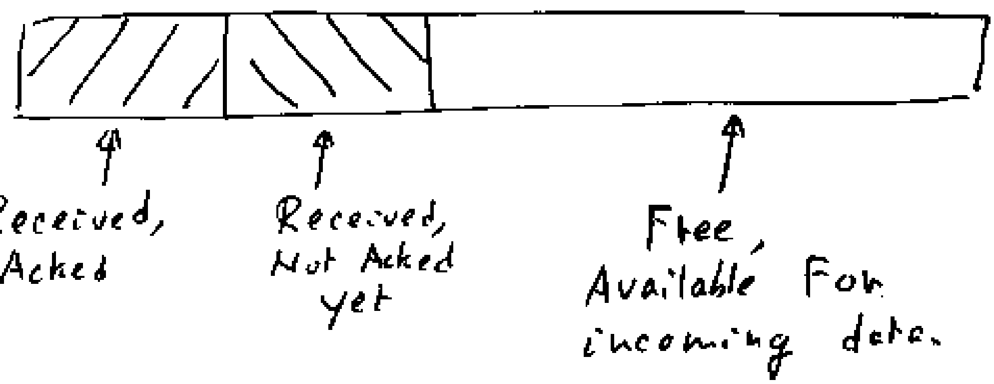
Goal of Sliding Window Protocols.

(1) Flow Control. ←

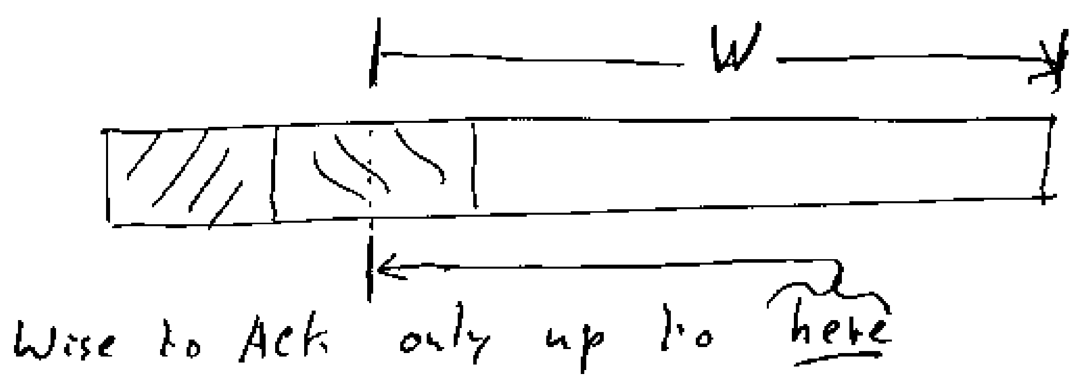
(2) Error Control (incl. missing, damaged, frames).

At Receiver Side:

Receive Buffer:



The receiver can choose to delay sending an ACK until it has enough space in its Rcve Buffer to get more.

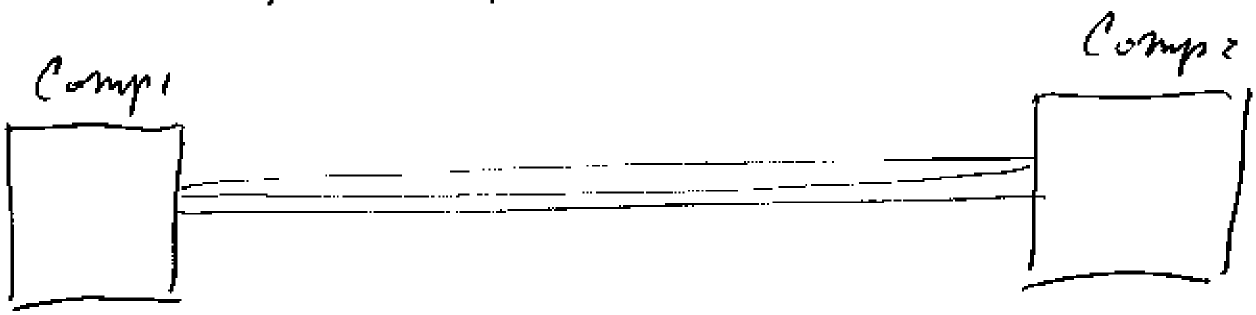


X.25: (Tanenbaum p 61)

First public data network.

Computer to computer over phoneline.

Computer places call. 64 kb/sec



Multiple <u>connections</u> inside one phonecall.

Packets. 3 Byte Header.
(Frame) Up to 128 Bytes of data.

Header: 12 bit connection identifier.
packet sequence number
acknowledgement number.
etc. Used flow control, Error Control.

Bell System had its own variation:
BX.25. ~ 1970-1985 ?

<u>Error Control, Flow Control</u>

"Not very compatible with Internet".

Because of the small X.25 frame, an IP packet had to be distributed over several X.25 frames. (IP fragmentation). See CIS 6456 / CIS 656

Feasible, not nice.

X.25 had own higher layers: not very compatible with IP.

Frame Relay. (1985? – ?) (still in use?)
Tanenbaum p 61

Similar to X.25

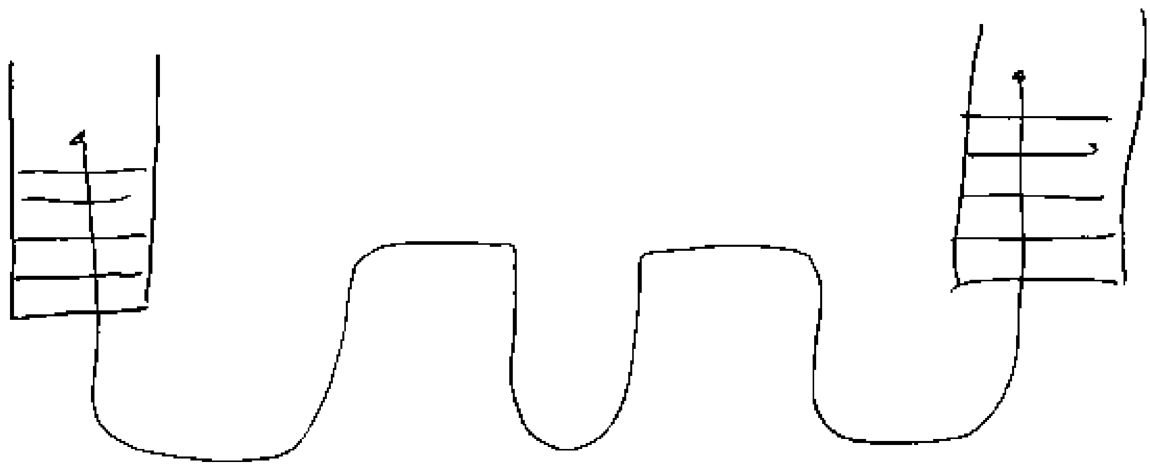
<u>Has</u> error detection
<u>No</u> error control (correction)

<u>No</u> flow control. No Re-transmission

Connection oriented. (in-order delivery)

Inter connecting LANs

<u>Why</u> no ... control ?



