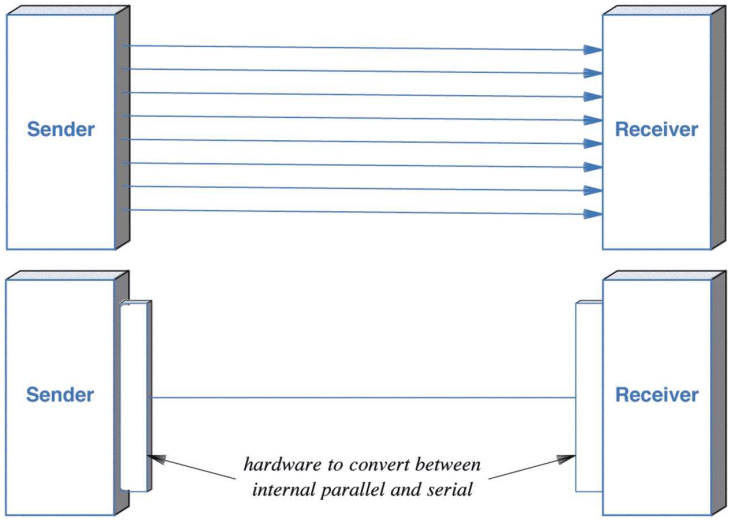
Coding and Connecting
Ch. 9–12.

Parallel v. Serial



Parallel v. Serial

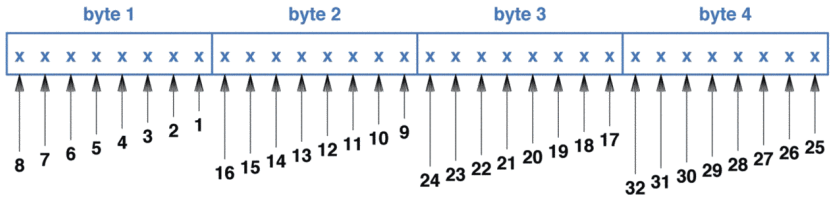
Parallel moves more data at a time.

Parallel better matches internal hardware.
Typically a UART

Parallel cables are larger and more expensive.

In practice, serial seems most used and increasing.

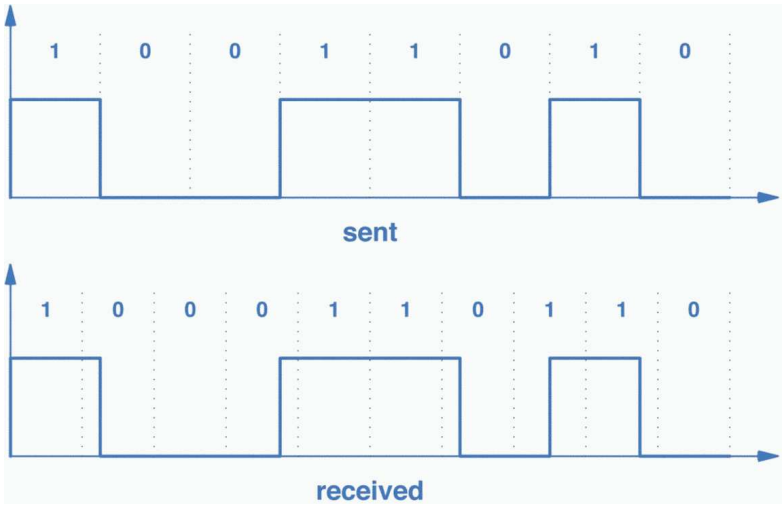
Byte Order



Ethernet standard.

Similar to order used by Intel CPUs.

Bad Timing



Synchronous v. Asynchronous

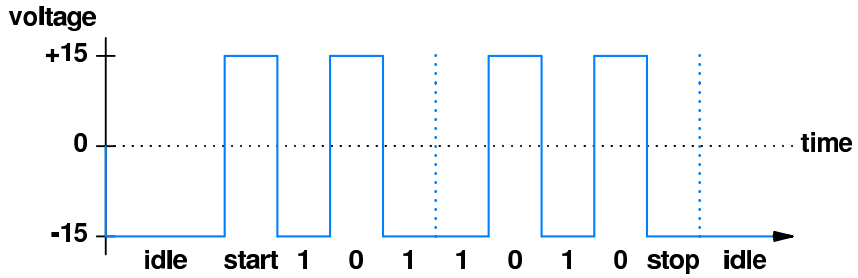
Keeping the sender and receiver synchronized.

Asynchronous

Data sent at random intervals.

Extra leading bits synchronize for that transmission.
Usually each byte.

