Public Switched Telephone Network

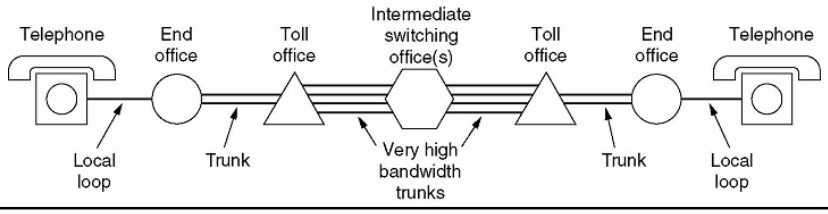
- Introduction
- Local loops
  - Modems, DSL, Wireless
- Trunk Lines
  - FDM, WDM
  - TDM, SONET/SDH
- Switching Offices
  - Circuit switching, Packet switching

Introduction

- Largest and most extensive network
- Designed for transmission of voice using analog transmission with a limited bandwidth (~3.1KHz)
- Uses: Transmission of voice and data over long distances

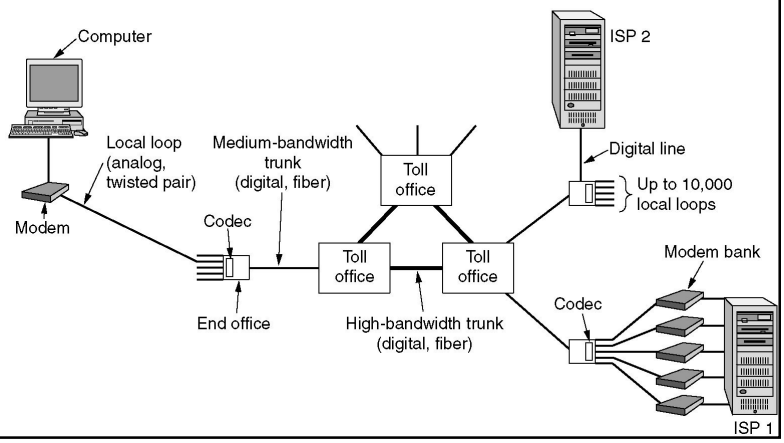
PSTN components

- Local loop: Analog TP going to houses and business from the local exchange,
  - Normally CAT 3 cables
- Trunk lines: Digital fiber optics connecting switching offices
  - Digital transmission now standard on trunk lines
- Switching offices where calls are moved from one trunk to another



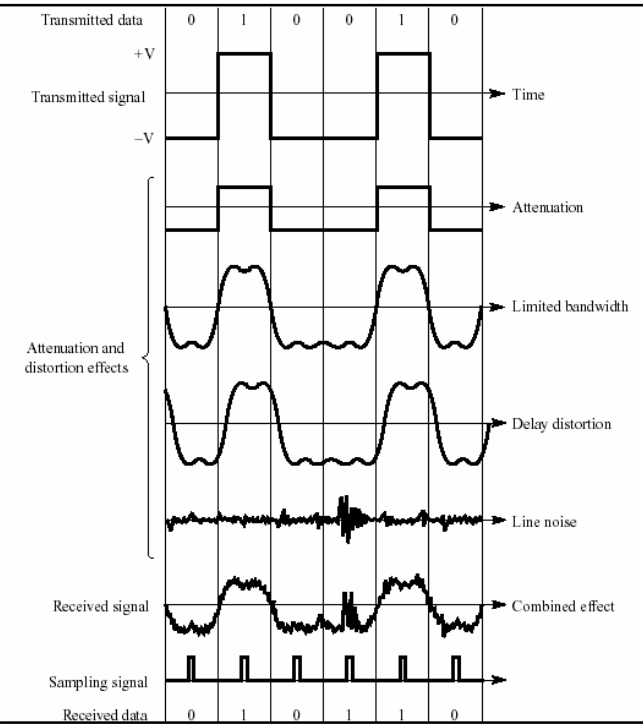
Data on the Local Loop

1. D/A Computer to End Office using modem
2. A/D Trunk lines now digital, so signal is converted back to digital in the end office



Signal Degradation

- Attenuation: The loss of signal energy as it propagates outward
  - Decibels/km
- Distortion
  - Fourier components propagate at different speeds
- Noise
  - Thermal noise is caused by the random motion of electrons in a wire and is unavoidable
  - Crosstalk is caused by inductive coupling between 2 wires which are close together
  - Impulse noise is caused by spikes on the power line