Links: <u>Highly</u> Reliable.

e2e control needed <u>anyhow</u>.

Lower Layer controls not needed.

Frame Relay:

max. Frame Size is 9000 Bytes.

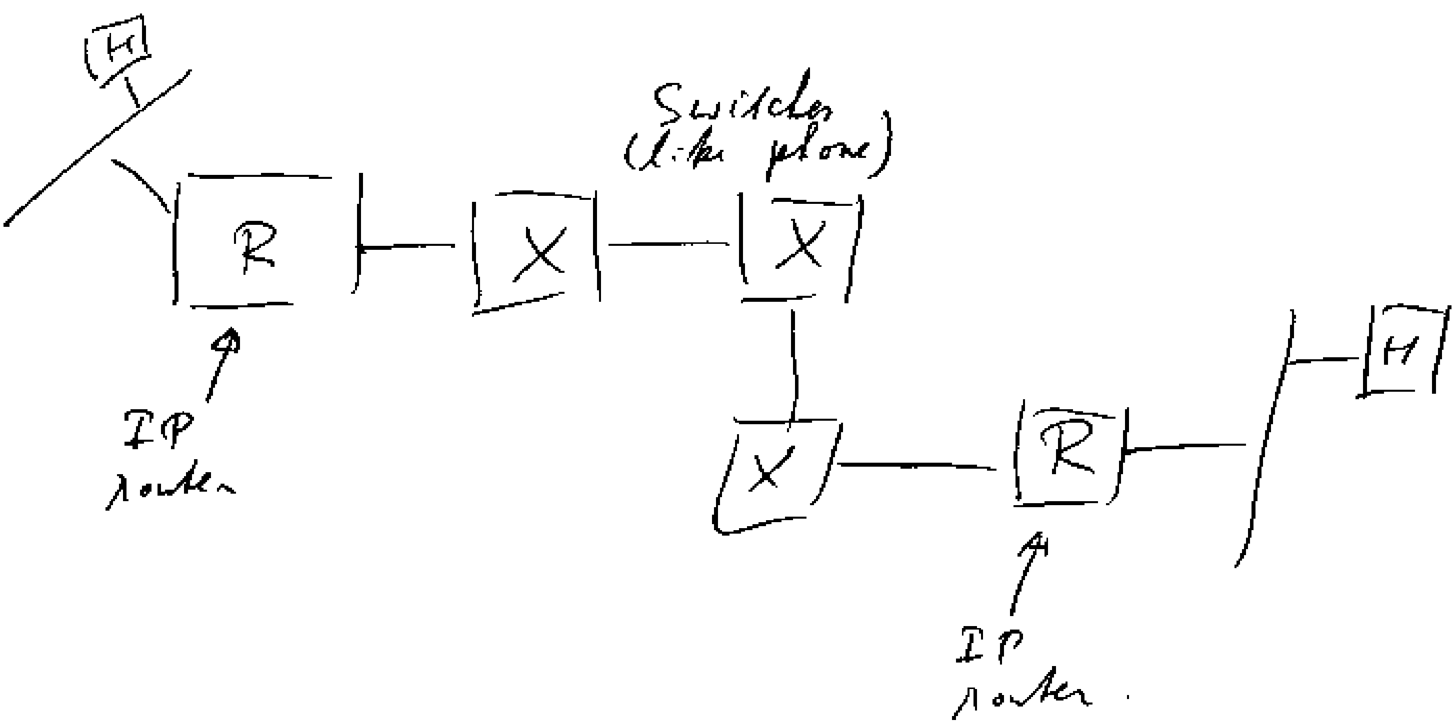
Much less need for IP fragmentation.

(in 1985: practically no need).

Frame Relay: Strictly layer 2.

Compatible with OSI,
IP.

Frame Relay used Virtual Circuits,
call set-up.



ATM.

Asynchronous Transfer Mode.
(Automatic Teller Machine).

Big Hype.
Small Flop.

Would do everything for everybody.

Now; Layer 2 only (?)

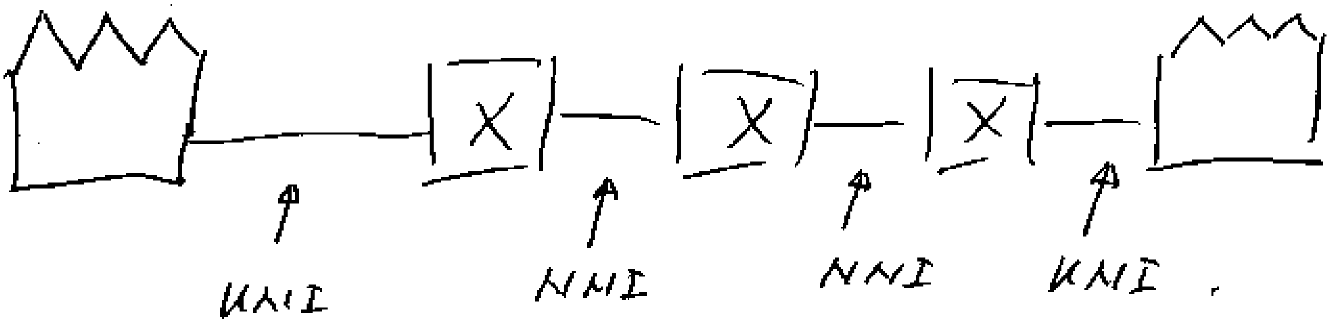
Fixed ~~packet~~ Frame size,
called cells.

48 data Bytes
5 header Bytes.

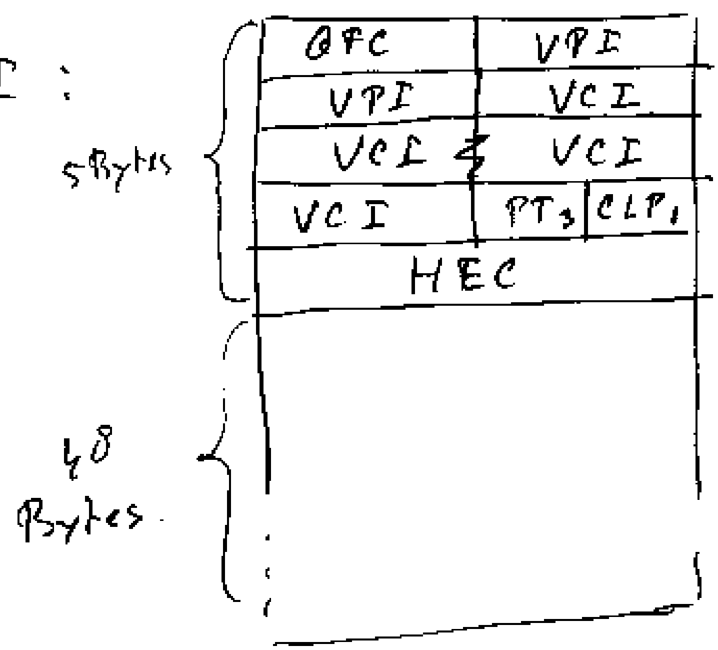
ATM cell.