RS 232



Synchronous

Produces a constant stream of bits.
Just send zeros if there's nothing to say.

Asynchronous Synchronization

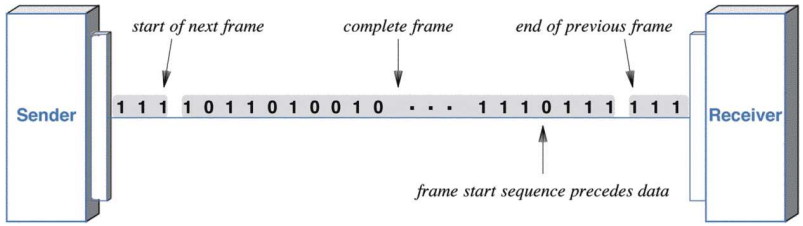
Just because your asynchronous doesn't mean clocks don't drift

USB uses NRZ-I with no change for 1
Extra zero after any six ones to assure a transition.

Ethernet frames are preceded by a *prefix* of ones.

Framing

Wrap frames of data in known sequence.
These markers re-synchronize the receiver's clock.



Some special marker meaning "no data."

Isochronous Transport

The network transports data at a constant rate.

The network must be fed data at exactly that rate.
No data? Send zero. The network must be fed.

Designed for transmission of audio or video streams.

Transitional for telephone networks.

Direction

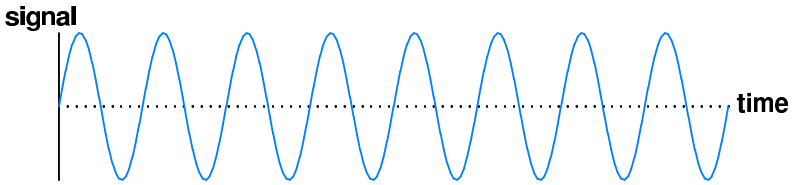
Simplex
One Way

Full-Duplex
Both ways all the time
Telephone

Half-Duplex
Both way one at a time
Walkie-Talkie

Carrying Data Over Sine Waves

Sine waves survive long distances better.



When using radio, certain frequencies propagate better.

Data is sent by modifying the carrier.

Modulation

A sinusoidal carrier is modified (modulated) under control of a digital signal.

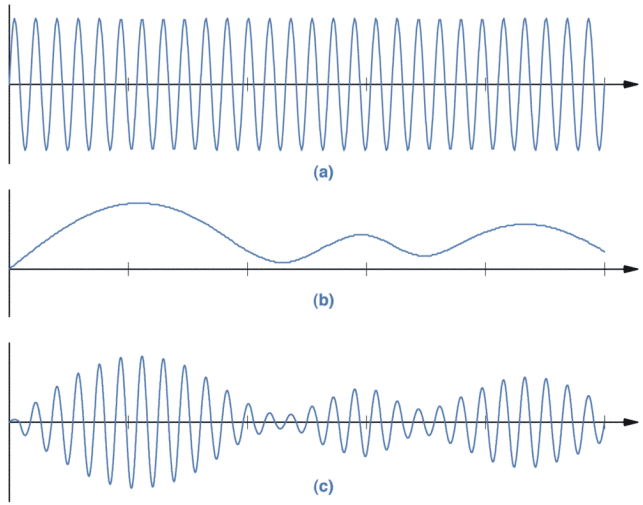
The digital signal can be recovered from the modulated carrier signal.

Modem stands for modulator-demodulator.

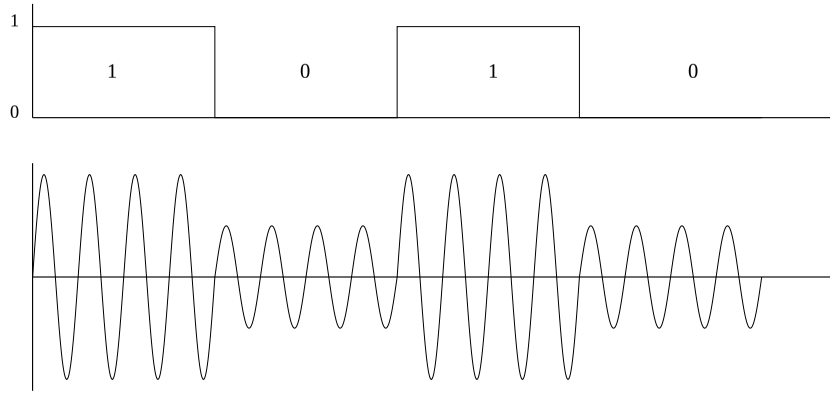
Can modulate: amplitude, frequency, or phase.

The carrier frequency is the channel bandwidth.

