Data Communication Networks Physical Layer

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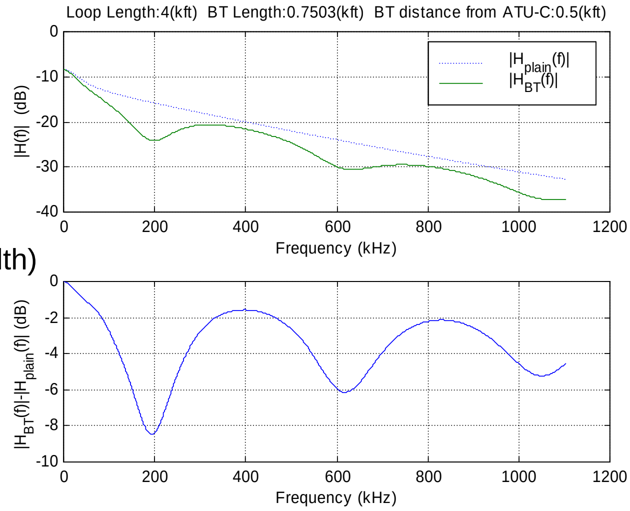
Physical Layer

- Maximum Data Rate of a band limited noiseless channel: $C=2W*\log_2(V)$ bits/sec where V is number of discrete signal levels, W is channel bandwidth
- For Noisy channels: $C=W\log_2(1+SNR)$ bits/sec
- Example: A channel with a bandwidth of 4kHz and SNR=30dB can carry 40kbps at most

- Important communication Media:
  - Guided Transmission Media
    - Twisted Pair
    - Coaxial Cable
    - Power Lines
    - Fiber Optics
  - Wireless Transmission
    - Radio/Microwave Transmission
    - Millimeter Wave Transmission
    - Light wave Transmission
    - Satellite Communication
      - Geostationary
      - Medium Orbit Satellites
      - Low Earth Orbit Satellites

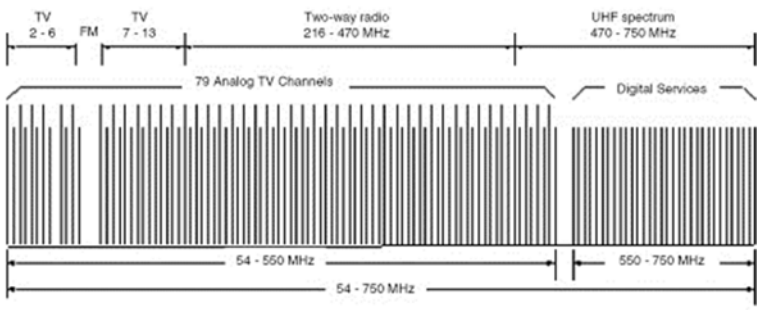
Twisted Pair

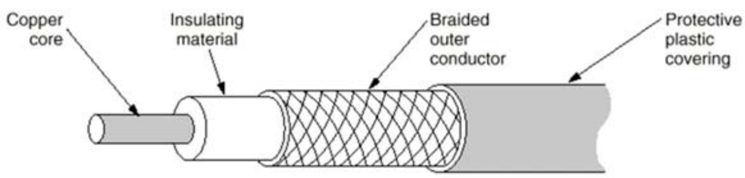
- Twisted Pair in Access Network:
  - The most important investment of a telephone company
  - Transfer function depends on loop length, wire type/diameter and wiring structure (bridge taps)
- Twisted Pair in Office (Mostly for LAN Cabling):
  - Important Standards set by EIA/TIA
  - CAT3: 4 unshielded wire pairs supporting 10 Mbps Ethernet (16 MHz BW)
  - CAT5: 4 wire pairs, supporting 100 Mbps Ethernet (100 MHz BW)
  - CAT6: 4 pairs, supporting 1 Gbps Ethernet (250 MHz Bandwidth)
  - CAT7: Four individually shielded pairs (STP) inside an overall shield (600 MHz Bandwidth)



Coaxial Cable

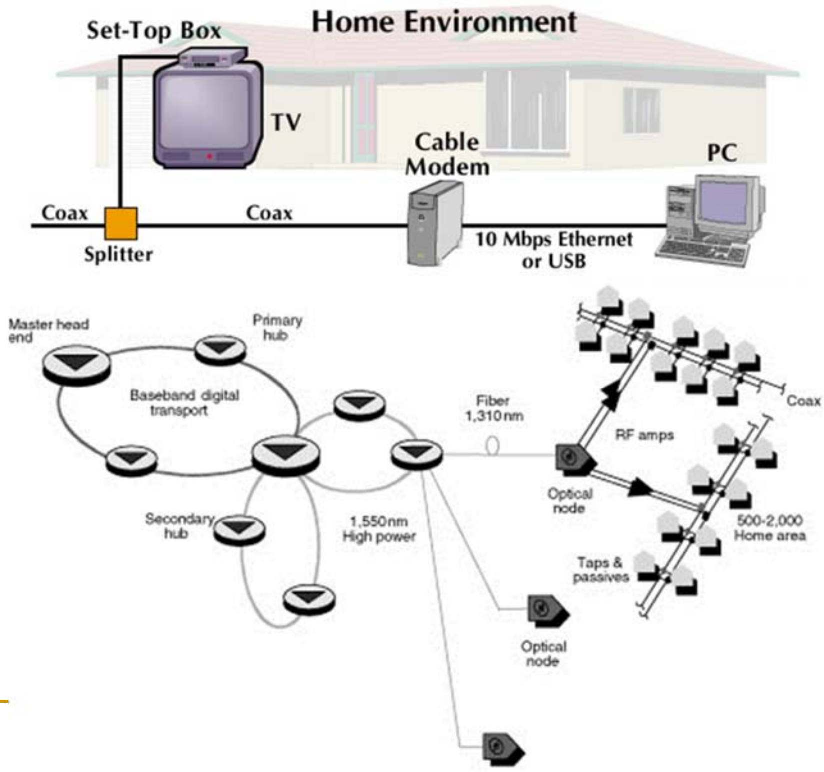
- Better shielding than twisted pair
- Lower attenuation & cross talk
- Can carry 1~2 Gbps in 1 km
- Telco's used it for their backbone communication. It is replaced by fiber optics.
- Cable TV companies use it for TV and data delivery services.





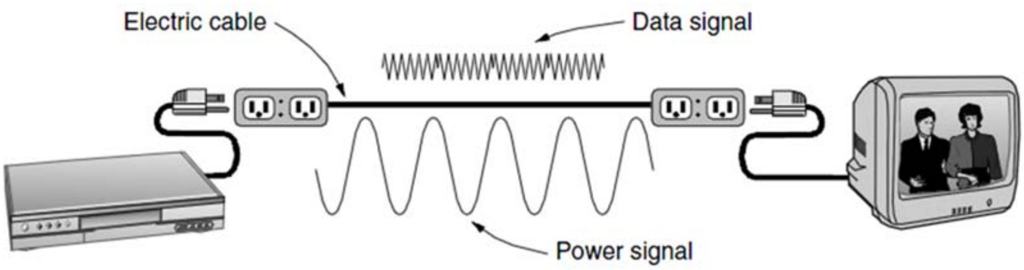
Hybrid Fiber Coax Architecture

- Combination of fibers and coaxes used to deliver the service
- Lasers are intensity modulated using the analogue RF signal
- Data Over Cable Service Interface Specification (DOCSIS) series of standards were developed to allow data service delivery over the TV cable network.
- DOCSIS 3.0 is the latest version of the standard (2007) which also supports QoS



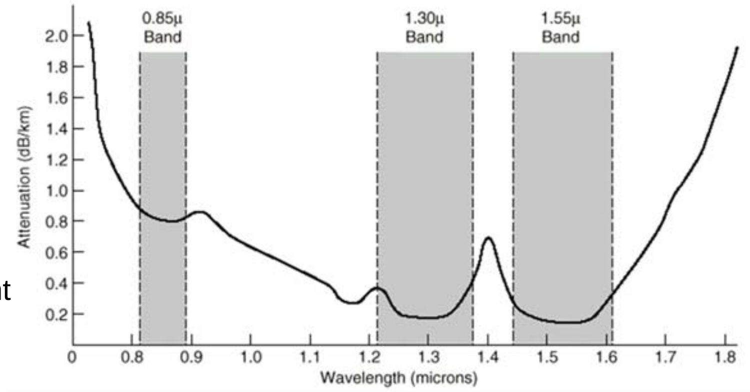
Power Lines

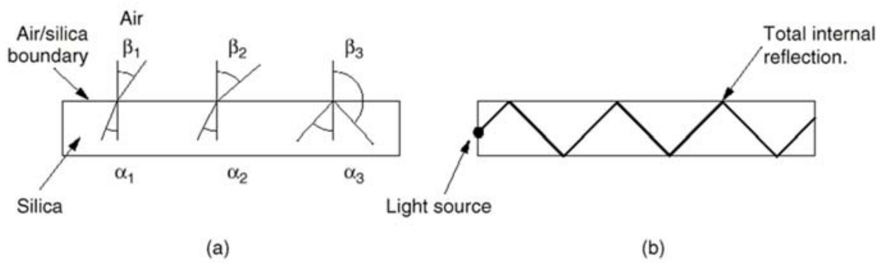
- Power Lines have been used by Electric companies for data transmission for many years (Low rate data communication for control and dispatching)
- Power Lines can be used for broadband data communication
  - Providing broadband access to homes using Electric grid as the access network
  - Creating a data communication network inside homes



Fiber Optics

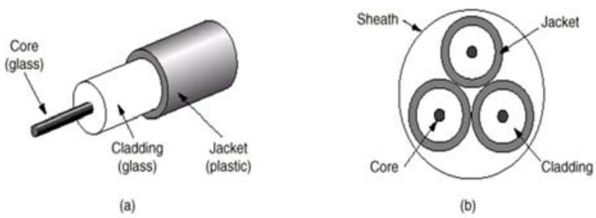
- Light is reflected if incoming angle is bigger than critical angle
- Single-mode
  - Very thin fiber => wave guide
  - Several Gbps over tens of kilometers without repeaters
- Multi-mode
  - Each light ray traveling different path, due to reflections
- Attenuation =10 $\log_{10}(P_{rx}/ P_{tx})$





