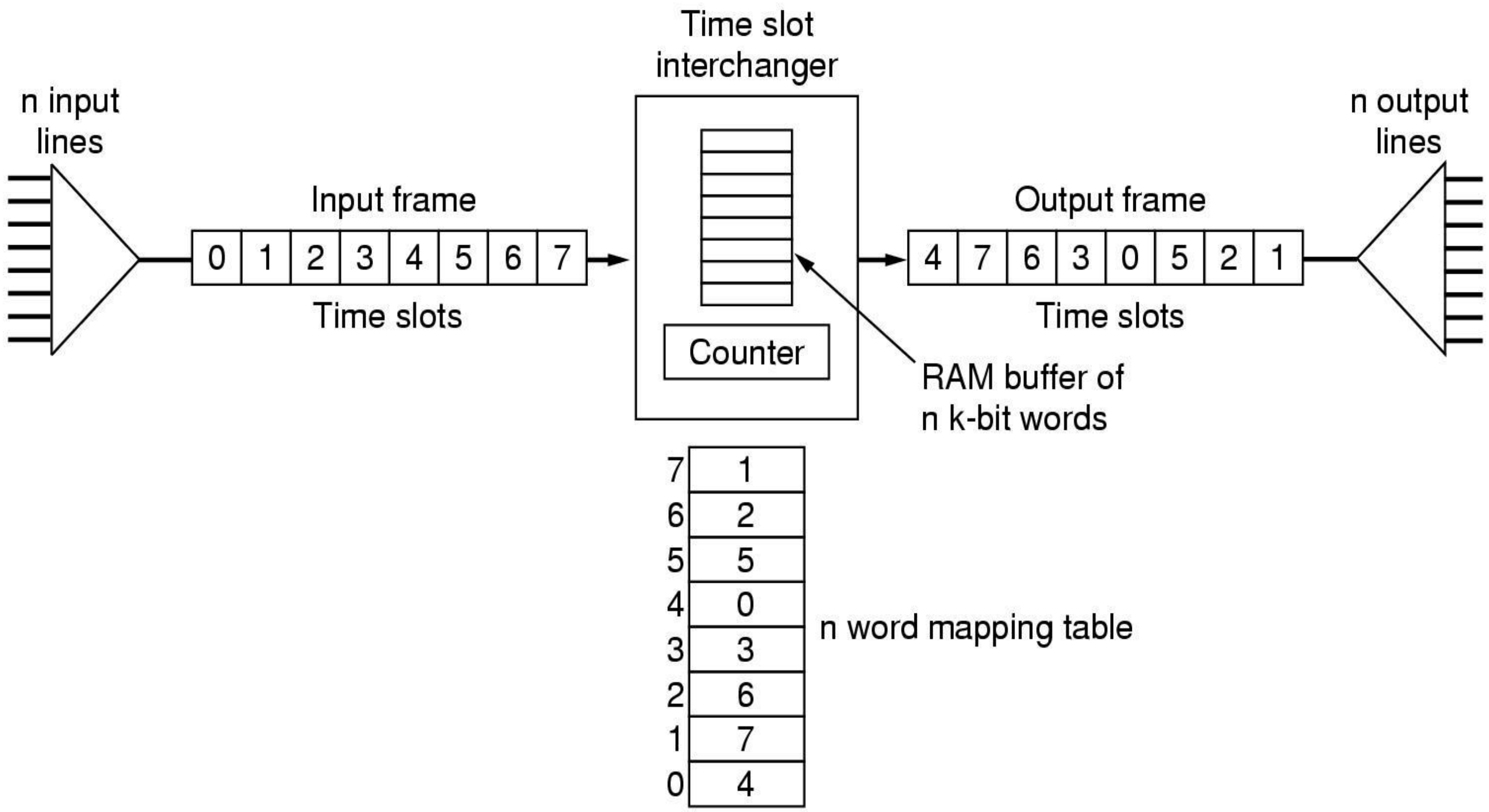
(a)



(b)

Time-Division Switch

- **Essence:** Based on TDM, reshuffle the packets in a frame so that packets will be forwarded to the right output line:



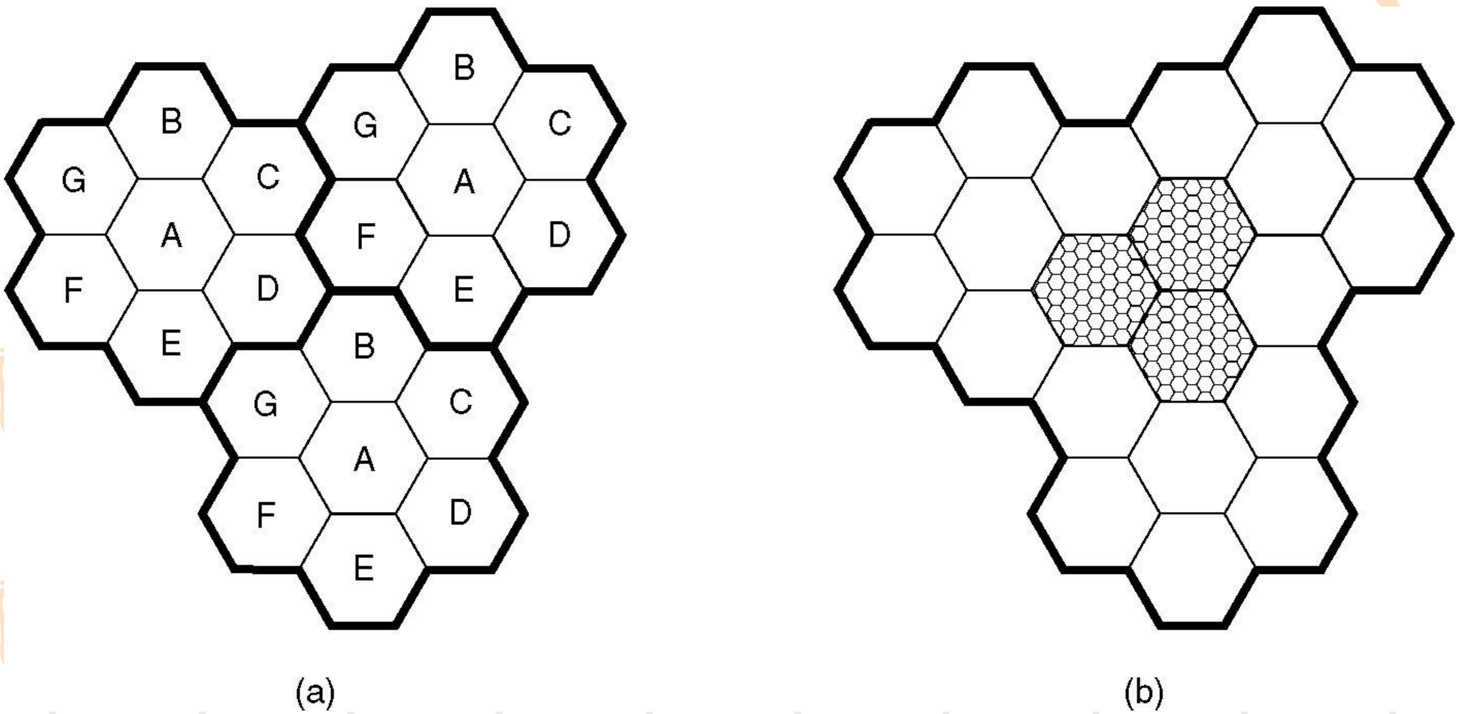
- **Observation:** This approach strongly resembles circuits switched networks, without using actual physical connections between sender and receiver. Note that the switch has to work as fast as the sampling in TDM, limits the number of in/output lines.

2.6 The Mobile Telephone System

- First-Generation Mobile Phones: Analog Voice
- Second-Generation Mobile Phones: Digital Voice
- Third-Generation Mobile Phones: Digital Voice and Data

First-Generation Mobile Phones: Analog Voice

Advanced Mobile Phone System



(a) Frequencies are not reused in adjacent cells.

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

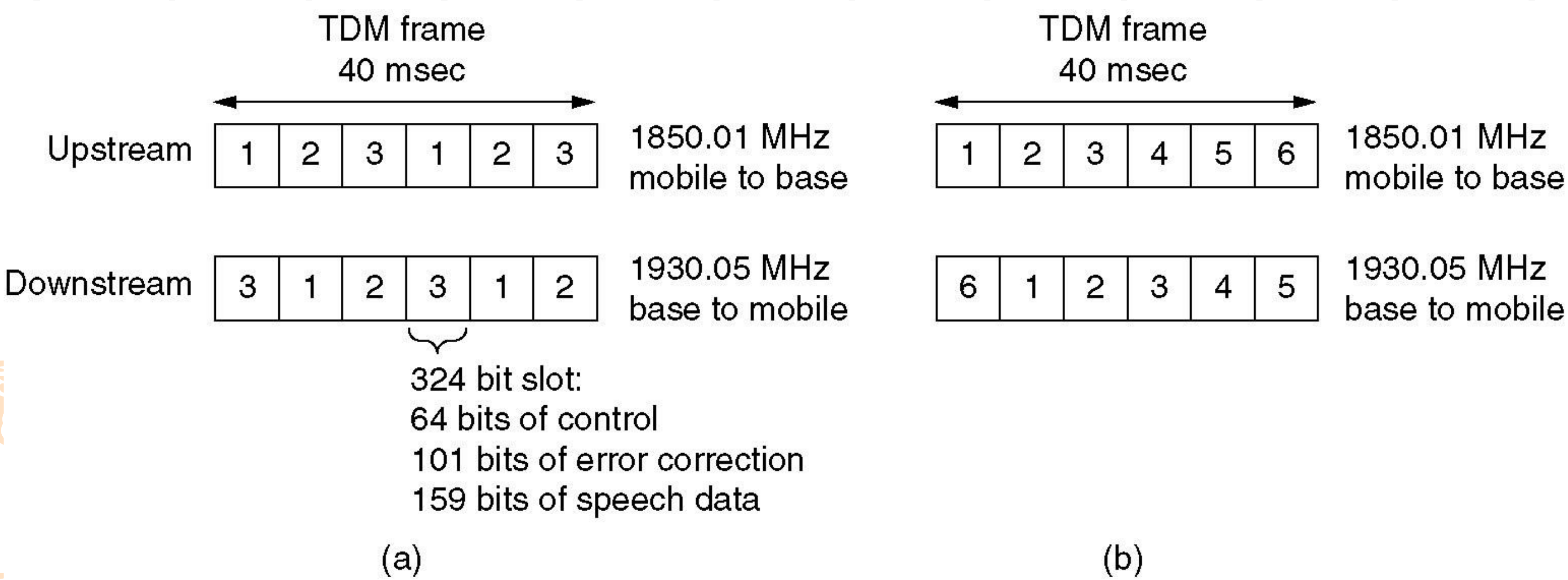
Channel Categories

The 832 channels are divided into four categories:

