CS 436

Episode 08

The Physical Layer

—

Data Encoding

Administrivia

Now on reserve in the library — one copy each of

- *"Business Data Communications" by Stallings (UWD 1609)*
- *"Computer Networking" by Kurose & Ross (UWD 1443)*

Reading from "Business Data Communications"

- *Chapter 8: Data Communications Fundamentals*
- *Sections 10.1-10.4 Transmission Efficiency*

Optional Reading

- *Cable — it's not just for TV,* IEEE Spectrum, May 1999
- *A Second Wind for Wiring,* IEEE Spectrum, Sept 1999

Midterm scheduling survey: Administrivia → Schedule Survey

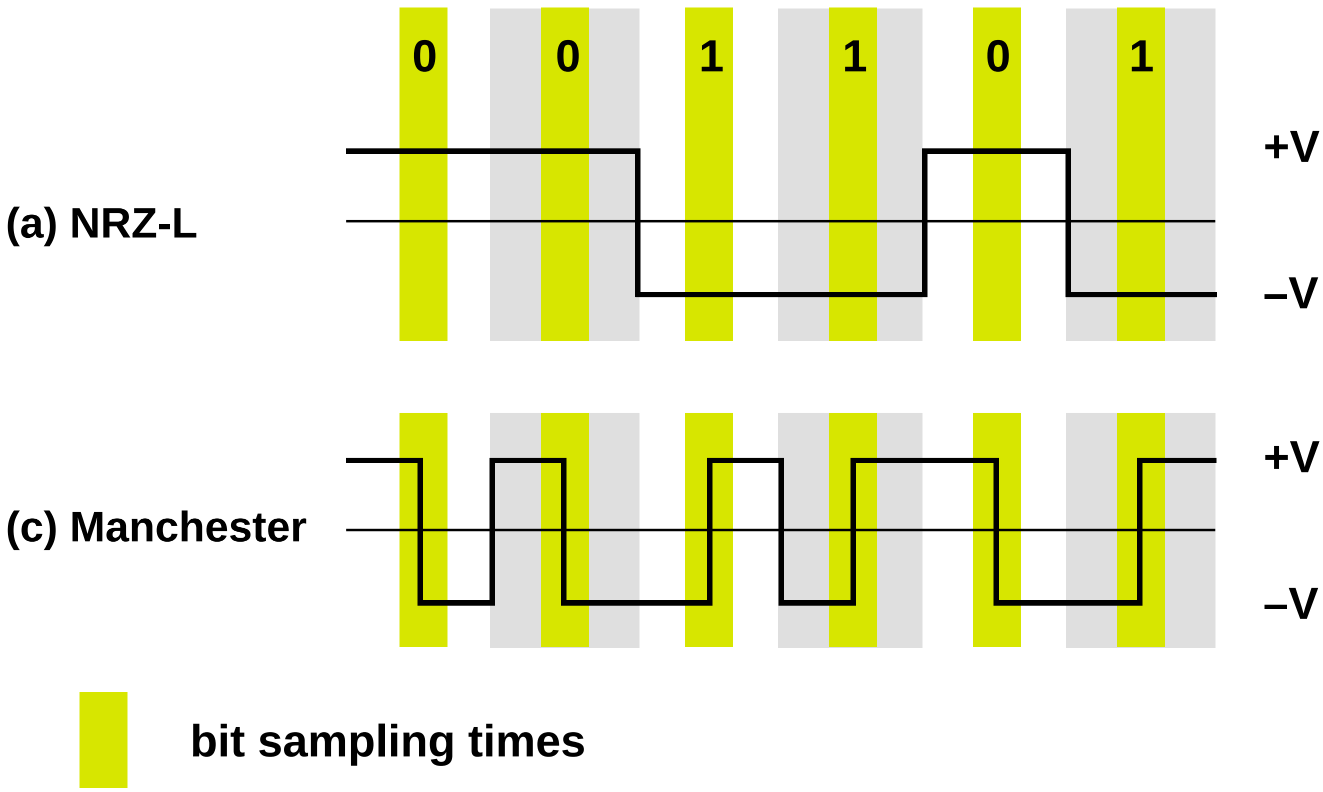
Goals for this episode: to understand

- *how bits are physically represented and transmitted (cont.)*
  - esp when using analog media
- *multiplexing multiple signals into a single channel*
  - Rogers and Bell ADSL at the physical layer

TA office hours

- *Bright: 2-4 pm Fridays in DC 3321 (the Networking Lab)*
- *Wayne: 3-4 Tuesdays in DC 3511*

Digital Encoding of Digital Data



Non Return to Zero Level (NRZL)

common inside PC's

easy to engineer

can loose sync over long runs of 0 or 1 on a data link

Manchester

used in ethernets

always a transition at bit sampling time
— effectively a clock signal

down for 0

up for 1

transition as needed at beginning of bit interval

See text for others

Digital Encoding of Analog Data

Pulse Code Modulation (PCM)

periodically sample the analog signal

sampling rate ≥ twice max frequency in signal

EG voice data

phone network transmits below 4,000 Hz

so 8,000 samples per second, 8 bits / sample

yields 64 Kbps of data

(actually done — telephone trunks are mostly digital now)

EG a CD

44,100 samples per second

16-bit samples (65,536 levels) = two bytes / sample

two channels for stereo

$2 \times 2 \times 44{,}100 = 176$ KB/sec — a 1x CD drive

Analog Data, Analog Signals

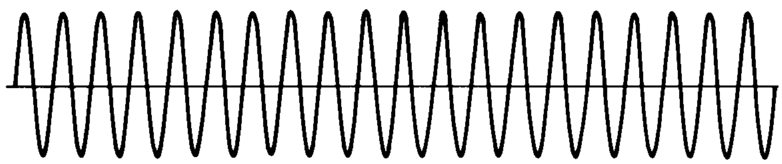
08

Modulating

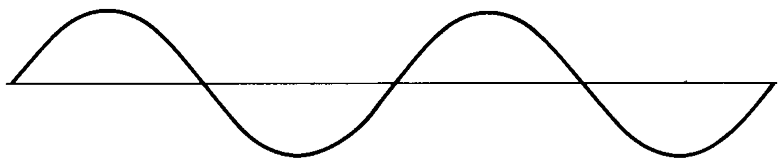
a relatively high-frequencey “carrier signal”

by a relatively low-frequency “data signal”