Fiber Optics

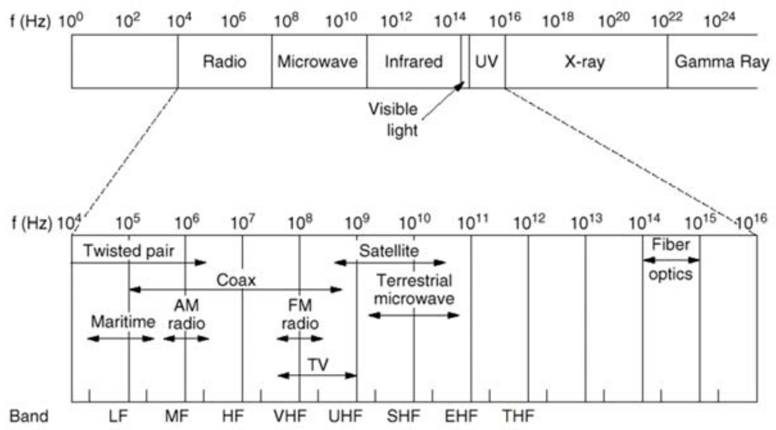
- Comparing fiber and copper wire:
  - High bandwidth
  - Few repeaters / km
  - No electromagnetic interference
  - No corrosion
  - Lightweight
  - Difficult to tap (both an advantage and disadvantage !!)
  - Unidirectional => Use two wavelengths, or use two fibers, or use time-slots (half-duplex)



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

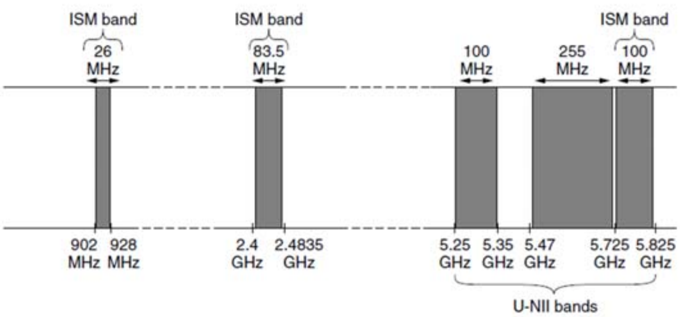
Wireless transmission

- Main Drivers
  - Communication without a physical attachment such as wires or fibers.
  - Mobility of users
  - Ease of deployment
  - Reduce cost of communication (For example, providing connectivity services to remote villages)
- Electromagnetic spectrum
  - $\lambda = cT = c/f$
  - $c = 3x10^8$ m/sec in vacuum
  - Higher frequencies (shorter wave lengths) have much larger available bandwidth



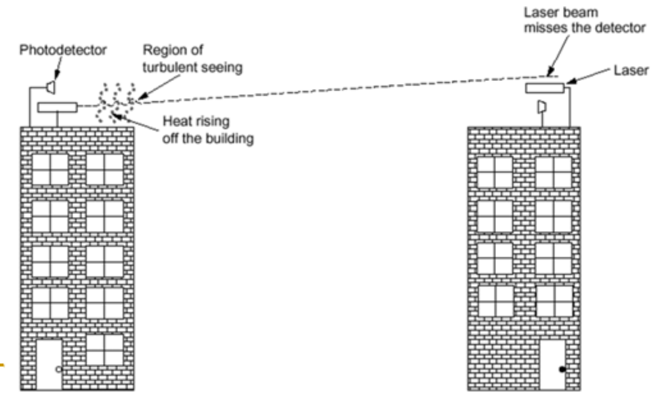
Wireless Transmission

- Radio range of frequencies (10KHz to 10MHz) usually used for broadcast communication
  - Long range, low attenuation, reflection from ionosphere
- Microwave range of frequencies (10MHz to 10GHz) usually used for point to point long distance transmission and local two-way communications
  - Medium range, affected by rain and weather conditions. Subject to multipath fading.
- Most radio frequency bands are regulated. Using frequency spectrum for commercial purposes is usually subject to a regulatory fee.
  - Since 1994, US government has earned more than 60 billion US$ from spectrum licensing fees
  - Irancell has paid 300 million Euro for its spectrum license to Communications Regulatory Agency (CRA)
- There are license free bands available in most countries (ISM bands)



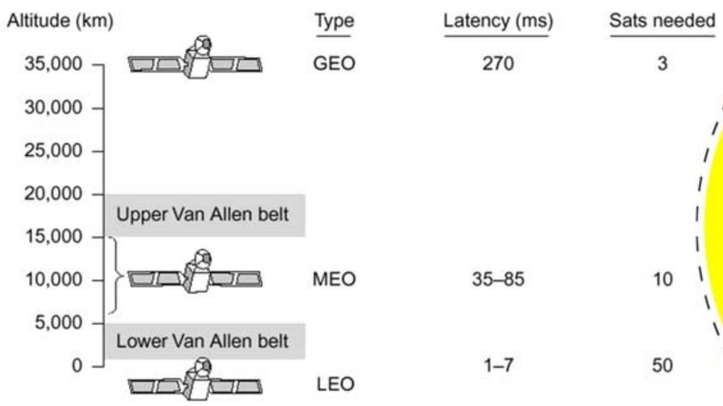
Wireless Optical Transmission

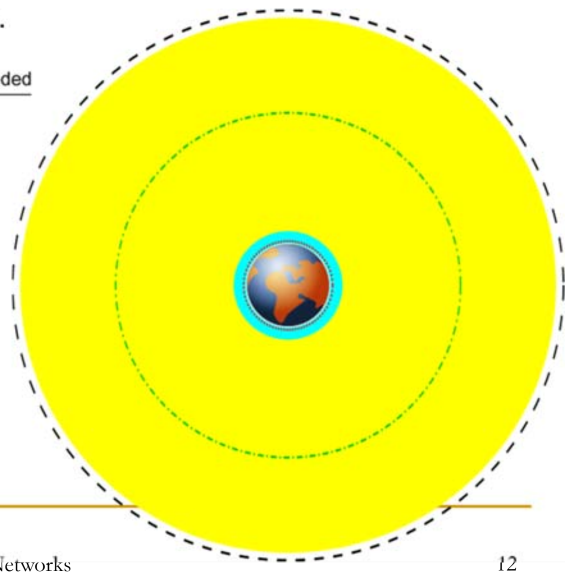
- Idea: Light as the information carrier for free space communication
- Indoor applications: Wireless LAN, IrDA standard
- Outdoor application: Building to building communication
  - Can transmit high data rates to distances of a few kilometers
  - Should cope with air turbulence effects and adaptively focus on target receivers



Satellite Communication

- Satellites can be used as a wireless node in the sky that can receive, amplify, process and transmit communication signals
- They are mainly used in three orbit ranges and therefore have different rotation period around earth.





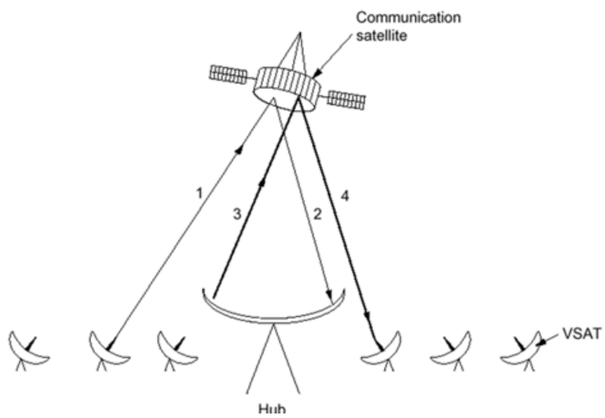
Satellite Communication

- Satellites generally have multiple transponders each with a given bandwidth/capacity for data transport
- They usually use “spot-beams” to focus their transmission on a given region.
- Most communication satellites are at Geostationary orbit
- Satellite operational frequency ranges:

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

Satellite Communication

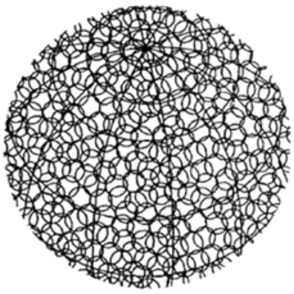
- Very Small Aperture Terminals (VSAT)
  - Small terminals that transmit 1W of power and communicate to each other through a Geostationary satellite and a HUB.
  - Can usually transmit at several megabits/sec and receive at around 1 Mbps
  - Low cost provisioning of voice and/or data services

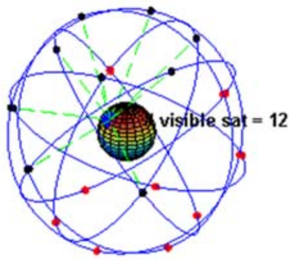


Satellite Communication

- Medium/Low Earth Orbit Satellites (MEO/LEO)
  - Rotate at 6 hours or less around earth
  - Many satellites are needed to cover the earth for providing communication services (Mobile phone, Internet access)
  - Iridium, Globalstar and Teledisc are some of the satellite systems that provide global voice and data services.

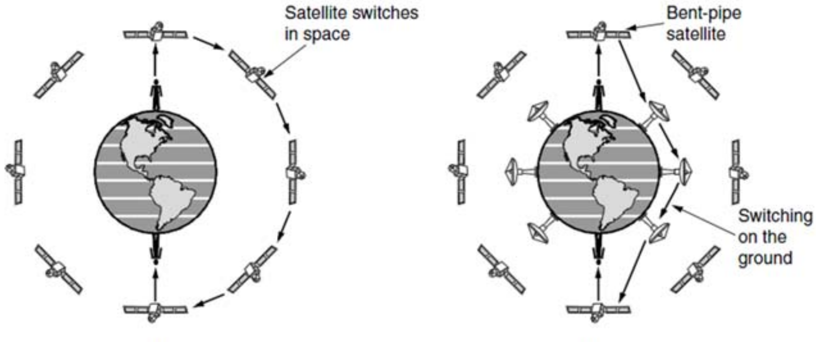

(a)


(b)



Satellite Communication

- In some LEO satellite systems such as Iridium, satellites are relaying and switching the data from source to destination
- In some other satellite systems such as Globalstar, satellites relay the signal to their ground station and switching is done by a terrestrial network. The advantage is that much of the complexity is on the ground and satellites are simpler.