1. Control (base to mobile) to manage the system
2. Paging (base to mobile) to alert users to calls for them
3. Access (bidirectional) for call setup and channel assignment
4. Data (bidirectional) for voice, fax, or data

Second-Generation Mobile Phones: Digital Voice

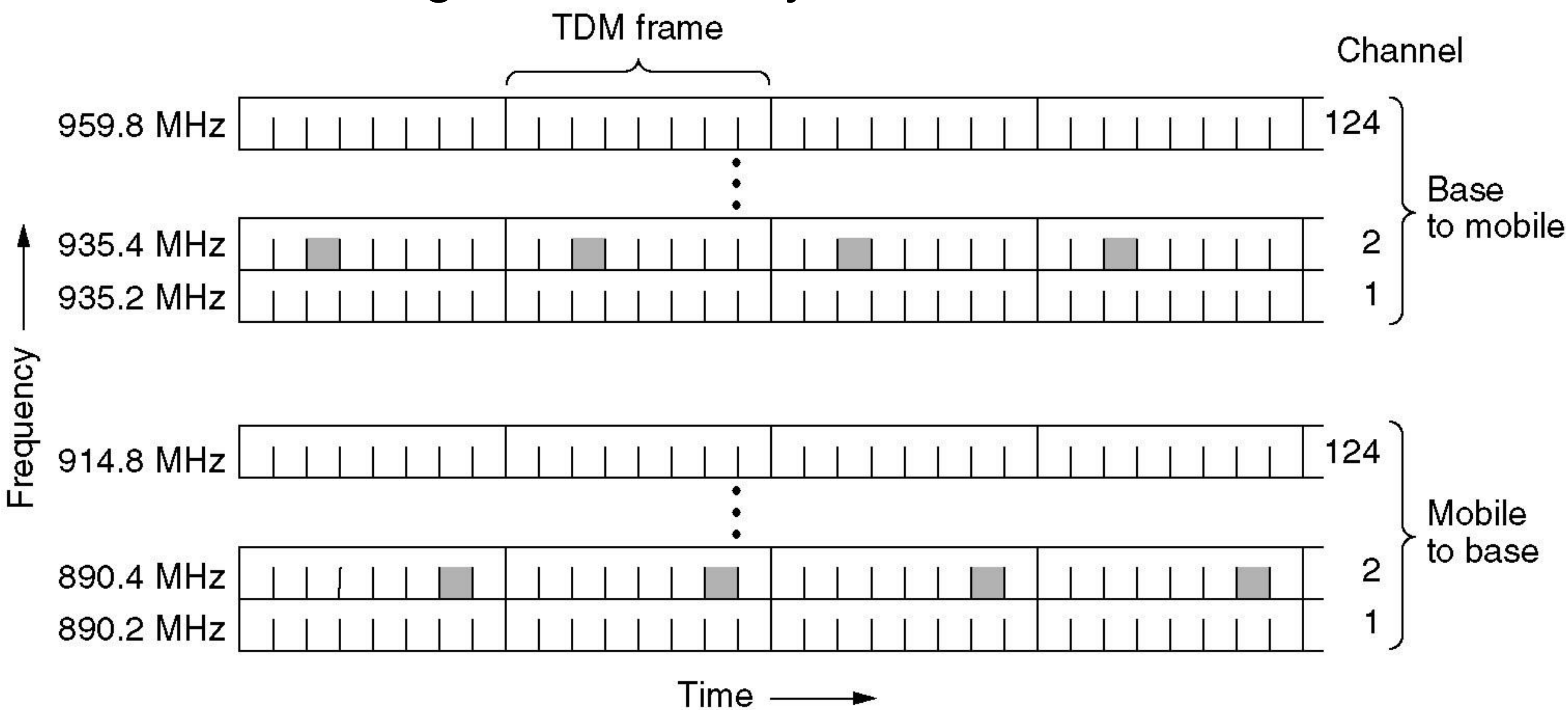
D-AMPS: Digital Advanced Mobile Phone System