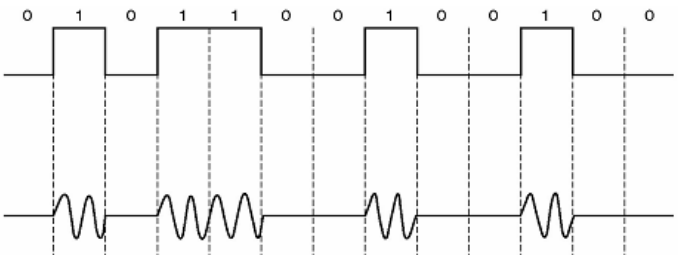


Digital Signal problems

- Avoid a wide frequency range
  - Why? Because of frequency dependent affects of attenuation and distortion discussed in the last 2 slides
- Digital Signals have a very wide frequency range (due to sharp transitions)
  - Baseband: The transmission of digital signals directly.
- Broadband Alternative to baseband
  - Signal modulated onto carrier
  - 3 methods of modulation…

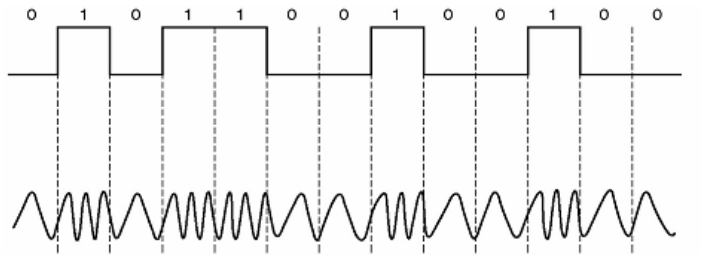
1. Amplitude Modulation

- Two different amplitudes
  - 0 represented by 0 amplitude
  - 1 represented by some fixed amplitude



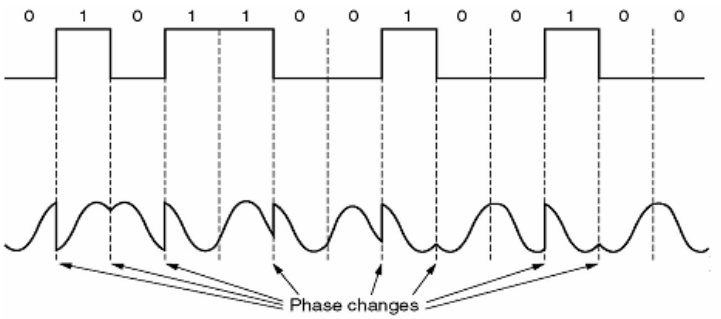
2. Frequency Shift Keying

- Two different tones
  - 0 represented as low frequency
  - 1 represented as high frequency



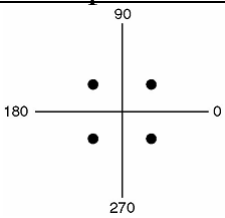
3. Phase Modulation

- Different phase shifts
  - 0→1 represented by a 180 degree phase shift
  - 1→0 represented by a 270 degree phase shift
  - 0→0 & 1→1 no phase shift



Modems

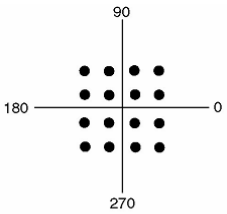
- Given 3.1KHz how often should we sample?
  - From Nyquist: no point sampling any more than 6200 times per second
- But the medium is not perfect…
  - Most modems sample at 2400 times per second
  - One symbol per baud…
  - How can we increase the bits per symbol?

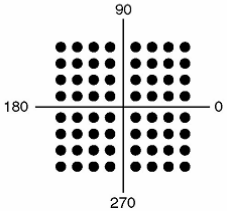


  - QPSK: Quadrature Phase Shift Keying

QAM Quadrature Amplitude Modulation

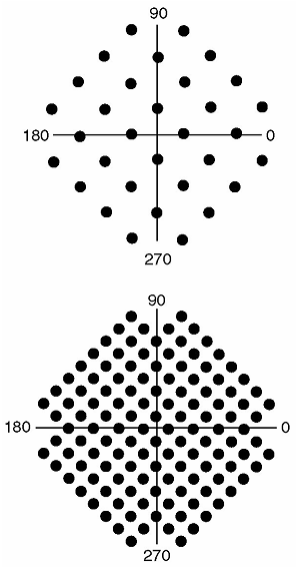
- Most modems use QAM
- Combination of amplitude and phase
- Constellation diagram…
- QAM-16
  - Bits: 4 bits per symbol
  - Data rate: 9600bps at 2400baud
- QAM-64
  - Bits: 6 bits per symbol
  - Data rate: 14400bps at 2400baud