(a) (b)

Satellites Versus Fiber

- Optical communication is the dominant technology for transmission of data.
- From office LANs to intercontinental communication networks, optical communication systems are used as a cost effective solution.
- Satellite communication serves some key demands
  - Networks that require rapid deployment (disaster recovery, military applications)
  - Communication in places where terrestrial networks are not well developed (jungles, countries with many islands, oil stations in the sea)
  - Broadcasting (TV, Radio)

Baseband Transmission

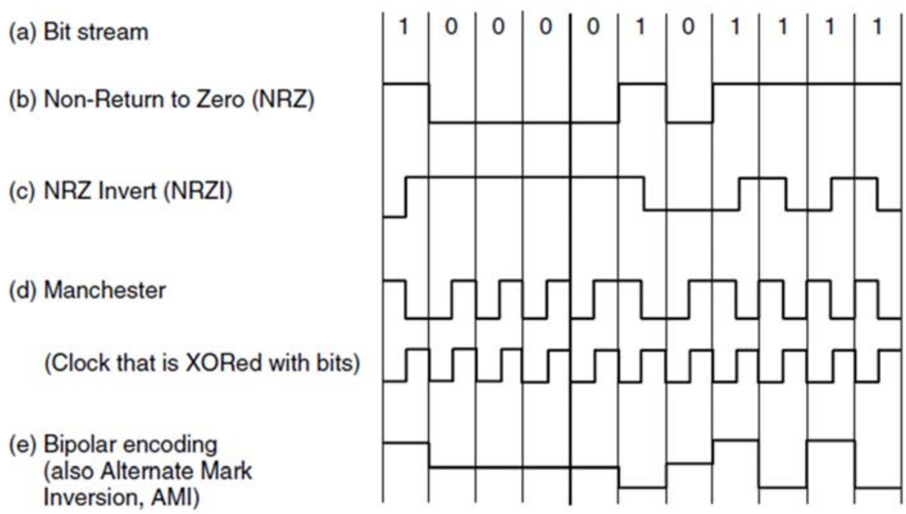


Figure 2-20. Line codes: (a) Bits, (b) NRZ, (c) NRZI, (d) Manchester, (e) Bipolar or AMI.

Passband Transmission

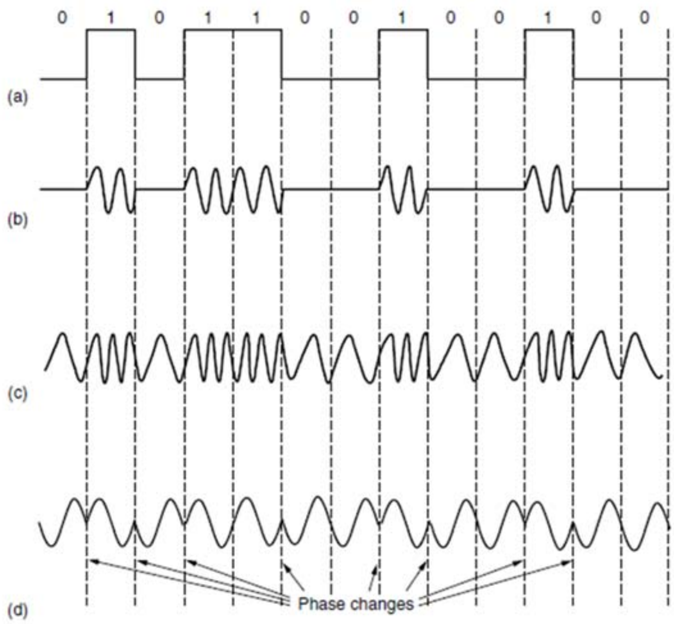


Figure 2-22. (a) A binary signal. (b) Amplitude shift keying. (c) Frequency shift keying. (d) Phase shift keying.

Frequency Division Multiplexing

- Information from multiple sources can be multiplexed in frequency domain by assigning different carriers to different sources.
- Usually there is a guard band between different frequency bands
- Orthogonal Frequency Division Multiplexing (OFDM) allows us to use different frequency bands for transmission of data in a more efficient way
- OFDM is used in 802.11, cable networks, power line networking, etc.

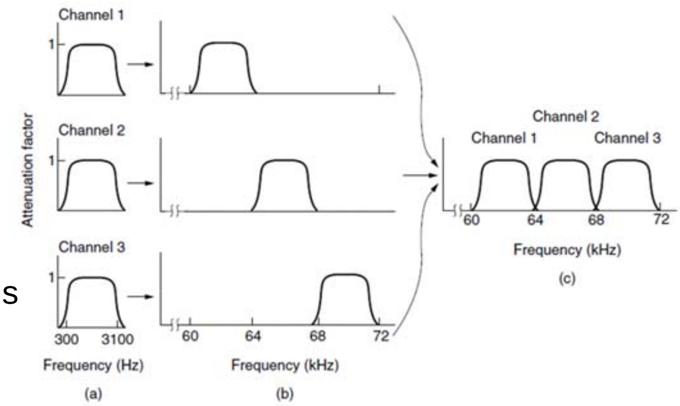


Figure 2-25. Frequency division multiplexing. (a) The original bandwidths. (b) The bandwidths raised in frequency. (c) The multiplexed channel.

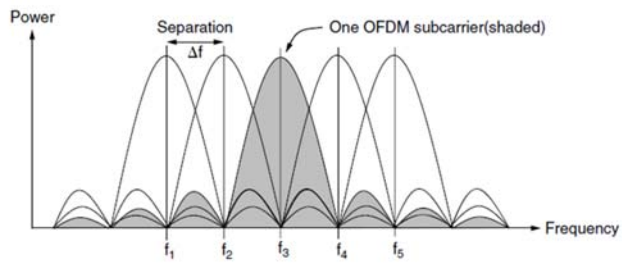
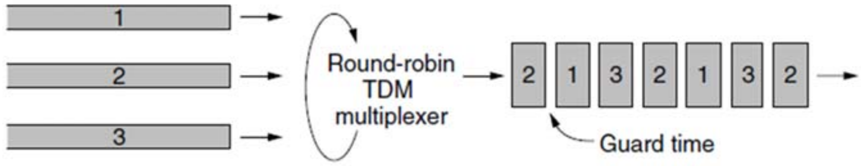


Figure 2-26. Orthogonal frequency division multiplexing (OFDM).

Time Division Multiplexing

- Different sources of data can be transmitted by dividing time into different slots
- TDM is used widely in telephone and cellular networks



Code Division Multiple Access (CDMA)

- A techniques which allows for a new multiple access mechanism and is proving to be very effective for mobile communication. (Used in 2G and 3G mobile systems)
- Time division: TDM
  - each speaker gets its turn
- Frequency division: FDM
  - concurrent speakers separated far enough
- Now: Code Division
  - every speaker speaks a different language ***at the same time***
- Key idea:
  - Each station uses the entire frequency band, but uses a different code.
- Each bit time interval is divided into m slots called chips
- Each transmitter uses a unique chip sequence to send 1 and its inverse to send 0.
  - Send 1 as: 1 1 -1 -1 1 -1 1 -1
  - Send 0 as: -1 -1 1 1 -1 1 -1 1
- Chips are chosen to have these properties:

$$S \bullet T = \frac{1}{m}\sum_{i=1}^{m} s_i t_i = 0$$

$$S \bullet S = \frac{1}{m}\sum_{i=1}^{m} s_i^2 = 1$$

CDMA

- Practical issues:
  - Keys should be known in advance
  - Power Control:
    - Senders should be received with same power
    - Send with inverse power of received signal strength
  - Synchronization: what if senders are not synchronized:
    - Lock into the ‘wanted’ channel
    - Other channels will be received as background noise

A: 0 0 0 1 1 0 1 1
B: 0 0 1 0 1 1 1 0
C: 0 1 0 1 1 1 0 0
D: 0 1 0 0 0 0 1 0

(a)

A: (−1 −1 −1 +1 +1 −1 +1 +1)
B: (−1 −1 +1 −1 +1 +1 +1 −1)
C: (−1 +1 −1 +1 +1 +1 −1 −1)
D: (−1 +1 −1 −1 −1 −1 +1 −1)

(b)

Six examples:

– – 1 –	C	$S_1 = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$
– 1 1 –	B + C	$S_2 = (-2\ \ 0\ \ 0\ \ 0\ +2\ +2\ \ 0\ -2)$
1 0 – –	$A + \overline{B}$	$S_3 = (\ 0\ \ 0\ -2\ +2\ \ 0\ -2\ \ 0\ +2)$
1 0 1 –	A + 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	$A + B + \overline{C} + D$	$S_6 = (-2\ -2\ \ 0\ -2\ \ 0\ -2\ +4\ \ 0)$

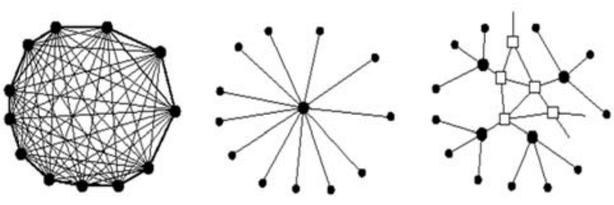
(c)

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

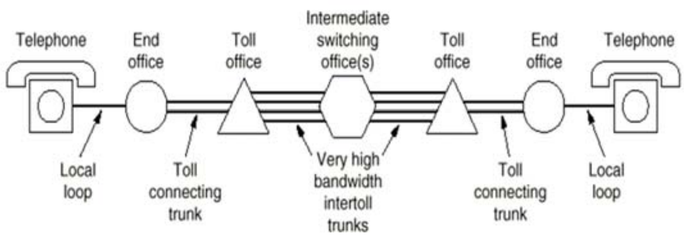
(d)

Telephone system

- Public Switched Telephone Network (PSTN)
  - Originally designed to transmit human voice
  - Loop plant with Limited bandwidth and complex interference environment
- Telephone system organization: hierarchical network with three important components:
  - Local loops:
  - Switching centers:
  - Trunks: connecting switching offices using various transmission technologies



(a) (b) (c)