UNI : User-Network Interface

NNI : Network-Network Interface.



UNI :



GFC : Generic Flow Control

VPI : Virtual Path Identifier

VCI Virtual Circuit Identifier

PT Payload Type (3 bits)

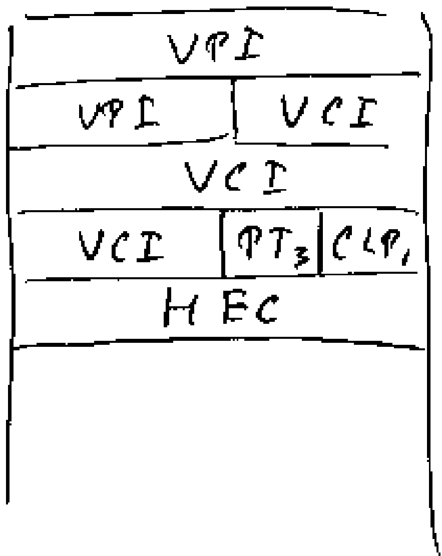
CLP Cell Loss Priority (1 bit)

HEC : Header error Control. (a CRC).

$2^8 = 256$ VPIs

$2^{16} = 65536$ VCIs

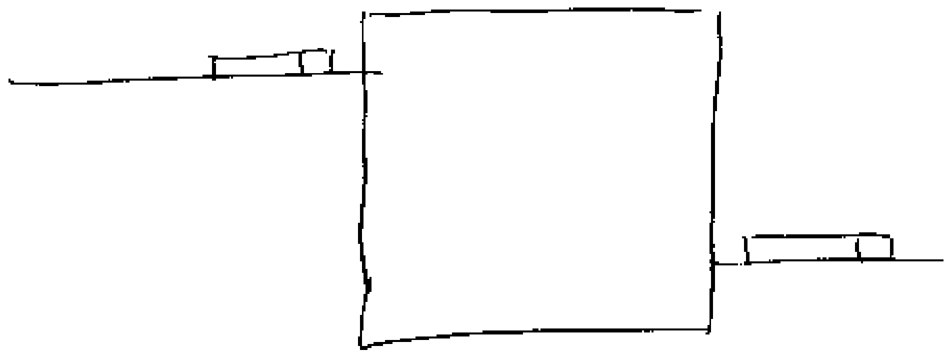
NNI



$2^{12} = 4096$ VPIs

$2^{16} = 65536$ VCIs

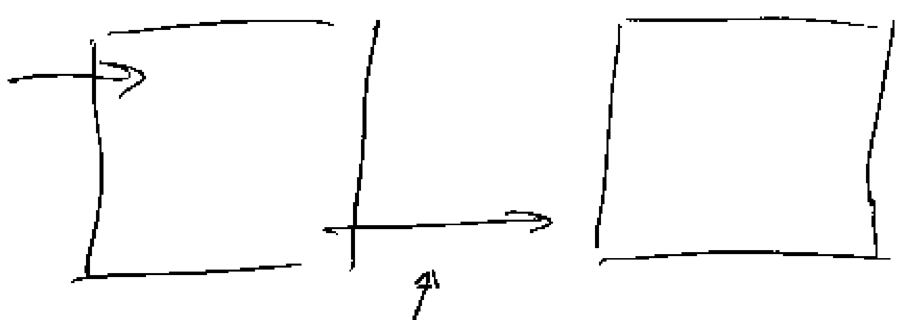
ATM
Switch



ATM input port:
Read VPI.
translate into output port,
new VPI.

~~Why? Call set-up.~~

~~[illegible]~~ 2
Why? call set-up



A VPI must be available

AAL.

ATM Application Layer.

There ~~are~~ were 5 of them.

Now only 4:

- AAL 1
- AAL 2
- AAL 3/4 } for IP.
- AAL 5 }

IP packet over ATM:

The IP packet ~~is~~ usually is >> 48 bytes:

Must be broken in pieces.

<u>SAR</u> Segmentation and Re-assembly.

(maybe later?)

ATM cell size:
48 Data ~~cell~~ bytes.

Fight in standards committee:

Europeans: 32 bytes
Americans: 64 bytes.

Compromise: 48 Bytes.
(worst possible?)

ATM: <u>connection oriented</u>.
~~The~~ product of PTTS.
Heavy weight.

Usual Mode:

IP over ATM over SONET (over optical fiber).

Moving toward:
IP over optics.

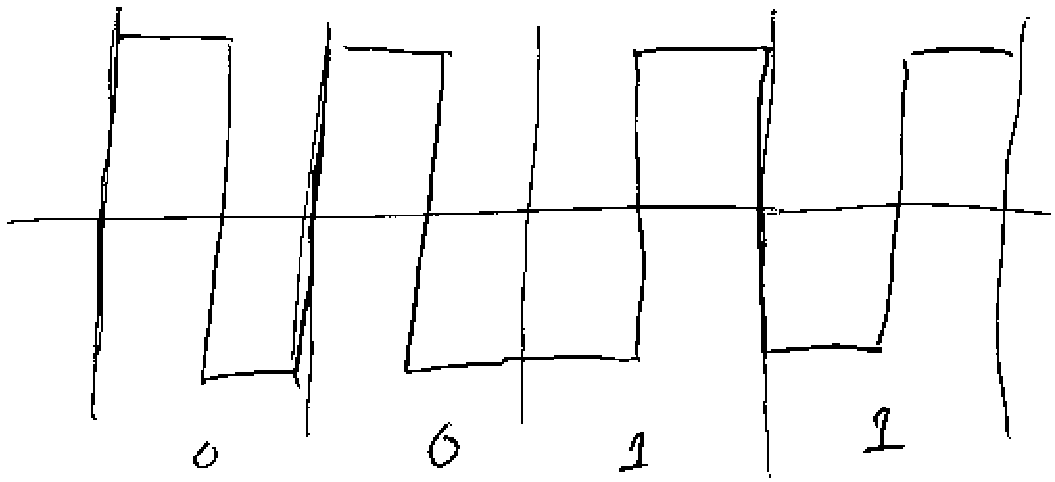
Start here 10/31/2003

More on Modulation.

