Chapter 2

The Physical Layer

The Theoretical Basis for Data Communication

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

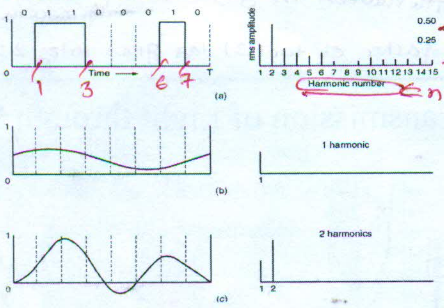
b → 01100010 [8-bit representaⁿ]

$$a_n = \frac{1}{\pi n}\left[\cos\left(\frac{\pi n}{4}\right) - \cos\left(\frac{3\pi n}{4}\right) + \cos\left(\frac{6\pi n}{4}\right) - \cos\left(\frac{7\pi n}{4}\right)\right]$$

$$b_n = \frac{1}{\pi n}\left[\sin\left(\frac{3\pi n}{4}\right) - \sin\left(\frac{\pi n}{4}\right) + \sin\left(\frac{7\pi n}{4}\right) - \sin\left(\frac{6\pi n}{4}\right)\right]$$

$c = 3/4$

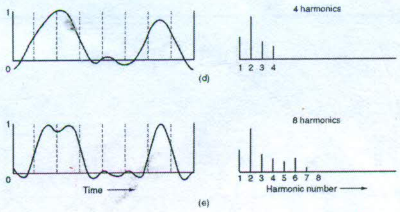
Bandwidth-Limited Signals



A binary signal and its root-mean-square Fourier amplitudes.
(b) – (c) Successive approximations to the original signal.

# of harmonics ↑ signal accuracy ↑
[Attenuaⁿ of different fourier components are different → distortion]

Bandwidth-Limited Signals (2)



Harmonic ↑ freq ↑

(d) – (e) Successive approximations to the original signal.

Bandwidth-Limited Signals (3)

(b/8) Hz

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

~~bps ↑ (freq ↑, T ↓) harmonics ↑~~

Relation between data rate and harmonics.

for a cutoff freq of 3000 Hz (Given), # of pass ~~freq~~ harmonics $= \frac{3000}{(b/8)} = \frac{24000}{b}$

Guided Transmission Data

- Magnetic Media (CD, DVD)
- Twisted Pair
- Coaxial Cable
- Fiber Optics

Fourier series

⇒ Any reasonably behaved periodic function, g(t) with period T can be constructed as sum of a (possibly infinite) number of sines and cosines:

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

where $f = \frac{1}{T}$ is the fundamental frequency, a_n and b_n are the sine and cosine amplitudes of the nth harmonics (terms), and c is a constant. [a_n, b_n, T, ⇒ unknow]

$a_n = \frac{2}{T}\int_0^T g(t)\sin(2\pi n f t)\,dt$ → through multiplying $\sin(2\pi n f t)$ on both sides and considering $\int_0^T \sin(2\pi k f t)\sin(2\pi n f t)\,dt = \begin{cases} 0 & \text{for } k \neq n \\ \frac{T}{2} & \text{for } k = n \end{cases}$

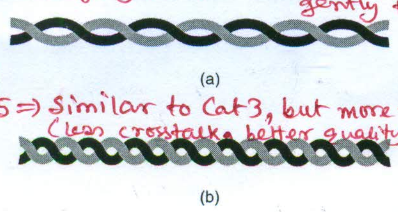
$b_n = \frac{2}{T}\int_0^T g(t)\cos(2\pi n f t)\,dt$

$c = \frac{2}{T}\int_0^T g(t)\,dt$

Twisted Pair

Cat3	16 MHz
Cat 5	100 MHz
Cat 6	250 MHz
Cat 7	600 MHz

Category 3 => two insulated ~~pairs~~ wires gently twisted together (4 such pairs are typically grouped in a plastic sheath)

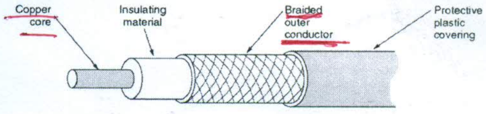


Cat 5 => Similar to Cat3, but more twists per cm (less crosstalk, better quality signal over long distance)

(a) Category 3 UTP.
(b) Category 5 UTP.

UTP (Unshielded Twisted Pair)

Coaxial Cable

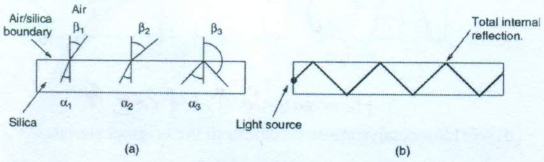


A coaxial cable.

Attenuation in dB = $10 \log_{10} \frac{\text{transmitted power}}{\text{received power}}$

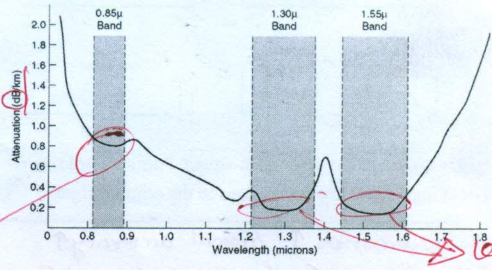
=> A factor of two (2) loss gives $10 \log_{10} 2 = 3$ dB

Fiber Optics



(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.