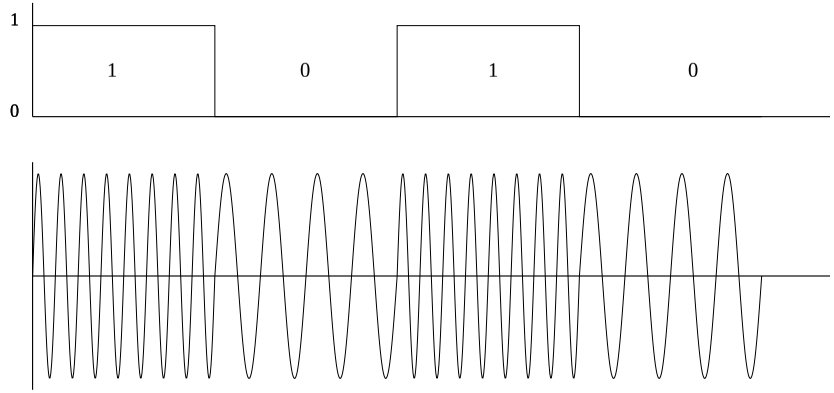
Analog Modulation



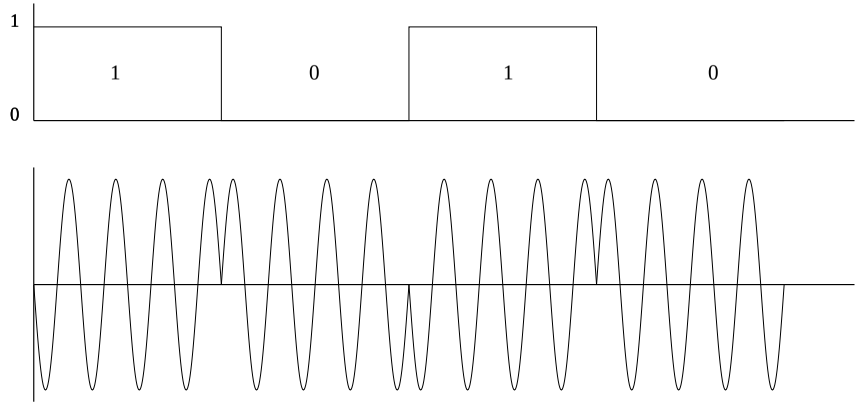
Digital Modulation
Amplitude Modulation Amplitude Shift Keying



Frequency Modulation
Frequency Shift Keying



Binary Phase Shift Modulation



Some Practical Concerns

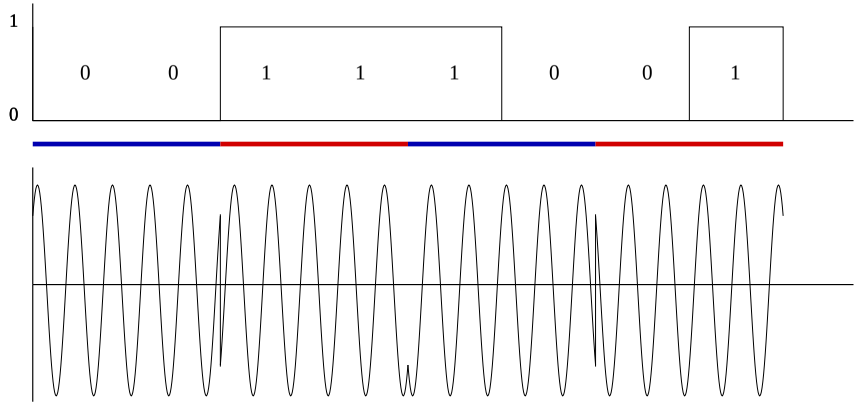
A carrier can be modulated with an analog or digital source.
Phase shift rarely used with analog.

Pictures tend to exaggerate magnitude of the change.

Amplitude needs to stay larger than the noise signal.

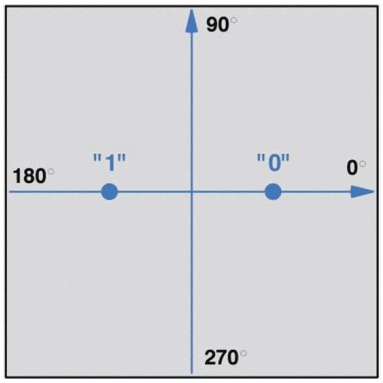
Frequency usually needs to stay inside a channel.