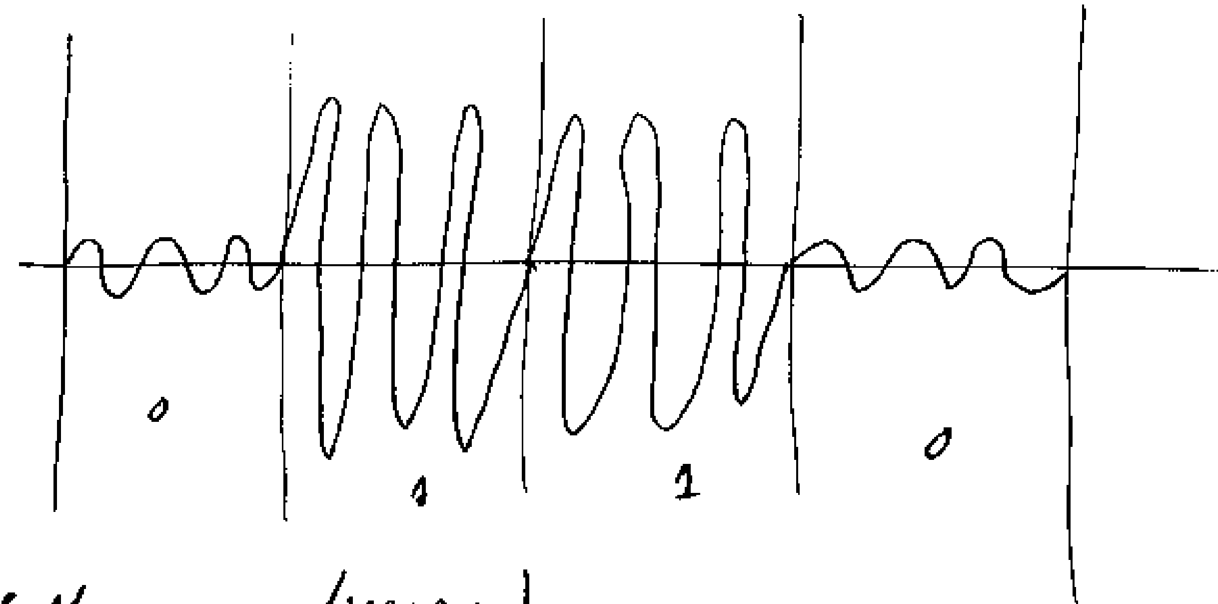
(Twisted Wire, Coax).

(1) Base band.

e.g. Manchester Encoding

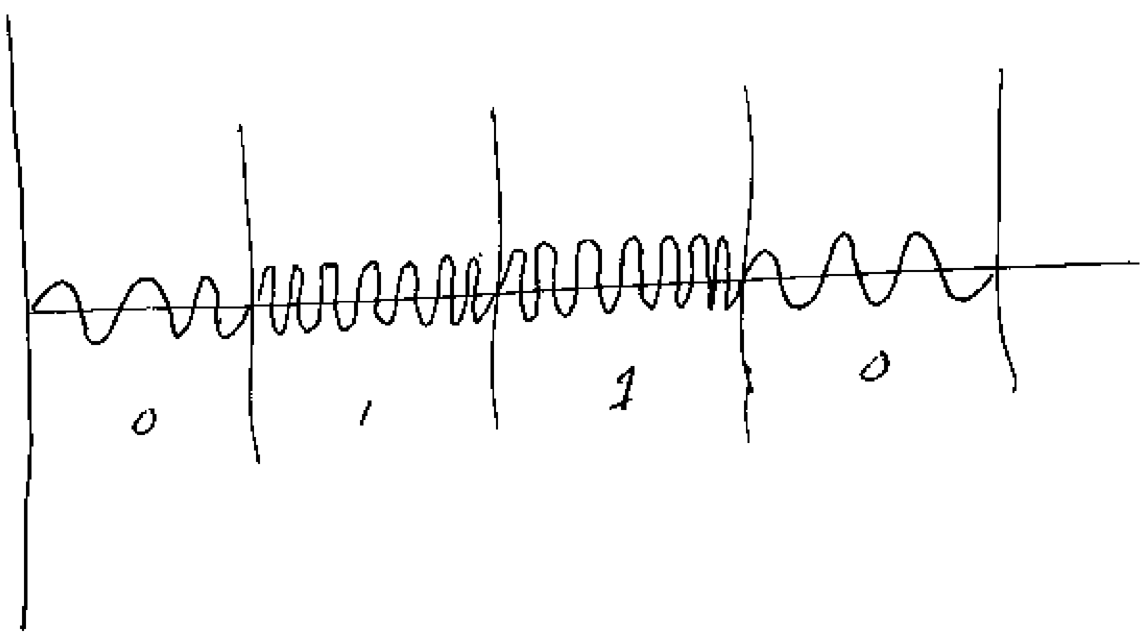


(2) Amplitude Modulation

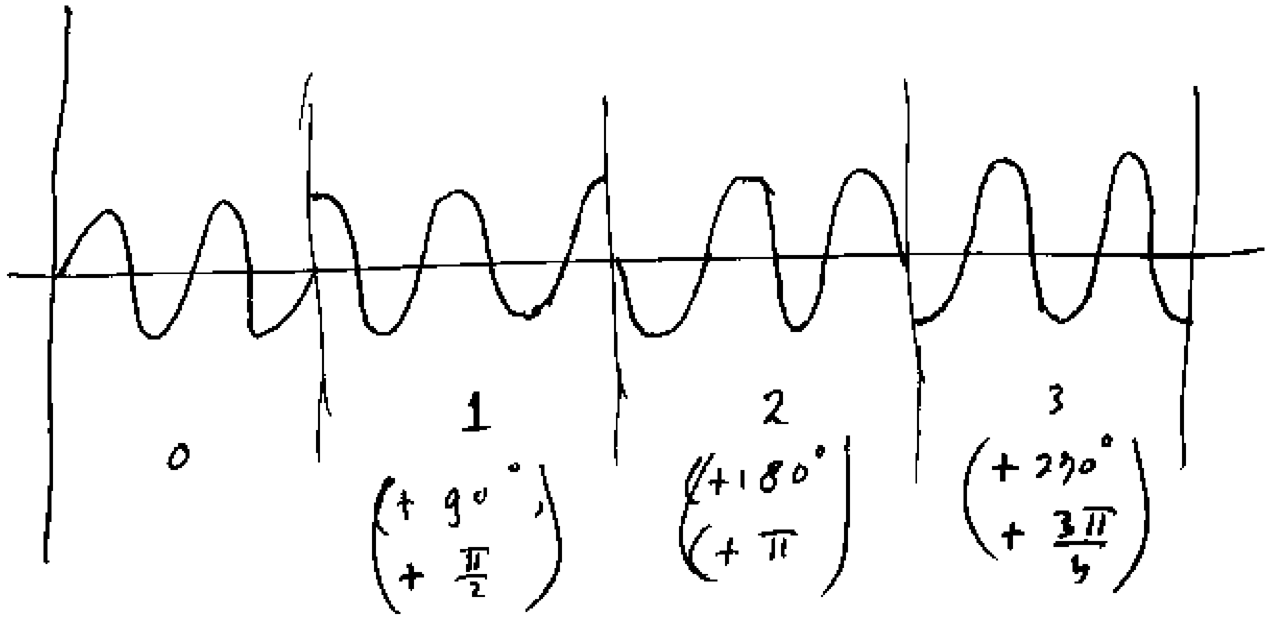


(all same frequency)

3 Frequency Modulation



4 Phase Modulation



~~4 symbols per~~

4 possibilities per symbol.

