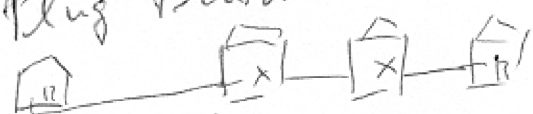
Circuit Switched,
~~Pack~~ (Message Switched,)
Packet Switched.

Tanenbaum p 147 – on.
(you will read this <u>before</u> Oct 07:
Feel free to read earlier but no <u>need</u>
to read it earlier: good to see it
twice.).

Circuit switched: (this is how the course <u>used to</u>
start!).

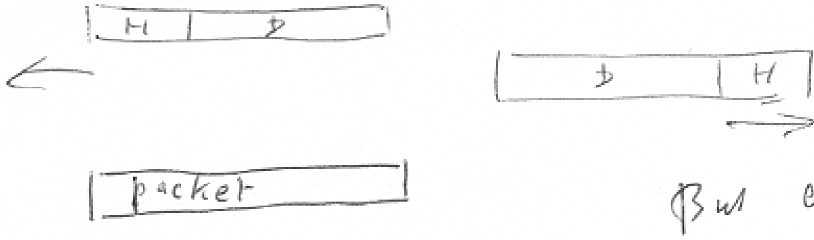
tip&ring

originally: few wires all the way,
(Analog). Plug Board

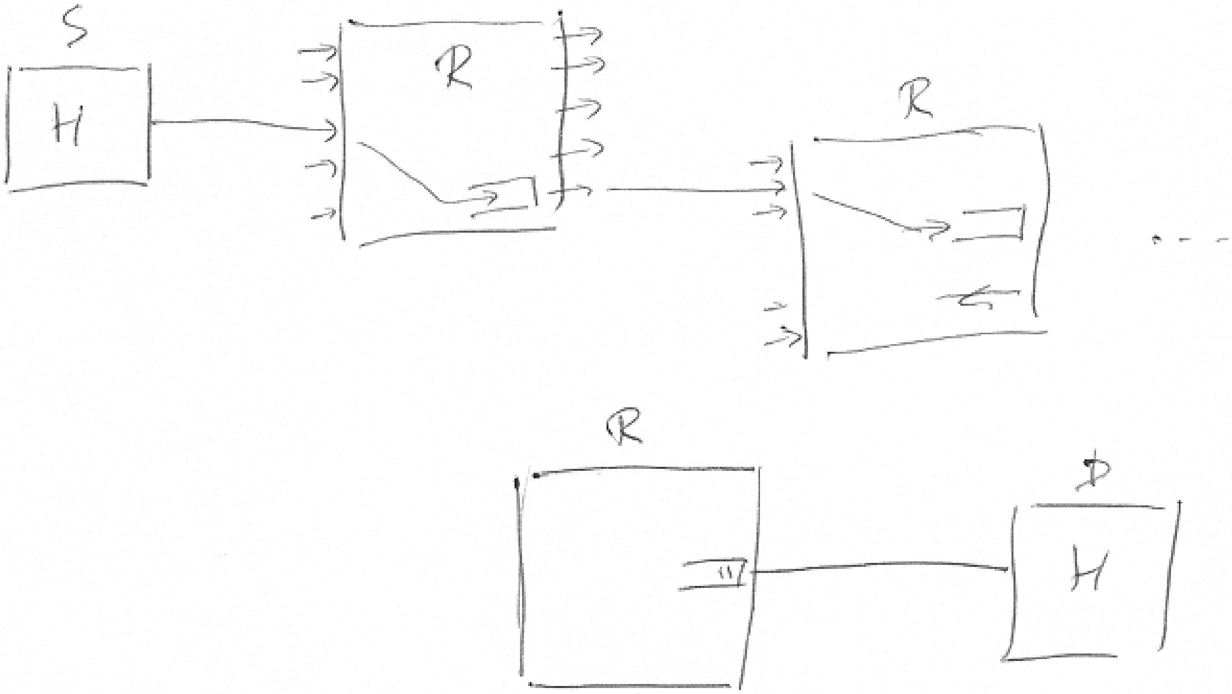


Later: <u>Bit stream</u> end-to-end, ~~...~~

Message Switching: "Torn Tape office".
Packet Switching: "Store and Forward". ←



But a *message* can span many *packets*.



Packet Switching.
Store and Forward.

Two flavors:

(1) "Full Address" (name?) *Router*

(2) "Virtual Circuit". *Switch*

Full Address:

Every packet contains a "full address" of the destination.

Every <u>router</u> (gateway, ...) looks at the address and finds

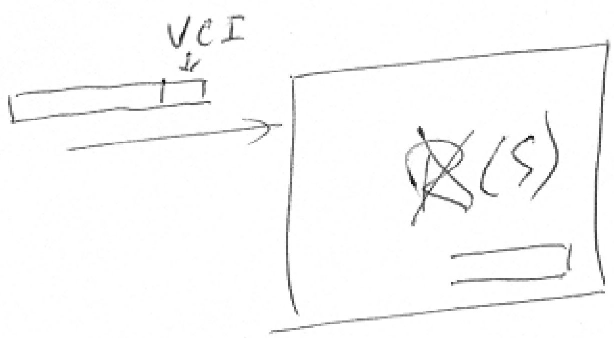
" ~~other routers~~ " ~~closer~~ to destination,

" other router, directly reachable (layer 2), that is "closer to" destination".

Virtual Circuit: <u>Switch</u>

Packet contains "virtual circuit identifier".

Wrong side!



~~Router~~ Switch: <u>this</u> VCI on <u>this</u> input port becomes <u>that</u> VCI on <u>that</u> output port.

Full address : Router.

Routing Table }
Forwarding Table }

Packets with following destination address
go to out on interface ... to
next hop ....
(Shorthand needed!) (the classes of addresses)

~~Q~~ Virtual Circuit : Switch.

Forwarding Table.

Packets with ~~following~~ this VCI in
~~following~~ this input port
get ~~following~~ that new VCI, go out on
~~following~~ that output port.