Switch Hierarchy, an example

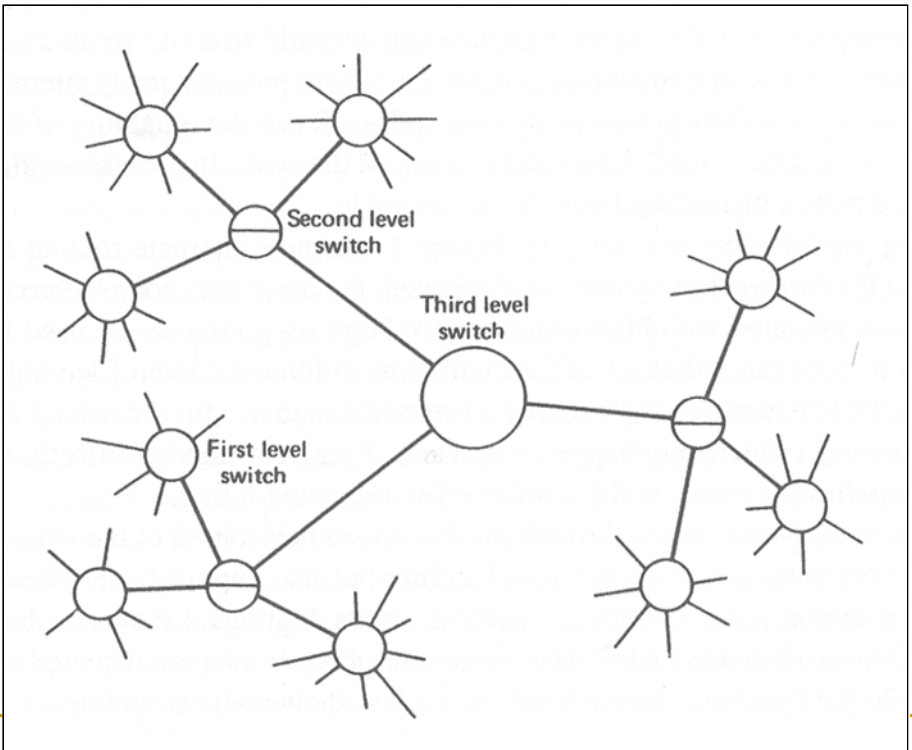
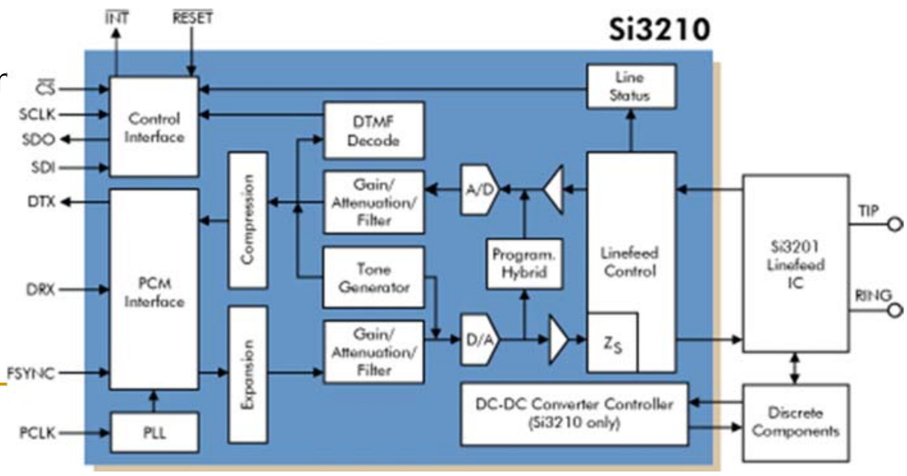


Figure 1.2 Three-level switching hierarchy.

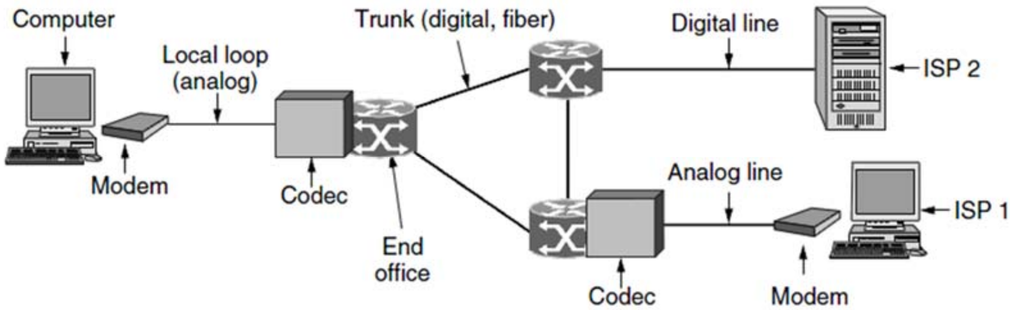
SLIC/CODEC

- Important User Side Functions
  - Battery supply to subscriber line
  - Overvoltage protection
  - Off/On hook detection
  - Ring Generation
  - Tone Detection
  - Tone Generation
  - Hybrid
  - Testing
- Important Network Side Function
  - PCM Coder/Decoder
  - Filtering and Amplification
  - Compression/Decompression



Telephone Modem

- Modem: A device that receives a stream of digital bits and sends/receives it properly from the transmission medium (such as twisted pair)
- Transmission problems:
  - Attenuation and Delays which are frequency dependent
  - Noise (Thermal Noise, Impulse Noise, etc)
  - Cross talk, caused by inductive coupling of wires
- For voice band modems, data rate is limited by PSTN sampling process and loop conditions

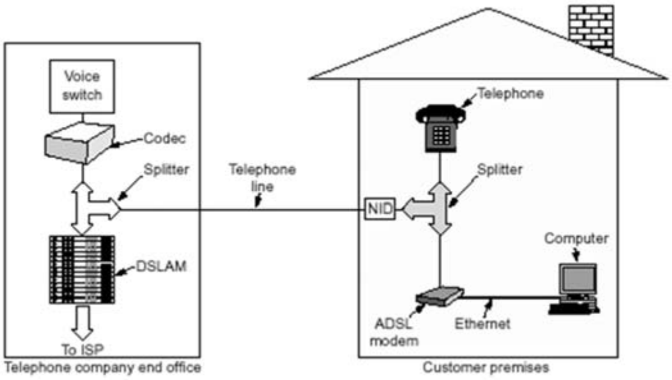


Voice band modem standards

- V.32: 9600 bps : 4 bits / baud
- V.32 bis: 14.4 kbps : 6 bits / baud
- V.34: 28.8 kbps (Using QAM Constellation)
- V.90: 56 kbps DS, 33.6 kbps US
- V.92: 56 kbps DS, 48 kbps US
- Compression schemes:
  - MNPs : run-length encoding (runs of zero's may be very common)
  - V.42 bis : Ziv-Lempel compression
  - Some advanced techniques used:
- Trellis Coding
  - Divide bandwidth (3000 Hz) into 512 bands of 20 bps $\Rightarrow$ adaptive optimal use of frequency bands and avoiding noisy bands

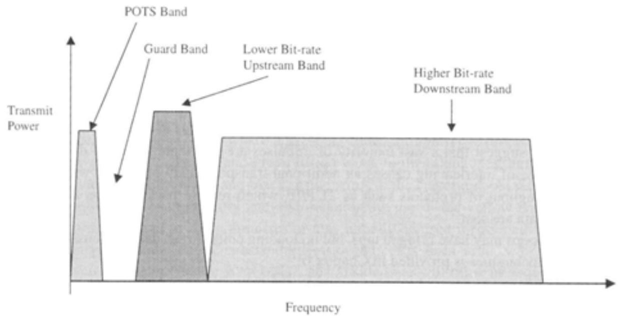
Local Loop, Broadband Access -ADSL

- Objective: Offering data services without impacting the voice service on twisted pair
- Central Office (CO) side:
  - Use splitter to feed low pass part to the voice switch while the higher frequencies to the feed the DSLAM
- Customer Premise End (CPE)
  - Use splitter or in-line filters to feed the low pass part of the spectrum to the telephone and the high pass part to the CPE ADSL modem
- ADSL signal power spectrum is defined carefully to reduce cross talk into other services

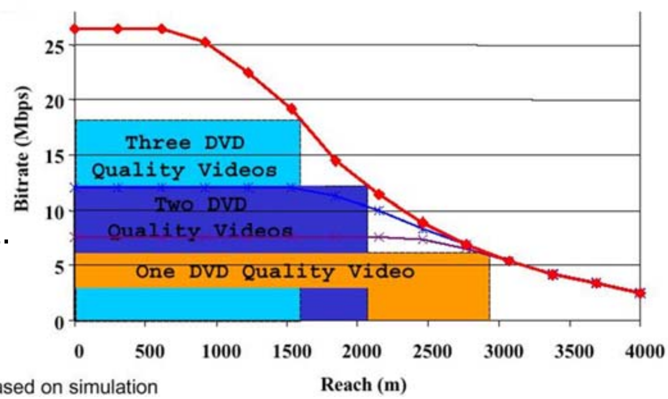


Local Loop, Broadband Access-ADSL

- Uses Discrete Multi tone technique (DMT) as the modulation scheme.
- Idea: Divide frequency into small bins each carrying a separate QAM constellation
  - Better use of channel capacity
  - More resistance to noise
  - Rate adaptability
- Most common mode of operation: Frequency Division Mode
  - Upstream (US) 25kHz to 130 kbps providing up to 1 Mbps
  - Downstream (D) 140 kHz to 1.1MHz providing up to 8Mbps
- New versions of ADSL (ADSL2+M) have improved the rate/reach curve by increasing the DS band to 2.2MHz. (24 Mbps DS, 3.5 Mbps US)



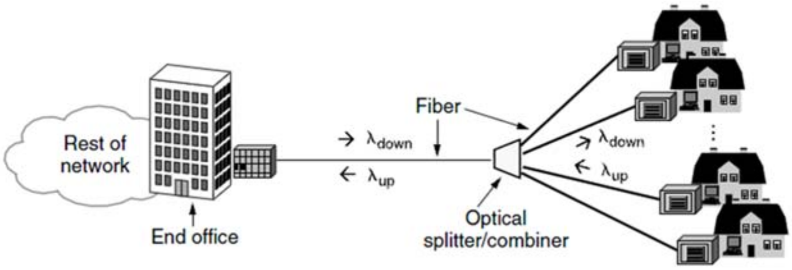
FDM ADSL.



Based on simulation

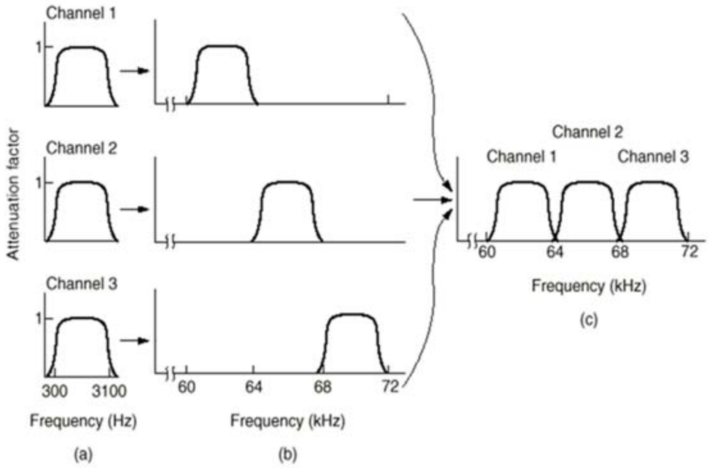
Fiber To The Home (FTTH)

- Fiber optic can provide a medium for providing very high speed data services.
- Bringing fiber deployment closer to the homes and businesses facilitates the deployment of higher speed data services for end
- Passive Optical Networks (PON) are becoming very popular and can run at around gigabits per second to provide different services such as
  - Ethernet PONs (EPON)
  - Gigabit capable PONs (GPON)