Quad Phase Shift Modulation

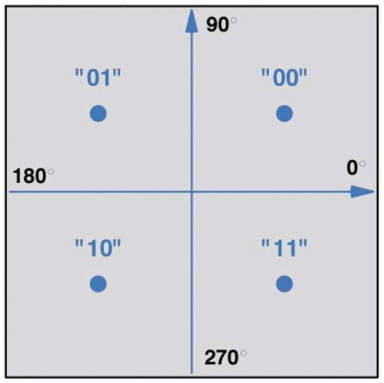


Two bits at a time.

Constellation Diagrams

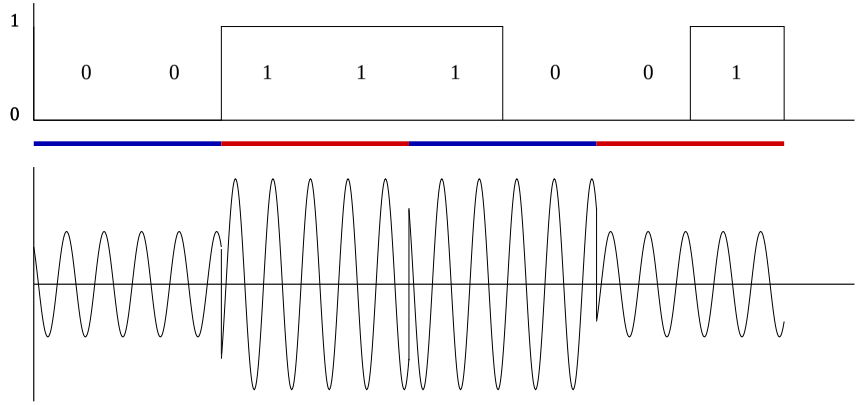


Two Phases

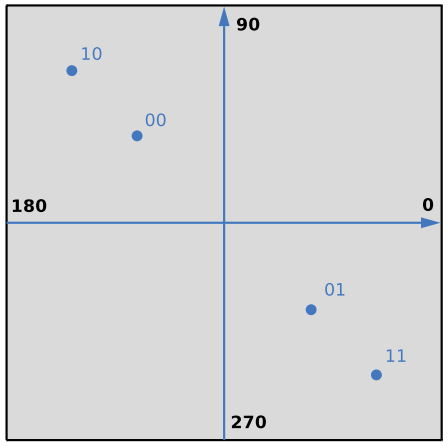


Four Phases

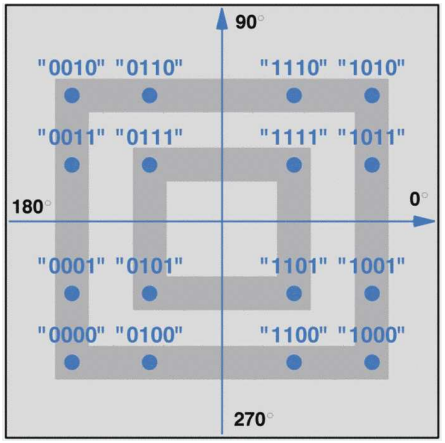
Combine Amplitude and Phase



Combine Amplitude and Phase



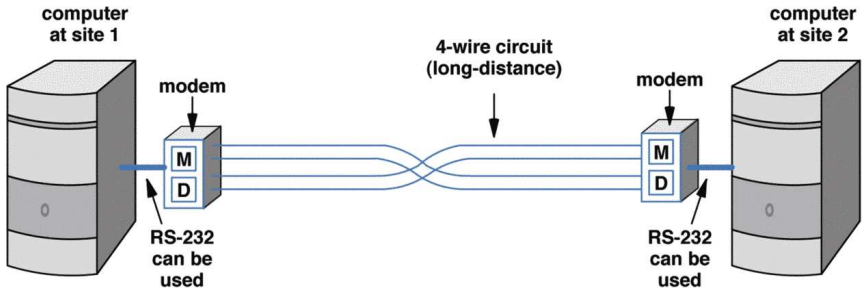
Quadrature Amplitude Modulation



16-QAM

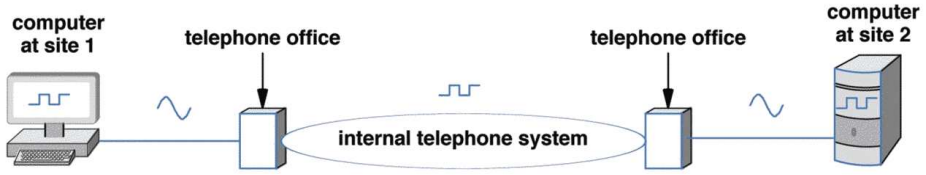
Modems

Modem = Modulator/Demodulator



Wire, radio, optical.

