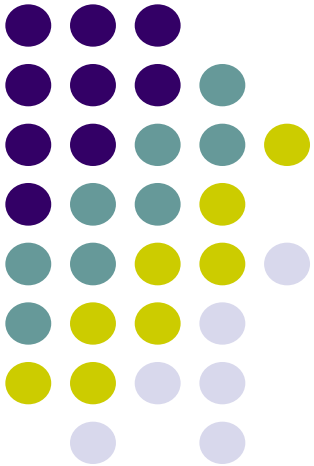
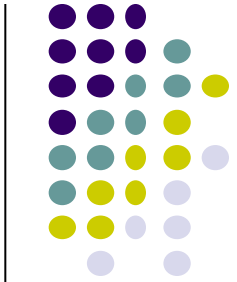
Long-Distance Digital Connection Technologies



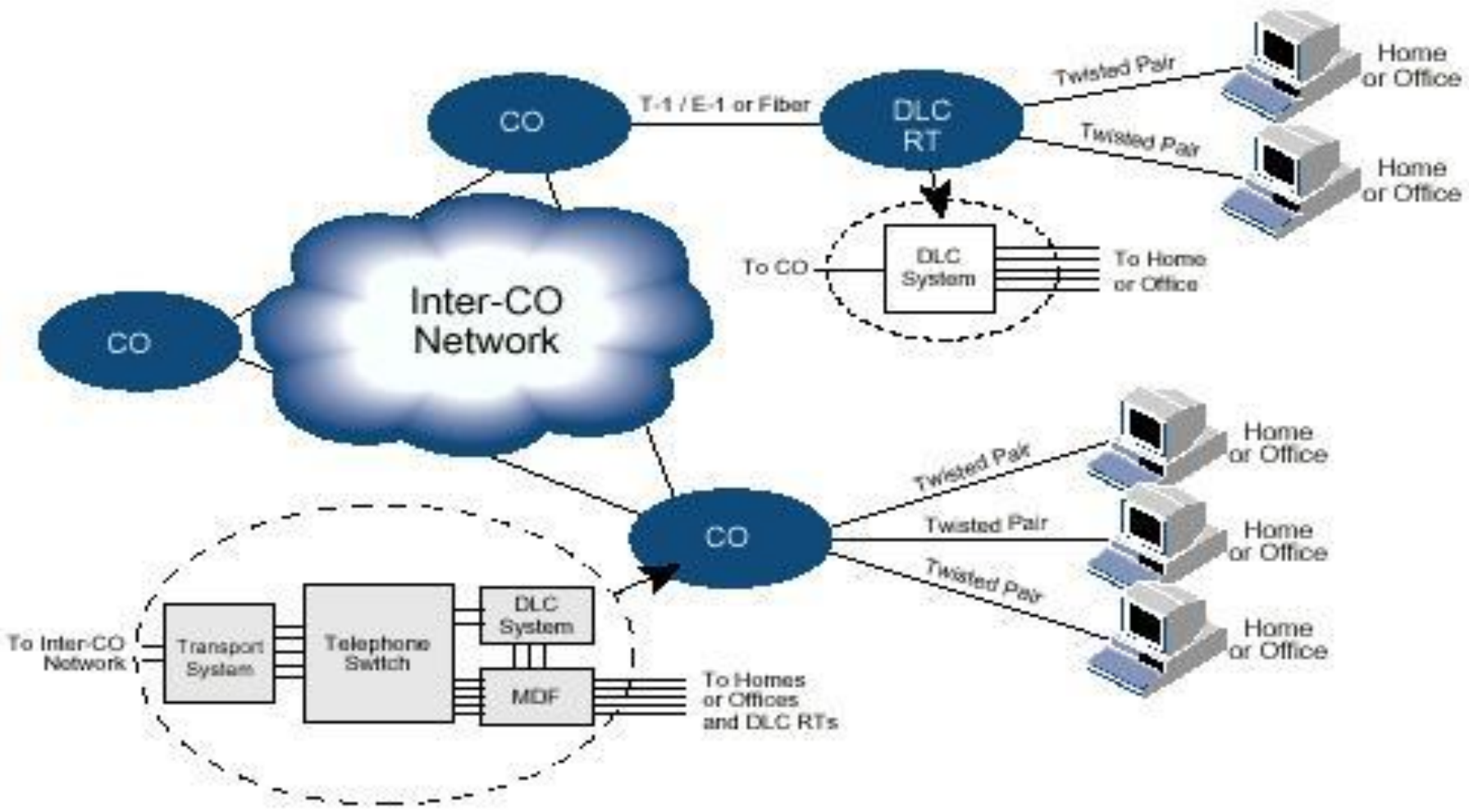
Objective

Bit-wise Data Transmission



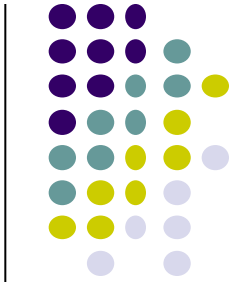
- Data transmission requires:
  - Encoding bits as energy
  - Transmitting energy through medium
  - Decoding energy back into bits
- Energy can be electric current, radio, infrared, light.
- Transmitter and receiver must agree on encoding sheme and transmission timing.