Real Modems

- Risk of Error with a large number of points in the constellation pattern
- Trellis Code Modulation
  - E.g. Using parity bits
  - V.32
    - Points 32 points in the constellation pattern
    - Error bits 1 used for parity
    - Data Rate 9600 bps
  - V.32 bis 14.400bps,6 data bits, 1 parity
  - V.34 28.000bps, 12 data bits
  - V.34 bis 33.600bps, 14 data bits



Some modem issues

- Compress the data? Some modems do, to get higher than 36.000bps
- Choosing a speed: All modems attempt to operate at the highest speed
  - Test the line to see what data rate the noise characteristics will allow reliably
- Direction of traffic, duplex, using direction frequency bands,
- Why no more than 33,600bps?
  - Shannon's limit is 35kbps, based on 2 local loops between sender and receiver and the average length and quality of these lines

V.90 modems

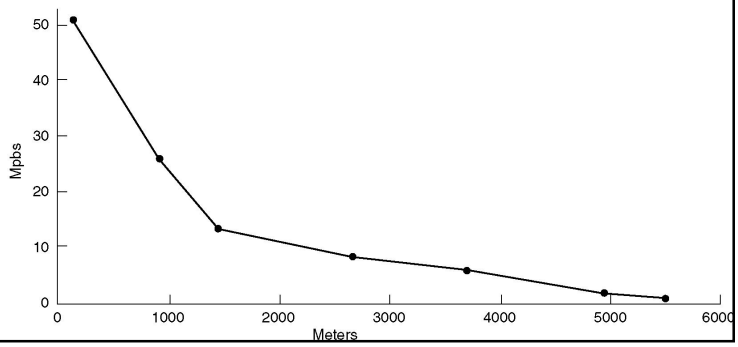
- Digital connection to ISP
  - Theoretical max data rate up to 70.000bps
  - Bandwidth 4kHz including 2 guard channels
  - Max samples 8000 (Nyquist)
  - Bits per symbol U.S. imposed 7 bits per symbol
  - Data Rate 56kbps
- V.90
  - Data rate provides for 33.6 kbps upstream and 56 kbps downstream
- V.92
  - Data rate upstream 48 kbps
  - Set up time is halved from 30 seconds

DSL concept

- Goals
  - Work on existing cable
  - No affect on existing telephone/fax
  - Much faster
  - Always on
- Changes
  - In the end office: Remove the filter which attenuates all frequencies below 300Hz and above 3400Hz
  - In the home: Move houses closer to your end office?

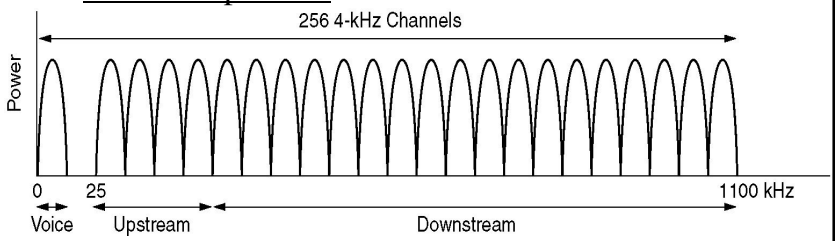
DSL Limitations

- Capacity of line related to
  - Length: The main limitation for increased bandwidth,
  - Quality: thickness, newness of line play a role,
  - Bundling: small number of wires is better as it reduces crosstalk.



DMT Discrete MultiTone

- 0 – POTS Plain Old Telephone System
- 1 5– Used to prevent interference
- 6 255 – Used for data
  - 125 125 This could be split evenly between upstream and downstream,
  - 218 32 or have 218 channels downstream and 32 channels upstream

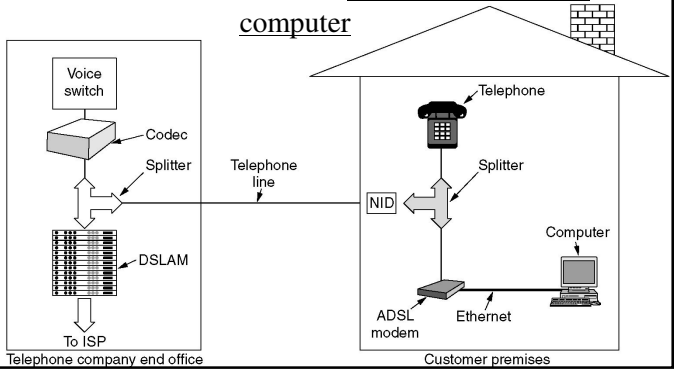


ADSL Speeds

- ADSL standard
  - Up to 8Mbps downstream and 1 Mbps upstream
  - Standard service 512kbps downstream, 64kbps upstream
  - Premium service 1Mbps downstream, 256kbps upstream
- Modulation
  - Similar to V.34 but at 4000 baud
  - QAM is used with up to 15 bits per baud
  - 218 channels => downstream bandwidth is 13.08Mbps
  - Line quality is never that good to achieve that number