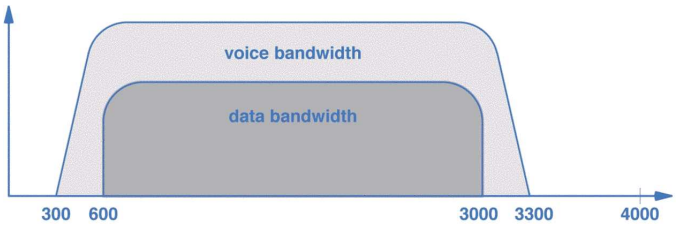
Dialup



Digital to voice frequency

Sound sampled and digitized by the phone system

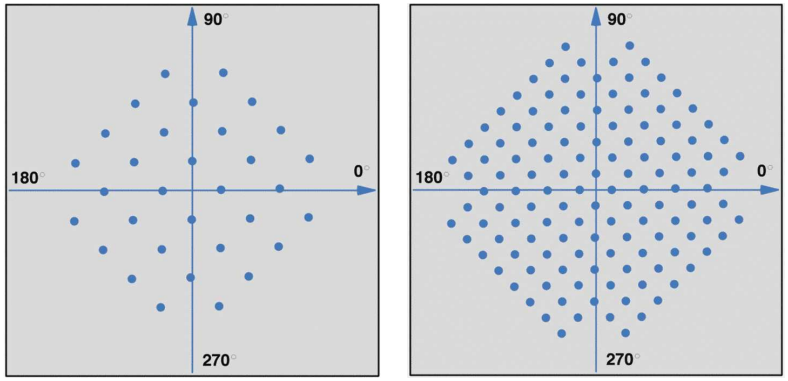
Dialup



Dialup has about 2400Hz bandwidth.

One bit at a time gives 4800bps maximum rate.

We Can Do Better

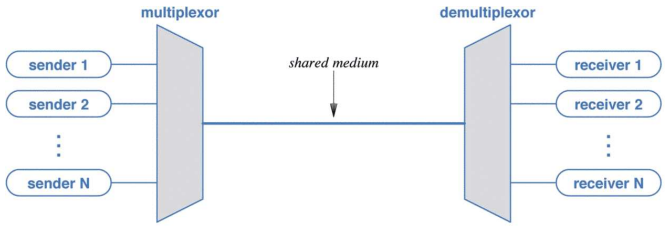


V.32 (32 points) V.32bis (128 points)

V.32bis gets 14,400bps

Multiplexing

Sending multiple streams over a shared medium.



Types of Multiplexing

Frequency Division Multiplexing
Channels

Wavelength Division Multiplexing
FDM for optical fiber

Time Division Multiplexing
Take turns

Code Division Multiplexing
Mathematical combination

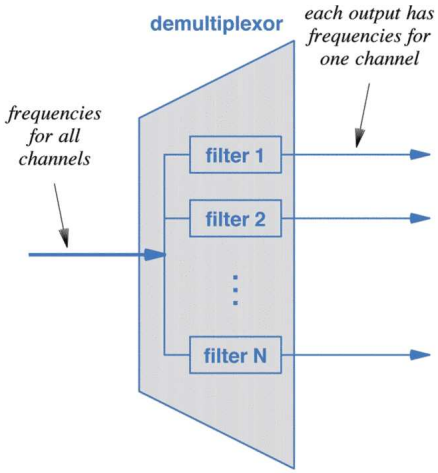
Frequency Division Multiplexing

Signals on various carriers are easily combined.

Filters for each channel (frequency range) separate it out.

A tuner is a single adjustable filter.

Each channel is a virtual connection.



Practical Matters

Channels have a particular width.

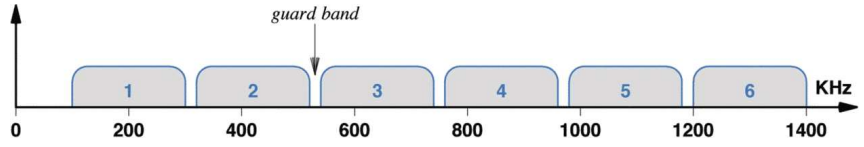
Filters may not be perfect.

Channels have a separation
Avoids interference.