No Shorthand : complete list of
(port * VCI).

Full ~~a~~Address:

if network changes (link up, down, router up, down, etc) routing tables can be modified in flight.

Stream of packets can continue

Robustness.

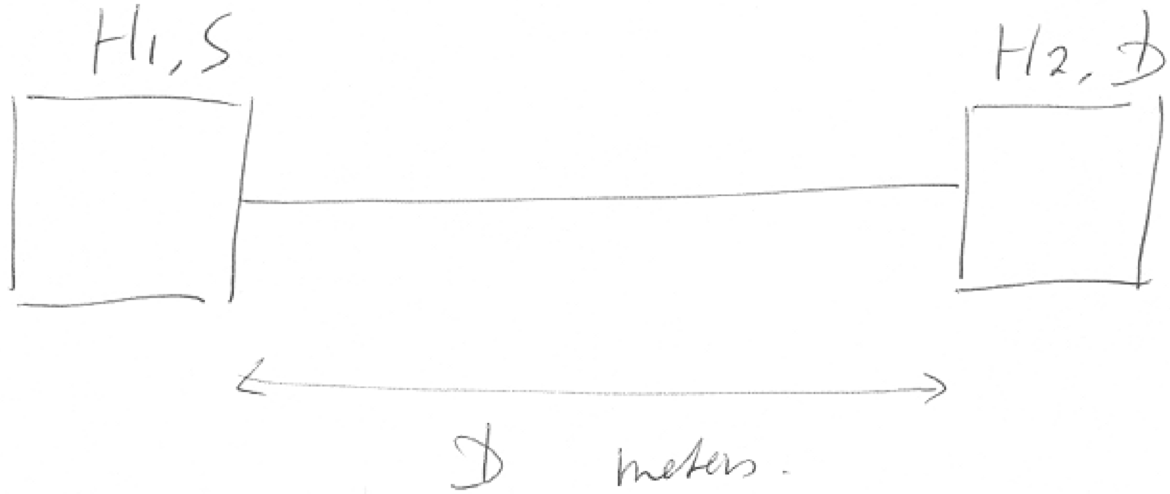
No overhead for set-up of VC.
Multiple packets of same "flow" do not need to follow the same path.
Can arrive out of order.

Virtual Circuit.

~~Routing~~ Forwarding Tables can not be modified in flight.
~~Router~~ Switch or link down ⟹ all VCs on it down.

Overhead for set-up.
All packets same path: in order delivery.

Packet Switching : Delay.



Bandwidth : B bits/sec.

Packet size : S.

Delay =

$$\frac{S}{B} + \frac{Dist}{(.7 * c)}$$

c: speed of light.

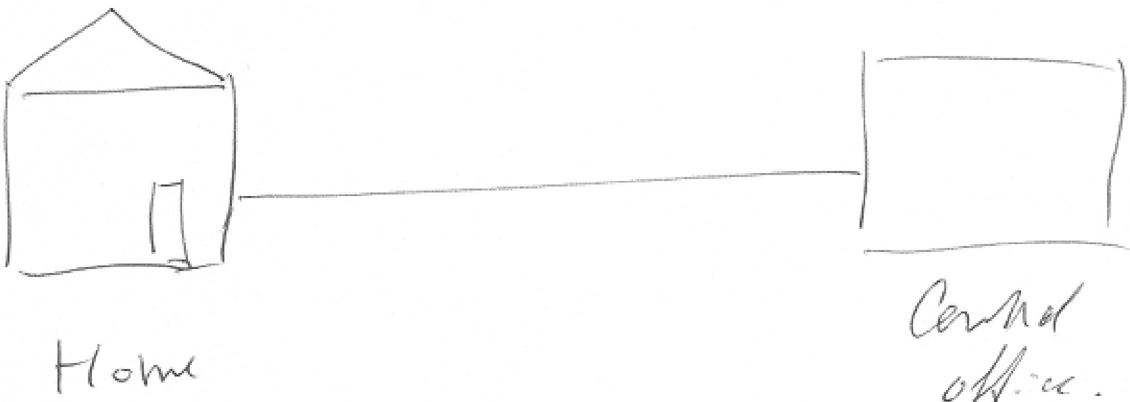
(.7*c): "typical" speed of signal on conductor (copper wire, coax, optical fiber).

Serialization Delay + Propagation Delay.

Transmission Delay =
Serialization Delay + Propagation Delay.

Examples:

(1) 1500 byte packet,
32 kb/sec. modem.
4.375 ~~5~~ mile (7 ~~8~~ km) distance to C.O.



Serialization delay:

$$\frac{1500 * 8}{32{,}000} = \frac{12{,}000}{32{,}000} = .375 \text{ sec.} = 375 \text{ msec.}$$

Propagation Delay: $\frac{7}{(.7) * 300{,}000} = \frac{1}{30{,}000} =$ .000033 sec

$= .033$ msec. $= 33\ \mu$sec.

Prop. Delay << Serialization Delay.

Other way of looking at it:

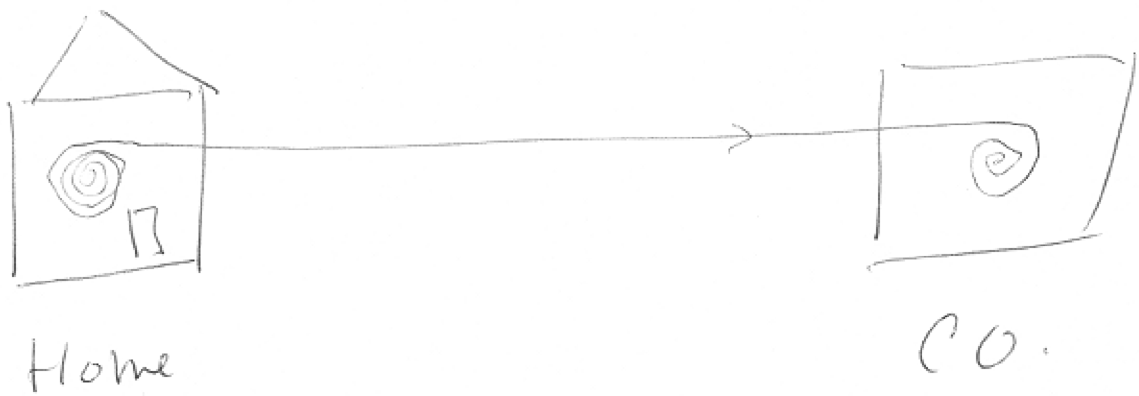
At 32 kbit/s, a 1500 byte packet is

$\frac{1500 * 8}{32,000}$ seconds long

= 375 m sec. long.