EXISTING TELEPHONE INFRASTRUCTURE



CO =Central Office, RT = Remote Terminal, DLC = Digital Loop Carrier
MDF = Main Distribution Frame

EXISTING TELEPHONE INFRASTRUCTURE

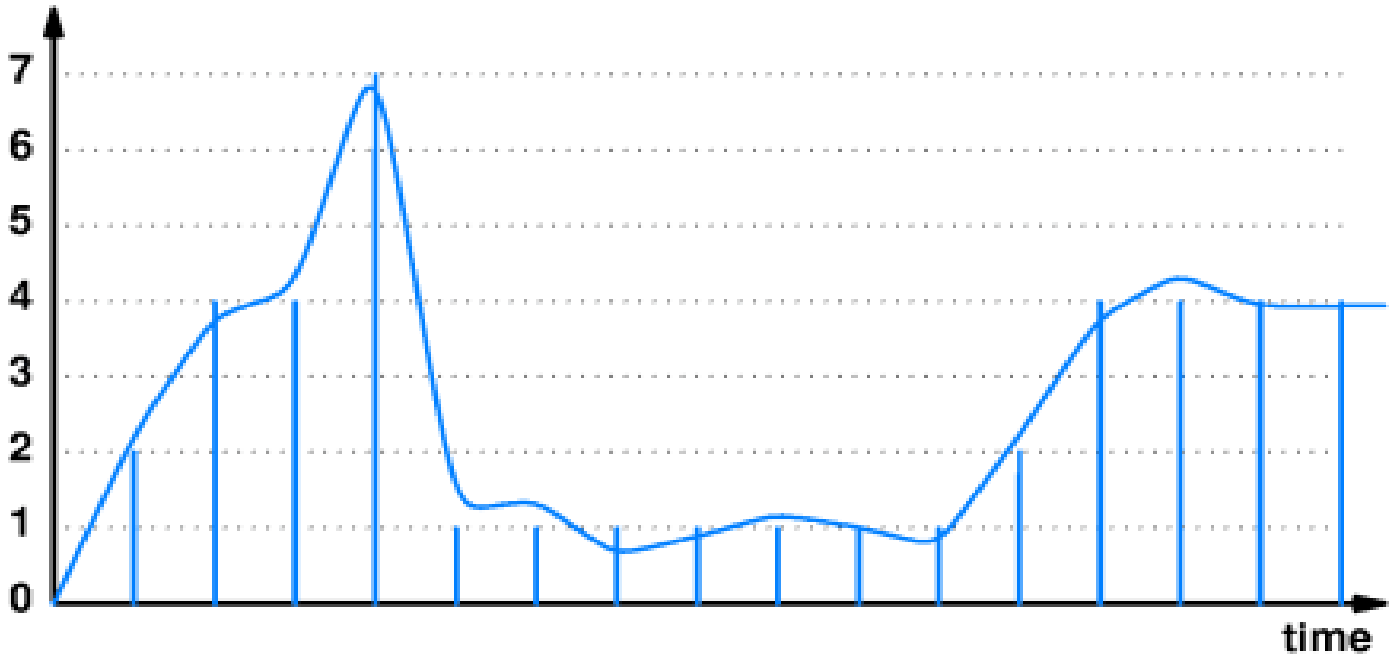


Why Digital Telephony?

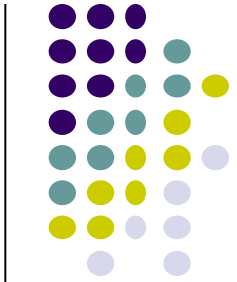
- Analog signals, the mechanism used in early telephone systems had problems in a long distance environment. Because electrical signals degrade as they pass over copper wires. Amplifiers, boosting the signals, distort the original signals and introduce noise.
- Digital communication avoids the problem of noise by encoding the original audio signal into digital form.