2 bits per baud.

Difference between baud rate

and bit rate.

Phase Modulation.

The method we just saw is called <u>QPSK</u>.

Quadrature Phase Shift Keying.

We did it with 4 (possible) symbols per baud: 2 bits per baud.

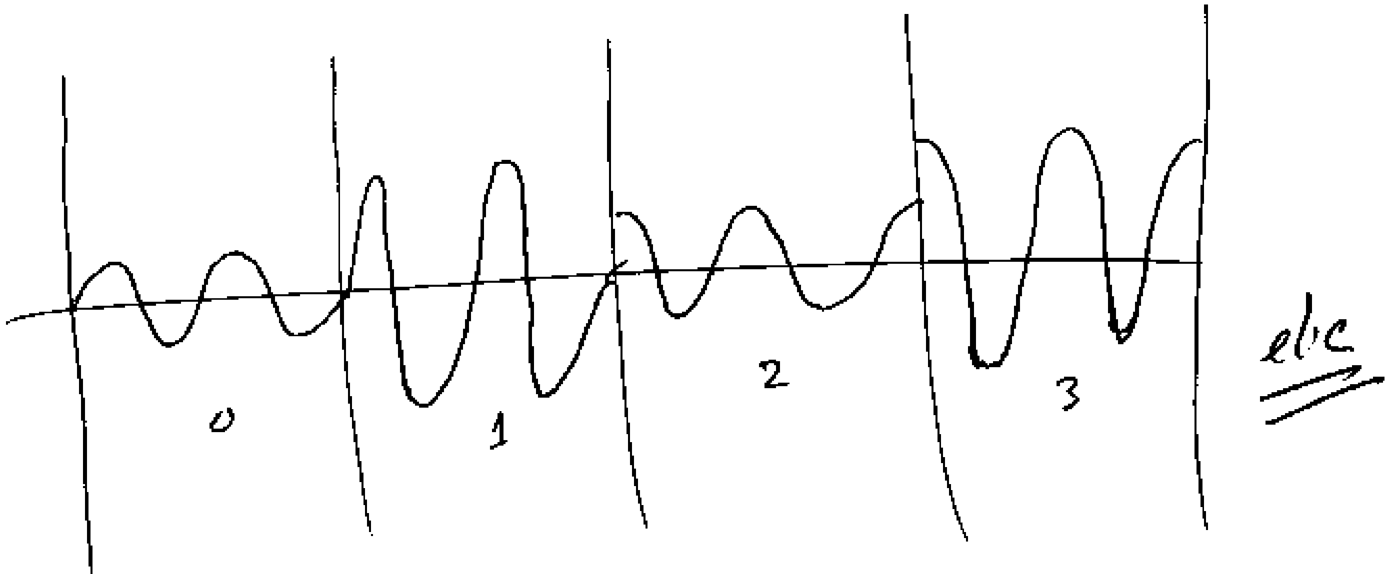
baud rate: # "samples" per second.

bit rate: # bits/sec.

with 2^k different phases: k bits/baud.

(5) QAM.

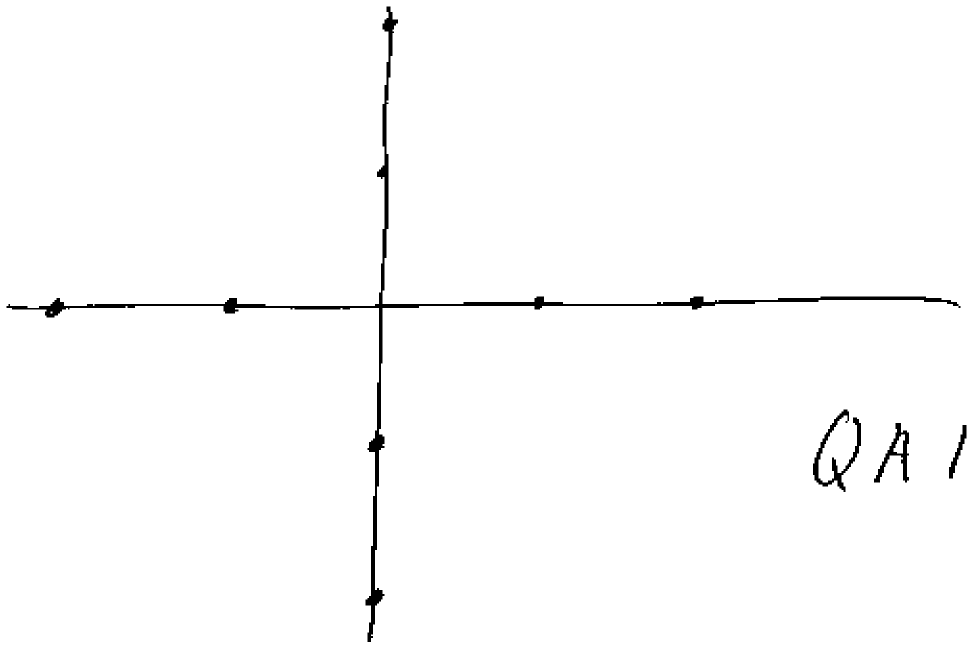
Quadrature Amplitude Modulation.



2 possible amplitudes }
4 possible phases }

} 8 possible symbols.
3 bits per baud.

QAM-8.