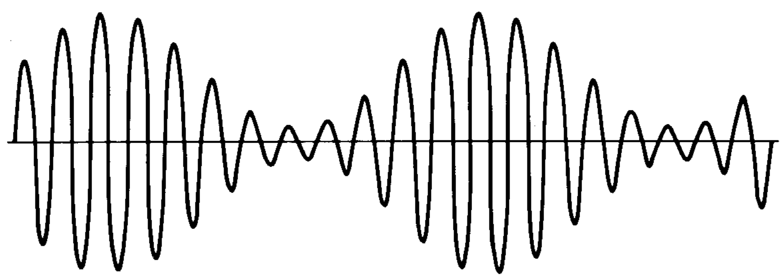
The signals



Carrier

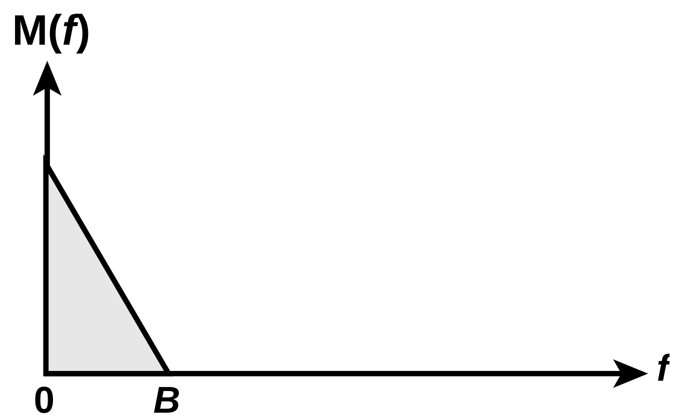


Data



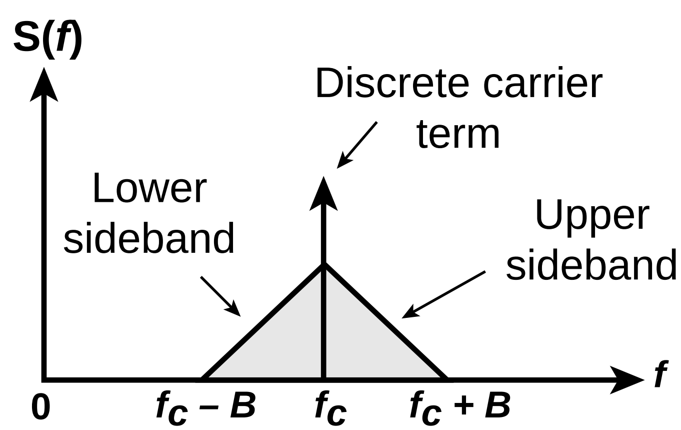
(1+Data) × Carrier

If a signal with Fourier coefficients M(f)



Spectrum of modulating signal

is used to modulate the carrier f_C, we get



Spectrum of AM signal with carrier at f_C

Qualitatively the same story for frequency & phase modulation

Why do this?

perhaps you simply can't transmit at the base frequency

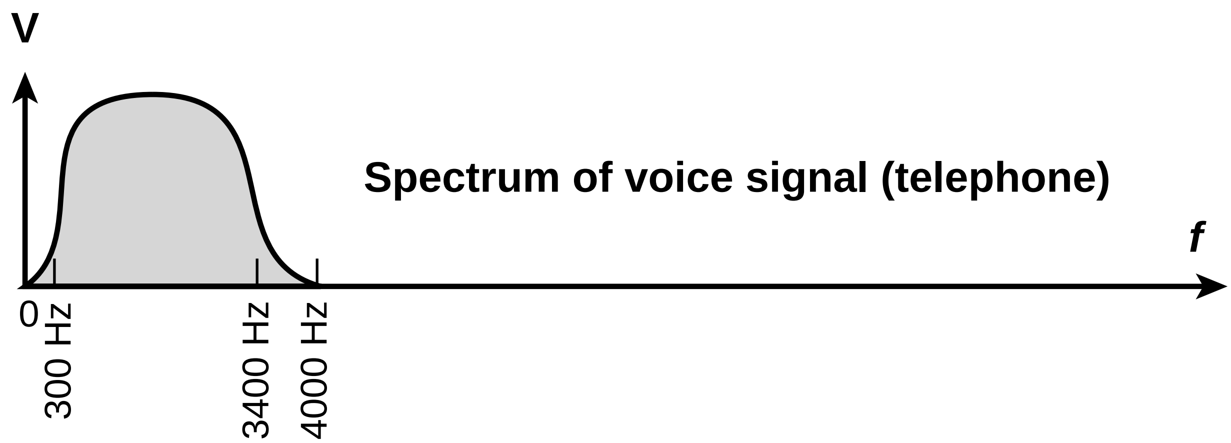
perhaps to share a single channel among several signals

eg transmit multiple telephone calls simultaneously

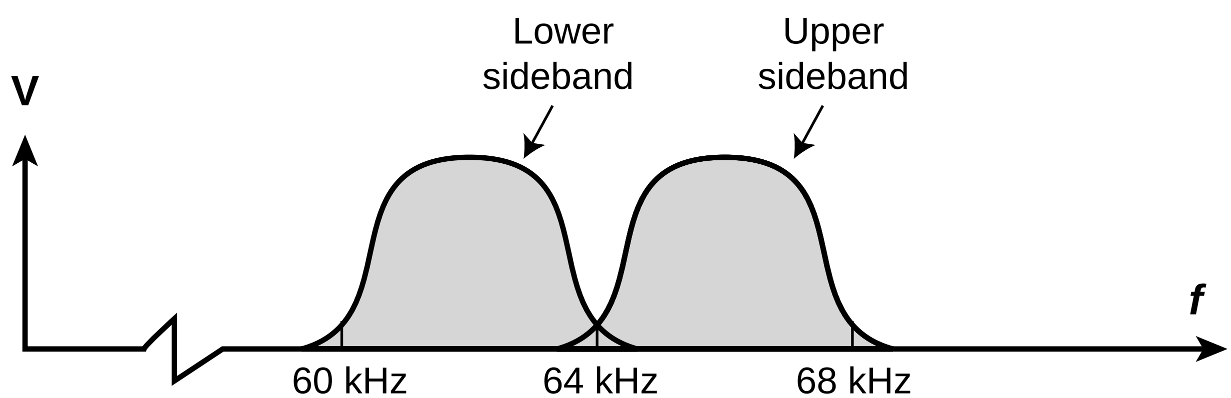
eg AM radio, FM radio, television

— "frequency division multiplexing" (FDM)

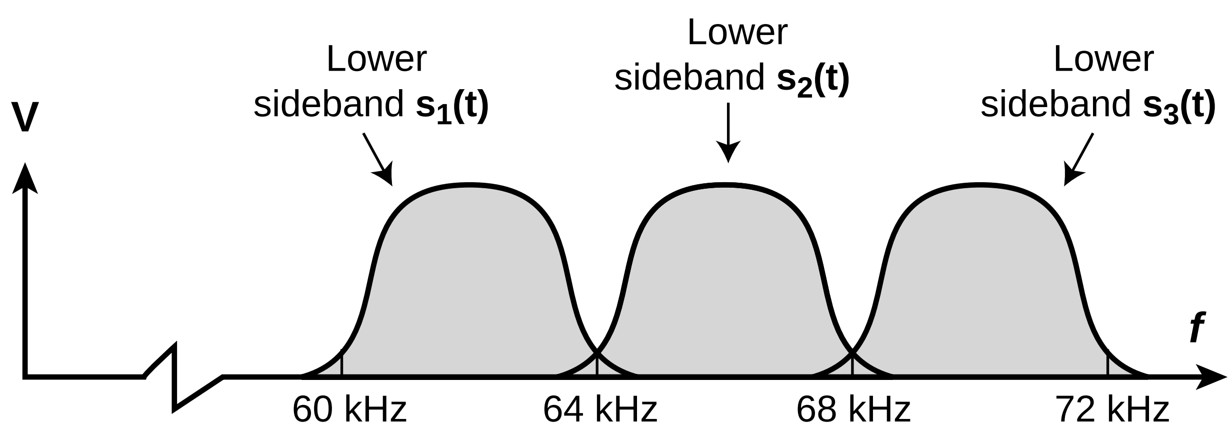
FDM of Three Voiceband Signals



Spectrum of voice signal (telephone)