EXISTING TELEPHONE INFRASTRUCTURE

Digitization (A-to-D converter)

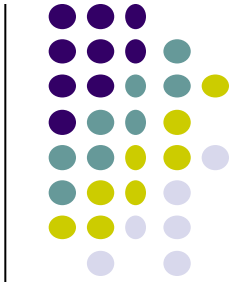


EXISTING TELEPHONE INFRASTRUCTURE



- PCM (Pulse Code Modulation) is a standard for digital encoding of audio used in the telephone system.
- PCM samples a signal once every 125μ seconds and converts each sample into an integer between 0 and 255.

Nyquist Theorem



- The Nyquist Theorem, also known as the sampling theorem, is a principle that engineers follow in the digitization of analog signals.
- For analog-to-digital conversion (ADC) to result in a faithful reproduction of the signal, slices, called *samples*, of the analog waveform must be taken frequently. The number of samples per second is called the sampling rate or sampling frequency.
- Teoretical limit on the maximum speed at which data can be sent over an error-free (noiseless) medium.

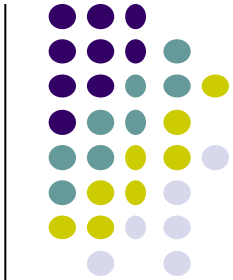
Nyquist Rate

- The Nyquist rate is the minimum sampling rate required to avoid aliasing, equal to twice the highest frequency contained within the signal. Aliasing is an effect that causes different signals to become indistinguishable when sampled, and the distortion or artifact that results when the signal reconstructed from samples is different from the original continuous signal.

N=2B, where B is the highest frequency at which the signal can have nonzero energy.

- A 4000 Hz voice signal is sampled 8,000 times in a second, every 125μ seconds a signal is sampled.
- A typical 4 kHz voice signal is sampled 8,000 times a second, with each sample converted into an 8-bit number, resulting in a 64 Kbps data stream (PCM Standard).

Shannon’s Theorem



- Shannon's Theorem gives an upper bound to the capacity of a link, in bits per second (bps), as a function of the available bandwidth and the signal-to-noise ratio of the link. The theorem can be stated as:

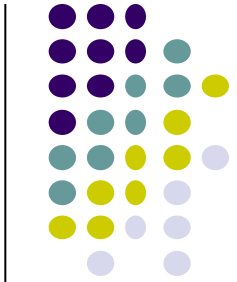
  C = B * log2(1+ S/N)

  where C is the achievable channel capacity, B is the bandwidth of the line, S is the average signal power and N is the average noise power.
- The signal-to-noise ratio (S/N) is usually expressed in decibels (dB) given by the formula:

  10 * log10(S/N)

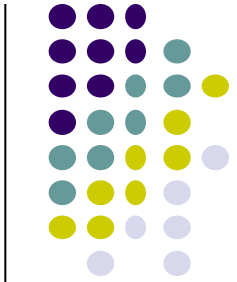
so for example a signal-to-noise ratio of 1000 is commonly expressed as

10 * log10(1000) = 30 dB.



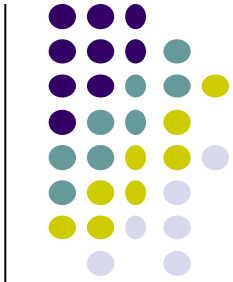
- Shannon's Theorem deals with noisy medium.
- The signal-to-noise ratio (S/N) is the strength of the signal compared to the strength of the noise.
- Capacity: max. data rate on a noisy medium
- Example: How fast data can be sent across a voice telephone call?