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

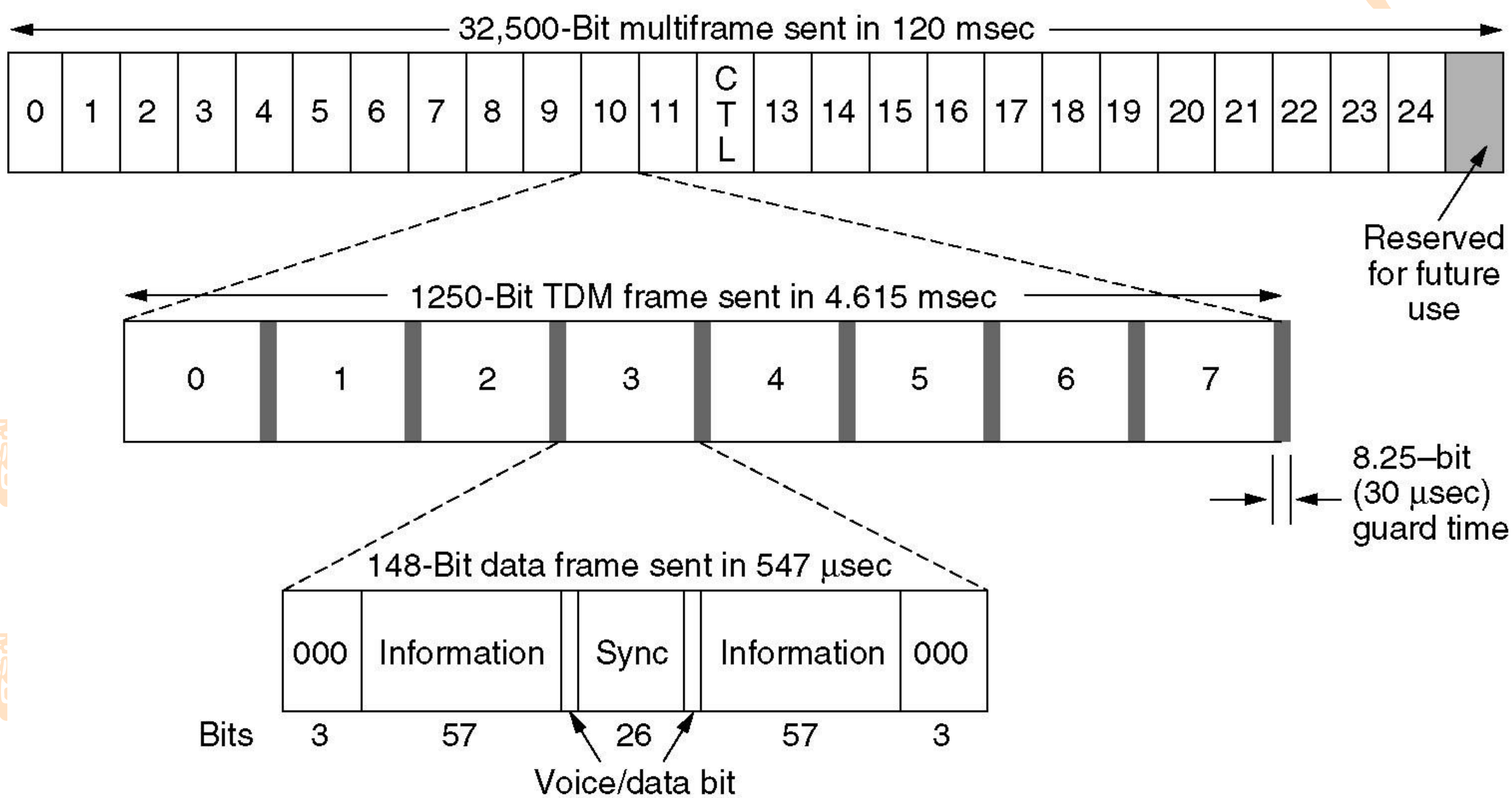
GSM: Global System for Mobile Communications

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



GSM (2)

A portion of the GSM framing structure.



CDMA – Code Division Multiple Access

(a)	(b)
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)

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

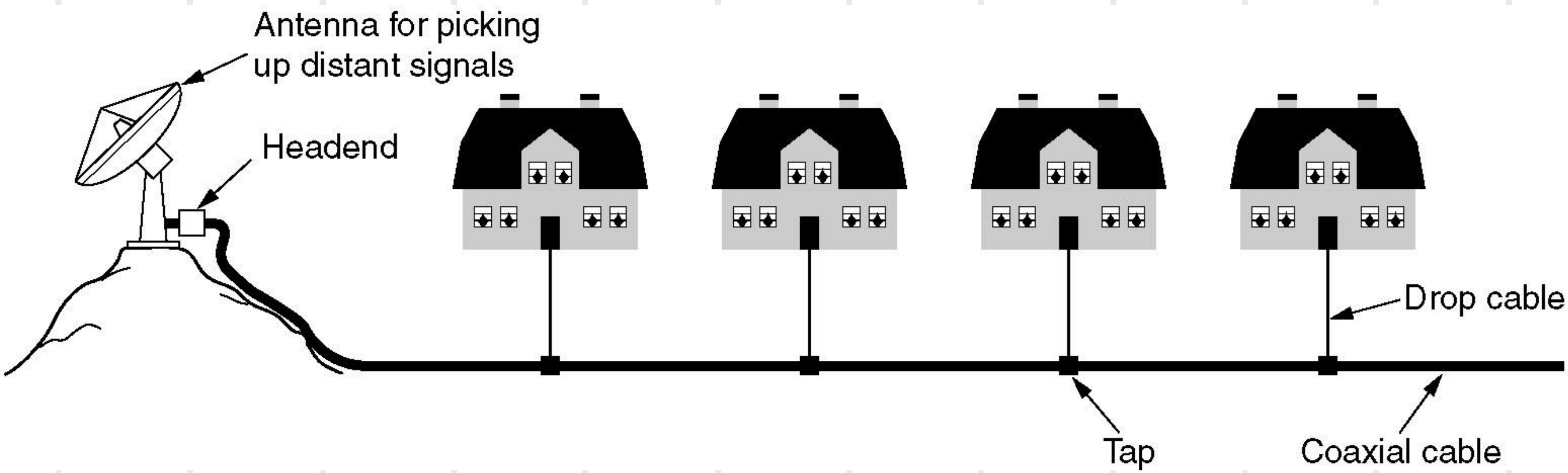
- Basic services an IMT-2000 network should provide
  - High-quality voice transmission
  - Messaging (replace e-mail, fax, SMS, chat, etc.)
  - Multimedia (music, videos, films, TV, etc.)
  - Internet access (web surfing, w/multimedia.)