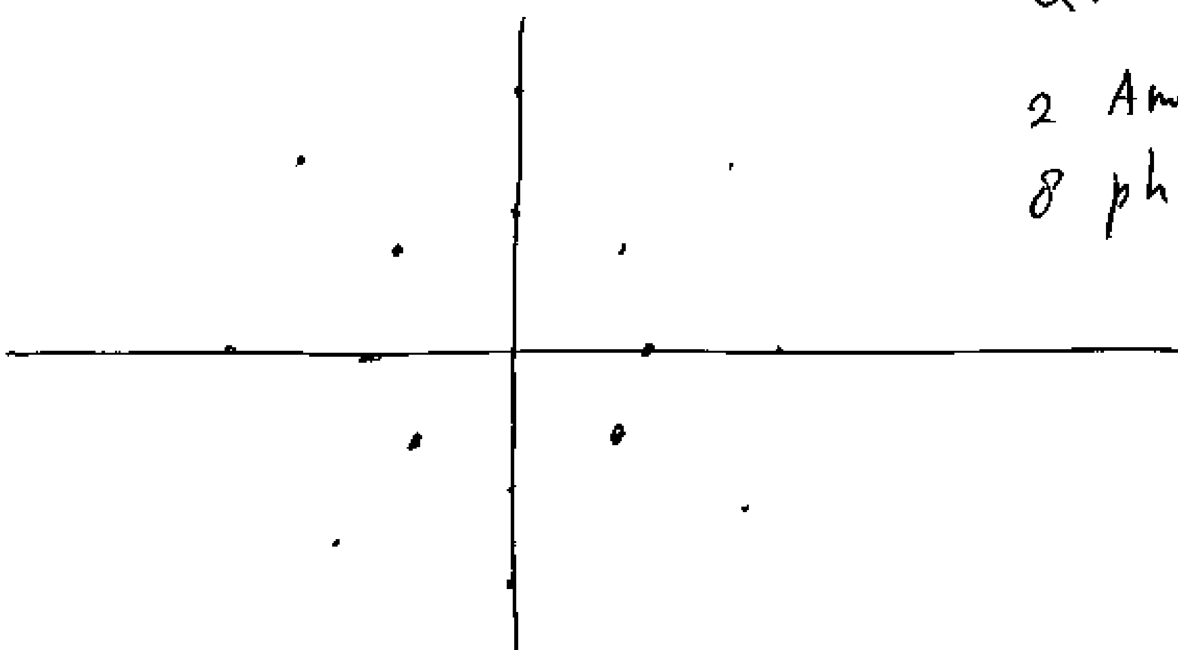


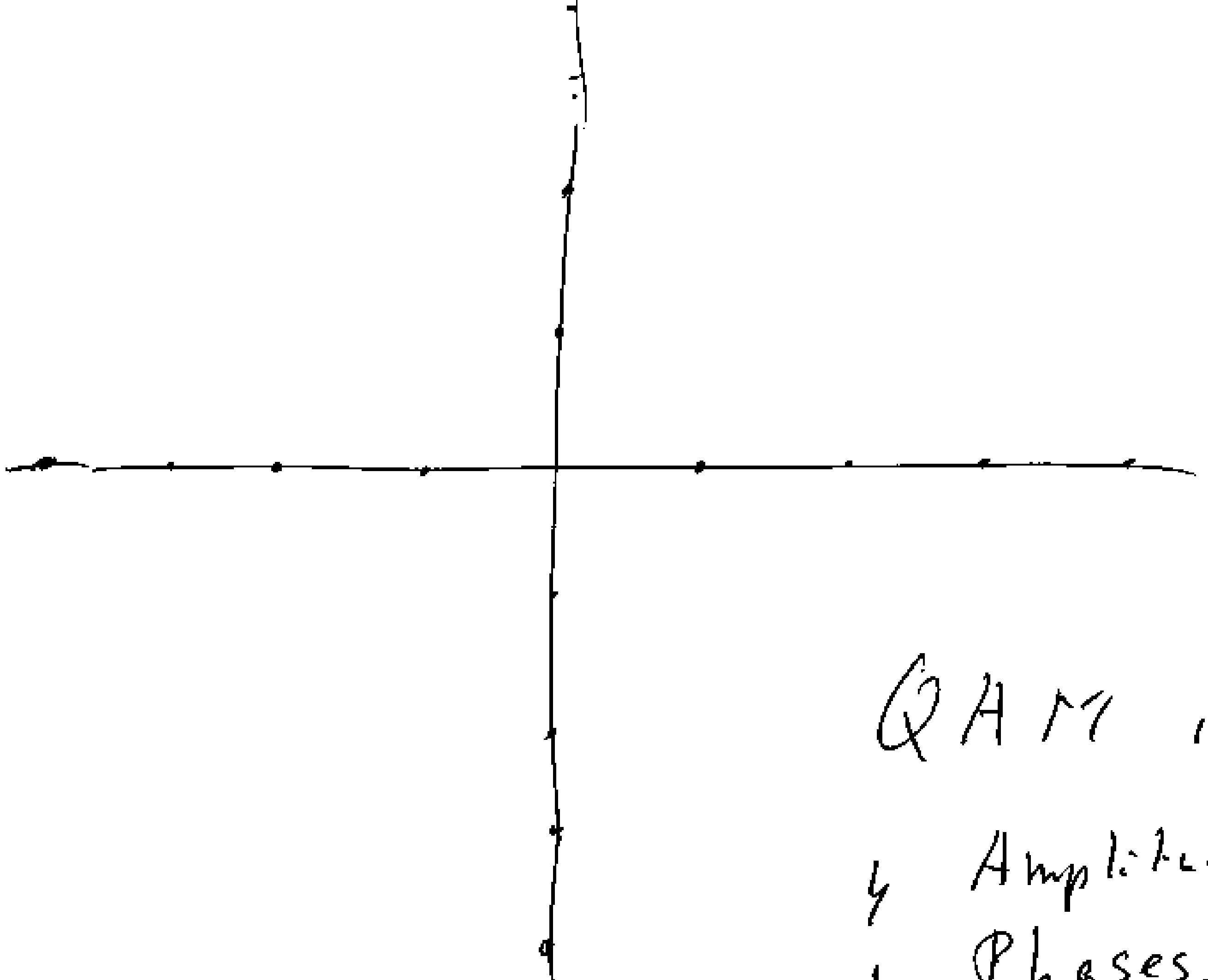
QAM-8.

Tanenbaum's pictures (p 128 etc)
are <u>wrong</u>.

QAM-16

2 Amplitudes,
8 phases





QAM 16.

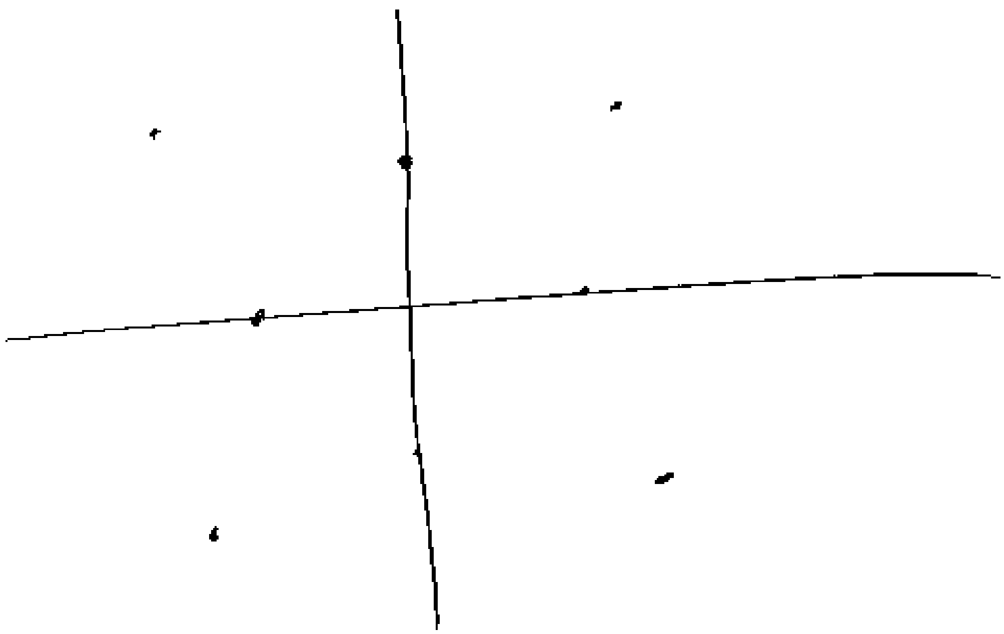
4 Amplitudes
4 Phases.