= .375 * (.7) * c = 78,750 km long.

= 49,219 miles long



Most of packet is
"at home" or "in CO".
only tiny part is underway.

Other case:

1500 byte packet.

45 Mb/sec.

NY → San Francisco (2900 miles)
4640 km.

Serialization delay:

$$\frac{1500 * 8}{45,000,000} = \frac{12,000}{45,000,000} = .000266 \text{ sec.}$$
$$= .266 \text{ msec.}$$
$$= 266\ \mu\text{sec.}$$

Length of packet

$$.000266 * .7 * 300,000 = 56 \text{ km.}$$

Propagation delay:

$$\frac{4640}{(0.7) * 300,000} = .02209 \text{ sec} = 22.09 \text{ msec}$$
$$= 220.9\ \mu\text{sec.}$$

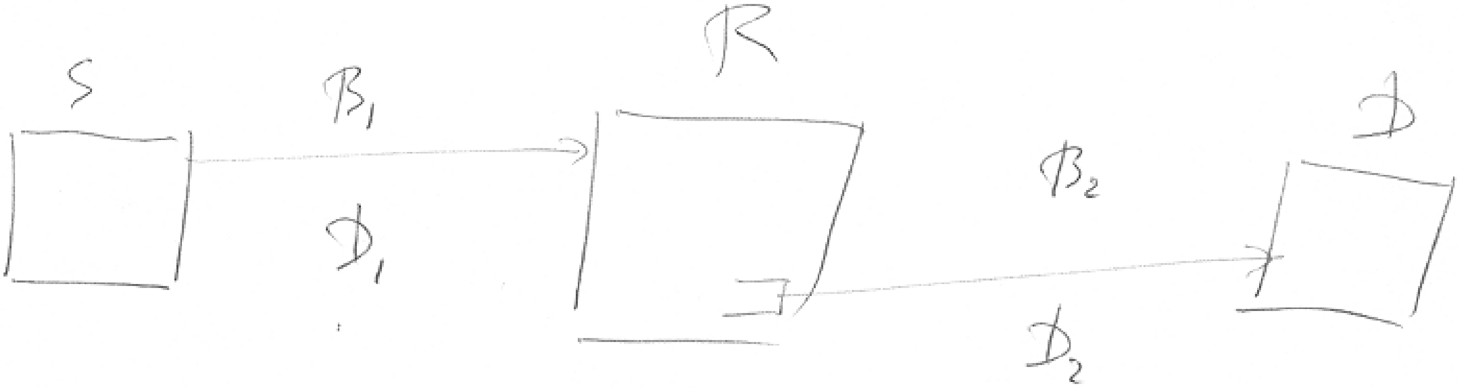
$$\frac{4640}{56} = 82.8$$ packets underway (one way).

$\boxed{\text{Bandwidth-Delay product}}$

Even worse with ~~geostat~~ geostationary satellites.

More on delays:

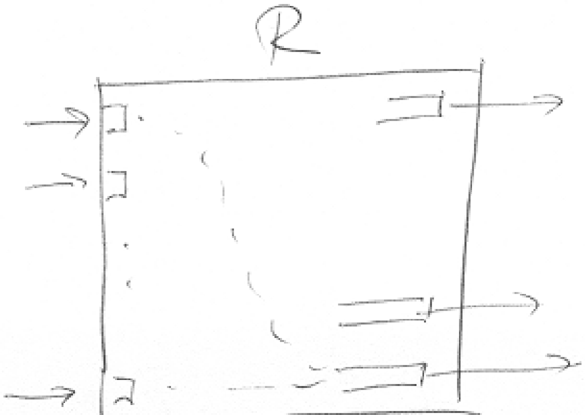
Packet Size S



Delay:

$$\frac{S}{B_1} + \frac{D_1}{(.7*c)} + \text{Router Delay} + \frac{S}{B_2} + \frac{D_2}{.7*c}.$$

Router Delay: Processing Time
+ Queueing Delay.



Still a good conceptual model.

Extreme Case of Circuit Switched

Circuit Switched Telephony.

Tanenbaum, pp 140 – 143.

DSϕ : 8000 bytes/sec = 64,000 bits/sec.

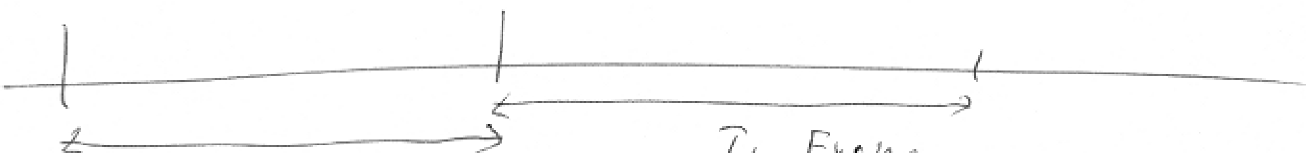
Actually, each <u>byte</u> is
7 bits for the customer (ie information)
1 bit for the network. (Signalling).

1 DSϕ channel carries <u>1</u> telephone call.

Q1: How? Later. (Soon).

Q2: Why 8000 bytes/sec? Later.