Cable Television

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

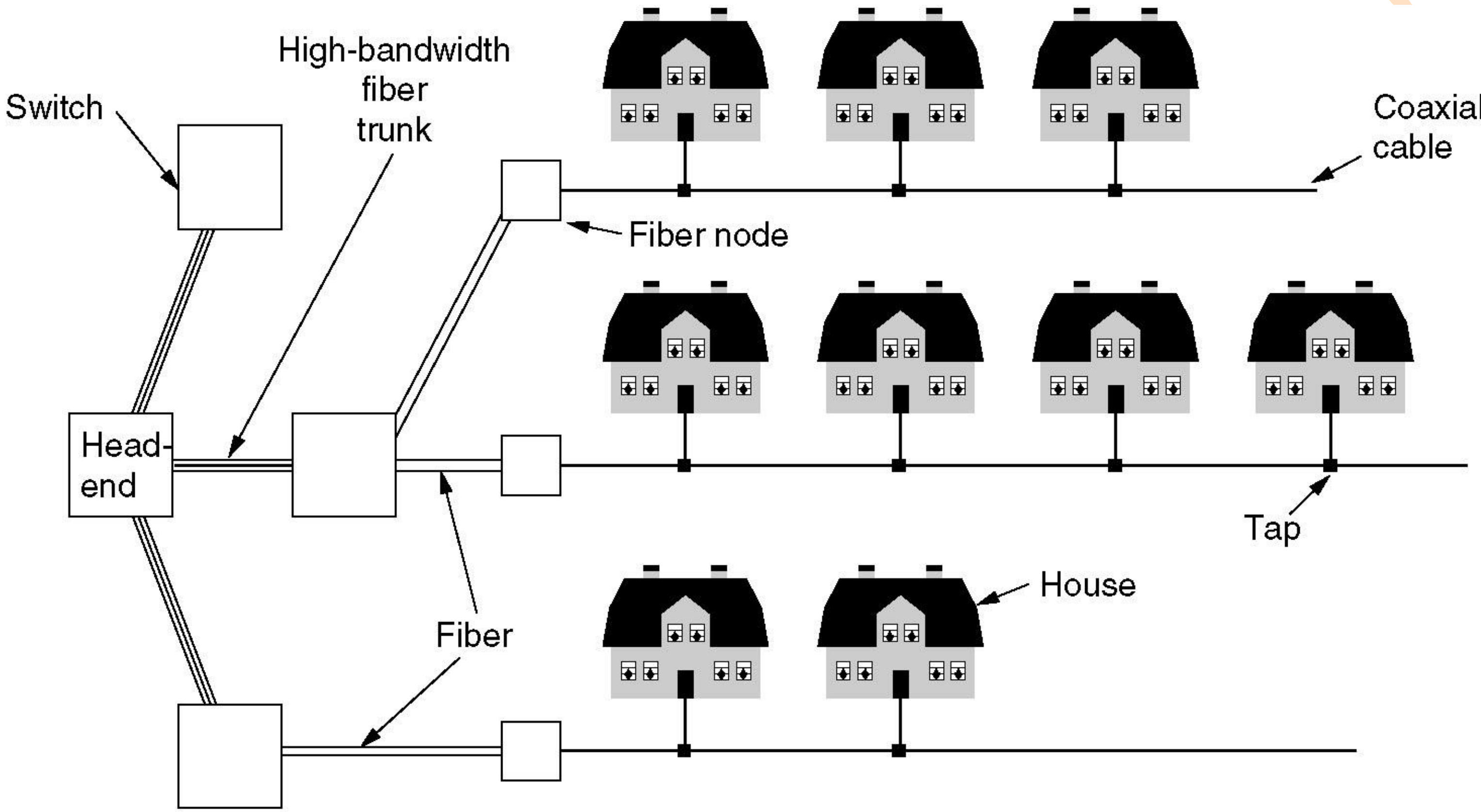
Community Antenna Television

An early cable television system.