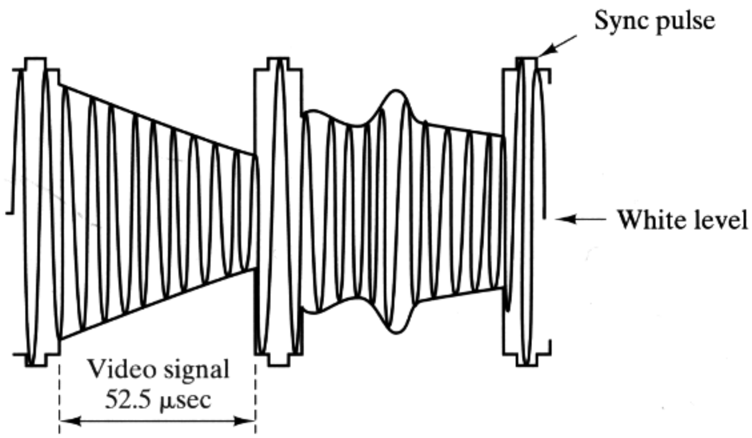


Spectrum of voice signal modulated on the carrier 64 kHz

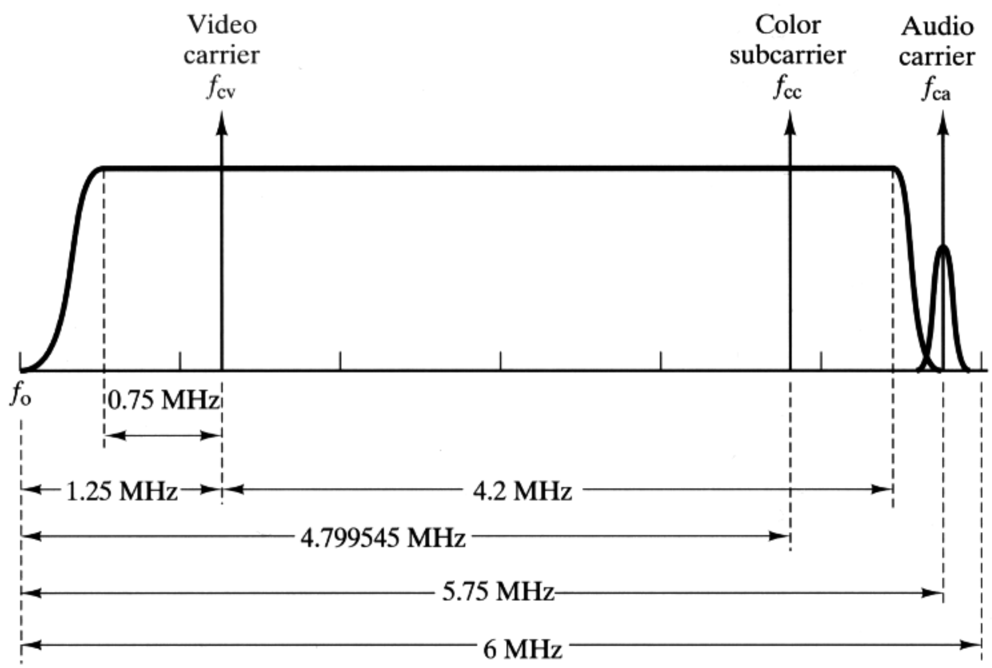


Spectrum of a composite signal using subcarriers at 64 kHz, 68 kHz, and 72 kHz

Encoding for One Cable TV Channel



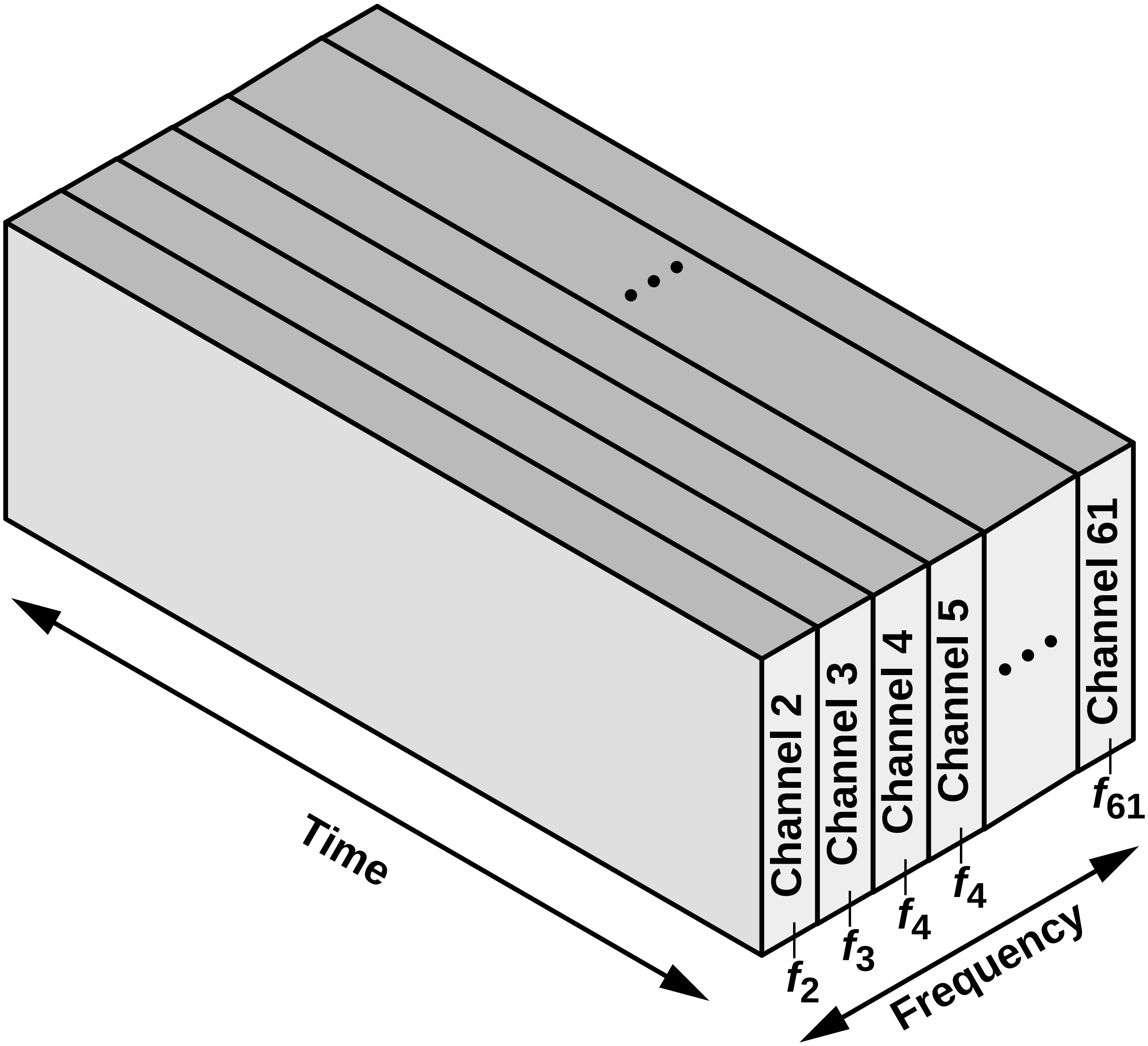
(a) Amplitude modulation with video signal