There is another QAM 16, See Tanenbaum p 128 Fig. 2-25-b.
However, Tanenbaum is <u>wrong</u>: that one has <u>12</u> phases and <u>3</u> Amplitudes.

(<u>NOT</u> 4 and 4, as Tanenbaum says on page 127.) Some people might call this a <u>Trellis Code</u>.

Trellis Codes

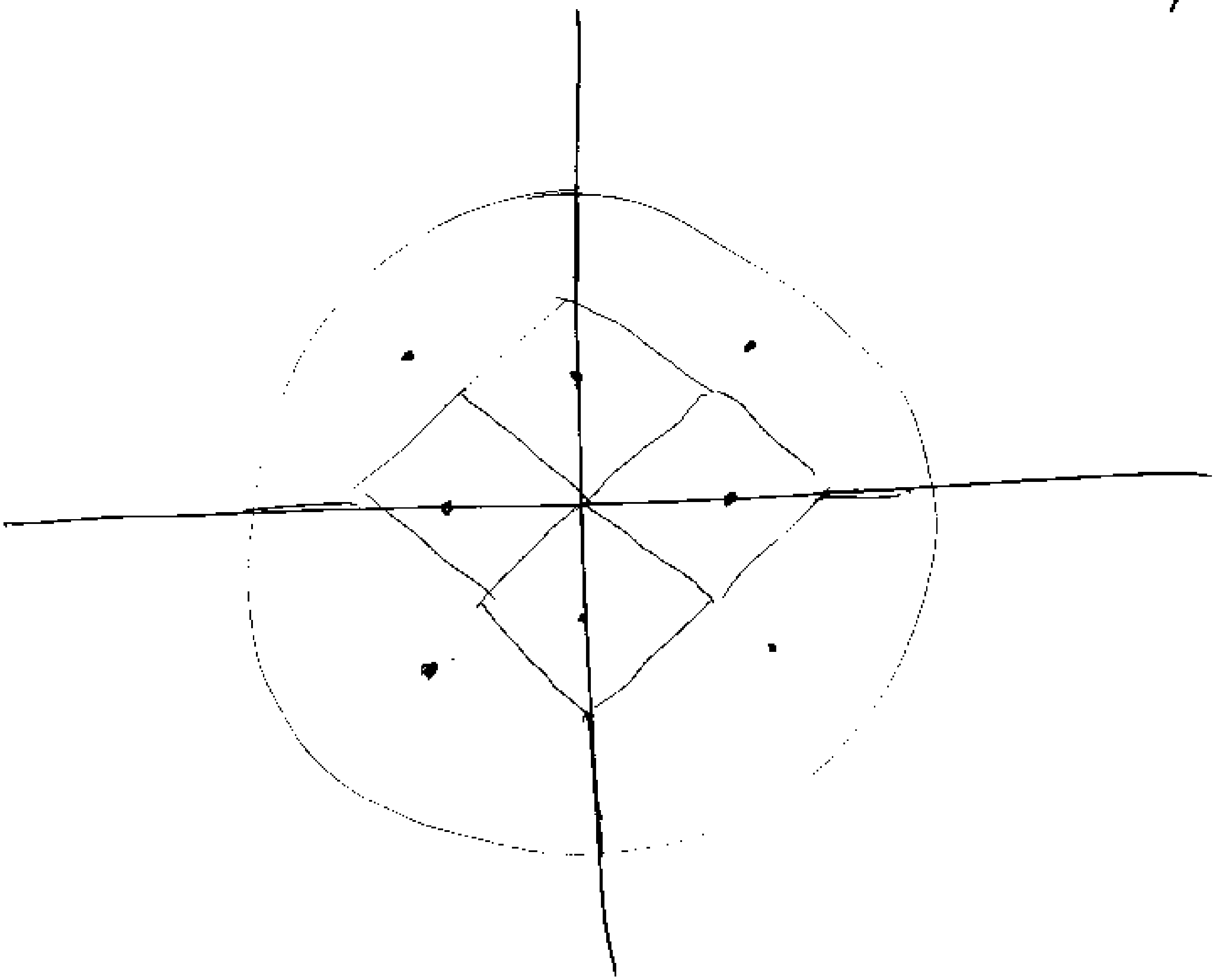
TCM Trellis Coded Modulation



8 points : 3 bits / baud.

Not : "so many amplitudes,
so many phases".

Vector Quantization



Design of Trellis Codes:

"Maximize # points subject to minimal "distance".
("maximize minimal distance").

This one has 8 phases,
2 amplitudes,
but only 8 points, not 16.
(8 symbols / baud).

Trellis Codes:

Plus "Forbidden Regions".
(If you get a symbol in that area: <u>error</u>).
Like a parity bit.

We already saw:

Error <u>detecting</u> codes.

(IP checksum,
CRC in ethernet, ATM).

Now:

Error <u>Correcting</u> Codes.

The ultimate:

Reed - Solomon. (1960).
(etc.)

Research still going strong!

Tough Math.

Used in CDs.

Used by Space Probes.

Error <u>correcting</u> codes: only way of getting close to Shannon bounds.

Error Correcting Codes:

Send m message bits
r redundant bits
(check bits),

Such, that as long as at least k bits are Ok,
(arrive Ok),
we can reconstruct the whole message. (Some specific k, $m < k < m+r$).

IF: $P\{$at least k bits Ok$\} \sim 1.0$
practically 1.

Data rate: $\sim m$ bits / ~~sec~~ codeword.