Synchronous Communication



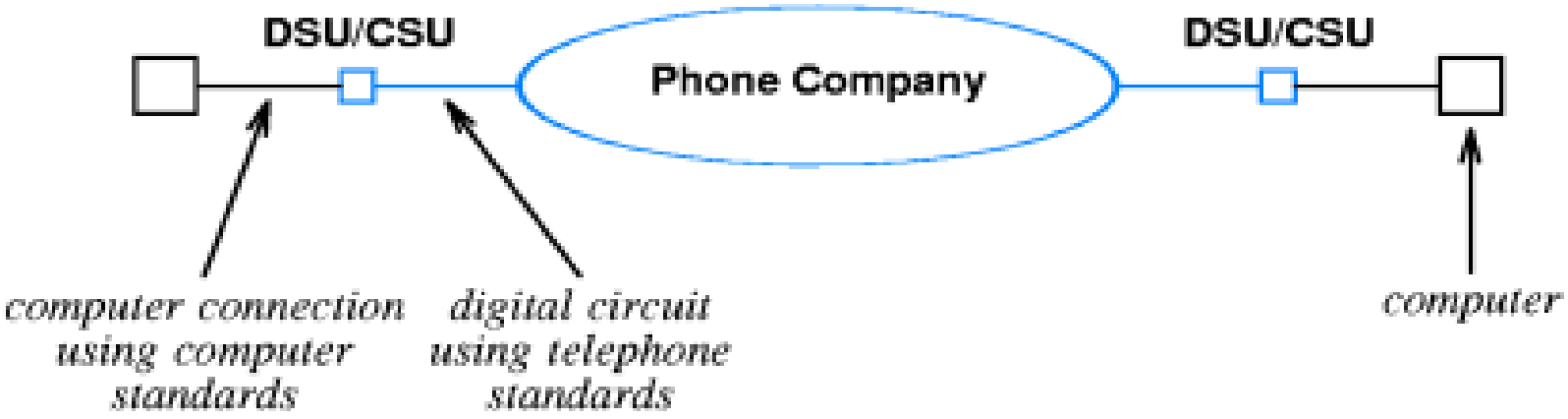
- A synchronous network consists of a system designed to move data at a precise rate.
- The network does not slow down as the traffic increases, data emerges from the network at exactly the same rate it enters.
- The facilities used for digital voice differ from the systems used for data because voice systems use *synchronous or clocked technology*, while most data networks use *asynchronous technology*.

Digital Circuits and DSU / CSUs

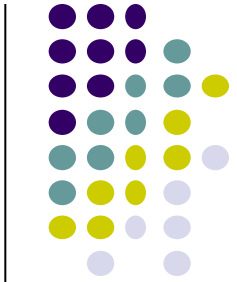


- Digital circuits leased from common carriers form the fundamental blocks for long distance computer networks. Each circuit extends between two specified points and the fee depends on the circuit capacity and distance.
- A digital circuit needs a device known as a DSU/CSU (Data Service Unit / Channel Service Unit) at each end. In addition to terminating the line, the DSU/CSU translates between the digital representation used by phone companies and the digital representation used by the computer industry.

Digital Circuits and DSU / CSUs



Digital Circuits and DSU / CSUs



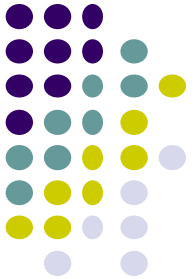
CSU (Channel Service Unit)

- Handles line termination and diagnostics
- Accommodate current surges
- Checking the CSUs at the other end, has loop back capability
- Performs bit stuffing or balanced encoding scheme

DSU (Data Service Unit)

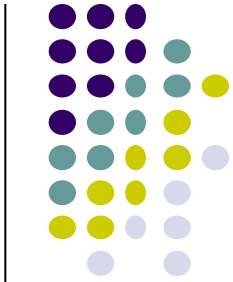
- Translates data between the digital format used on the carrier's circuit and the digital format required by the customer's computer equipment.

Telephone Standards



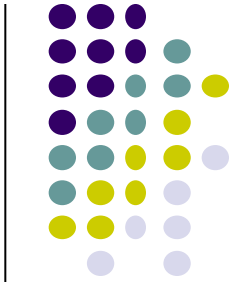
Name	Bit Rate	Voice Circuits	Location
–	0.064 Mbps	1	
T1	1.544 Mbps	24	North America
T2	6.312 Mbps	96	North America
T3	44.736 Mbps	672	North America
E1	2.048 Mbps	30	Europe
E2	8.448 Mbps	120	Europe
E3	34.368 Mbps	480	Europe

DS Terminology And Data Rates



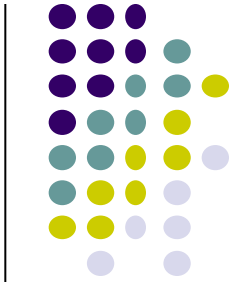
- T standards define the underlying carrier system.
- Multiplexing multiple phone calls on a single connection is defined by DS or Digital Signal Level standards.

Lower Capacity Circuits



- A company does not need T1 capacity can save money by leasing a fractional T1 digital circuit. The phone company uses TDM to subdivide a T1 circuit.

Intermediate Capacity Circuits

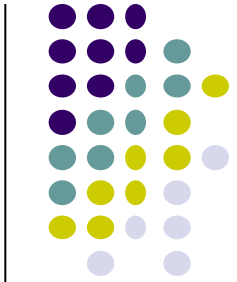


- What if the company needs a circuit with slightly more than T1 capacity, but only T3 circuits are available?
- T3 costs more than T1, but has 28 times the capacity of T1 circuit.
- Inverse Multiplexing technology allows one to lease multiple T1 circuits between two points and use them as a single higher capacity circuit.