Guard band

For Instance

Channel	Frequencies Used
1	100 KHz - 300 KHz
2	320 KHz - 520 KHz
3	540 KHz - 740 KHz
4	760 KHz - 960 KHz
5	980 KHz - 1180 KHz
6	1200 KHz - 1400 KHz



Dividing a Channel

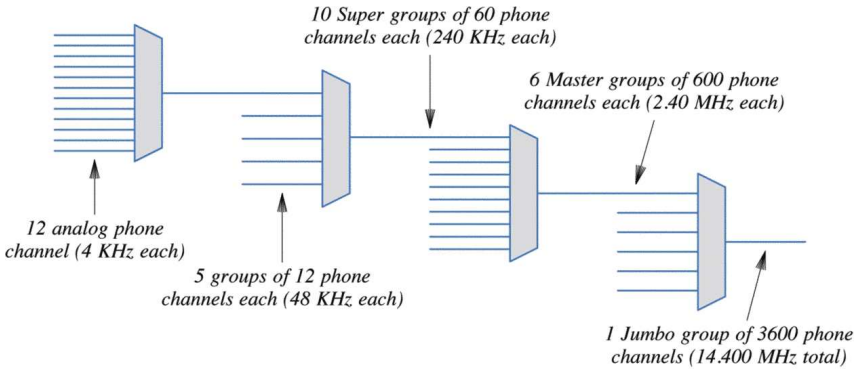
FDM can be used to re-divide a channel.

Subchannels

Provide additional bandwidth.

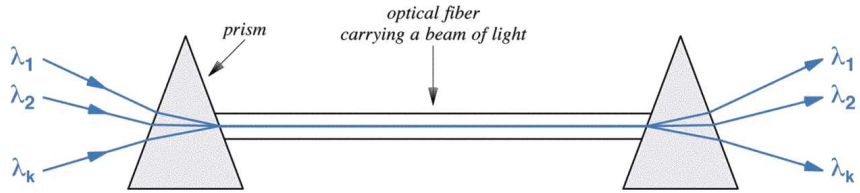
Provide redundancy for error correction.
Send the same data on multiple subchannels
See which one works best

A Multiplexed Channel May Be Multiplexed

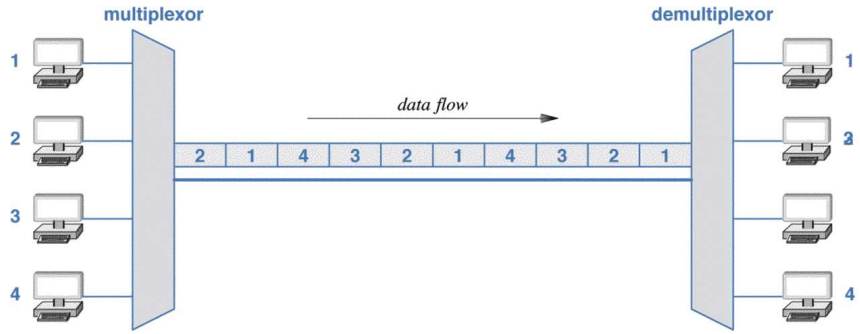


Wavelength Division Multiplexing (WDM)

Same idea up in lights.



Synchronous TDM



Synchronous TDM

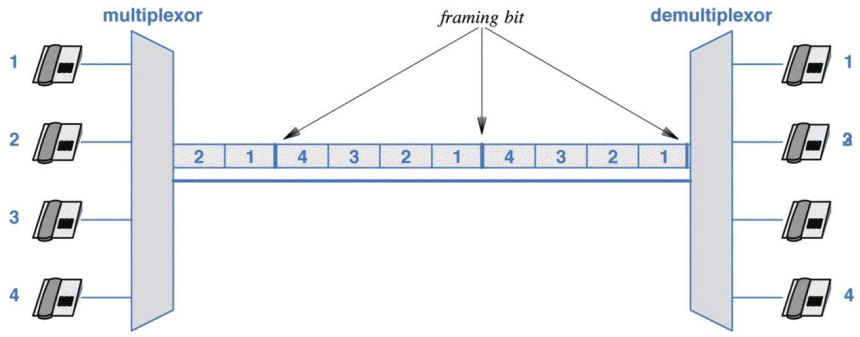
Used for digital phone calls.

Framing channel is added which sends one bit each round.

Receiver simply makes sure it is sending alternating 1 and 0.

Keeps clocks synchronized.

Framing Channel



Synchronous TDM, Etc.

Of course, TDM-multiplexed channels may be multiplexed again.
TDM or otherwise.

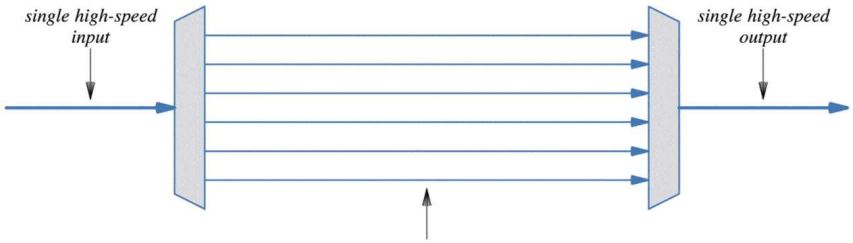
Statistical TDM

Skip blocks when sender has nothing to say.