Internet over Cable (1)

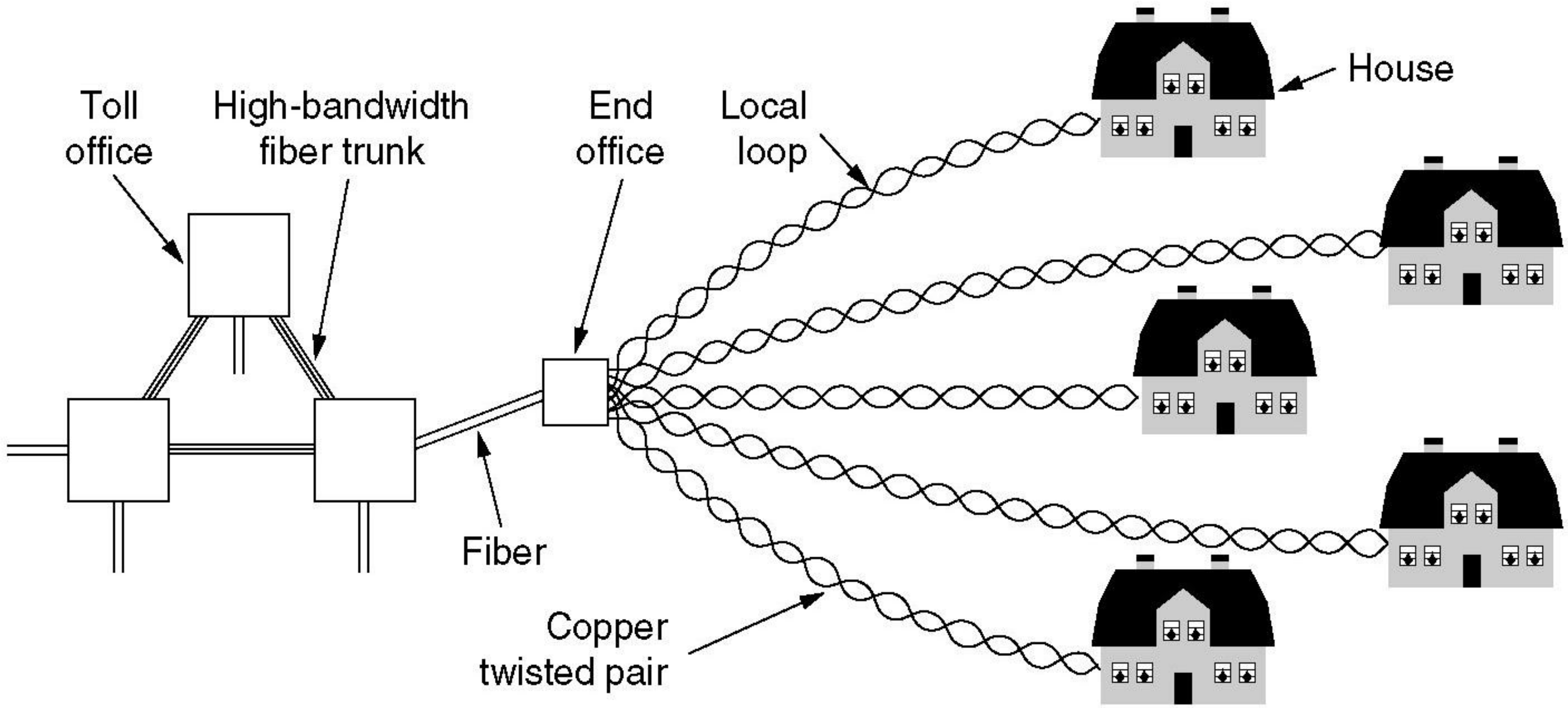
Cable television



(a)

Internet over Cable (2)

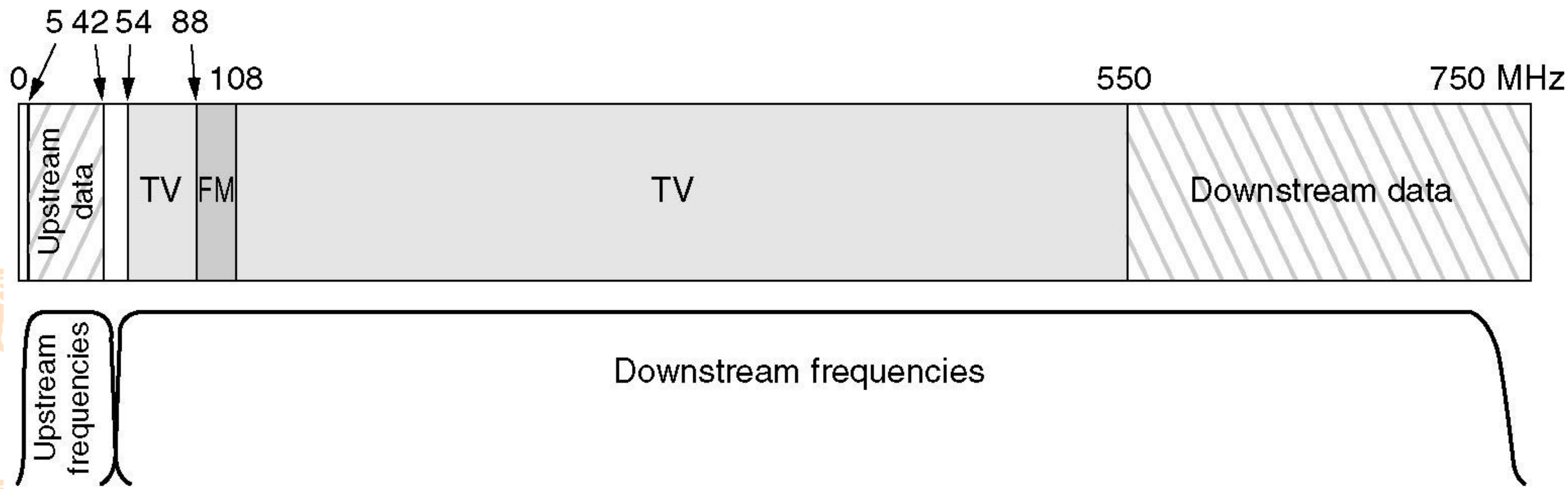
The fixed telephone system.