With C codewords/sec:

Data Rate = $(m * C)$ bits/sec

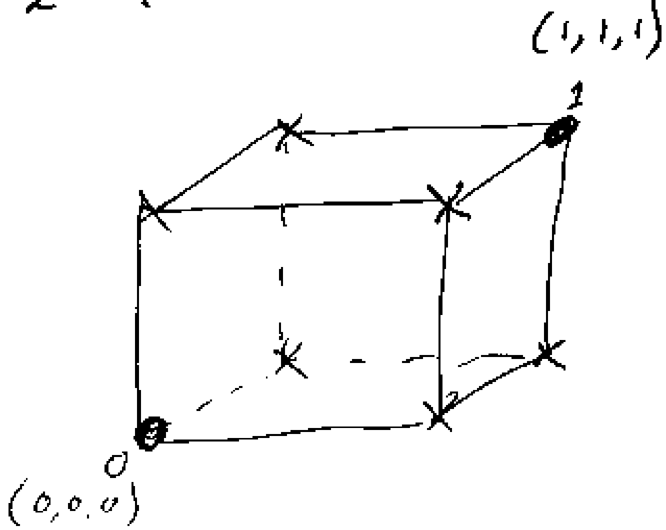
(send $m+r$, get m).

IF $k = m + r - 1$:

we can correct single bit errors .

Example (Not silly). (Almost Silly!)

$m = 1$,
$r = 2$.



IF you want to send 0 : send (0,0,0)
" " " " " 1 : send (1,1,1)

IF you receive (0,0,0) or (0,0,1) or (0,1,0) or (1,0,0)
interprete 0

IF you receive (1,1,1) or (1,1,0) or (1,0,1) or (0,1,1)
interprete 1.

"Only (0,0,0) and (1,1,1) are legal."
If you receive an illegal codeword:
find (interprete) the nearest legal
codeword.

Nearest: <u>Hamming Distance</u>.

\# bits different.

$$H((0,0,1,1),(0,1,0,1)) = 2$$

```
0 0 1 1
0 1 0 1
  ↑ ↑
```

Codeword: length $m+r$

(2^{m+r}) total number codewords.

of these: 2^m are <u>legal</u>

all others <u>illegal</u> : $2^{m+r} - 2^m = 2^m(2^r - 1)$.

If we ~~find a~~ receive an <u>illegal</u> codeword:

As long as there is a <u>unique</u> <u>closest</u> <u>legal</u> codeword: that is the one.

Not necessarily: "some bits are message, some are check".

Other example:
" $n*n$ " code word

Parity
↓ (even parity).

$$
\begin{array}{ccc|c}
d_{1,1} & \cdots & d_{1,n} & D_{1,n+1} \\
d_{2,1} & \cdots & d_{2,n} & D_{2,n+1} \\
\vdots & & & \vdots \\
d_{n,1} & \cdots & d_{n,n} & D_{n,n+1} \\
\hline
D_{n+1,1} & \cdots & D_{n+1,n} & D_{n+1,n+1}.
\end{array}
$$

P → (row $n+1$)

$m = n*n = n^2$ message bits.

$r = 2n+1$ check bits.

As long as among $(n+1)^2$ bits <u>at most one bit error</u>: error can be <u>corrected</u>.

(<u>One</u> row, <u>One</u> column.
Can be $(N+1)$-th row and/or column).

Other example:

Hamming Codes.

Tanenbaum, pp 192–195.

m message bits
r check bits.

As long as

$$2^r - r - 1 \geq m$$

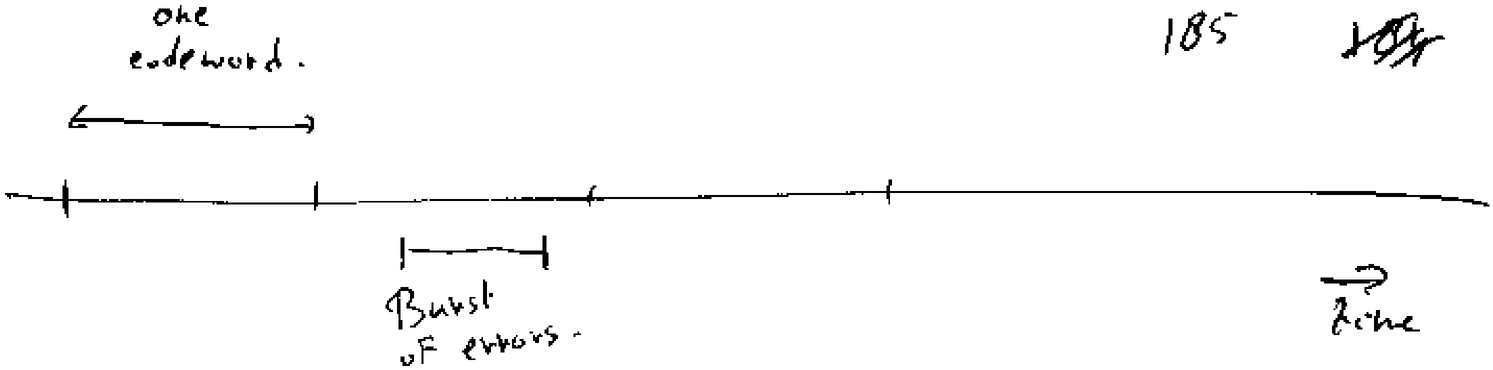
it is possible to have a code with ~~2~~ 2^m legal codewords,

$$2^{m+r} - 2^m = 2^m (2^r - 1)$$ <u>illegal</u> codewords,

and that <u>corrects</u> all ~~sig~~ single bit errors.

In real life we are not interested in correcting single bit errors.

Errors come in <u>bursts</u>.



Suppose <u>one</u> codeword contains
 m message bits,
 r check bits
 Can correct up to k errors.
 (out of m+r bits).

Errors: bursty.

High probability : <u>No</u> error in codeword.
Small prob : > k errors
Negligible prob : 0 < # errors < k.

Error Correcting Code is useless!
Solution: Make codewords <u>long</u>.

Reed Solomon: Used in CDs,
 Space Probes,
 ... .

For Real-Time Traffic:

Long Code words introduce Delay.

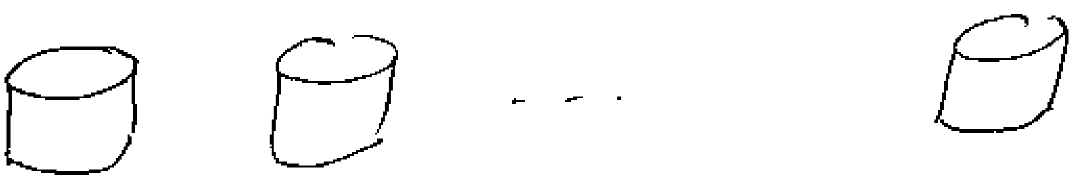
("Like" packetization Delay).

Related to Error Correcting Codes:

RAID.

Redundant Array of Inexpensive Disks.

Tanenbaum p308.



M Disks.

(M+1)-th : contains "bit by bit" "parity bit". (Simplified).

As long as at most one of the M+1 disks breaks: Content can be re-constructed from other M.

With Reed-Solomon:

As long as at most k out of $M+R$ disks break, content can be reconstructed.

$$(K \leq R).$$