Add a block ID so the receiver can reconstruct.

Save time unless senders are rarely silent.

Inverse Multiplexing



Creates a higher-capacity channel from several of lower capacity.

Code Division Multiplexing

Senders have ID numbers which we represent with 1 and -1.

IDs are *orthogonal*, meaning their dot product is zero.

1010 1100

$$(1,-1,1,-1)\cdot(1,1,-1,-1) =$$
$$(1\times 1)+(-1\times 1)+(1\times -1)+(-1\times -1)=0$$

Code Division Multiplexing (cont)

Multiply (cross product) the data by each sender code.

011 101

$$(1,-1,1,-1)\times(-1,1,1) =$$
$$((-1,1,-1,1),(1,-1,1,-1),(1,-1,1,-1))$$

$$(1,1,-1,-1)\times(1,-1,1) =$$
$$((1,1,-1,-1),(-1,-1,1,1),(1,1,-1,-1))$$

Code Division Multiplexing (cont)

Add the two products together

-1	1	-1	1	1	-1	1	-1	1	-1	1	-1
1	1	-1	-1	-1	-1	1	1	1	1	-1	-1
0	2	-2	0	0	-2	2	0	2	0	0	-2

Transmit the sum numbers as combined signal.

Should allow some scaling.

Code Division Multiplexing (cont)

Multiply by the code again.

$$(1,-1,1,-1)\cdot$$
$$(0,2,-2,0),(0,-2,2,0),(2,0,0,-2)$$
$$=(0-2-2+0),(0+2+2+0),(2+0+0+2)$$
$$=(-4,4,4)$$

011

Other sender code should produce similar results.

Code Division Multiplexing (cont)

Used in cell phones

No more efficient than TDM

But don't have to wait for your turn

Reduces delay

Connecting Homes and Small Businesses

Downstream: To the customer
Upstream: From the customer

Narrowband: up to 128 Kbps
Dialup *Leased circuit modems*
Fractional T1

Broadband: higher, but the boundary is unclear
DSL *Cable Modems*
Wireless *T1 and higher*

Digital Subscriber Line

DSL varieties

ADSL: *Asymmetric; for residences*
ADSL2: *Faster version*
SDSL: *Symmetric; for businesses with servers*
HDSL: *Faster version, for close-by businesses*
VDSL: *Very-high bit rate; proposed*

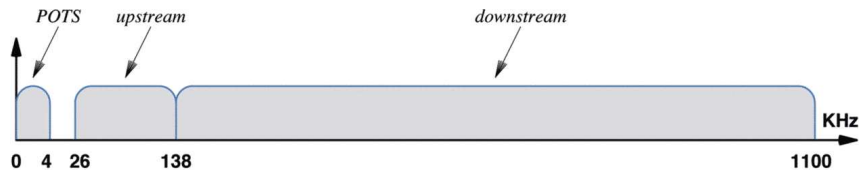
ADSL

High data rates to home.
Max: Download 6.144 Mbps, 640Kbps upload.

Asymmetric refers to fact the the
upload and download rates differ

Operates over standard twisted pair.

Does not interfere with ordinary calls.



ADSL Frequencies

Uses frequencies above the audio channel.

Different lines support different frequencies.
interference
geometries

ADSL is adaptive – chooses frequencies that work.
Discrete Multi-Tone Modulation (DMT)

DMT

286 frequencies (subchannels)
255 download, 31 upload.

4.1325 KHz intervals, above 26K
well above 4 KHz calls

Ends probe each available frequencies to see what works.

Noisy subchannels are modulated less densely.

Actual speed depends on how many channels can be used and how well.

ADSL Speeds

Speeds depend on line conditions.

Up: 32–640Kbps

Down: 32Kbps–8.448Mbps

A splitter separates the phone frequencies for extra protection

Cable Modems

Download

Frequency multiplexing: Channels assigned to a neighborhood.