Transmission of Light through Fiber



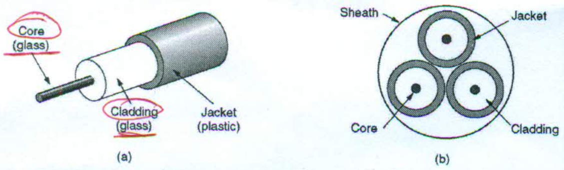
=> 3 wavelengths are used for optical comm.

less than 5% loss per km

Attenuation of light through fiber in the infrared region.

=> Higher attenuation, however, at this attenuation, laser and electronics can be made from the same material (~~GA~~ GaAs)

Fiber Cables



(a) Side view of a single fiber.
(b) End view of a sheath with three fibers.

Fiber Cables (2)

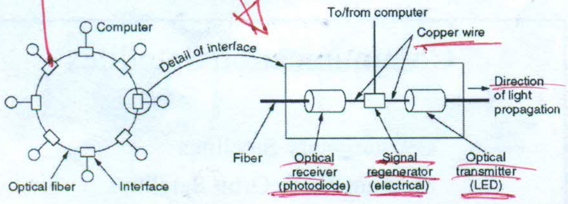
Item	LED	Semiconductor laser
Data rate	Low	High
Fiber type	Multimode	Multimode or single mode
Distance	Short	Long
Lifetime	Long life	Short life
Temperature sensitivity	Minor	Substantial
Cost	Low cost	Expensive

single mode

A comparison of semiconductor diodes and LEDs as light sources.

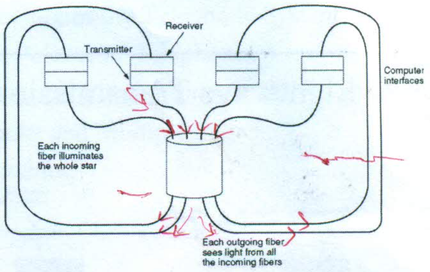
Can be —
① Passive interface (one LED/Laser diode + one photodiode)
or ② Active ~~filter~~ repeater
or ③ Purely optical repeater

Fiber Optic Networks



A fiber optic ring with active repeaters.

Fiber Optic Networks (2)

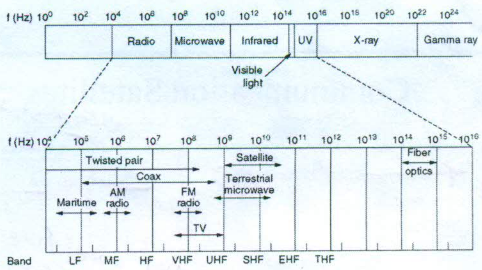


A passive star connection in a fiber optics network.

Wireless Transmission

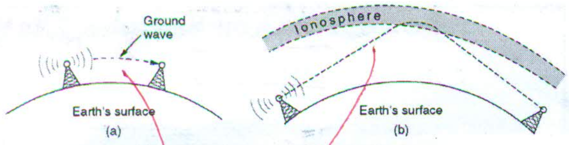
- The Electromagnetic Spectrum
- Radio Transmission
- Microwave Transmission
- Infrared and Millimeter Waves
- Lightwave Transmission

The Electromagnetic Spectrum



The electromagnetic spectrum and its uses for communication.

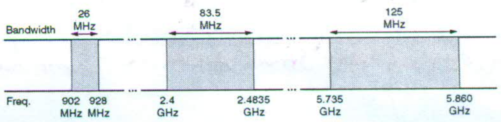
Radio Transmission



(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.

Politics of the Electromagnetic Spectrum



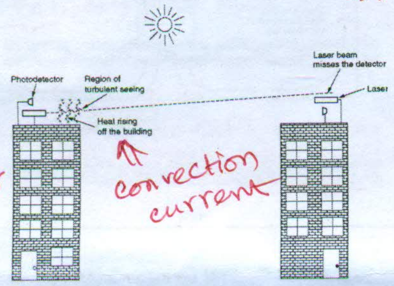
→ local authority does not follow the global assignment
→ So, have some freq allocated for all
→ Each transmits with shorter ranges so that none interferes

The ISM bands in the United States.

Industry
Scientific
Medical

Lightwave Transmission

→ High BW with low cost



works at → night, however does not work on day

convection current

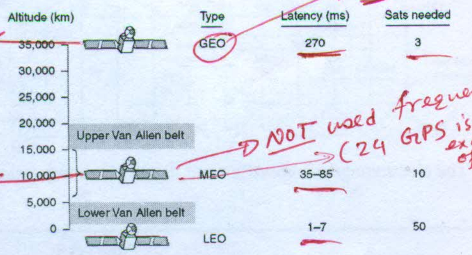
Convection currents can interfere with laser communication systems. A bidirectional system with two lasers is pictured here.