(b)

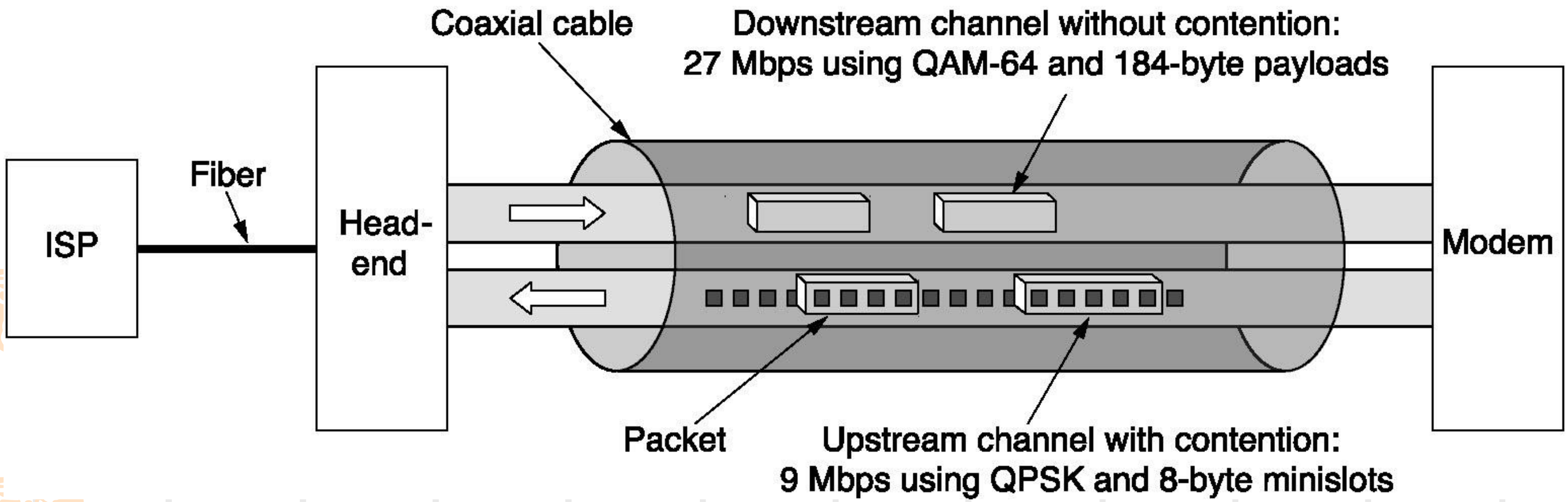
Spectrum Allocation

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



Cable Modems

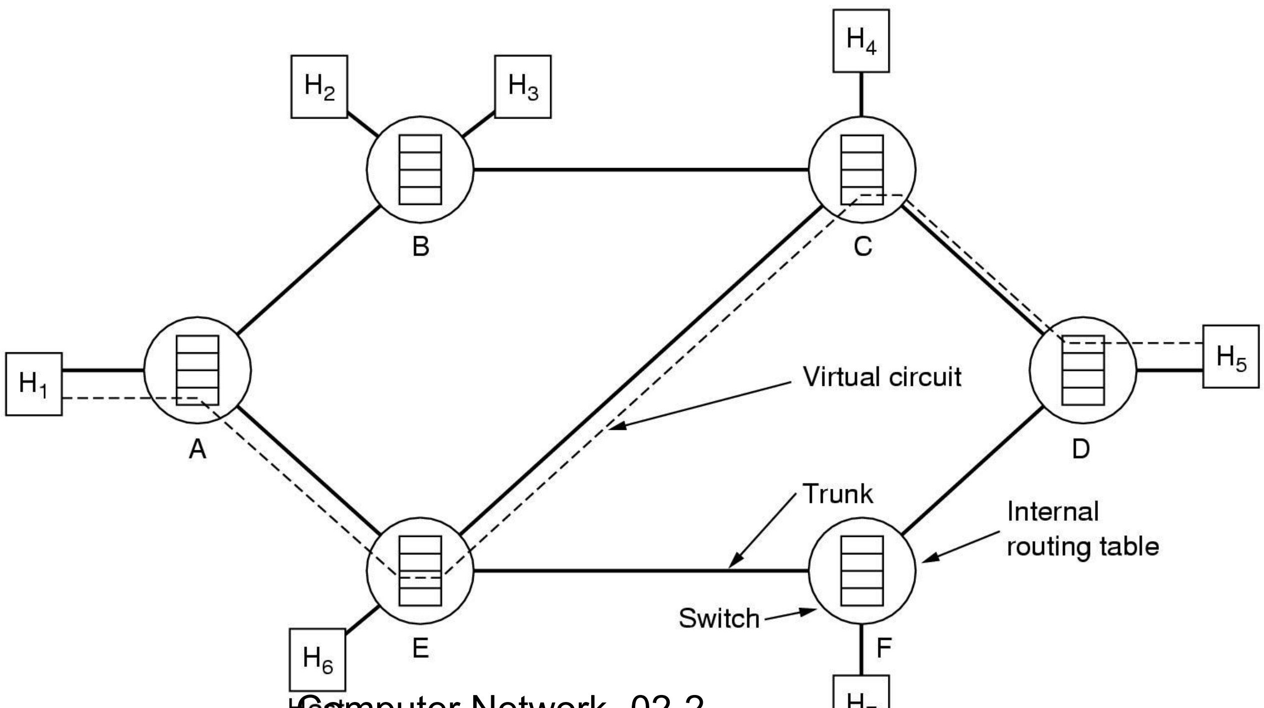
Typical details of the upstream and downstream channels in North America.