Traditional cable TV

- *"thick" coax cable*
- *roughly 400 (500?) MHz of bandwidth*
- *one channel requires about 6 MHz of bandwidth*
- *so you have room for roughly 60 (75?) channels*
  - starting at 54 MHz (channel 2)
  - [Rogers offers channels 2 through 78]

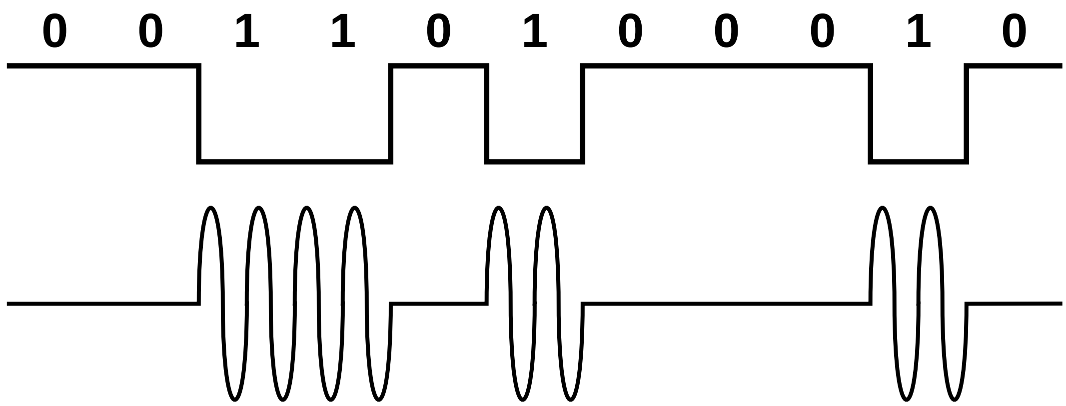
FDM for Cable TV



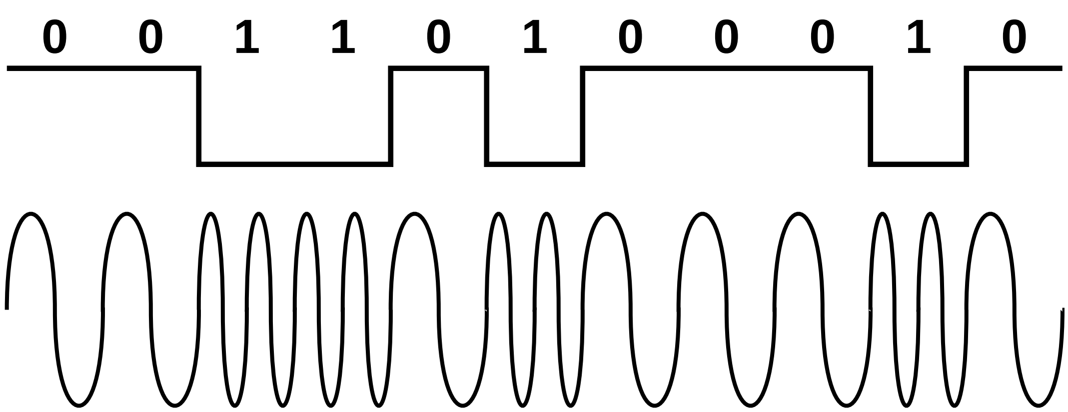
Cable TV frequency allocation

Channel	*Frequency Band*
2	*54 - 60 MHz*
3	*60 - 66 MHz*
...	
61	*444 - 450 MHz*

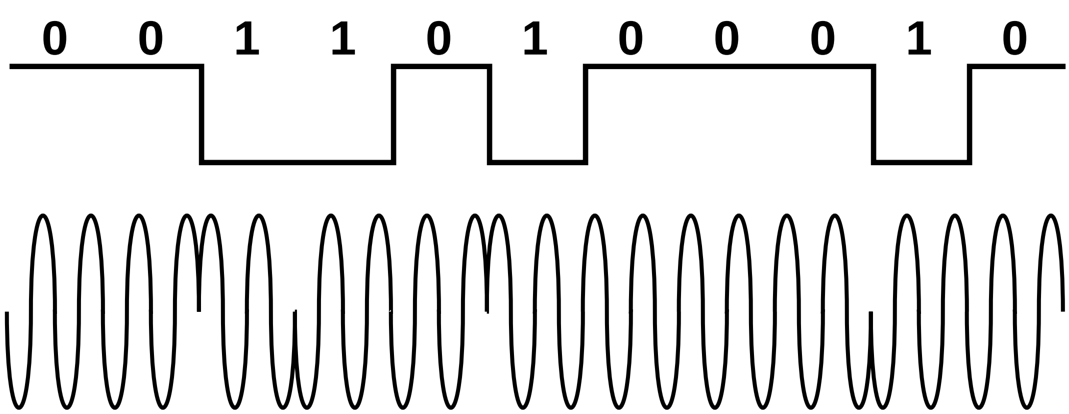
Analog Encoding of Digital Data



Amplitude-shift keying



Frequency-shift keying



Phase-shift keying

Voice modems

designed to transmit 300–3,600 Hz

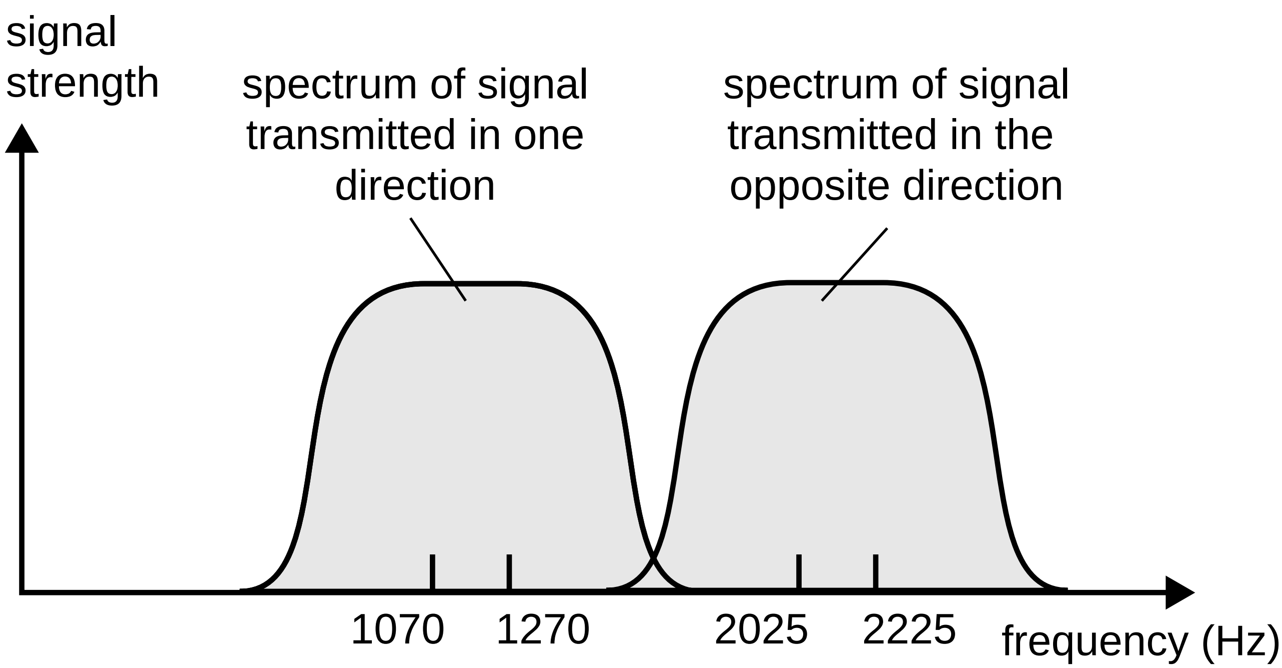
predated computer communications

Bell 108 (103?) modems (300 bps?)

frequency shift encoding

1170 Hz ± 100 Hz for 0 and 1 in one direction

2125 Hz ± 100 Hz for 0 and 1 in the other direction