Communication Satellites

- Geostationary Satellites
- Medium-Earth Orbit Satellites
- Low-Earth Orbit Satellites
- Satellites versus Fiber

Communication Satellites

→ Geostationary Earth Orbit



24 hrs to circle

6 hours to circle

→ NOT used frequently → (24 GPS is an example of it)

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

Communication Satellites (2)

→ Narrow and crowded

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

→ later added

→ first assigned for commercial satellite

→ K- ~~upper~~ under

→ K-above

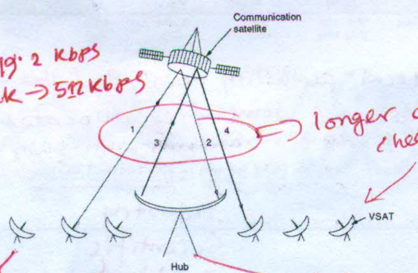
Not (yet) congested ?

The principal satellite bands.

Communication Satellites (3)

VSAT → very small Aperture Terminals

Uplink → 19.2 kbps
Downlink → 512 kbps



→ longer delay but cheaper end-station

→ large, high gain

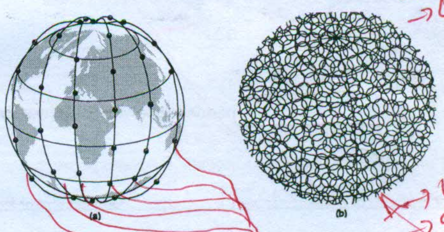
~1m (smaller antenna) [Cannot directly communicate to each other]

VSATs using a hub.

Low-Earth Orbit Satellites

Iridium

→ by Motorola
→ first planned to have 77 satellites [Iridium → 77]
→ Later revised to 66 [→ Dysprosium → sounds like a disease; so, not adopted]



→ launched in 1997
→ almost no commerce
→ Bankruptcy in 1999
→ Later restarted in 2001

(a) The Iridium satellites from six necklaces around the earth.

(b) 1628 moving cells cover the earth.

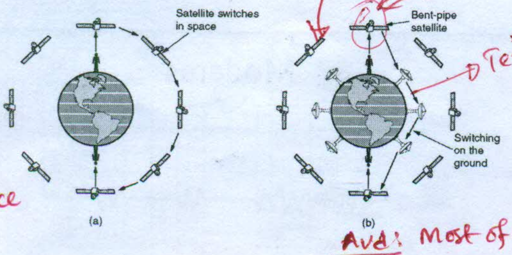
— Max of 48 cells → spot beams per satellite; Total 1628 cells

— 3840 channels from each satellite
So, ~~total # of~~ channels 253,440 channels

[Terrestrial microwave link]

	delay	Broadcasting
Satellite	270 msec	good
Terrestrial	3 µs/km	bad (mostly point-to-point)

Globalstar (48 LEO)



(a) Relaying in space.
(b) Relaying on the ground.

Bent pipe

Terrestrial

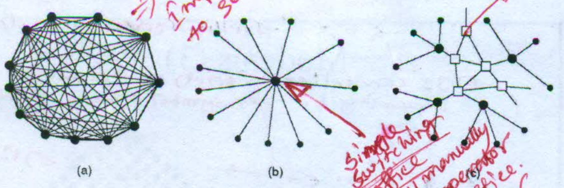
Iridium → comm^n from North pole to south pole
→ comm^n in space

Avd: Most of the complexities are on earth; easier to manage

Public Switched Telephone System (PSTN)

- 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



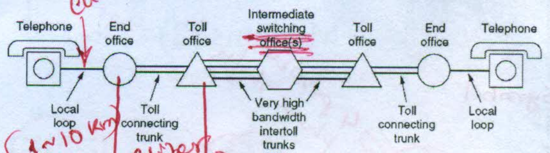
(a) Fully-interconnected network.
(b) Centralized switch.
(c) Two-level hierarchy.

Too hazy, impractical to scale up.

simple switching office (call manually to an operator in the office. The operator manually connects the caller to callee)

2nd level switching office

Structure of the Telephone System (2)



A typical circuit route for a medium-distance call.

Cu cable (twisted pair)

(1~10 km)

(fiber optics)

T

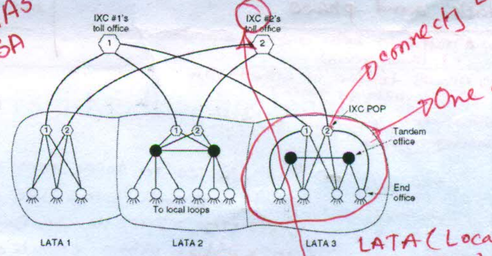
T

T

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, LECs, and IXCs. All the circles are LEC switching offices. Each hexagon belongs to the IXC whose number is on it.