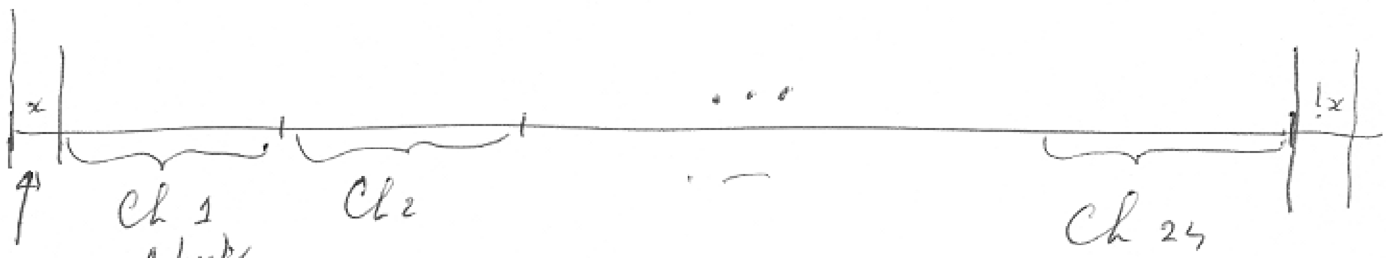
DS1 (or T1) 24 DSϕ channels.



T1 Frame T1 Frame. etc.

$\frac{1}{8000}$ sec = .125 msec
= 125 μsec

Each T_1 Frame:



1 bit
Framing
information
(101010 ...)

The 24 bytes of the 24 DS ϕ channels are <u>byte interleaved</u>.

T_1:

$8000 * (1 + 24 * 8) = 8000 * (1 + 192) = 8000 * 193 =$
1,544,000 bits/sec = ~~1,552,000 bits/sec.~~

$8000 * 192 =$ 1,536,000 bits/sec.

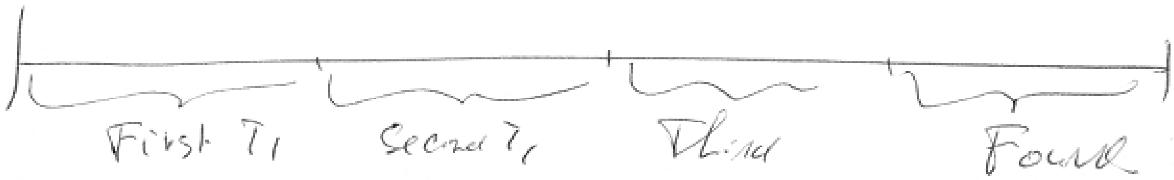
T_1: 1.5 Mb/sec. (remember this).

Until here 09/08/2003

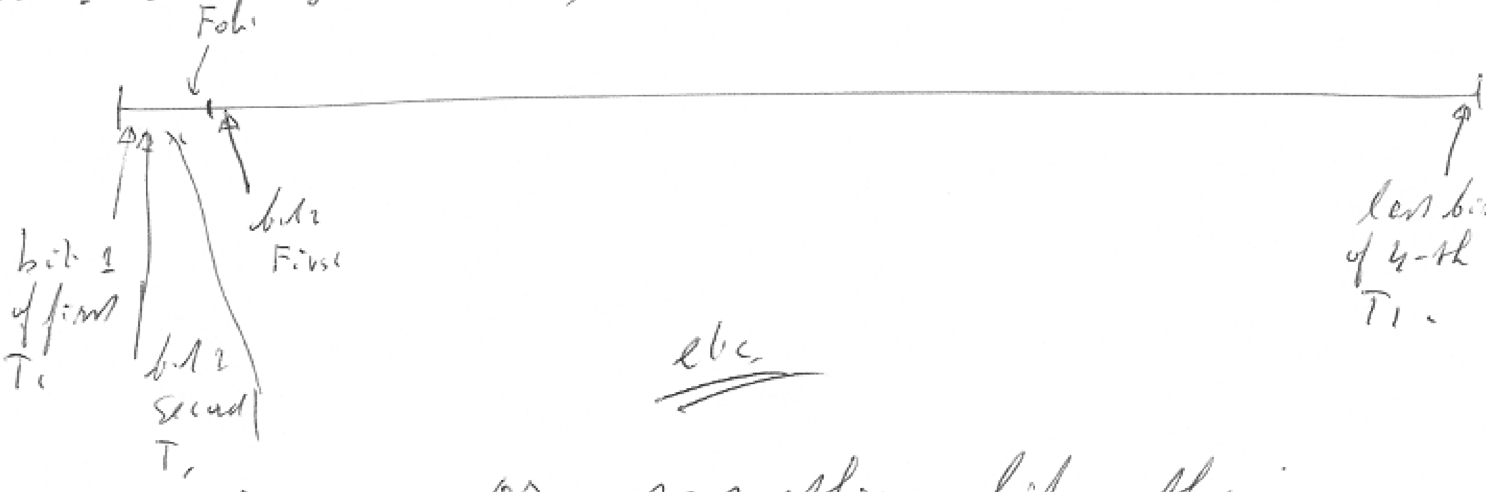
T2 : 4 * T1 + framing bits.

6.312
6.176
236 000 bits/sec.
29.5 bits/(T2 frame).

NOT!



But: (I forget details)



Or something like that:
I forget the details.

Bit-interleaved.

Why Bit-interleaved? Cheaper Equipment.

Ra

DSϕ : 64,000 bits/sec.

T1 : $24 * 64{,}000 + 8000 = 1{,}544{,}000$ bits/sec.
(24 DSϕ + framing) ($\sim$ 1.5)
Byte interleaved.

T2 : $4 * T_1$ + framing $\sim$ 6.312 Mb/sec.