Inverse Multiplexing for Intermediate Capacity Digital Circuits

Inverse Multiplexer devices may have built-in DSU / CSU functionality.

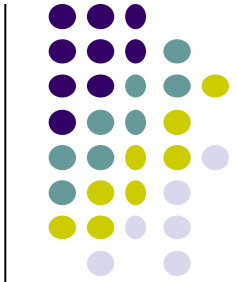
Highest Capacity Circuits



Standard Name	Optical Name	Bit Rate	Voice Circuits
STS-1	OC-1	51.840 Mbps	810
STS-3	OC-3	155.520 Mbps	2430
STS-12	OC-12	622.080 Mbps	9720
STS-24	OC-24	1,244.160 Mbps	19440
STS-48	OC-48	2,488.320 Mbps	38880

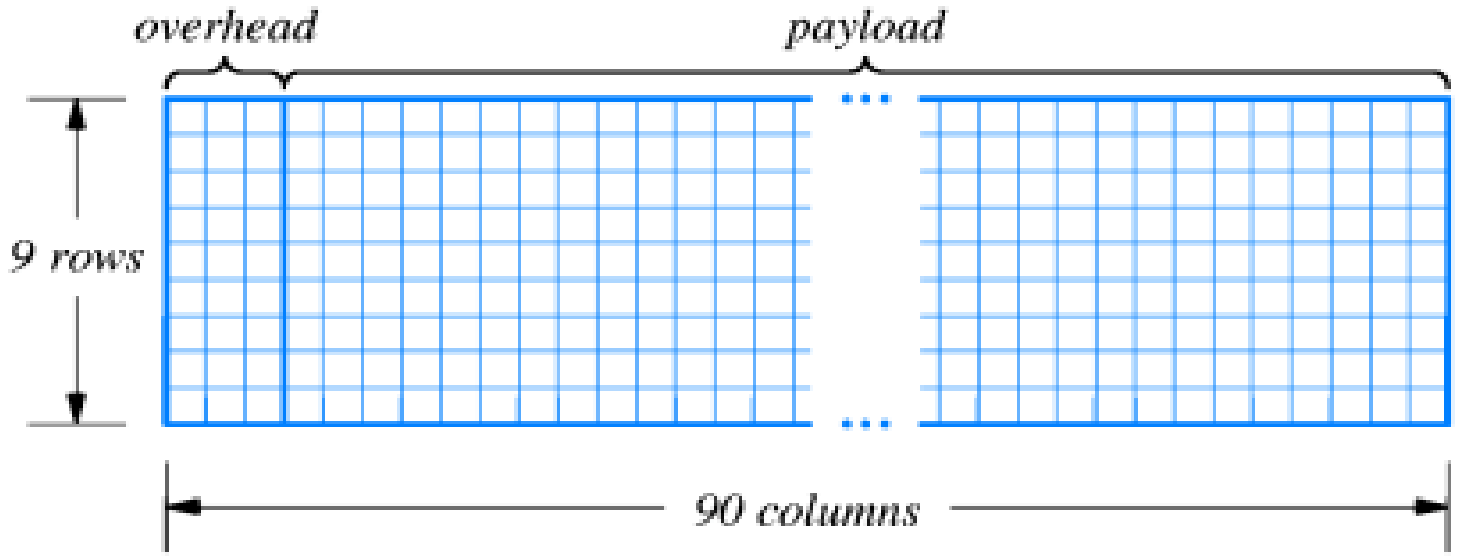
Synchronous Transport Signal (STS) standards were defined for high-capacity digital circuits, which specify the details of high speed connections.

Synchronous Optical Network (SONET)



- In addition to STS and OC standards SONET brings some other standards
- Specifies how data is framed
- Specifies how lower capacity circuits are multiplexed into a high capacity circuit
- Provides transmission of clock information along with data

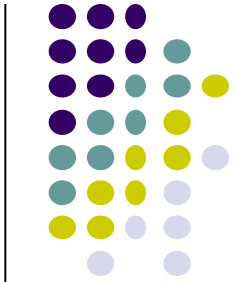
Synchronous Optical Network



STS1 SONET frame with 810 octets.

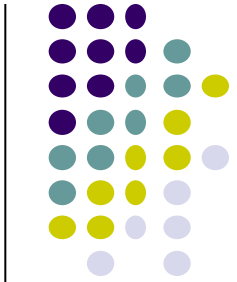
STS1 : 6480 bits (810 octets) are transferred at every 125μ seconds
STS3 : 2430 octets are transferred at every 125μ seconds

The Local Subscriber Loop



- Connection between telephone company central office (CO) and an individual subscriber's residence or place of business.
- The term adopted to refer to the connection from network provider to individual subscriber.