9600 bps is achieved by combining phase and amplitude encoding

data is processed 4 bits at a time

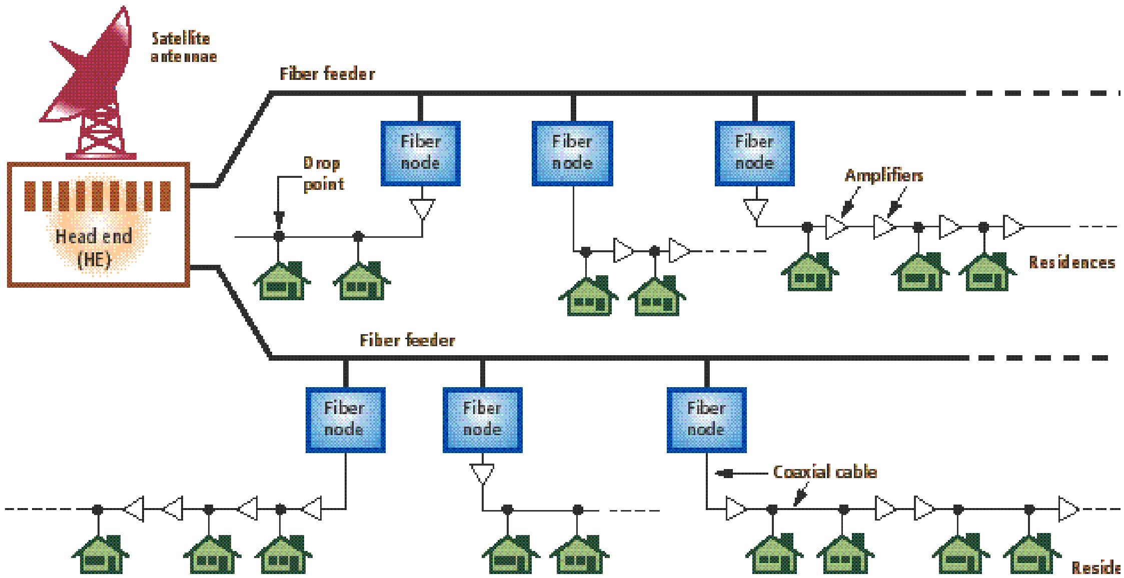
phase changes of 0°, 90°, 180°, 270° at either of 2 amplitudes

phase changes of 45°, 135°, 225°, 315° at either of 2 amplitudes

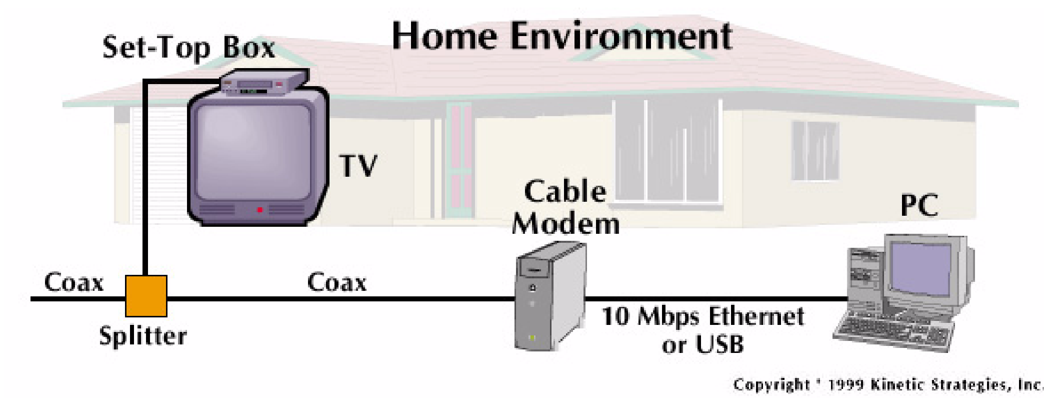
“Quadrature Amplitude Modulation” (QAM)

Higher speed modems use something called “Trellis coding”

Hybrid fibre-coax distribution[1]



At each house[2]



1. IEEE Spectrum, May 1999, *Cable—It's not just for TV*
2. http://www.cabledatacomnews.com/cmic/cmic1.html

Cable Modems (2)

One channel is reserved for “downstream” (incoming) data

at speeds up to 30 Mbps using 64 QAM

ie 6 bits of data per signal change (baud)
encoded by various combinations of amplitude and phase

“Upstream” (outgoing) data

in a separate frequency band
somewhere between 4 and 42 MHz

at speeds between 500 Kbps and 10 Mbps
using QPSK (phase shift keying)