[164] LATAs in USA

connect LATA

One area code

LATA (Local Access and Transport Areas)

local Exchange Carriers (determines one rate; monopoly)

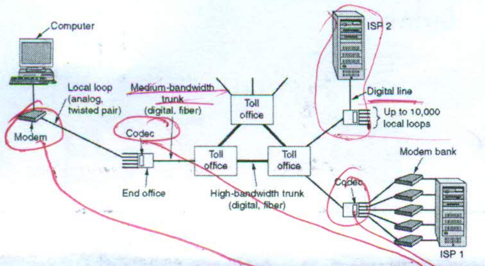
InterXchange Carriers

[One LATA can have one or more LECs]

=) Square wave: wide frequency spectrum (used in digital signal) that are subject to strong attenuation and delay distortion
– So, AC signals are used instead of DC

8/26

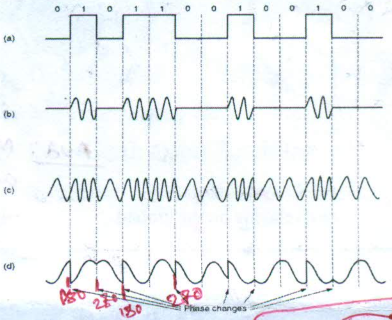
The Local Loop: Modems, ADSL, and Wireless



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

3 Problems encountered by tx lines
1. Attenuation: Loss of energy as the signal propagates outward [Differ for different Fourier components]
2. Distortion: Due to different propagation speed by different Fourier component over the wire
3. Noise: unwanted energy from sources other than the transmitter.

Modems

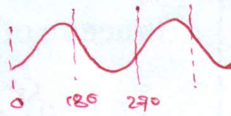


=) Sine wave carrier

(a) A binary signal
(b) Amplitude modulation
(c) Frequency modulation (Freq shift keying)
(d) Phase modulation

2 different amplitudes represent 0 and 1

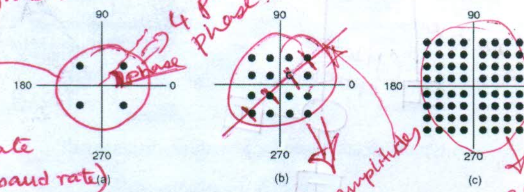
2 diff freqcies for 0 and 1



Modems (2) =???

baud → symbol

1 baud = 2 bit
(So, bit rate = 2 * baud rate)



4 possible phase shift

4 amplitudes and 4 phase

8 amplitudes and 8 phases

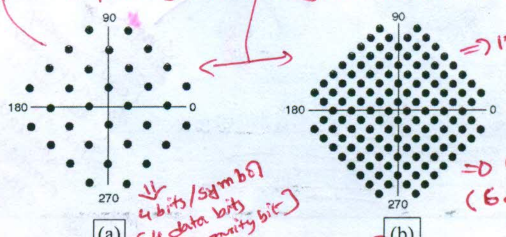
(a) QPSK. — Quadrature Phase Shift Keying — 2 bits/symbol
(b) QAM-16 — Quadrature Amplitude Modulation — 4×4 — 4 bits/symbol
(c) QAM-64 — 8 + 8 — 6 bits/symbol

Constellation Diagram
=) Legal combination of amplitude and phase

Modems (3)

Trellis Coded Modulation (TCM)

=) 32 ($=2^5$) constellation points to transmit 4-bit data and 1 parity bit per symbol (Total 5 bits/symbol)



4 bits/symbol [4 data bit + 1 parity bit]

=) 128 constellation points to transmit 6 bits data and 1 bit parity

=) 6 bits/symbol (6 data bits and 1 parity bit)

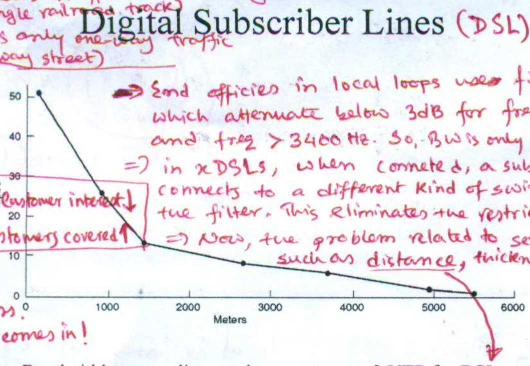
over a 2400 baud rate
(a) V.32 for 9600 bps.
(b) V32 bis for 14,400 bps.

=) With many points in constellation graphs, small noise in detected amplitude and phase can result in an error, potentially, many bad bits. To reduce this, modems do error corrections. → TCM (Trellis Coded Modulation)

	# of points	total bits/sym	data bits	Parity	data rate over 2400 baud rate
QPSK	4	2	2	0	4800bps
QAM-16	16	4	4	0	9600
QAM-64	64	6	6	0	14,400
V.32	32	5	4	1	9600
V.32 bis	128	7	6	1	14,400
V.34			12		28,800
V.34 bis			14		33,600

Full duplex =) Traffic in both direc's simultaneously (2-lane road)
Half " =) Allows traffic in either way (single railroad track)
Simplex =) Allows only one-way traffic (one-way street)

Digital Subscriber Lines (DSL)



=) End offices in local loops use filters which attenuate below 3dB for freq < 300 Hz and freq > 3400 Hz. So, BW is only 3100 Hz
=) in xDSLs, when connected, a subscriber connects to a different kind of switch omitting the filter. This eliminates the restriction of 3100 Hz
=) Now, the problem related to several factors such as distance, thickness, ...

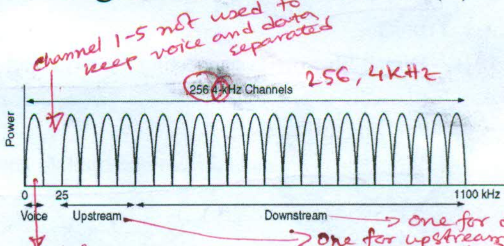
dist ↑ speed ↓ customer interest ↓
dist ↑ # of customers covered ↑
conflicting in terms of business! Here, technology comes in!