T3 : $7 * T_2$ + framing $\sim$ ~~45 Mb/sec.~~
44.736 Mb/sec
($\sim$ 45)

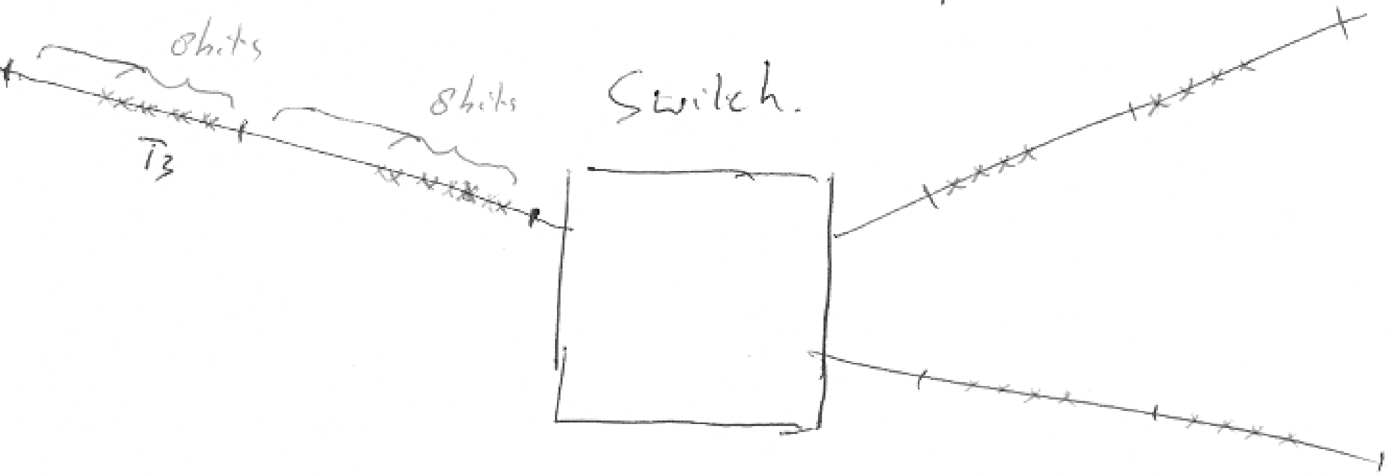
T4 : $6 * T_3$ + framing
$\sim$ 274.176 Mb/sec.

T1, T3
(DS1, DS3) are services you can buy.
Also DSϕ (now)., Also 56 kb/sec.
(leased line).

T2, T4: only inside network.

Ra

Telephone Switching.



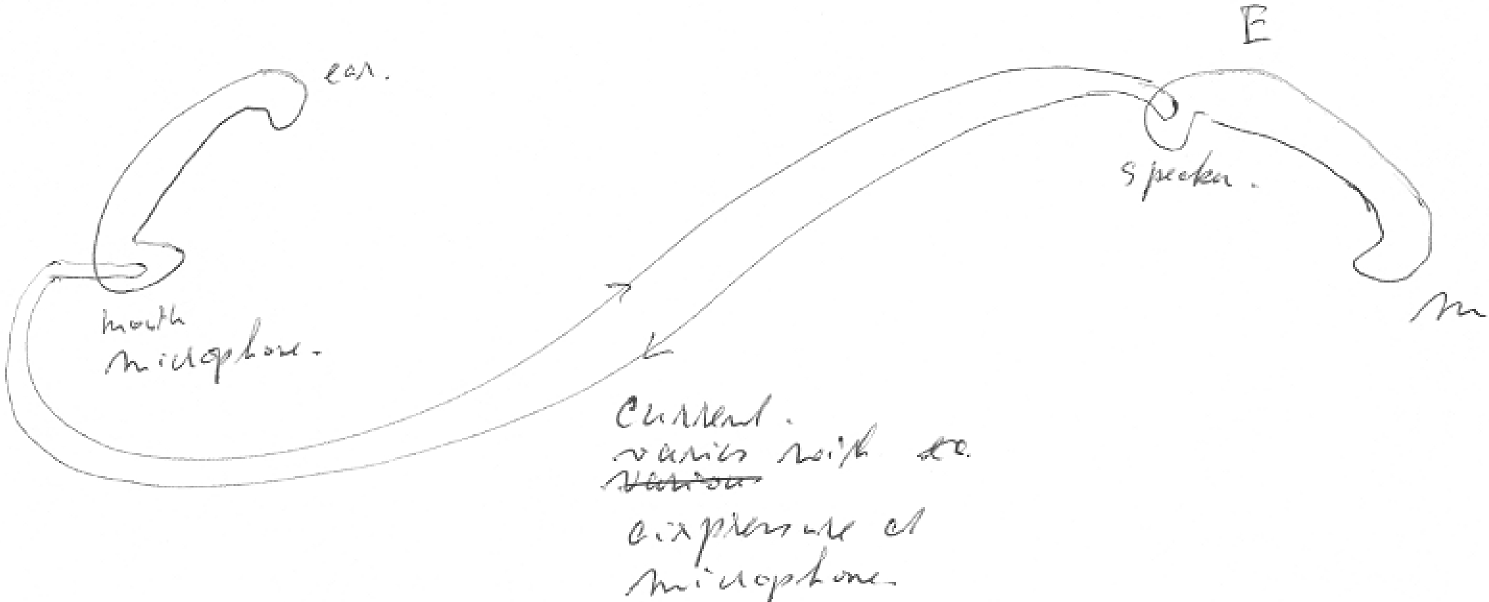
(1) Bits of 1 connection spread-out:
Decreases required speed of switching circuitry.

(2) • Requires bit-level synchronization of all links! ← expensive.

Store and forward:
whether "full address" or "VC":
synchronization between various links no longer required. Cheaper technology.

Analog vs Digital

Olden days:

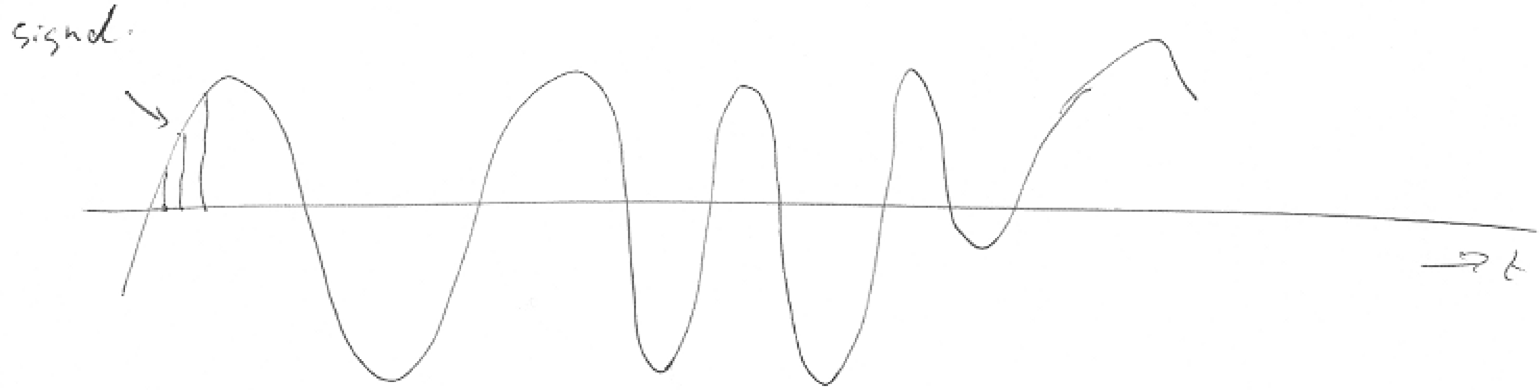


very old: carbon dust microphone (Don't know current technology)

Some time in the sixties or seventies
digital transmission became cheaper, better.

A to D, D to A conversion

How does it work?



8000 times/sec.: sample the signal strength.

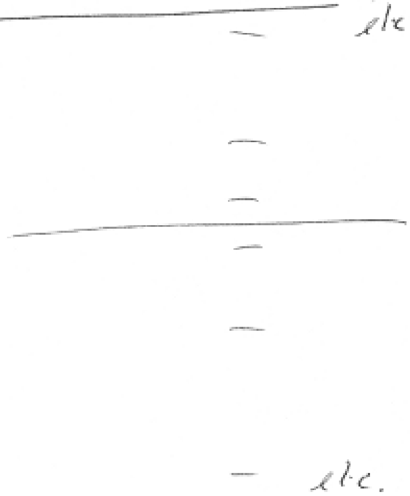
translate into number.

Nonlinear scale. (~ logarithmic).

~~7 bits: 2^7 = 128 levels~~

PCM: Pulse Code Modulation

7 ~~8~~ bits: 2^7 levels
128



Every 128 μsec: 7 bits.

(~~pl~~ (in transmission: plus one signalling bit).

<u>Why</u> 8000 times/sec. ?

Instead of (e.g.) 14,000 times/sec. 4 bits ?

$4 * x =$ ~~64000~~ 56,000

$x = \frac{56,000}{4} =$

$12 * x = 56,000$ or 4666 times/sec. 12 bits ?

$x = \frac{56,000}{12} =$

etc.

Nyquist, ~ 1924.

To be discussed later. "8000 times/sec is right".

"Fourier Analysis". Tanenbaum, p 89.

PCM : 8000 times/sec.

7 bits.

56,000 bits/sec.

~~[illegible]~~

Differential PCM.

Transmit <u>differences</u> between successive representations.

16 levels enough: ~~4 bits~~

8000 times/sec 4 bits

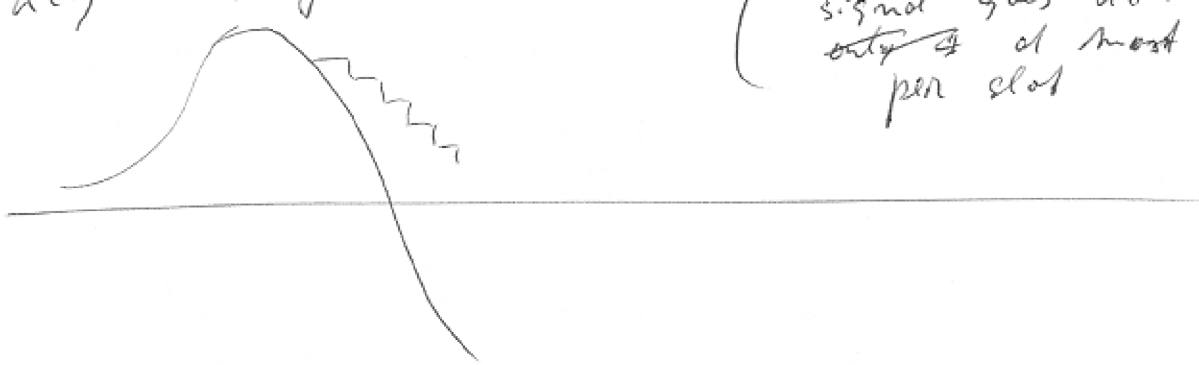
$8000 * 4 = 32{,}000$ bits/sec

Used in cellular phone. ? Tanenbaum, p142

Delta Modulation: $+1$ -1. 8000 bits/sec.

May "Lag".

(the transmitted signal goes down ~~only 1~~ at most 1 per slot).



Fancy Coding Schemes:

Use model of human larynx.

of human ear?

Predictive coding.

Down to 4000 bits/sec. (even lower?)

Fancier Coding Schemes:

(1) Lower bandwidth required, for same voice quality.

(2) More sensitive to loss.