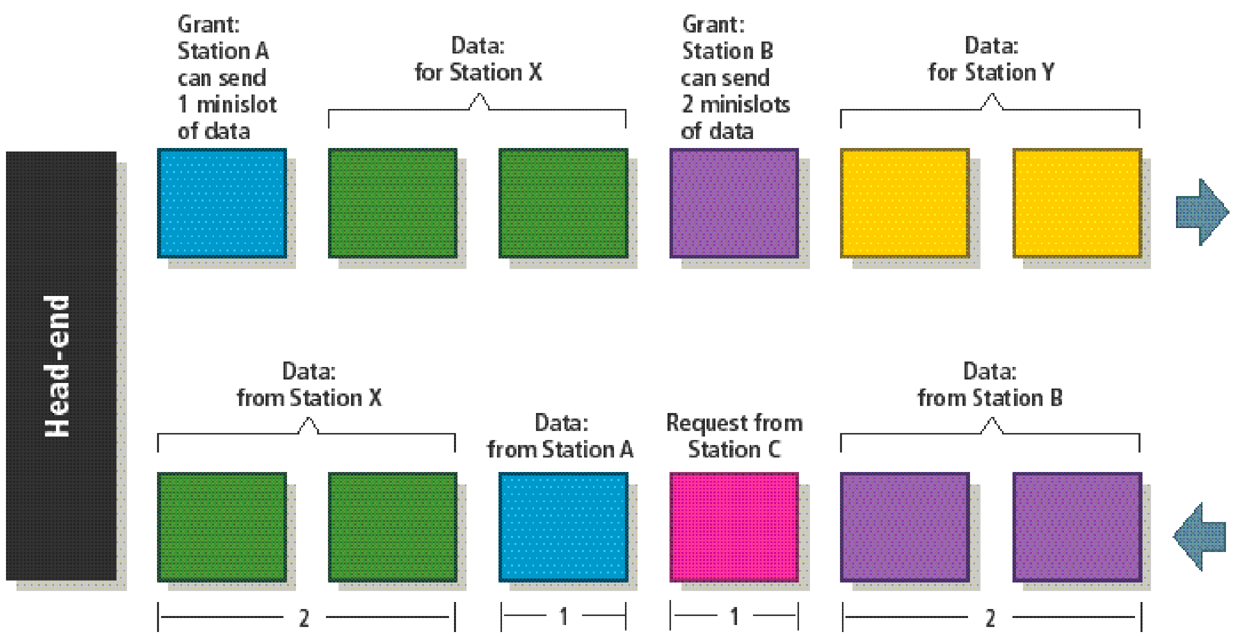
Headend is responsible for multiplexing / demultiplexing

internet traffic

cable TV

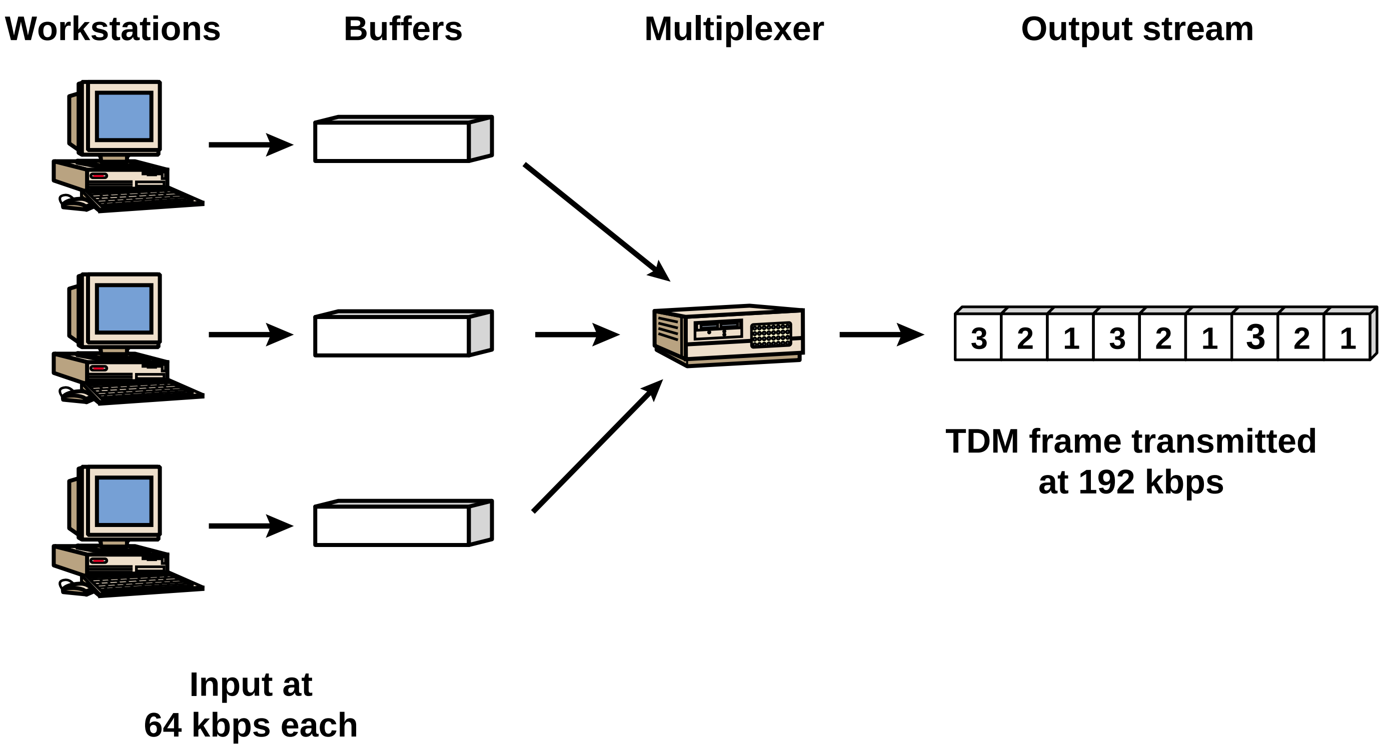
internet telephony (not much used ... yet)

Access is shared using “Time Division Multiplexing” (TDM)



“Pure” TDM

each node takes its turn in a regular, repeating sequence



eg telephone trunk lines

the DS-? hierarchy of standard data rates / frame structure which multiplex “circuit-switched” phone calls

Possible inefficiency

one workstation may have nothing to transmit
but a slot / frequency band is reserved for it anyway

Possible solutions

statistical multiplexing

CSMA/CD

“Carrier Sense Multiple Access with Collision Detection”

need for buffering, danger of overflow

adds overhead of identifying whose data is whose

Rogers Cable In Particular

Although the cable modems we currently use are capable of speeds up to 10 Mbps we have throttled the cable modems back to 3 Mbps downstream (to the home) and 400 Kbps upstream (to the Internet). This allows us to maintain a more consistent level of network performance.