Integrated Services Digital Network (ISDN)



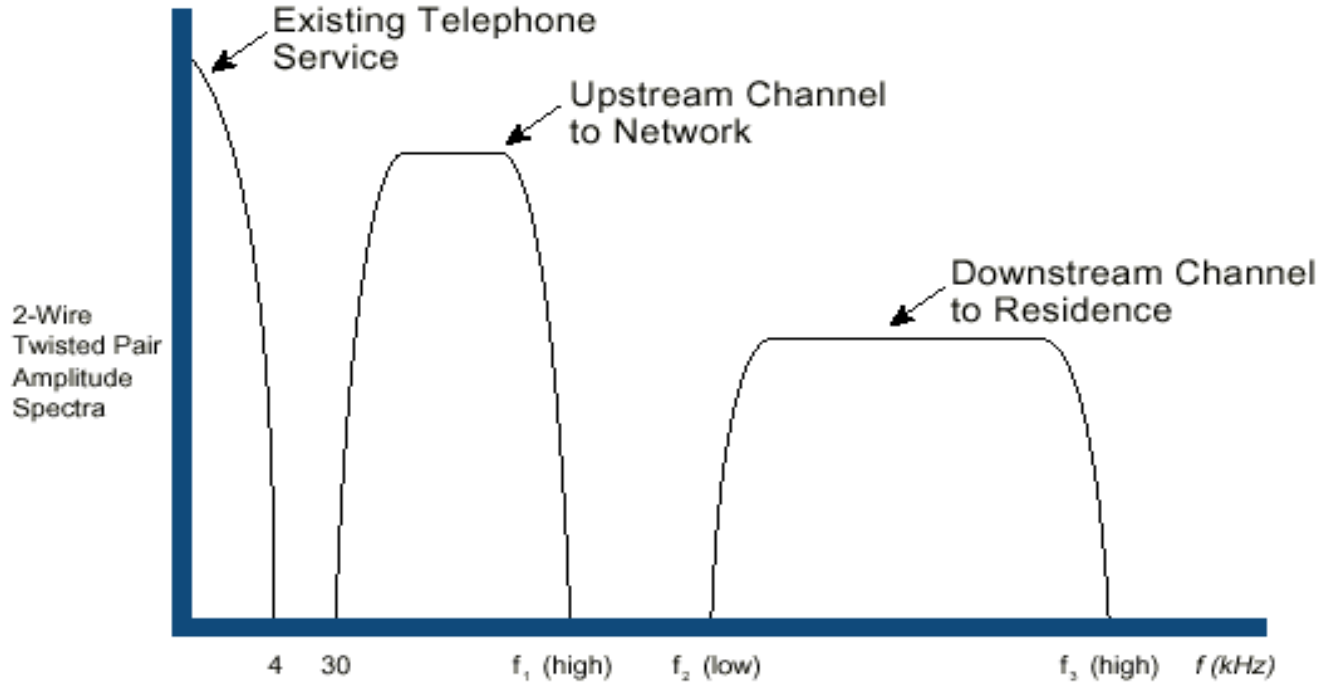
- Uses existing twisted pair copper wiring for analog telephone system and provides digitized voice or data.
- ISDN offers three different digital channels: B, B, and D (2B+D).
- B (bearer, 64Kbps) channels are intended to carry digitized voice or data, D (data, 16 Kbps) channels support signaling for the B-channel and is capable of carrying packet data, intended as a control channel.
- A subscriber uses the D channel to request services which are then supplied over the B channel.
- B channels can be combined or bonded to produce signal.
- 2B+D are known as the ISDN Basic Rate Interface (BRI).

DSL Technologies

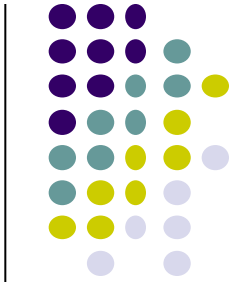
- DSL(Digital Subscriber Line) is technology that provides digital data transmission over the wires of a local telephone network.
- DSL refers to the technology used between a customer's premises and the telephone company, enabling more bandwidth over the already installed copper cabling than users have traditionally had.
- xDSL is a generic abbreviation for the many flavors of DSL technology; ADSL, ADSL2, ADSL2+, SDSL, IDSL, HDSL, VDSL, VDSL2, etc.

Asymmetry in DSL Technology

- You can more reliably transmit a higher-speed signal from the CO to the remote location than can be transmitted from the remote location to the CO.