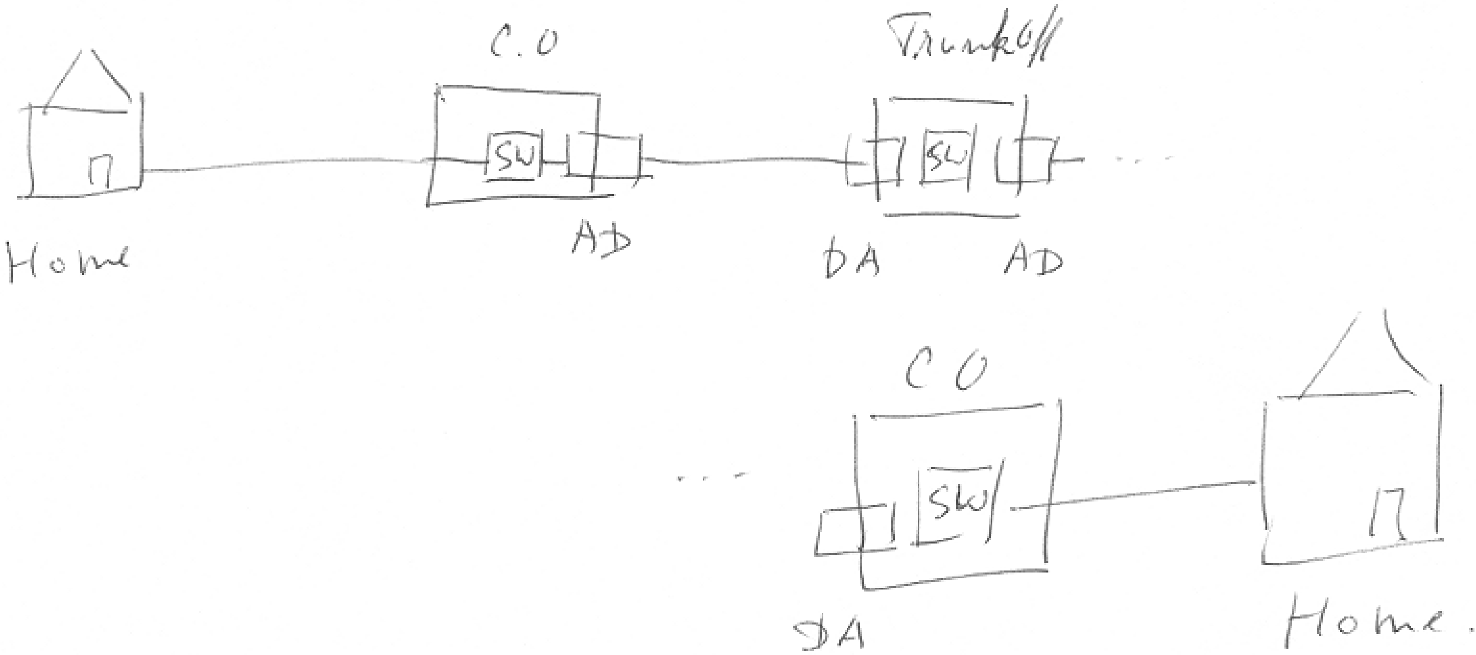
Ordinary PCM: if ~ 2% of the samples are lost, human hardly notices.

Sophisticated coding schemes:
Small loss can make the result incomprehensible.

Pre- ~1960 ~~1970~~ : everything analog.

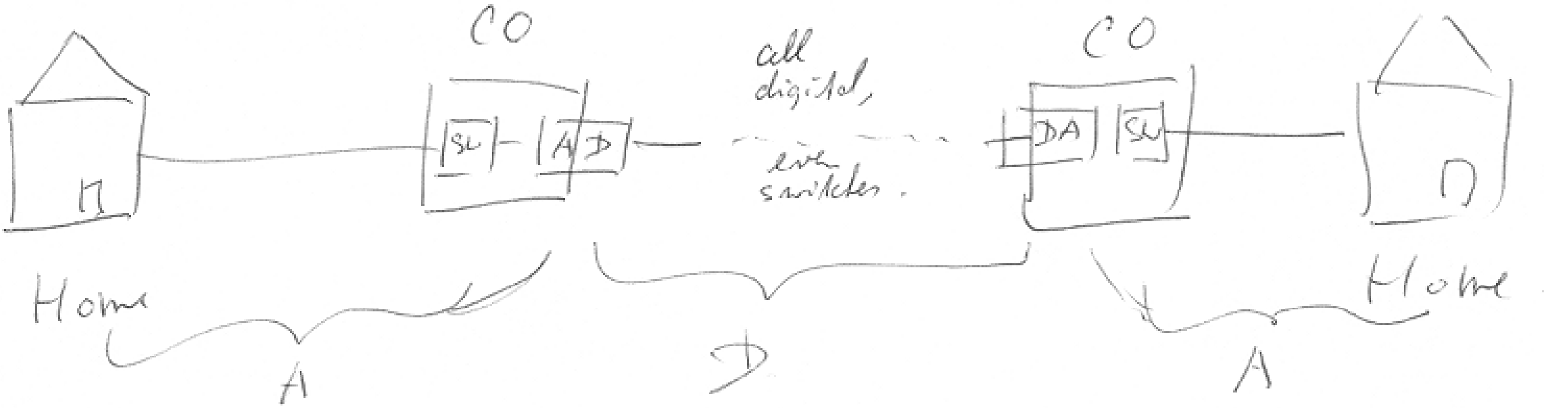
1960 - 1970 : Transmission Analog or Digital.

→ Switching Analog.