DSL Configuration

- Splitter to extract the voice signal,
- DSLAM Digital Subscriber Line Access Multiplexer
- NID Network Interface Device
- Splitter separate the phone signal from the data signal
- ADSL modem DSP acting as 250 QAM modems
- Ethernet between modem and computer

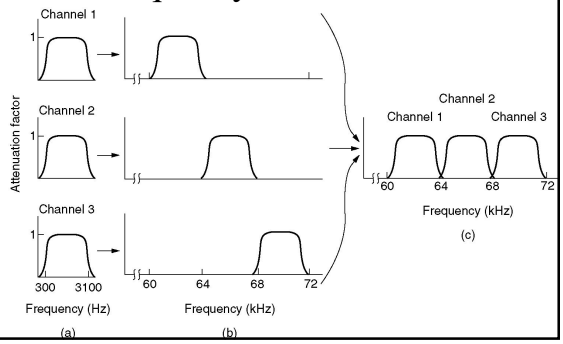


Trunk lines

- Cost of installation, it costs the same to install a high bandwidth line as it costs for a low bandwidth one
  - Hence there has always been an interest in sharing/multiplexing lines.
- Two Categories:
  - FDM Frequency Division Multiplexing
  - TDM Time Division Multiplexing

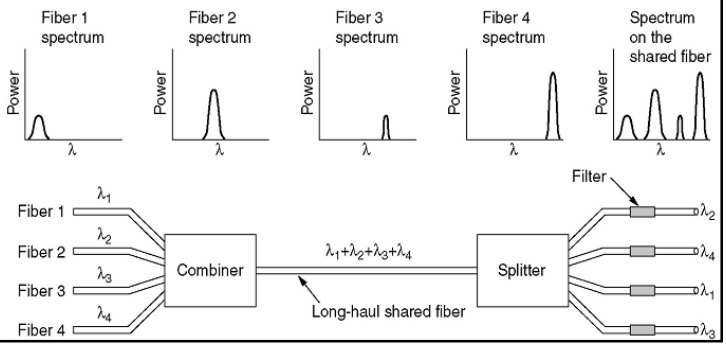
FDM

- Channels
  - 3.1KHz for each voice grade channel
  - 4.0KHz to provide guard channels so that signals do not interfere
  - Raise to a different frequency
  - Combine…



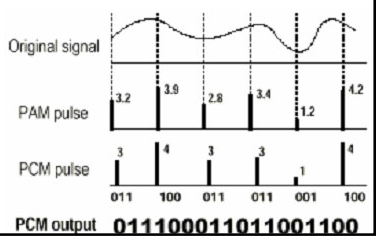
WDM Wavelength Division Multiplexing

- FDM @ higher frequencies
- Speed:
  - 2001: Already products with 96 10Gbps bands
  - Limit: Theoretical limit is 25000GHz on a single fiber with data rate 1 bit/Hz or higher



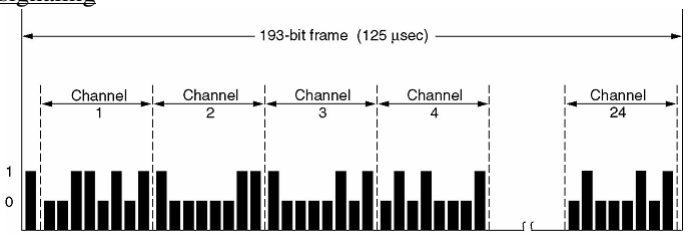
TDM – PCM Time Division Multiplexing

- Allow each channel full use of the bandwidth for very short intervals of time
  - Only possible for digital data
- To recreate a 4 kHz voice channel
  - Need 8000 samples/sec
  - First the signal is sampled (using PAM Pulse Amplitude Modulation)
  - Then it is quantised
    - PCM → bits per sample