Bandwidth versus distanced over category 3 UTP for DSL.
(assuming other factors remain optimal)

Digital Subscriber Lines (2)

channel 1-5 not used to keep voice and data separated

256, 4KHz



=) 1.1 MHz

→ one for downstream control
→ one for upstream control
Rest for data
used for POTS (Plain Old Telephone Service)

Operation of ADSL using discrete multitone modulation.

Asymmetric
(DMT)

Bandwidth =) Range of freq that passes through a medium with minimum attenuation (property of a medium)

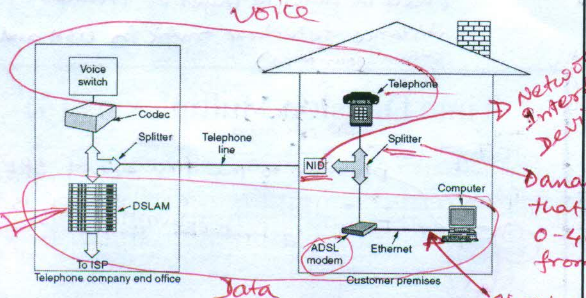
Baud rate/Symbol rate =) # of samples per sec

Bit rate =) baud rate * $\frac{\text{bits}}{\text{symbol}}$

Determined by modulation technique

For new competetive LECs (CLEC) (Local Exchng Carriers), its tough to connect its new customers to its end office

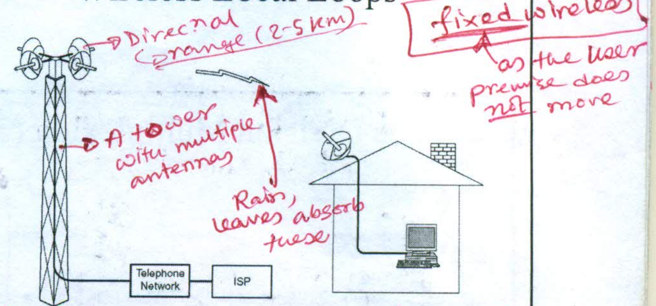
Digital Subscriber Lines (3)



A typical ADSL equipment configuration.

Wireless Local Loops

connect betw end office & customer



BW → Asymmetric (Downstream 36 Gbps, Upstream 1 Mbps)

Architecture of an LMDS system. (Local Multipoint Distribut Service)

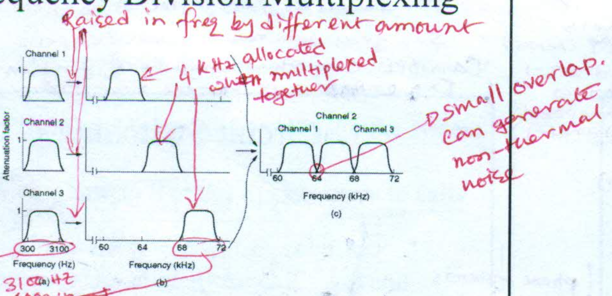
⇒ Operates in millimeter wave
- 28-31 GHz in USA; 40 GHz in Europe

△ 802.16 ⇒ Wireless MAN

Xmision of many signals over a single trunk ⇒ Multiplexing

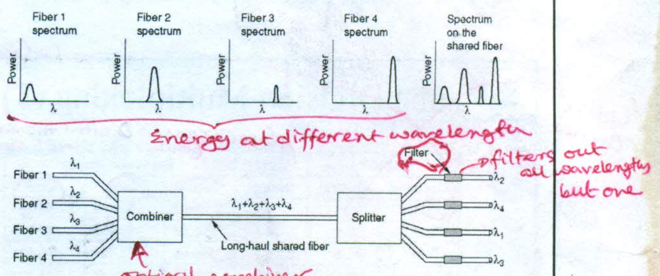
Frequency Division Multiplexing

Raised in freq by different amount



(a) The original bandwidths.
(b) The bandwidths raised in frequency. (3100 to 4000 Hz)
(b) The multiplexed channel.

Wavelength Division Multiplexing

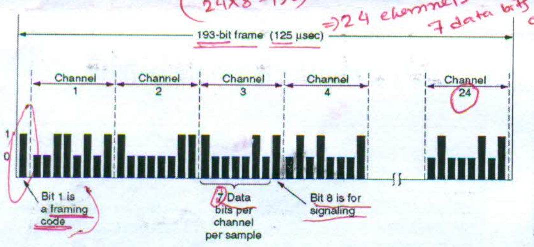


Wavelength division multiplexing.

Time Division Multiplexing

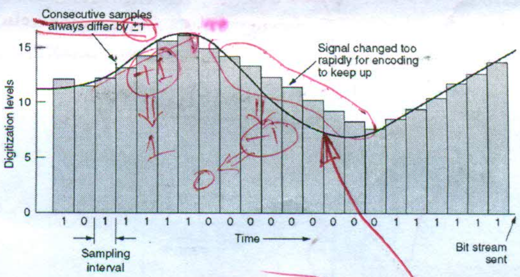
$(24 \times 8 = 192) + 1 = 193$ bit

⇒ 24 channels each having 7 data bits and one control bit



The T1 carrier (1.544 Mbps). (used is USA and Japan)

Time Division Multiplexing (2)



Delta modulation.