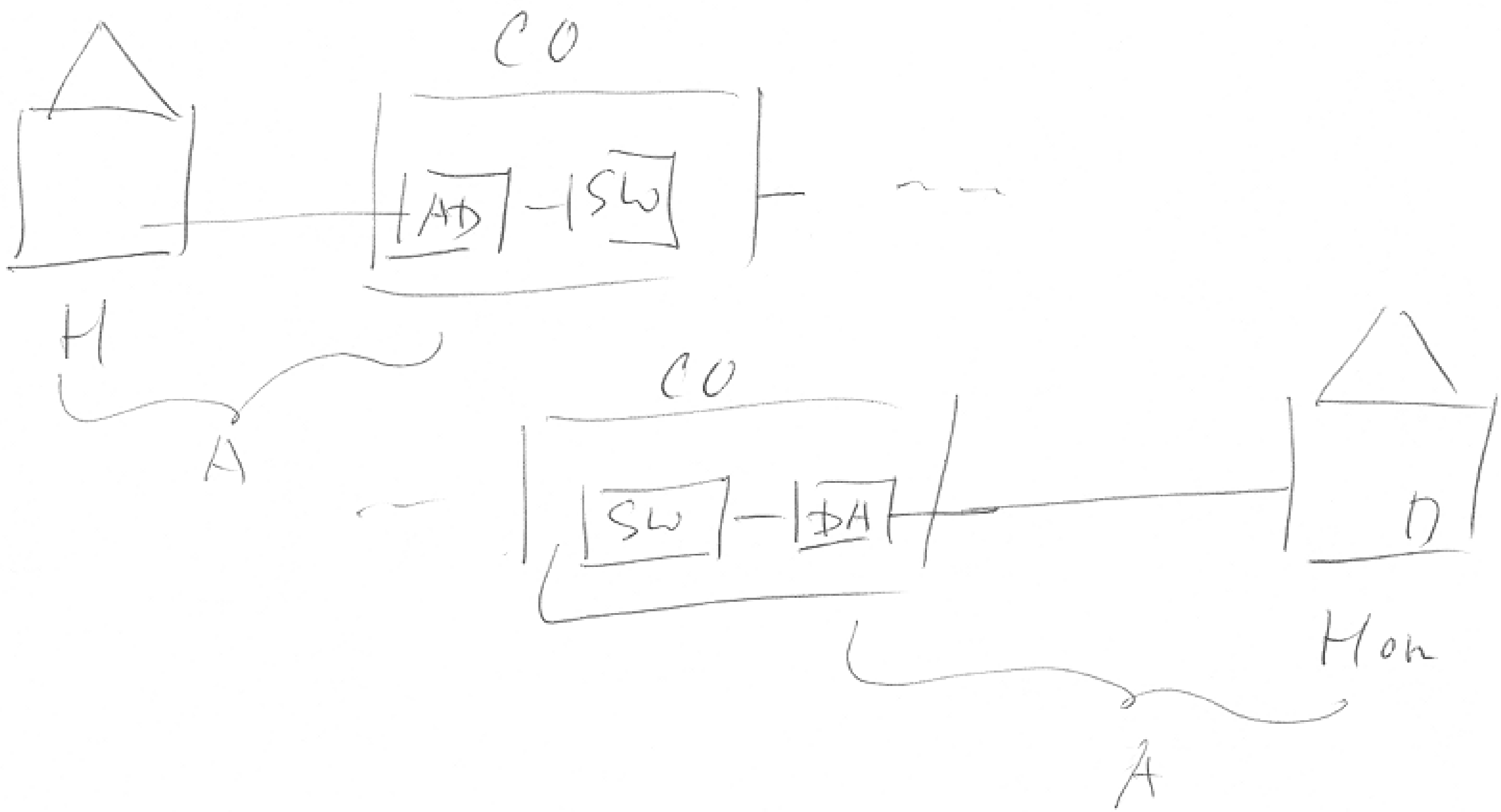


around 1970 (?) first digital switches.

Trunk only. 4ESS



Around 1981 (?)
Digital Switches in <u>Central Office</u>.

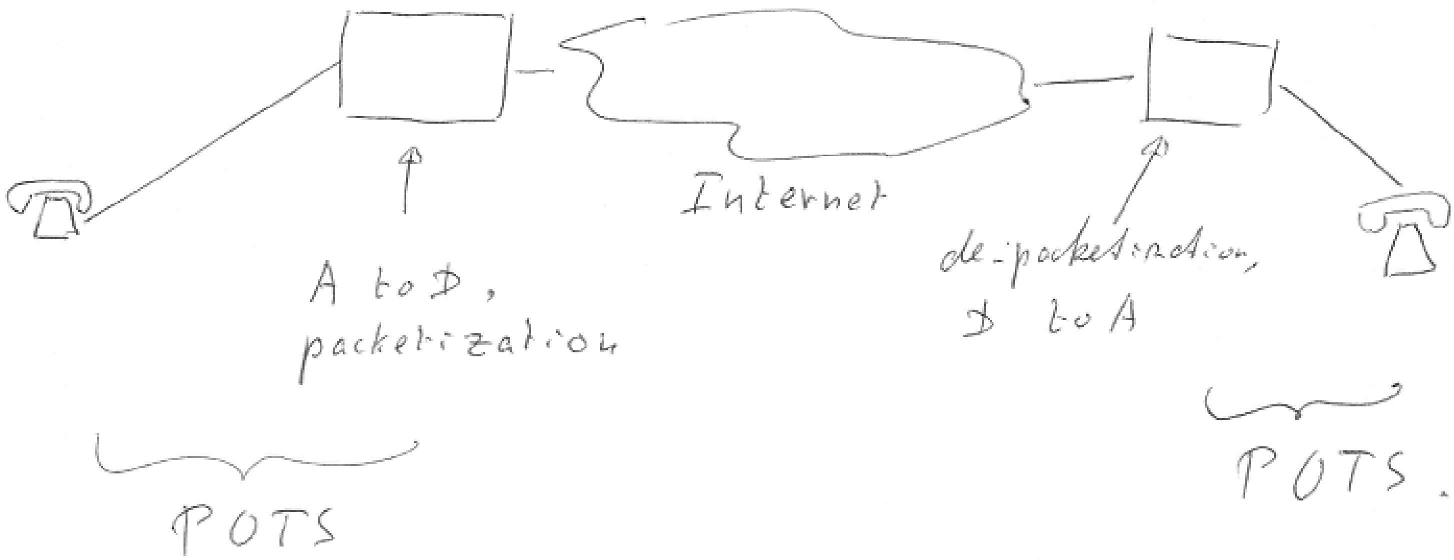


(ATT: 5E switch). (Northern Telecomm: <u>earlier</u>)

Later: (1990?) ISDN.
A-D, D-A can be <u>in the home</u>.
Integrated Services Digital Network.

~ 1995 (?) VoIP

Voice over IP.



A to D & Packetization:

At Home, or

At "CO", or

At IP-PBX, or

At Separate company.

Issue: Packetization Delay.

A to D $\rightarrow$ bitstream.

bitstream into packet:

Packet must be <u>Finished</u> before it can be sent.

Full PCM, 64,000 bits/sec = 8000 bytes/sec.

1000 data bytes ~~Ld~~ /packet:

$\frac{1000}{8000}$ = .125 sec = 125 msec.

Packetization Delay.
Unacceptable.

100 data bytes / packet:

$\frac{100}{8000}$ sec = .0125 sec = 12.5 msec.

Packetization Delay.
~ Acceptable. $\boxed{\text{But 10 * Header Overhead!}}$

Currently used: (often):