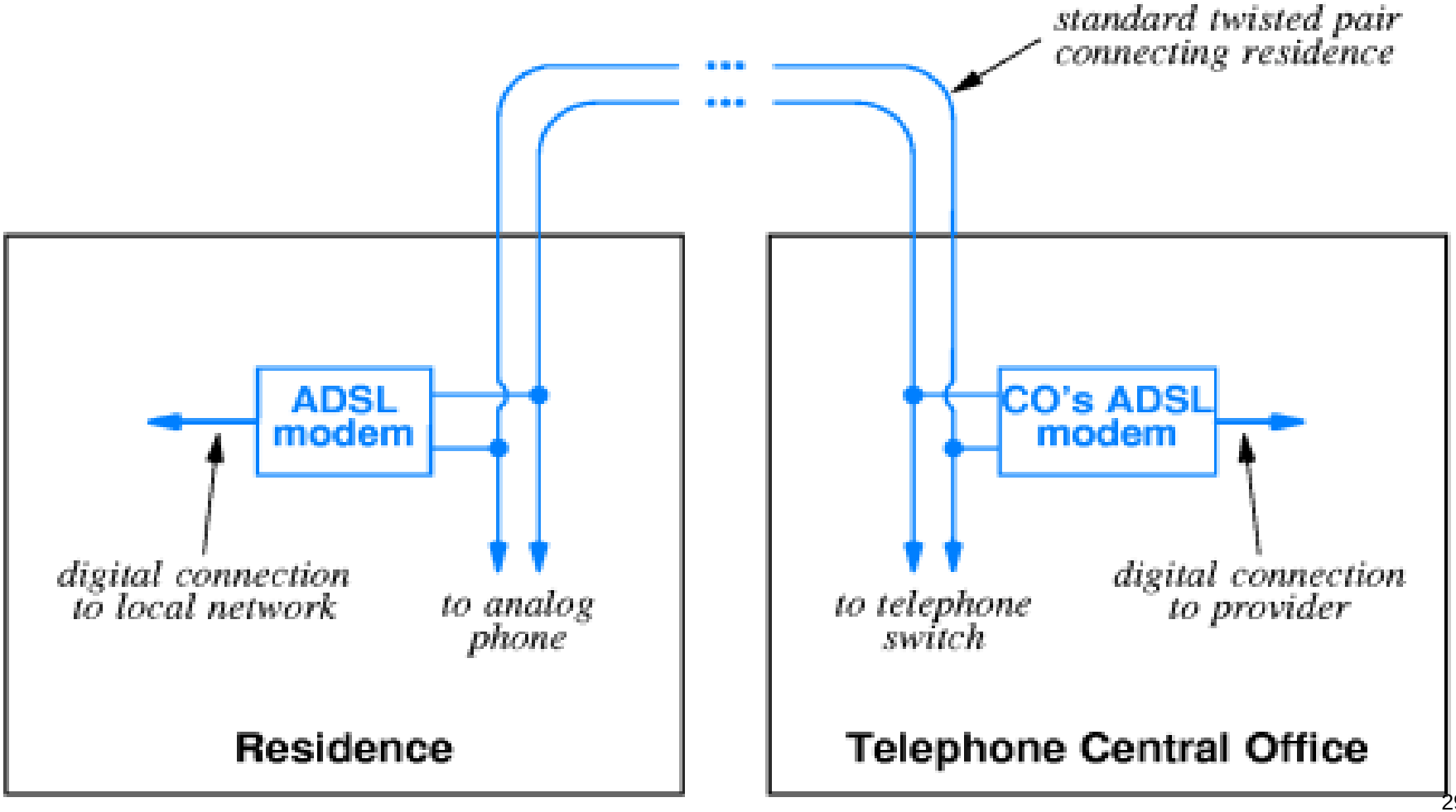


Asymmetric DSL (ADSL)

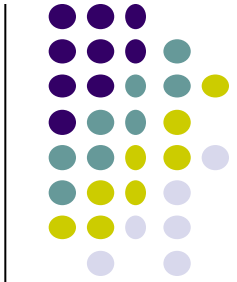


- Theoretically provides 6.144 Mbps maximum downstream rate, 640 Kbps maximum upstream rate.
- ADSL is adaptive. That is, when ADSL modems are powered on they probe the line between them to discover the characteristics of the line and select the optimal frequencies and modulation techniques.
- ADSL uses Discrete Multi Tone modulation (DMT) scheme, which combines frequency division multiplexing and inverse multiplexing techniques.