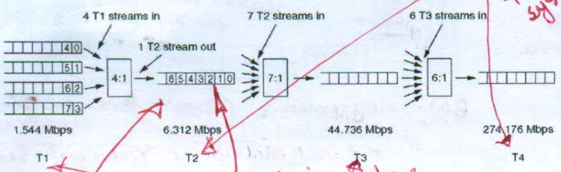
⇒ Differential Pulse Code Modulation: Not the digitized amplitude, but the difference between the current value and the previous one.

Variation → Delta modulation
- Require each sample to differ from its predecessor by either +1 or -1.
- A single bit can be transmitted telling whether the new sample is above or below the previous one.
- Get into trouble if signal changes too fast; Here, info gets lost.

SONET → Synchronous Optical NETwork (used in physical layer of trunks of long-distance telephone traffic in USA and many other countries)

Time Division Multiplexing (3)

only used by the telephone system itself



multiplexing is done bit by bit (Not byte by byte)

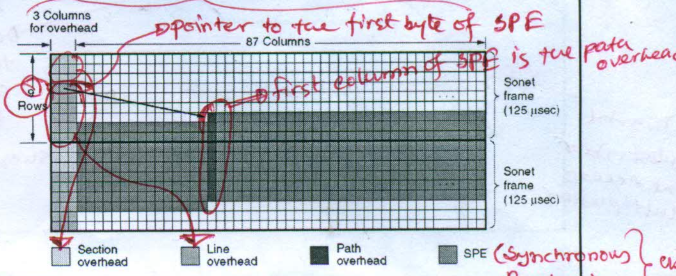
4×1'544 = 6'176; Additional bits are used for framing and recovery; So, 6'312

Multiplexing T1 streams into higher carriers.

used by customers

Time Division Multiplexing (4)

90 columns



pointer to the first byte of SPE

first column of SPE is the path overhead

SPE (Synchronous Payload Envelope) user data

Two back-to-back SONET frames.

⇒ 90 columns in 9 rows ⇒ 90×9 = 810 bytes = 8×810 bits = 6480 bits

⇒ 125 ~~frames~~ μs per frame ⇒ So, 8000 frames/sec (property of PCM)

⇒ So, gross data rate = 8000 × 6480 = 51'84 Mbps

[can SPE can start anywhere, and can span two frames]

[Need not to wait for the next frame to begin]

Basis SONET channel called STS-1 (Synchronous Transport Signal-1)

Time Division Multiplexing (5)

Optical Carrier

Synchronous Digital Hierarchy (similar to SONET standard)

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.

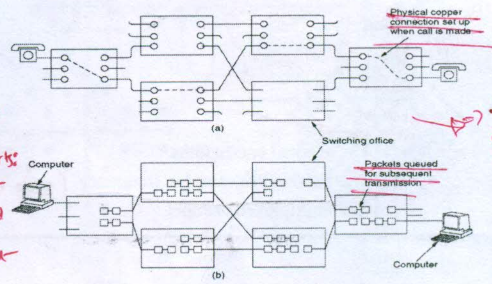
⇒ includes all overhead

⇒ excludes line and section overhead

⇒ excludes all overheads and counts only 86 payload column

Circuit Switching

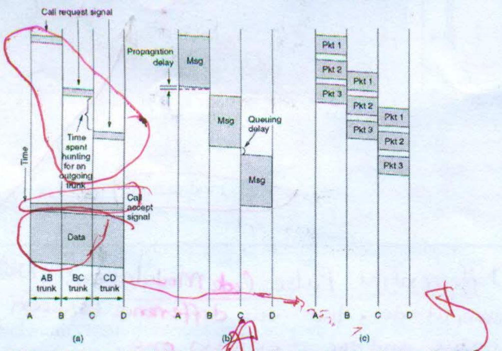
phone systems are divided in two principal parts:
i) Outside plant (local loop and trunks)
ii) Inside plant (switches)



establish a conceptual conn^n bet^n src & dest.

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

Message Switching



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

Stores user data ~~when~~ for ~~next~~ in switching office and sent ~~by~~ msg by msg

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.

Hand off ⇒ Getting a new channel from the BS which get the strongest signal from the mobile phone.
→ Takes around 300 ms

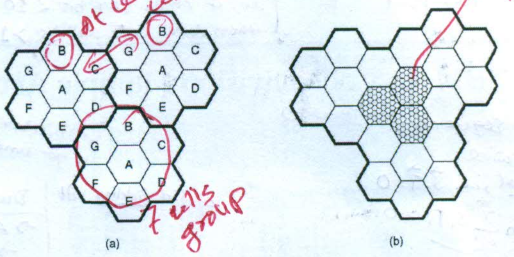
Soft handoff ⇒ Phone is acquired by the new BS before the previous one signs off.
Downside → Phone needs to tune two freqs at the same time.
Adv → No loss of continuity
hard handoff ⇒ old BS drops the phone before the new one acquires

The Mobile Telephone System

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

AMPS ⇒ 832 full-duplex channels, each consisting of a pair of simplex channels. [FDM is used to separate channels]
Each of 30 KHz → | 832 simplex tx channels from 824 – 849 MHz | 832 × 30 KHz
| 832 simplex receive channels from 869 – 894 MHz | ≈ 25 MHz