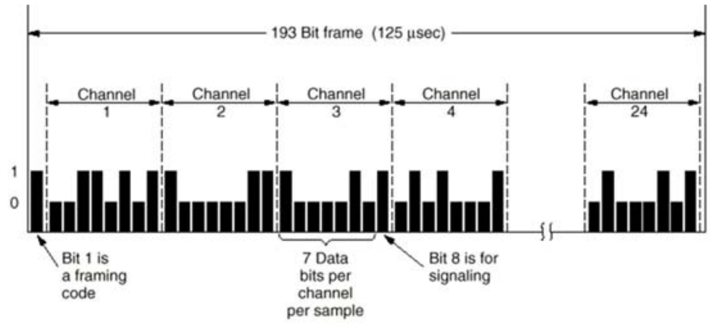
Trunks and Multiplexing

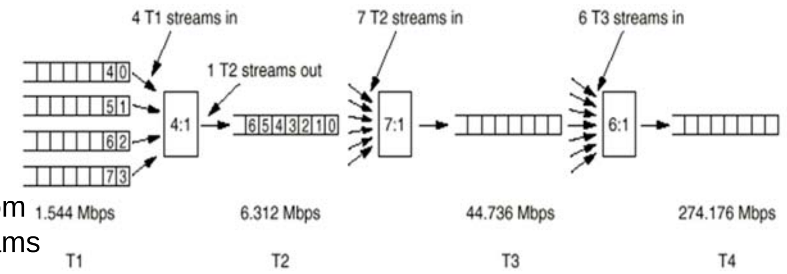
- FDM: frequency division multiplexing
- TDM: time division multiplexing
(can only be used in the digital domain)
  - Pulse Coded Modulation (PCM): Analog voice signals coming from local loop are sampled at 8000 samples/sec. Each sample is represented by 8 bits.
  $\Rightarrow$ 64 kbps representation of the voice signal
  - Several voice channels can be multiplexed in time to carry voice info between Telco offices.



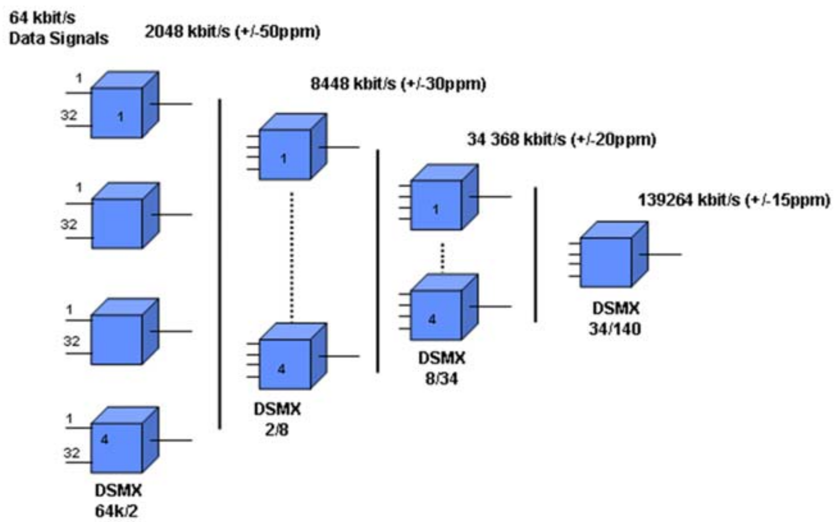
TDM carriers

- N. America : T1 carrier
  - 1.544 Mbps
  - 24 x 8 + 1 = 193 bits per frame
  - 1 frame per 125 microseconds
  - 8000 x 8 = 64 kbits/second per channel
  - 24 analog channels
  - AD-conversion: PCM 8-bit sampling at 8000 Hz
- Outside N. America : E1 carrier
  - 2.048 Mbps
  - 32 channels
  - 32 x 8 bits per frame
  - 30 data and 2 signaling channels
- Higher order rates are derived from multiplexing T1 or E1 signal streams





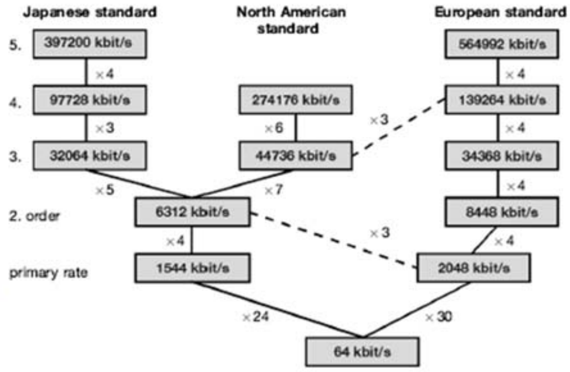
European PDH Hierarchy



ITU-T Standard	Signal Bit Rate	Frame Size (bits)	Frame Per Second
G.704/732	E1 (2.048 Mbps +/-50ppm)	256	8000
G.742	E2 (8.448 Mbps +/-30ppm)	848	9962.2
G.751	E3 (34.368 Mbps +/-20ppm)	1536	22375
G.751	E4 (139.264 Mbps +/-15ppm)	2928	47562.8

SONET/SDH

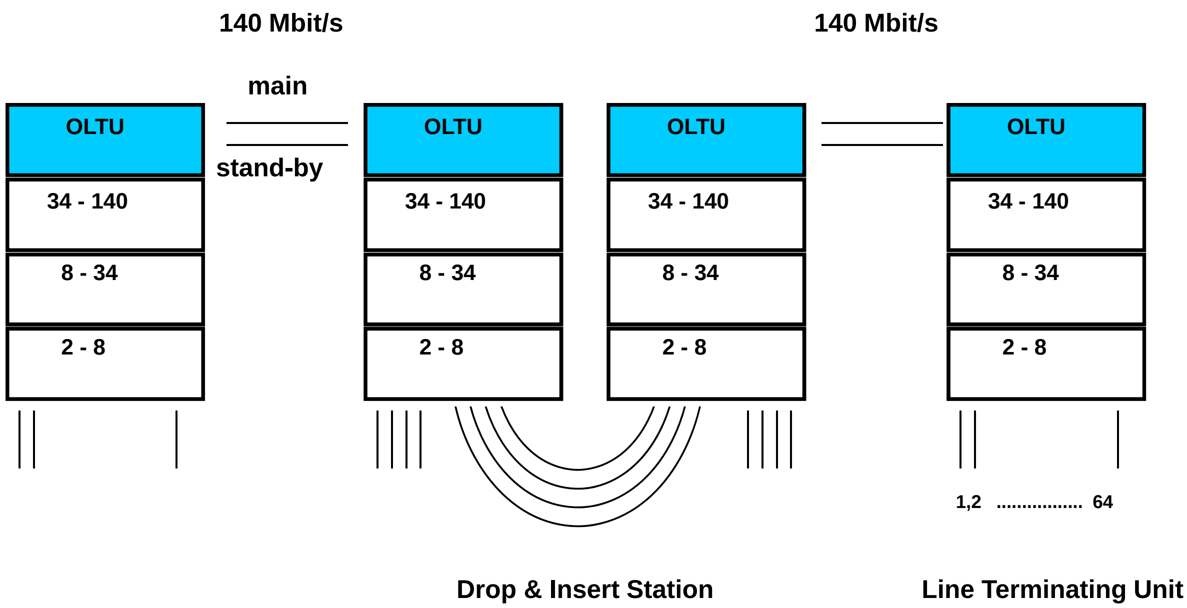
- SONET (Synchronous Optical Network) and SDH (Synchronous Digital Hierarchy) are the primary standards for all types of metro and long-haul transport of traffic over fiber networks.
- Design objectives:
  - Unify the US, European and Japanese digital transmission systems
  - Provide a multiplexing scheme or digital hierarchy
  - Provide OAM support
  - Direct access to low-level tributaries without the need to de-multiplex the entire signal



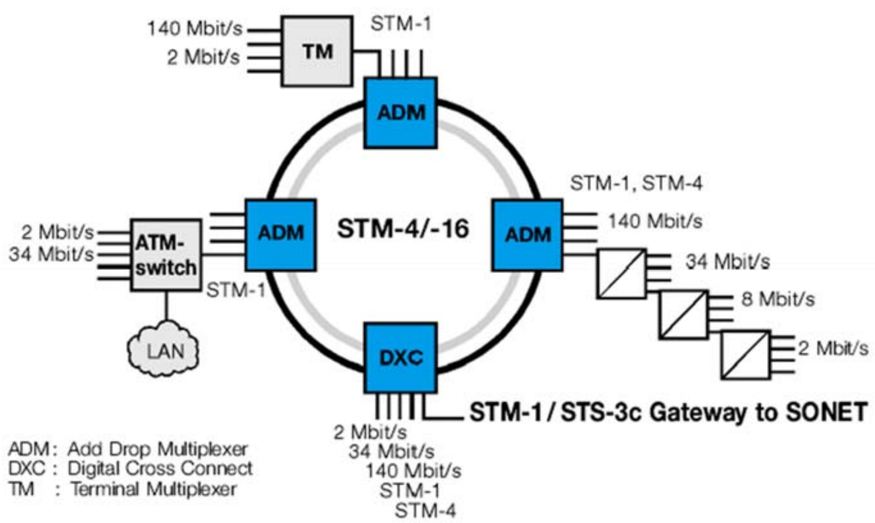
SDH/PDH Comparison

- PDH has some disadvantages.
  - Inability to identify individual channels in a higher order bit stream.
  - Insufficient capacity for network management.
  - There are different hierarchies in use around the world.
  - Specialized interface equipment is required to inter-work the two hierarchies.
- SDH has some advantages over PDH networks.
  - High transmission rates.
  - Simplified add & drop function.
  - Defined easy standard interconnection.
  - Reliability.
  - Future-proof platform for new services.