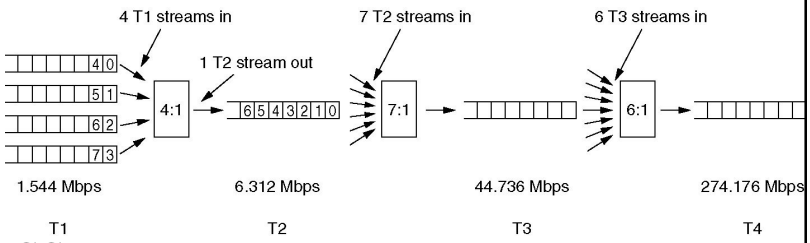
TDM – T1 / E1

- 193 bits/257 bits every 125µsec
  - Framing: First bit is used for synchronisation, (0101..)
    - Frame slips: When the pattern is lost, so receiver has to resynchronise
  - Data & Signaling (24/32 channels)
    - 7 bits per channel with 1 bit for signaling (T1)
    - Common channel signaling 8 bits per channel with the framing bit used for signaling information in the even frames (E1)
    - Channel associated signaling 8 bits per channel in 5 frames out of 6 and 7 bits in the 6th frame with the extra bit used for signaling



TDM – Multiplexing streams

- T1 streams
  - T2 = 4 * T1
  - T3 = 7 * T2
  - T4 = 6 * T3



- CCITT streams
  - Multiplexed 4 streams at every level giving …
  - 2.048 (32), 8.848 (128), 34.304 (512), 139.364 (2048), 565.148 (8192)

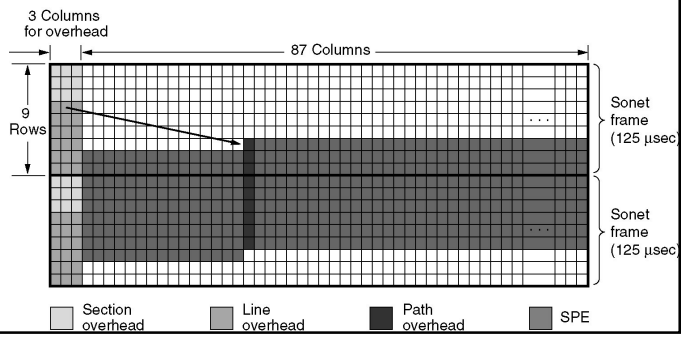
SONET/SDH

- Optical TDM
  - SONET: Synchronous Optical NETwork
  - SDH: Synchronous Digital Hierarchy
- Synchronous transmission: Sender and Receiver share a clock and transmission is constant

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/SDH

- STS-1
  - 810 bytes (9 rows * 90 columns) frames
  - Section & Line overheads
  - Data
    - SPE: Synchronous Payload Envelope can start in the middle of the frame

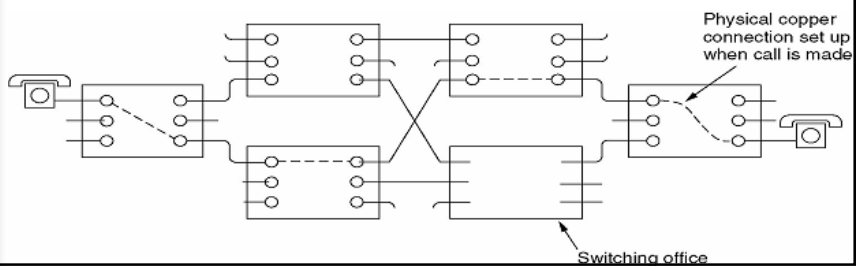


Switching

- Categories
  - Circuit Switching
  - Packet Switching

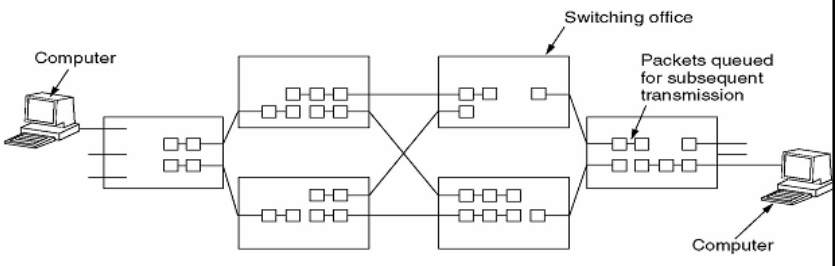
Circuit Switching

- Create a path
  - Physical path in the past
  - Conceptual nowadays, e.g., bandwidth reservation
- Path setup has to take place before communication can commence



Packet Switching

- Send packets
  - Routers
  - Store & Forward



Circuit vs. 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