Advanced Mobile Phone System (AMPS)



at least 2 cells gap
7 cells group
micro cells to allow more freq reuse and thus more # of users

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

micro cells

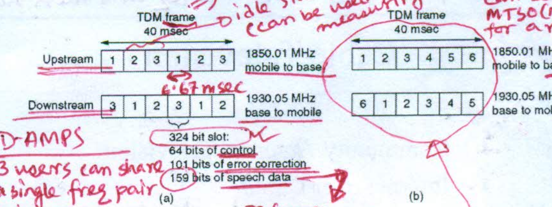
1st generation mobile ⇒ Analog
2nd " " ⇒ Digital → No standard (4 systems)
- D-AMPS
- GSM
- CDMA
- PDC

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 → USA & Japan
Digital Advanced Mobile Phone System

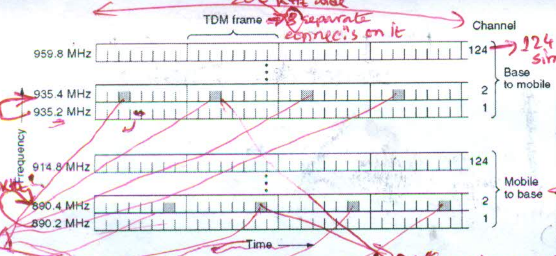


25 frames/sec
idle slots (can be used for measuring line quality)
can be used to inform MTSO (Mob Telp Switching Office) for a new channel. → Mobile assisted Handoff (MAHO)
4 kbps as 25 slots per sec
6.67 msec
D-AMPS
3 users can share a single freq pair using TDM.
Each freq pair supports 25 frame/sec of 40 msec each.
Each slot of 6.67 msec
25 frames/sec
2 slots/frame for 3 users
So, 50 slots/sec → 50 × 159 b ≈ 8 kbps

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

D-AMPS ⇒ 30 KHz channel; 3 users;
GSM ⇒ 200 KHz channel; 8 users; higher data rate

GSM → almost everywhere in the world → Global system for Mobile Comm?
Global System for Mobile Communications

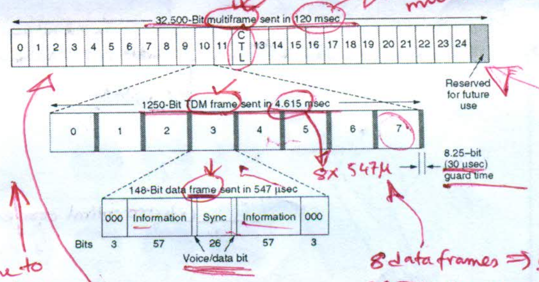


200 KHz wide
8 separate connec's on it
124 pairs of simplex channels
200 KHz
8 shaded slots belong to the same connection
Differs in upstream and d/s

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

124 × 8 = 992 channels theoretically. However, in practice, several channels are not available to avoid freq conflicts with neighboring cells.

GSM (2)



26 × 4.615 msec multiframe
8 × 547 μ
frame to multiframe
8 data frames ⇒ 1 TDM frame
26 TDM frames ⇒ 120 sec multiframe

A portion of the GSM framing structure.

(Framing hierarchy)

- Each TDMA slot consists of a 148-bit data frame (3+57+1+26+1+57+3 = 148) that occupies the channel for 577 μs (including a 30 μs guard time after each slot)
- Each data frame starts and ends with three 0s, both at beginning and at end.
- 57 bits information each having 1 control bit that says whether the following info field is voice or data.
- 26 bits training for the receiver to synchronize with the sender's boundary

CDMA → Completely different from AMPS, D-AMPS, and GSM, as it allows each station to transmit over the entire frequency spectrum all the time.
- Multiple simultaneous tx are separated using coding theory.
- Relaxes the assump^n that colloiding frames are totally garbled.

⇒ Each bit time is divided into m short intervals called chips.
- Typical: 64 or 128 chips per bit (In example 8 chips/bit)

⇒ Each station is assigned a unique m-bit code called a chip sequence. To tx 1, it send the chip seq; to tx 0, it sends one's complement of the chip seq

⇒ Example: 1 MHz band available for 100 users
FDM → 10 KHz, thus 10 Kbps per user | CDMA → chip rate 1 MHz so, if chips per bit < 100 then data rate will be > 10 Kpbs

CDMA – Code Division Multiple Access

Binary

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)

→ Bipolar notat^n for understanding

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 + $\bar{B}$	$S_3 = (0\ 0\ -2\ +2\ 0\ -2\ 0\ +2)$
1 0 1 –	A + $\bar{B}$ + 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 + $\bar{C}$ + D	$S_6 = (-2\ -2\ 0\ -2\ 0\ -2\ +4\ 0)$

(c)

Kind of adding volt

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

(d)

Recovery at C ⇓ Normalized inner prod [Synchroniza^n assumed]

During each bit time
→ A sta^n can Xmit
→ 1 by sending chip seq
→ 0 by a negative of chip seq
→ or be ~~st~~ silent by transmitting nothing

* All chip sequences are pairwise orthogonal, i.e., $\vec{S}\cdot\vec{T} = 0$

$\vec{S}\cdot\vec{T} = \underbrace{\frac{1}{m}\sum_{i=1}^{m} S_i T_i}_{\text{Normalized inner product}} = 0$

$\vec{S}\cdot\vec{S} = \frac{1}{m}\sum S_i S_i = \frac{1}{m}\sum (S_i)^2 = \frac{1}{m}\sum(\pm 1)^2 = 1$

$\vec{S}\cdot\overline{\vec{S}} = -1$

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

Genera^n of orthogonal chip seq ⇒ Walsh codes

↳ While doing so, inner prod of all other station's chip will give 0 as for being ~~ot~~ orthogonal. So, only part remains is to have inner prod with own chip seq and then normaliza^n.