PDH Add/Drop

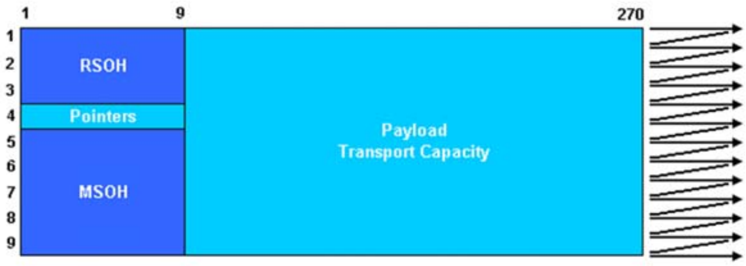


SDH Add/Drop

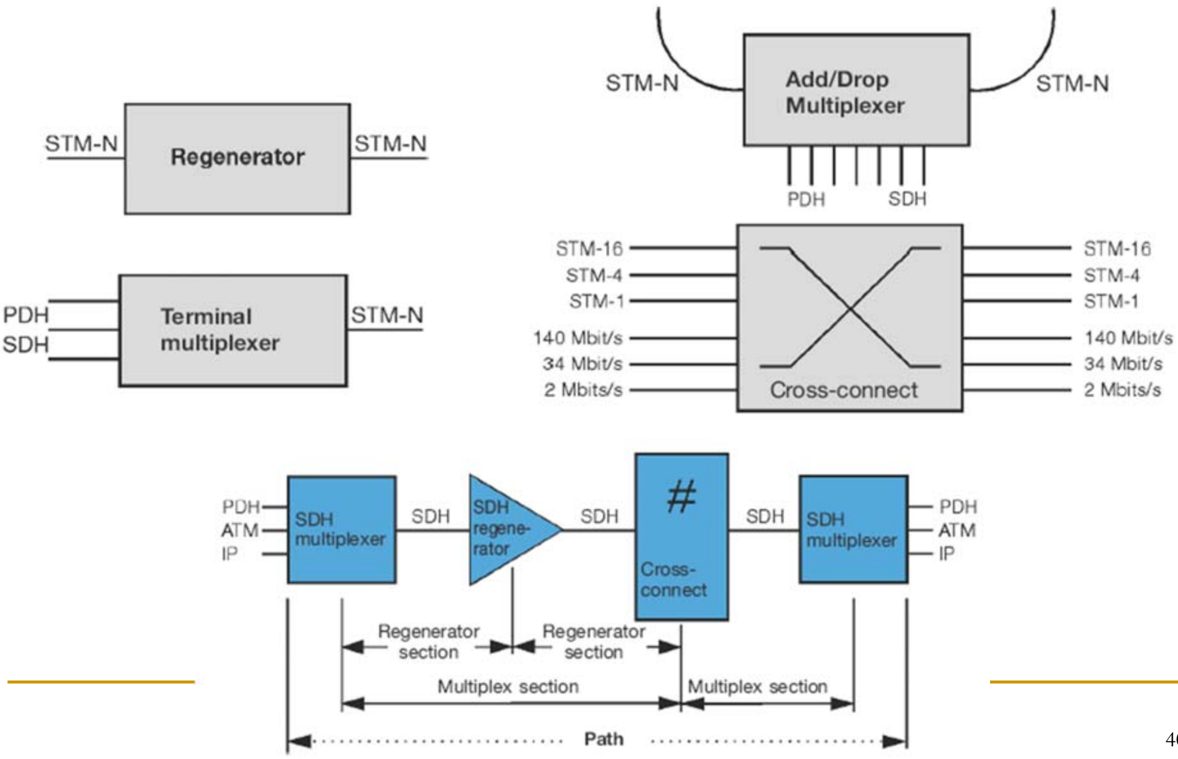


SONET/SDH

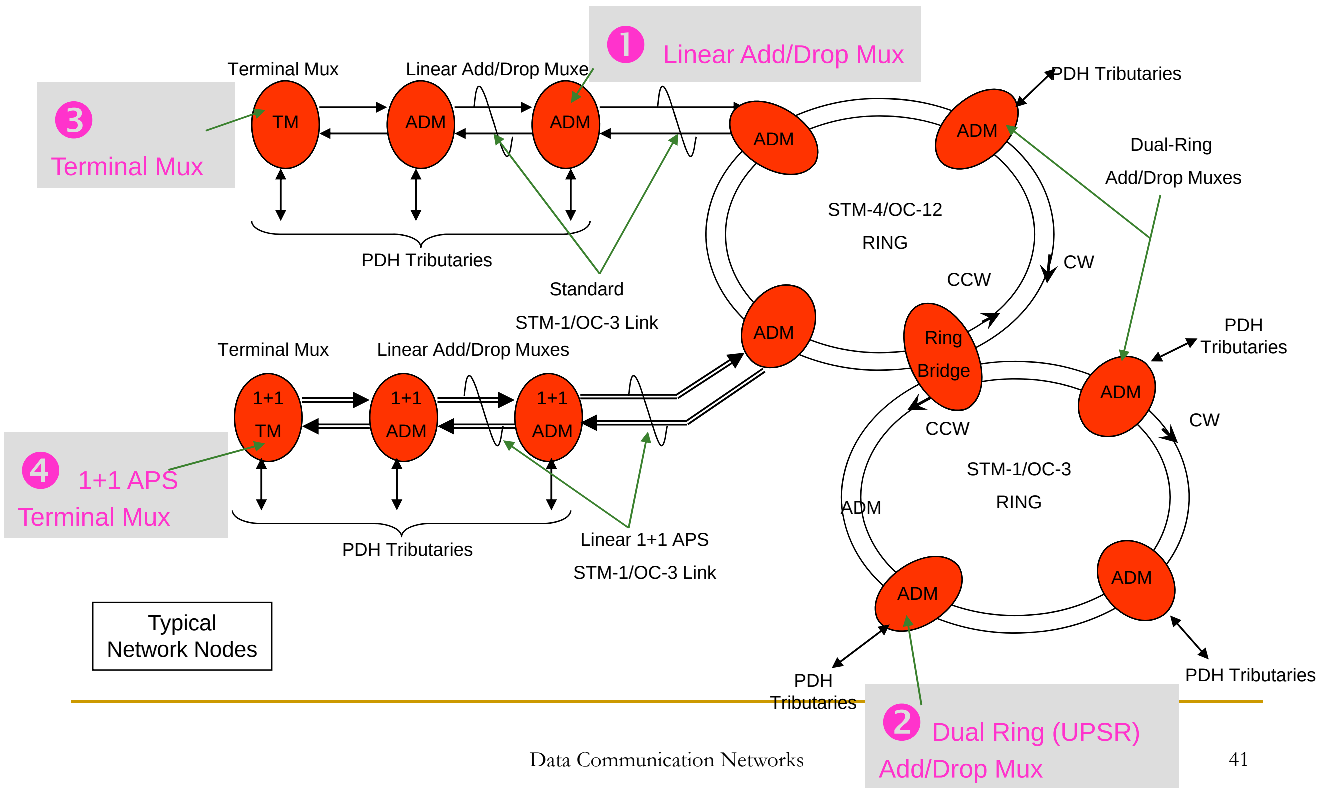
- SDH Rate and signaling
  - 155 Mbps or multiples
  - 270 x 9 x 8 bits per frame of 125 microseconds
- SDH multiplexing
  - 261 x 8 x 9 x 8 bits for synchronous payload envelope (SPE)
  - Payloads can carry many different types of traffic
  - Header bytes are used for framing, parity, voice channels, error monitoring, IDs, clocking and synchronization
- Standards: Multiples of 4nxSTM-1
  - STM-1: 155.52 Mbps
  - STM-4: 622.08 Mbps
  - STM-16: 2.5 Gbps
  - STM-64: 10 Gbps
  - STM-256: 40 Gbps



SDH Network Elements

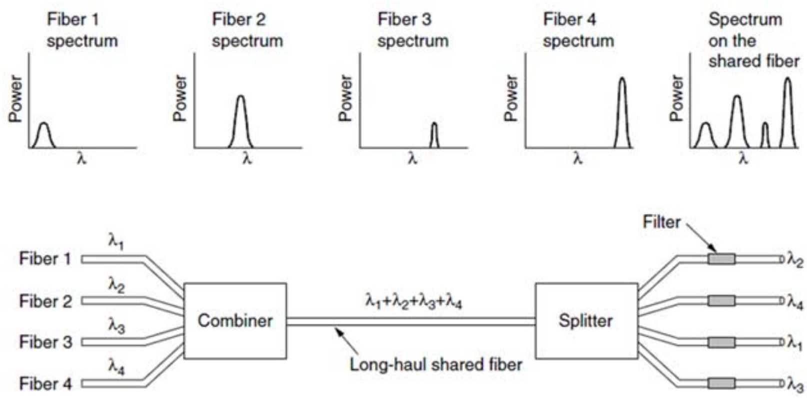


Typical Network Architecture



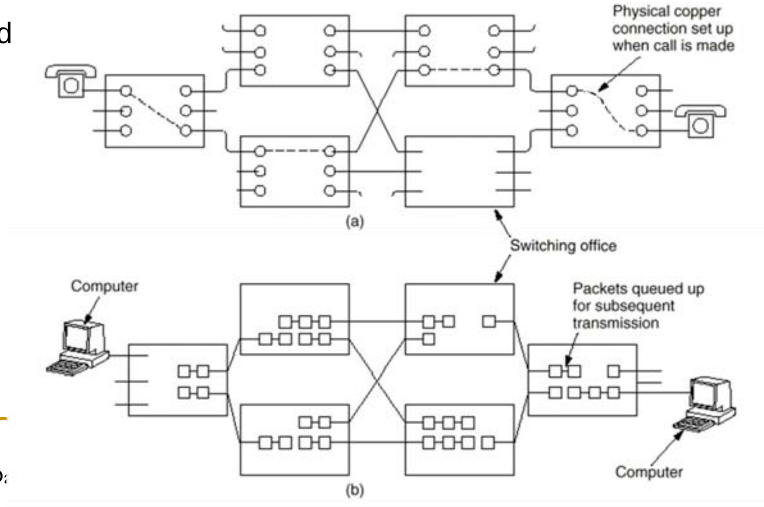
Wavelength Division Multiplexing

- Several independent streams of data each carried in a different wavelength can be multiplexed in optical domain and transmitted over a single fiber.
- This technology has drastically increased the capacity and lowered to cost of transmission networks



Switching

- **Circuit switching**
  - Dedicated path established between source and destination
  - Long set-up time: O(10 sec)
  - No congestion change: guaranteed bandwidth
  - No extra random delay while call is established. Only transport delay
  - Unused bandwidth is wasted
  - Transparent to data format and framing mode. (road vs. railroad)



Switching

- **Packet switching**
  - Store-and-forward technique used
  - No dedicated path
  - Packet size should be limited in order not to block switches and/or overflow buffers
  - First packet is forwarded while second is received.
  - Rate conversion is easy
  - Delivery order may not be guaranteed

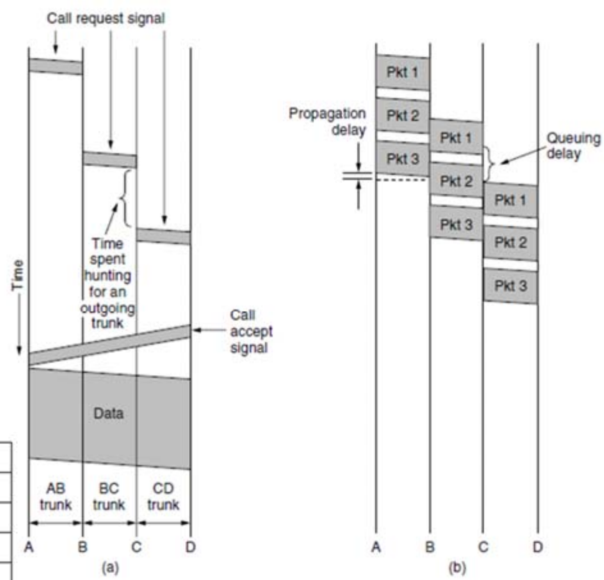


Figure 2-43. Timing of events in (a) circuit switching, (b) packet switching.