Virtual Circuits

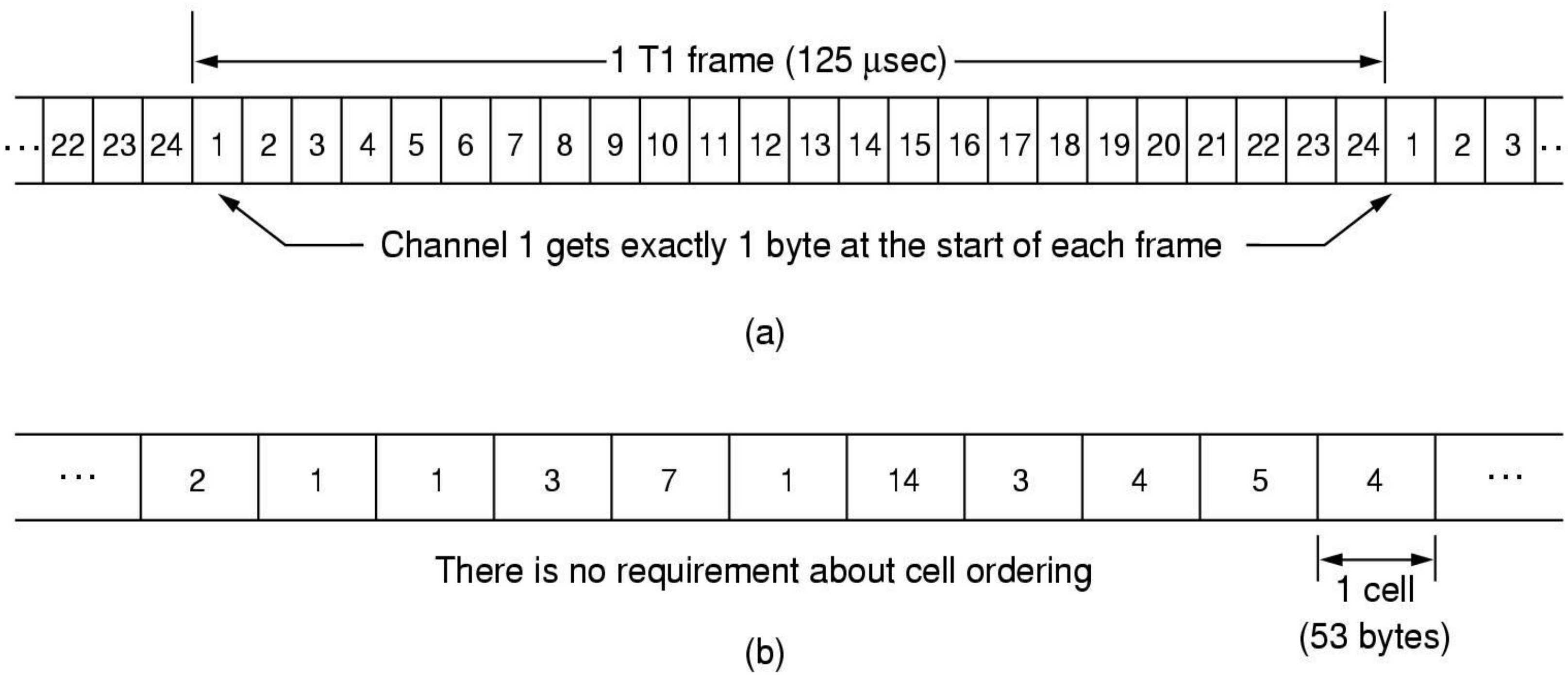
- The basic B-ISDN services are built around the concept of **virtual circuit**: A full connection is set up between sender and receiver, but is implemented through packet switching.

  Problem: how are we going to do the actually switching--ATM



ATM Technology

- **Basic idea:** we transfer very small packets, called **cells** and maintain the order in which a single sender transmits, but not that of a collection of senders, i.e. we do not impose **synchronicity**:



- **Observation:** In synchronous mode, a sender is obliged to provide all its data in a **predefined** time slot; we drop that requirement with **asynchronous transmission mode** (ATM).

Assignments

- Please see separate ppt.