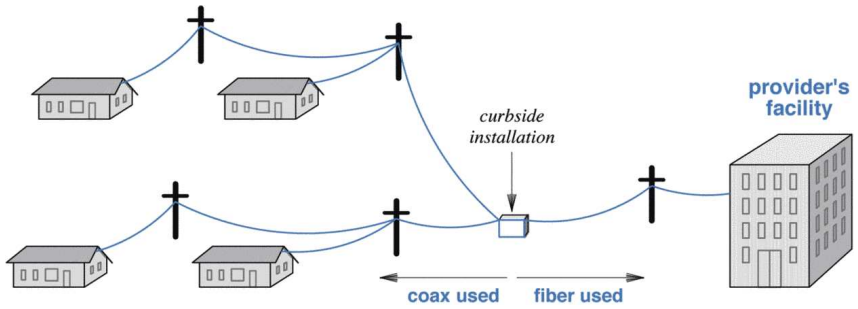
Time multiplexing within the frequency:
Receivers get all — discard messages destined elsewhere.

Upload

Neighborhoods share one 6 MHz channel by time multiplexing.
Data relayed from there over fiber.

Some early systems required a dialup connection for upload.

Hybrid Fiber Coax



Cable TV is one-way.

The box and fiber return link are added to provide networking service.

Cable Frequencies

5 to 50 MHz for upload.

50 to 450 MHz used for TV.
6 MHz per channel.

450 MHz to 750 MHz for download.

Speed

Up: 512 Kbps
Down: 52Mbps

Generally shared between some groups of customers.

Actual speed depends on how many of those are active and what they're doing.

More Fiber

FTTC: Fiber to the curb.
Provide extra services, such a telephone.

FTTB: Fiber to the building.
Faster upload for businesses.

FTTH: Fiber to the home.
Deliver extra data, such as more entertainment channels.

FTTP:Fiber to the premises.
Either of last two.

CMTS

Cable Modem Termination System.

Head-End Modem: At the cableco.
Tail-End Modem: At the subscriber.
A bank of head-ends at the cable office.

Tail-ends communicate with head-end.

Tail-ends do *not* communicate with each other.

DOCSIS

Data Over Cable Service Interface Specification.

Specifies the data format over the cable.
Open industry standard.

Broadcast Satellite

Broadcast with station addresses, LAN style.

Originally, upload by phone.

Now, uploads through the satellite.

Wireless Broadband Services

3G cell phone services

Data transferred through the cell phone network

WiMAX
IEEE 802.16

Operates at frequencies similar to WiFi

Signals are directional
Subscriber units must be aimed correctly.

Requires multiple base stations

Services to Providers

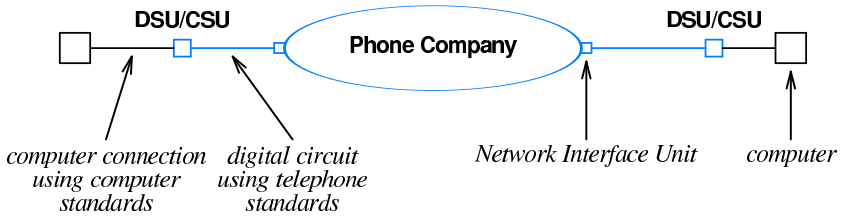
Access technologies solve the *last mile problem.*

ISPs and large businesses need higher-capacity connections.
core technologies

These are often leased from telephone companies.

DSU/CSU

Adapts telephone standards to computer standards.



CSU talks to the phone side.
DSU talks to the computer side.
NIU is the edge of phone-company-owned equipment.

Data Rates

Standard circuits

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

0.064 Mbps is 8000 8-bit samples per second.

T1 Data Rates

T1 is 1.544 Mbps.

24 calls is $0.064 \times 24 = 1.536$ Mbps

The extra 0.008 is control overhead.

There is also a minimum rate at which you data must contain 1's.

You generally cannot get 1.544 Mbps.
Can always get 1.344 Mbps; maybe better.

Many odd complications.

More Speed

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
STS-192	OC-192	9,953.280 Mbps	155520

OC = Optical Carrier

Suffix of C means no inverse multiplexing.

SONET

A standard for frames over STS circuits.

All frames are the same size.

Frame size depends on line speed.
8000 samples/sec is 125μ-sec/sample.

Each frame takes 125μ-sec to transmit.

OC-1: 51.840 Mbps $\times$ 125 μ-sec = 6480 bits = 810 bytes
OC-3: 155.520 Mbps $\times$ 125 μ-sec = 19440 bits = 2430 bytes

Simplifies synchronous multiplexing.

Sources

Comer, *Computer Networks and Internets*
(Our beloved textbook.)

`http://www.faculty.iu-bremen.de/birk/lectures/PC101-2003/14usb/FINAL%20VERSION/usb_protocol.html`

`http://www2.rad.com/networks/2000/usb/maintxt.htm-#Physical_Layer`

http://www.techfest.com/networking/wan/t1.htm

http://searchnetworking.techtarget.com/sDefinition/-0,,sid7_gci548418,00.html

Wikipedia WiMAX article