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
Charging	Per minute	Per packet

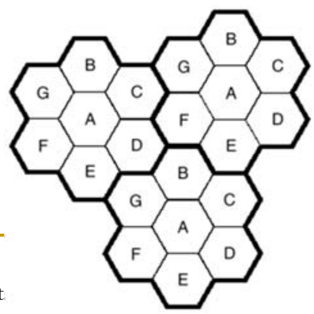
Mobile Phone System

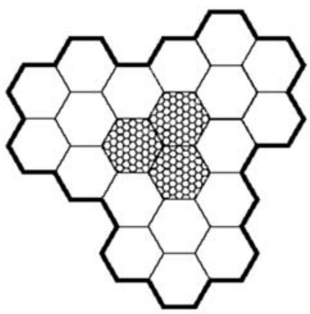
- Mobile Phone Evolution
  - First Gen: Analog Voice
  - Second Gen: Digital Voice
  - Third Gen: Digital Voice and Data
  - Fourth Gen: Mainly Data
- First Generation:
  - Started from push to talk one to many systems (Police, Taxi's)
  - In 1960, Improved Mobile Telephone System (IMTS) was installed with separate US and DS channels
  - Had a high power transmitter with 23 channels from 150 MHz to 450MHz
  - Problems with channel capacity (Low number of channels) and interference

Mobile Phone System

- Advanced Mobile Phone System (AMPS) (1982)
  - Divide area into radio cells to avoid interference and allow frequency re-use
  - Cells are around 10 km wide
  - Multiple base stations talk to a Base station switching center (BSC)
  - Multiple BSC's talk to a Mobile Switching Center (MSC) and then to the PSTN network
  - 832 upstream channels from 829-849 MHz, 832 downstream channels from 869-894 MHz each 30 kHz wide


AMPS HANDSET (MOTOROLA)





Mobile Phone System

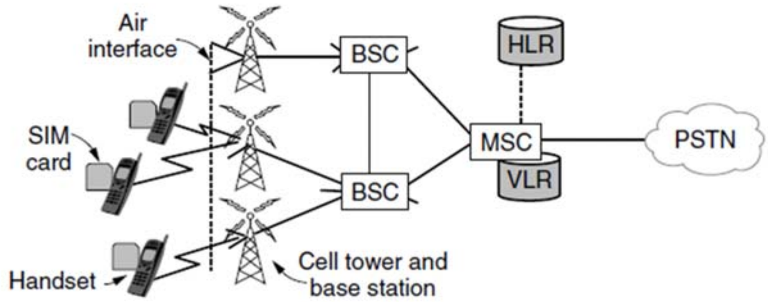
- Channels are used for
  - Control (Base to Mobile) to manage the system (21 channels)
  - Paging (Base to Mobile) to alert mobile users for a call
  - Access (Bi-directional) for call setup and channel assignment
  - Data (Bi-directional) for voice, fax and data (usually around 45 channels due to frequency re-use)
- Call handling
  - When handset is powered on, it scans control channels to find the most powerful signal
  - It then broadcasts its 32 bit serial number and phone number in digital format
  - BTS reports to MSC and it will decide if the user should be accepted for service
  - When mobile is dialing, MSC decides upon the channel and service availability and connects the call
  - MSC should also handle roaming and handoff
  - For incoming call, handset should continuously monitor the paging channel and respond through the control channel when a call request comes in

Mobile Phone System - 2G

- D-AMPS
  - IS-54, IS-135, backward compatible with AMPS.
  - Uses the same 30 kHz channels as AMPS. Therefore, D-AMPS (Sometimes call PCS) and AMPS can coexist in the same network.
  - A new band was opened for D-AMPS:
    - 1850-1910 MHz for US
    - 1930-1990 MHz for DS
  - Systems with much smaller phone size and longer battery life were developed
  - D-AMPS Vocoder can compress the voice down to 8kbps or less
  - Mobile Monitors the Rx quality and requests a handover to another base if there is a need

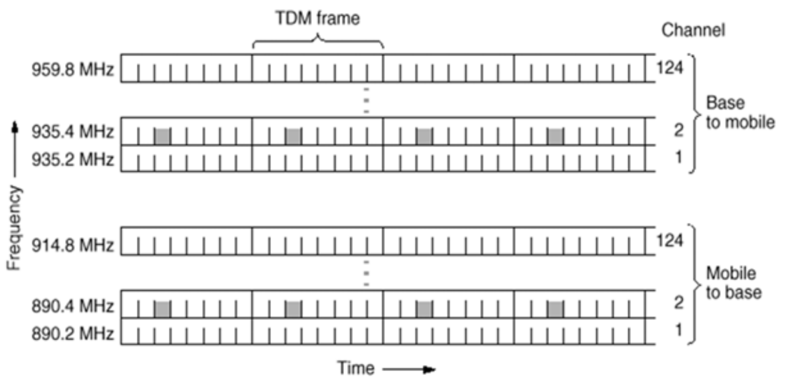
Mobile Phone System - GSM

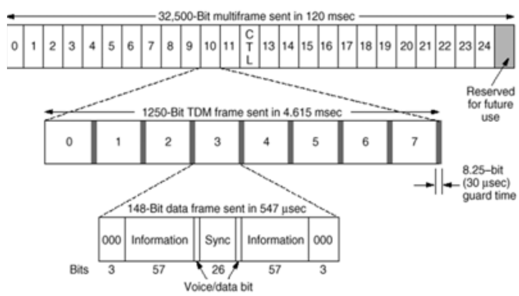
- GSM: Global system for mobile communication
  - Developed in Europe in 1990s
  - Second generation mobile system
  - Can offer voice and data



GSM Air Interface

- FDM: divide frequency spectrum into 124 duplex channels of 200kHz each
- TDM: multiplex 8 time slots (frames) per channel
- Together this gives 8*124 = 992 channels.
- Each cell uses a small number of available channels frequencies to allow frequency re-use.



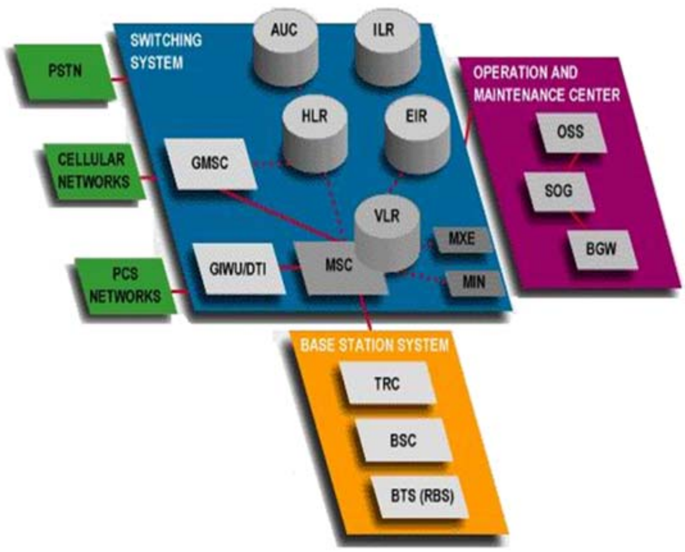


GSM Specifications

- Access Method: TDMA/FDMA
- Important frequency bands:
  - P-GSM-800: 124 Channels
    - Uplink: 890-915 MHz, Downlink: 935-960 MHz
  - GSM-1800: 375 Channels
    - Uplink: 1710-1785 MHz, Downlink: 1805-1880 MHz
- Channel Bandwidth: 200 kHz
- Number of TDMA channels per carrier: 8
- Modulation: Digital Gaussian Minimum Shift Keying (GMSK)
- Speech Coding:
  - Full Rate: 13 kb/s
  - Half Rate: 6.5 kb/s
  - Enhanced Full Rate: 12.2 kb/s
- Offered Services: Voice and Data

Network and Switching Subsystem

- Main tasks of NSS
  - Call control
  - Routing
  - Locating
  - Mobility management
  - Signalling to other network



Mobile Switching Center (MSC)

- Specific functions of a MSC
  - Switching of 64 kbit/s channels
  - Paging and call forwarding
  - Termination of SS7 (signaling system no. 7)
  - Mobility specific signaling
  - Location registration and forwarding of location information
  - Support of short message service (SMS)
  - Generation and forwarding of accounting and billing information
- Switching functions
  - Additional functions for mobility support
  - Interworking functions via Gateway MSC (GMSC)
  - Integration of several databases

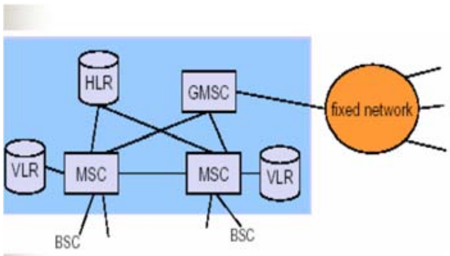
Home Location Register (HLR)

- Central master database that contains data from every user that has subscribed to the operator, includes:
  - Subscriber data
  - IMSI - International Mobile Subscriber Identity
  - List of subscribed services with parameters and restrictions
  - Location data
  - Current MSC/VLR address
- Responsibilities of the HLR include:
  - Management of service profiles
  - Mapping of subscriber identities (MISDN, IMSI)
  - Supplementary service control and profile updates
  - Execution of supplementary service logic e.g. incoming calls barred.
  - Passing subscription records to VLR

Visitor Location Register (VLR)

- Local database:
  - Data about all users currently in the domain of the VLR
  - Includes roamers and non-roamers
  - Associated to each MSC
- Responsibilities of the VLR include:
  - Executing supplementary service programs (outgoing calls barred)
  - Initiating authentication and ciphering
  - Initiating paging
  - Passing location information to HLR

NSS Elements



- Gateway MSC
  - Connects mobile network to a fixed network
  - Request routing information from the HLR and routes the connection to the local MSC
- Authentication Center (AuC) (Associated to HLR)
  - Supports authentication and encryption mechanisms
  - Ki - subscriber secret authentication key
  - A3 - authentication algorithm
  - A8 - cipher key generation algorithm
- Equipment Identity Register (EIR)
  - Stores mobile stations IMEI (International Mobile Equipment Identity)
  - white list - mobile stations allowed to connect without restrictions
  - black list - mobile stations locked (stolen or not type approved)
  - gray list - mobile stations under observation for possible problems