Third-Generation Mobile Phones: Digital Voice and Data

Basic services an IMT-2000 network should provide

IMT → International Mobile Telecom^n; 2000 → year, freq of op.^n (2000 MHz), B.W of service (2000 KHz)

Nothing such actually happened in year 2000.

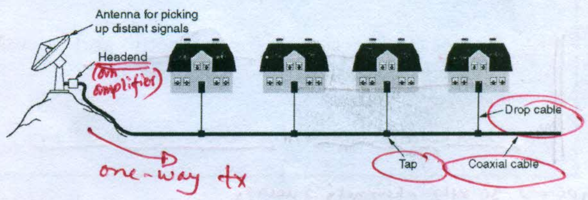
- High-quality voice transmission
- Messaging (replace e-mail, fax, SMS, chat, etc.)
- Multimedia (music, videos, films, TV, etc.)
- Internet access (web surfing, w/multimedia.)

Cable Television

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

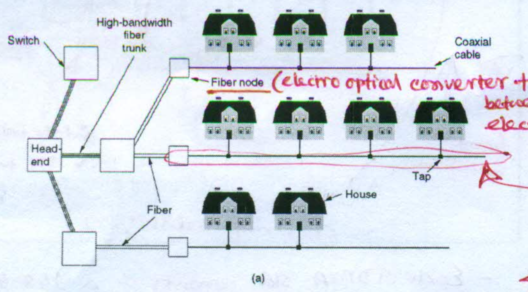
Community Antenna Television

→ For people living in rural or mountainous area



An early cable television system.

Internet over Cable

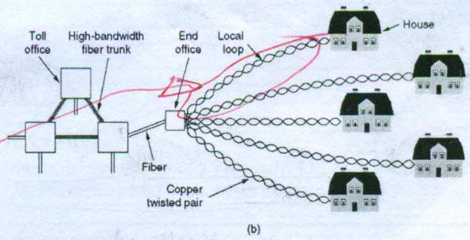


Fiber node (electro optical converter that interfaces between optical and electrical part)

Cable television

Hybrid Fiber Coax (HFC)

Internet over Cable (2)



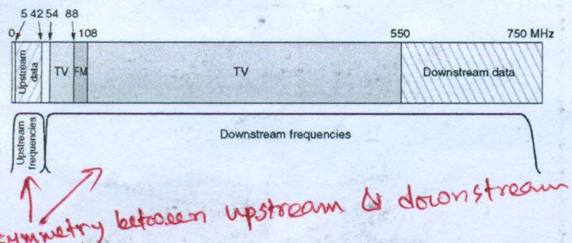
The fixed telephone system.

⇒ Cable operators wanted to get into the Internet access business and often the telephony business as well. However, there are some ~~tch~~ technical challenges

→ Technical challenge
① One-way amplifiers are needed to be replaced by two-way amplifiers
② Down ~~to~~ in the neighborhoods, a single cable is shared by many houses, whereas in the telephone system, every house ~~is~~ has its own local loop.
Sol^n: Limit the # of subscribers ~~on~~ each cable through splitting up long cables and connect each one directly to a fiber node.
(# of hoses per cable → 500 ~ 2000) typical

Spectrum Allocation

for Cable TV and Internet coexist simultaneously

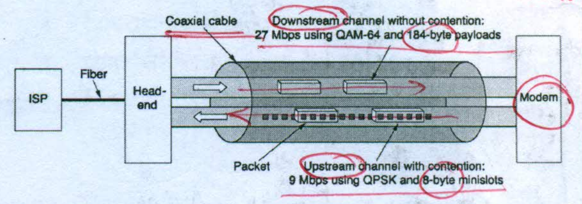


Frequency allocation in a typical cable TV system used for Internet access

Cable Modems

⇒ for Internet access

Two interfaces
- One to computer
- One to cable network



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

	ADSL	Cable
Backbone	Fiber	Fiber
Edge	Twisted pair (less BW, but, less wastage)	Coax (more BW, but, more wastage)
Specific statement on BW	Yes	No (as ~~no~~ # of users may vary)
Impact of increasing # of users	less	More
Availability	Everyone has a telephone but not all users are close to their end office to get ADSL	Not everyone has cable. But, if you have cable and the company provides Internet access, you can get it
Security	More (as has own cable)	Less (as shared cable)
Reliability	More (has backup power to continue work even during a power outage)	Less (if any amplifier down the chain fails, all downstream users are cut off instantaneously.)

comparable service and comparable price