ADSL


standard twisted pair
connecting residence
ADSL
modem
digital connection
to local network
to analog
phone
Residence
CO's ADSL
modem
to telephone
switch
digital connection
to provider
Telephone Central Office

Other DSL Types



High-Bit-Rate DSL (HDSL):

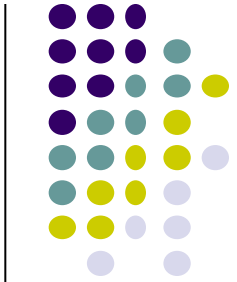
- HDSL was the first DSL technology to use a higher frequency spectrum of copper, twisted pair cables.
- Disadvantages:
  - Short distance limitation on local loops.
  - Wiring requirements: HDSL requires two independent twisted pairs unlike ADSL, which uses a single twisted pair. To overcome the wiring disadvantage, a varient known as HDSL2 has been proposed, this technology relies on fewer wires – single twisted pair, instead of two- and therefore costs less to set up.

Other DSL Types

Symmetric Digital Subscriber Line (SDSL):

- SDSL provides symmetric bit rates in both directions. Businesses that export information may prefer SDSL. Because SDSL uses a different encoding scheme than ADSL, it can operate over local loops for which ADSL is inappropriate.

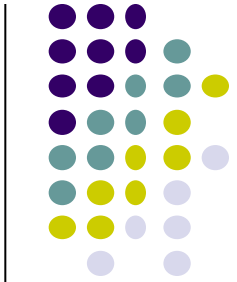
Other DSL Types



Very-High-Bit-Rate DSL (VDSL):

- The newest emerging variant of DSL is VDSL, or Very High Speed DSL.
- VDSL is a DSL technology providing faster data transmission (up to 52 Mbps downstream and 16 Mbps upstream) over a single flat untwisted or twisted pair of copper wires. These fast speeds mean that VDSL is capable of supporting high bandwidth applications such as HDTV, as well as telephone services (Voice over IP) and general Internet access, over a single connection.

Cable Modem Technology



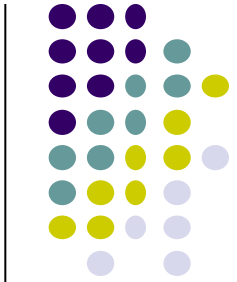
- Engineers have devised ways to use the existing Cable Television (Community Antenna TV - CATV) infrastructure as a local loop technology that delivers digital data to subscribers.
- It offers higher speed than telephone wiring, is less susceptible to electromagnetic interference, and does not require completely new infrastructure.
- In theory it's possible to use FDM for each user. But for millions of users it is very difficult to dedicate a separate frequency to each individual. Instead, cable supplier provides separate frequencies to sets of subscribers and TDM is used to subdivide each channel.
- The media consists of coaxial cable.

Cable Modem Technology

Upstream Communication

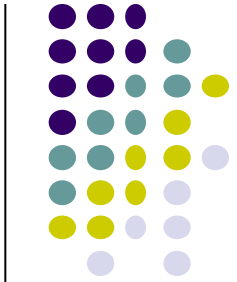
- Because the original cable infrastructure only provided downstream delivery, the original system could not be used to provide two-way digital communication.
- Dual Path Approach: While cable system handles only downstream traffic, upstream traffic travels across a dialup telephone connection.
- To implement the scheme, a subscriber needs a hardware interface device that connects to two modems, a cable modem and a standard dialup telephone modem.
- Low cost for cable providers, the existing cable system does not need to change.

Hybrid Fiber Coax (HFC)



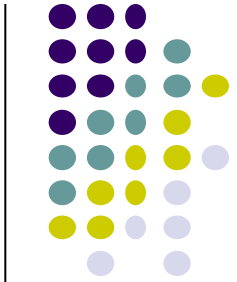
- The system uses a combination of optical fibers and coaxial cables, with fiber used for the central facilities and coax used for the connections to individual subscribers.
- It uses fiber optics for the portion of the network that requires the highest bw, and uses coax for parts that can tolerate lower capabilities.
- To use Hybrid Fiber Coax, cable companies must change much of the central infrastructure. Trunk lines must be replaced with fiber and all amplifiers must be modified to operate in both directions. However the system can use existing coax feeder circuits to reach individual subscribers.

Fiber to the Curb (FTTC)



- Similar to HFC because it uses optical fiber for high capacity trunks.
- Run optical fiber close to the end subscriber, and then use copper for the feeder circuits.
- Both coaxial cable (for CATV) and twisted pair (for data networking) is extended to subscribers.

Broadcast Satellite Systems



- Use air as a shared medium
- Instead of using satellites as a point to point communication systems a broadcast mechanism was devised.
- Instead of a large, expensive ground station, an alternative uplink transmission path was used.