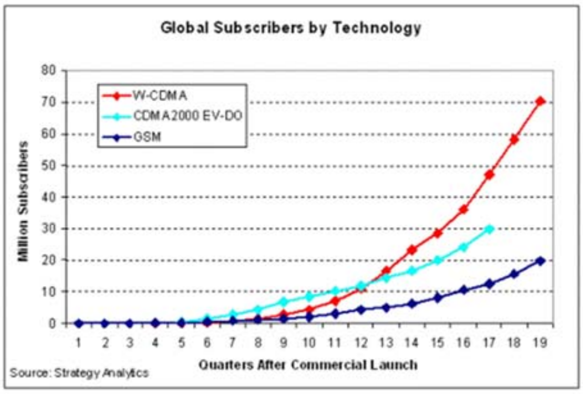
GSM Call Process

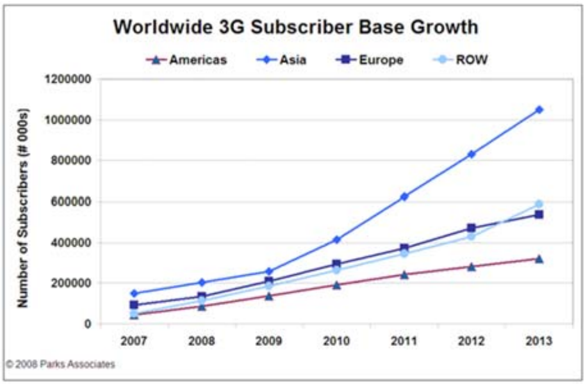
- GSM Channels:
  - Traffic Channels
  - Signaling Channels
- Signaling Channels:
  - Broadcast channel for:
    - Outputting identity of base station
    - Each mobile checks its signal strength to see if it has moved to another cell
  - Dedicated channel for:
    - Location updating
    - Registration
    - Call setup
  - Common Control channel for:
    - Paging (of incoming calls); each mobile monitors this channel
    - Random access channel, using slotted Aloha to request a slot on the dedicated channel, to set up a new call
    - Access grant channel
- Setting up a call:
  - Mobile requests a dedicated access channel# using random access channel; this is the only channel where we can get collisions; so it is used very shortly
  - Base grants channel# on access grant channel
  - Setup the call on dedicated channel
  - Start the conversation on one of the agreed regular channels

Third Generation Mobile Systems (3G)

- Objectives:
  - High quality voice
  - High speed data for messaging, multimedia and internet access.
  - Up to 2 Mbps rate to fixed users and up to 384 kbps to mobile users
- Three main standards:
  - Wideband CDMA
    - Developed mostly in Europe
    - Runs in a 5 MHz band
    - Can inter-work with GSM but not backward compatible
  - CDMA2000
    - Developed mostly in USA
    - Uses 5 MHz bandwidth
    - Designed to interwork with IS-95 which is a 2G CDMA standard used in North America
  - TD-SCDMA
    - Chinese version of 3G systems
- Interim Standards and Technologies between 2G and 3G:
  - General Packet Radio Service (GPRS)
    - An overlay packet network on top of GSM or D-AMPS
    - Slots are reserved for IP data traffic based on demand.
  - Enhanced Data Rate for GSM (EDGE)
    - Enhanced GSM with more data rates
    - Can provide up to 384 kbps of data rate to users

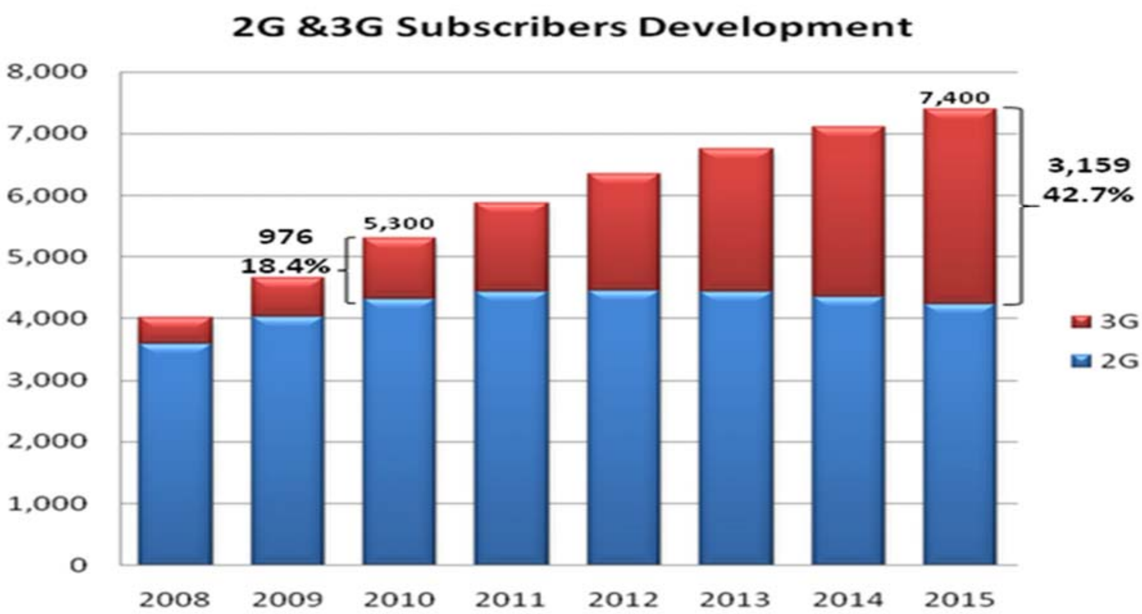
3G roll out





Source: cellular-news.com
Jan 2009

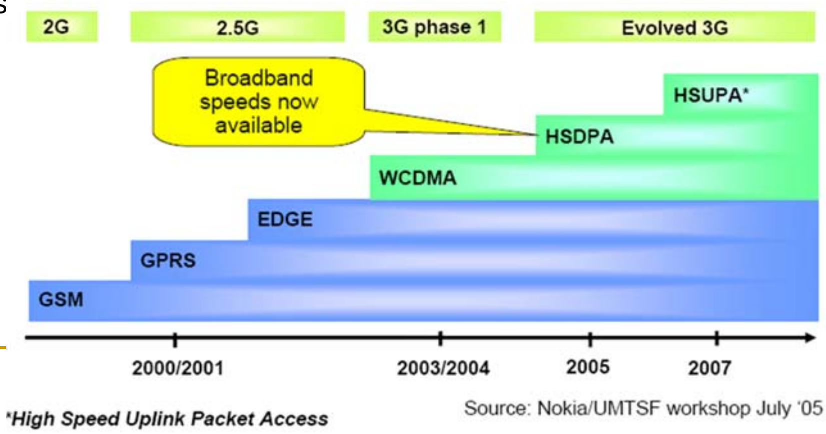
2G vs 3G



Source:

3G Mobile Systems

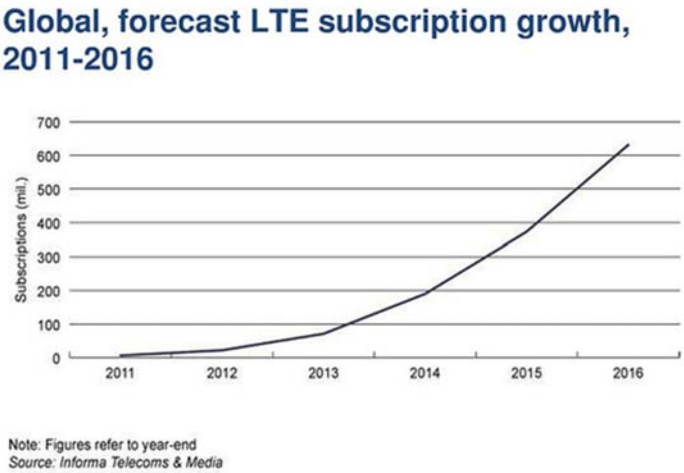
- High Speed Downlink Packet Access (HSDPA)
  - A mobile telephony protocol, allowing for higher data transfer speeds, up to 14.4 Mbit/s per cell in the downlink and 2 Mbit/s per cell in the uplink.
  - Reduces latency
  - Increases data capacity up to 5x in dense urban environments (micro-cells)
- High-Speed Uplink Packet Access (HSUPA)
  - A data access protocol for mobile phone networks with extremely high upload speeds up to 5.76 Mbit/s



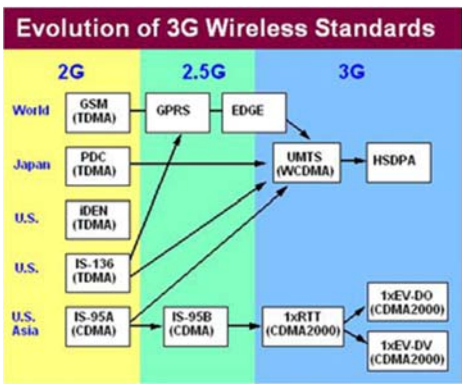
Long Term Evolution (LTE)

- The LTE specification:
  - Downlink peak rates of at least 100 Mbit/s for a single antenna, Peak download rates of 326.4 Mbit/s for 4x4 antennae, and 172.8 Mbit/s for 2x2 antennae (utilizing 20 MHz of spectrum)
  - Peak upload rates of 86.4 Mbit/s for every 20 MHz of spectrum using a single antenna
  - RAN round-trip times of less than 10 ms. Sub-5 ms latency for small IP packets
  - Scalable carrier bandwidths, from 1.4 MHz to 20 MHz
  - Five different terminal classes have been defined from a voice centric class up to a high end terminal that supports the peak data rates. All terminals will be able to process 20 MHz bandwidth
  - Supports both frequency division duplexing (FDD) and time division duplexing (TDD).
  - Simpler core network architecture resulting in low operating cost

LTE forecast



Evolution of Mobile Standards



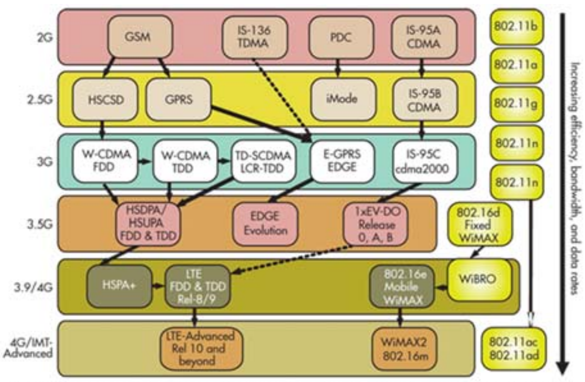


Fig1. In the evolution of wireless cellular standards, all paths eventually lead to some form of LTE or a WiMAX alternative. (courtesy of Agilent Technologies)