Chris W., Rogers@Home Electronic Support Group, Mar 99

ADSL (Asymmetric Digital Subscriber Line)[1]

Everyone has a phone

it only uses 4 KHz of bandwidth for voice (0 - 4000 Hz)

but the wire has ~ 1 MHz of usable bandwidth

So the phone company

multiplexes/demultiplexes voice and data on your phone line at the central office

and rents you a modem that does the same thing at your house

Downstream

occupies the 250 KHz to 1 MHz frequency band

1.5 - 9 Mbps, depending on line quality

up to 5.5 km

Upstream

occupies the 25 KHz to 200 KHz frequency band

16 Kbps to 1 Mbps

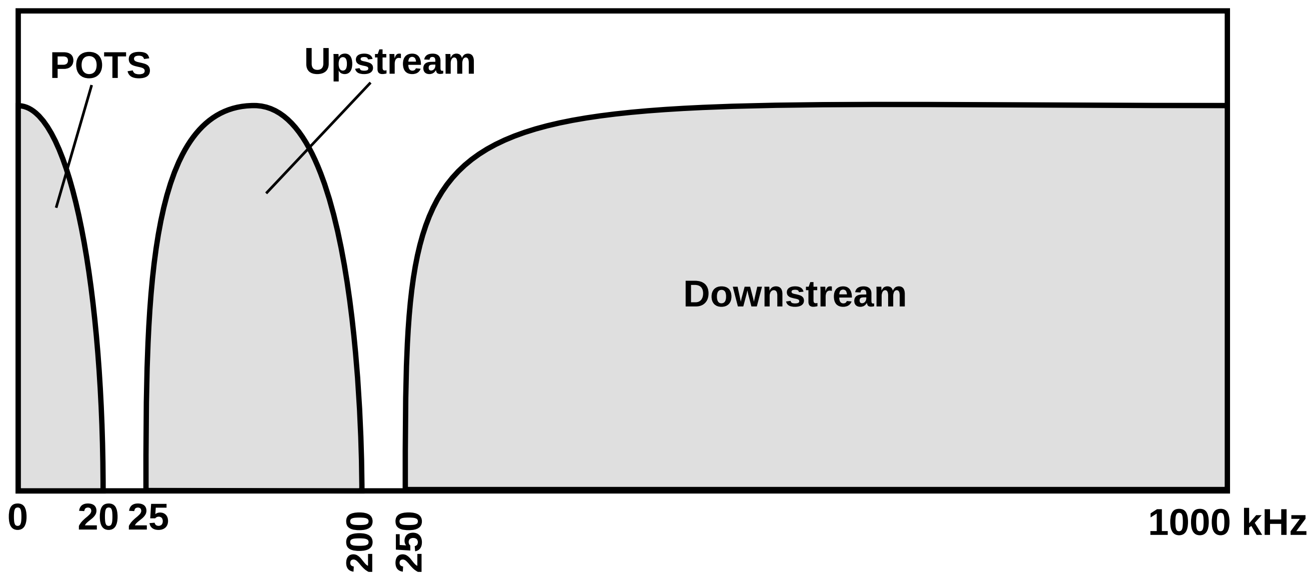
FDM is used WITHIN each stream: “discrete multitone”

subdivide 250 KHz - 1 MHz into 4 KHz subchannels

test on initialization, decide bit rate per subchannel (0-60 Kbps)

1. http://www.adsl.com/adsl_tutorial.html. See also *A Second Wind for Wiring*, IEEE Spectrum, September 1999.

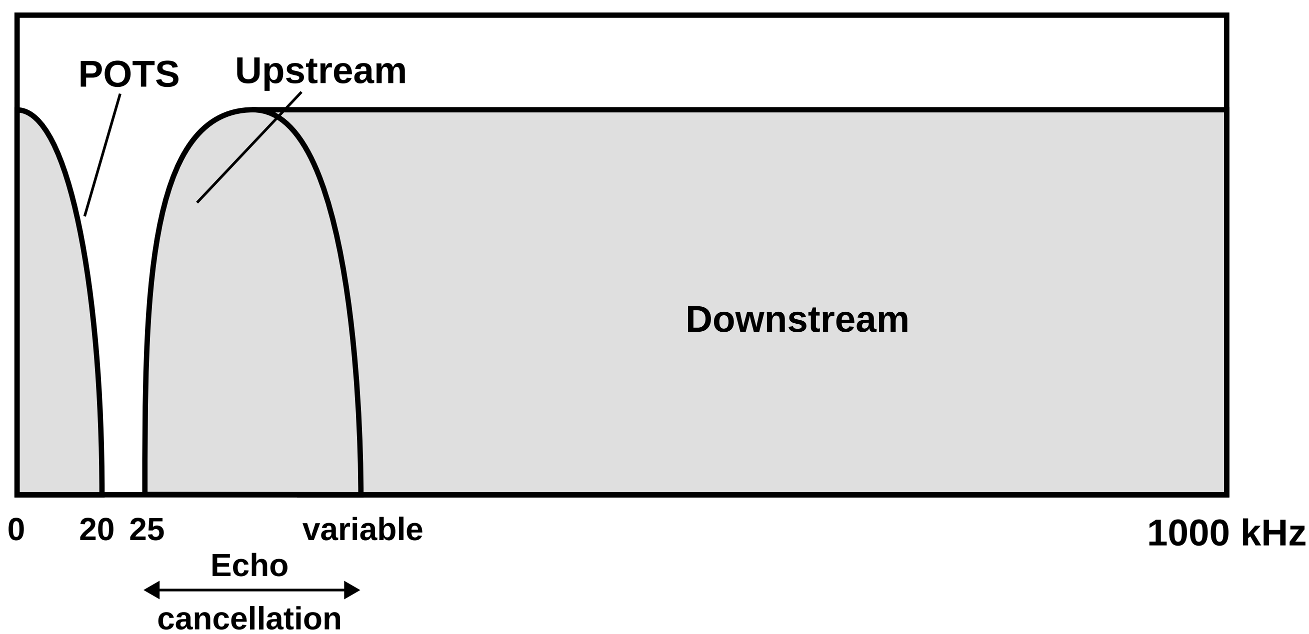
ADSL via FDM



POTS

Plain Old Telephone Service

Adding “echo cancellation” to increase downstream bandwidth



Echo cancellation

sender subtracts its own signal from what’s on the wire yielding the other party’s signal (!)

Comparing Cable and ADSL Internet Access

Is the medium in place?

stringing the wire or cable is expensive
(that's why we don't all have fibre...)

Bandwidth

coax wins

— or does it? cable access is shared...

Security

ADSL wins

— it's not shared, so packets can't be sniffed

— can be tapped, but that's much more work

Nominal asymmetry is roughly the same (8 to 1)

both assume you're surfing

not hosting a web site

Real Life — Rogers vs Bell (March 2000)

Measured at about 6 am

Time to ping my home from a university machine (average of 50 trials)

Rogers:	56 ms
Bell:	64 ms

Download speed (Netscape installer from Netscape)

Rogers:	305 KB / sec
Bell:	96 KB / sec

Upload speed (to a university machine, namely Oscar.math.uwaterloo.ca)

Rogers:	44 KB / sec
Bell:	13 KB / sec

Measured at about 7:30 pm

Time to ping my home from a university machine (average of 50 trials)

Rogers:	214 ms
Bell:	69 ms

Download speed (Netscape installer from Netscape)

Rogers:	224 KB / sec
Bell:	96 KB / sec

Upload speed (to a university machine, namely Oscar.math.uwaterloo.ca)

Rogers:	40 KB / sec
Bell:	13 KB / sec

Comments

Cable is a “shared access medium”
ADSL is not (at least to the local office)

Latency

comparable when lightly loaded

cable latency deteriorates more under (presumed) load

ADSL should not deteriorate at all (on the subscriber loop)

Bandwidth

cable bandwidth deteriorates during high-usage times of day, but is “always” much superiour to ADSL’s.

Advertised performance

Bell quotes 120 KB/sec incoming and 15 KB/sec outgoing

Rogers quotes 384 KB/sec incoming and 50 KB/sec outgoing

Nobody guarantees anything

Prices are comparable if you have Bell long distance service

Bell provides a DYNAMIC IP address
Rogers provides a STATIC IP address (changing?)

Both disable Windows file sharing, but not Mac file sharing

Both appear to make about the same number of people unhappy

Synchronization

How does the receiver know when to sample the signal?

circuits inside a PC share a common timing signal

but what about circuits at two ends of a comm link?

how do they synchronize their clocks?

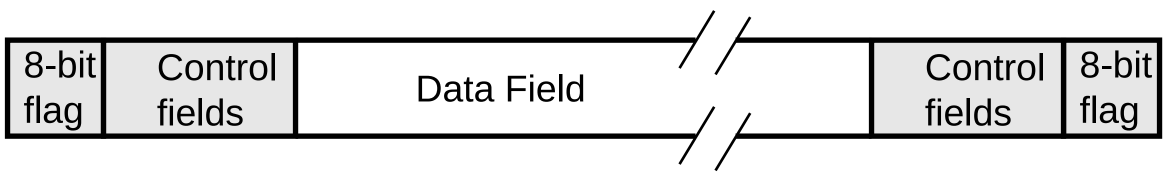
how do they KEEP them synchronized?

Synchronous communication

embed a clock signal in the data — eg Manchester encoding

special leading bits to identify the beginning of a data block

generic example “frame”



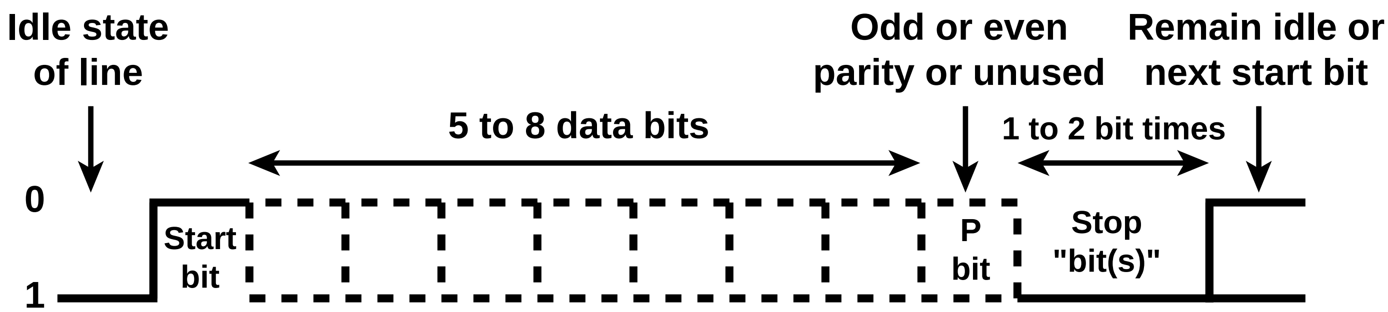
Asynchronous communication

don’t try for long-term / constant synchronization

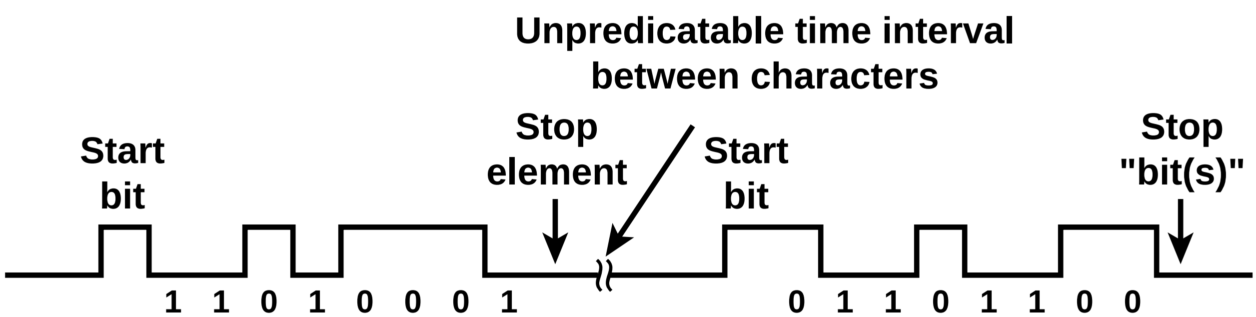
instead, synch at the beginning of a data block

keep data blocks small so clock drift doesn’t matter

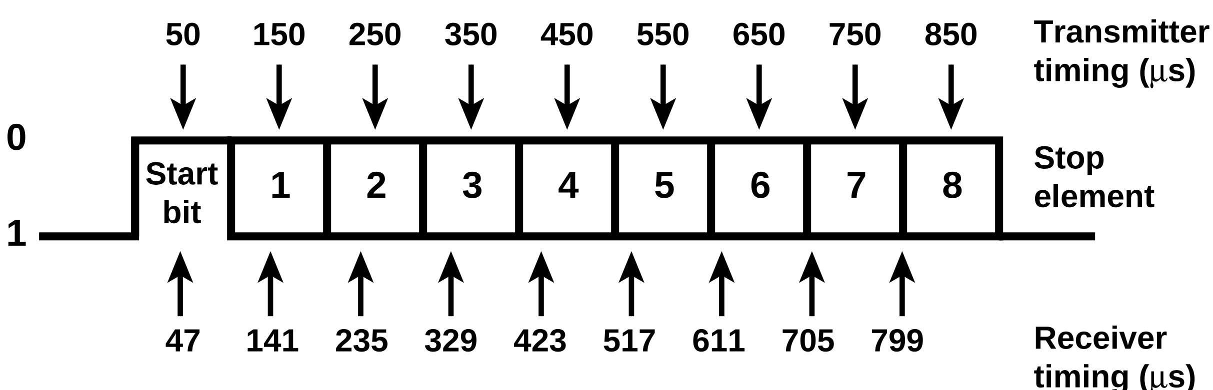
Asynchronous Transmission



(a) Character format



(b) 8-bit asynchronous character stream



(c) Effect of timing error