TRANSMISSION IMPAIRMENTS

→ Attenuation & attenuation distortion

→ Delay distortion

→ Noise (Thermal, Crosstalk, Impulse, Intermodulation)

$$N_f = -10 \log_{10} \frac{P_f}{P_{1000}}$$: Relative attenuation

$$N_0 = kT \quad (W/Hz)$$: Thermal Noise of 1 Hz of Bandwidth

k: Boltzman's constant $= 1.38 \times 10^{-23}$ J/K ; T: (K)

Thermal Noise :

$$N = kTB$$

$$N = \underbrace{10 \log_{10} k}_{-228.6 \text{ dBW}} + 10 \log_{10} T + 10 \log_{10} B$$

Nyquist Bandwidth :

$$C = 2B \log_2 M$$

M: Signal level

Shannon Capacity :

$$C = B \log_2 (1 + SNR)$$

(bps)

SNR: dB değil (linear)

← error free capacity

$$SNR = \frac{S}{N} = \frac{\text{Signal power}}{\text{Noise power}} \quad ; \quad SNR_{dB} = 10 \log_{10} \left(\frac{S}{N}\right)$$

Spectral or Bandwidth Efficiency :

$$\frac{R}{B} = \frac{C}{B} = \log_2 (1 + SNR) = \gamma \quad (bps/Hz)$$

Do not forget $\Rightarrow$ $C = R$ $\Rightarrow$ $\frac{C}{B} = \frac{R}{B} = \gamma$

$$\frac{E_b}{N_0} = \frac{S/R}{N_0} = \frac{S}{kTR}$$

$$E_s = R_s E_b$$

R = Data Rate

$$E_b = S\,T_b \rightarrow R = \frac{1}{T_b} \leftarrow \text{bit rate}$$

$$N = N_0 B$$

$$\frac{E_b}{N_0} = \frac{S}{N} \cdot \frac{B}{R}$$

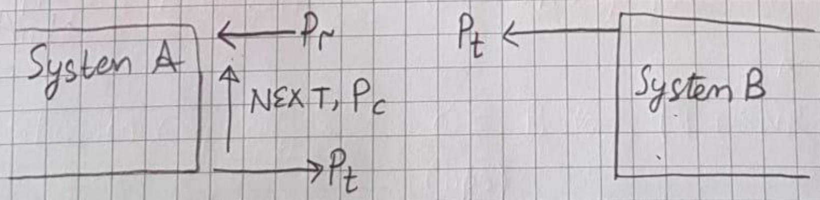
$$\frac{E_b}{N_0} = \frac{B}{\underset{(C)}{R}} \left(2^{C/B} - 1\right)$$

$$\left(\frac{E_b}{N_0}\right)_{dB} = S_{dBW} - 10\log_{10} R - 10\log_{10} k - 10\log_{10} T$$

Modulation Rate:

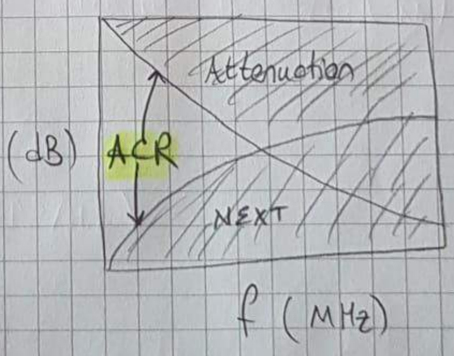
$$D = \frac{R}{L} = \frac{R}{\log_2 M} \quad \text{(baud Rate)}$$

$$R_s = \frac{R_b}{\log_2 M}$$



$$NEXT_{dB} = 10\log_{10} \frac{P_t}{P_c}$$

$$A_{dB} = 10\log_{10} \frac{P_t}{P_r}$$



$$ACR_{dB} = NEXT_{dB} - A_{dB}$$

ANTENNAS

$$G_{dB} = 10 \log_{10} \frac{P_{out}}{P_{in}}$$

$$L_{dB} = 10 \log_{10} \frac{P_{in}}{P_{out}}$$

$$P_{dBm} = 10 \log_{10} \frac{P_{mW}}{1mW}$$

$30dBm \rightarrow 1W \rightarrow 0dB$

Received $G_r = \frac{4\pi A_{eff}}{\lambda^2} = \frac{4\pi f^2 A_{eff}}{c^2}$ → $[m^2]$

$$PL_{dB} = 10 \log_{10} \left(\frac{4\pi R}{\lambda}\right)^2 = 20 \log_{10} \left(\frac{4\pi R}{\lambda}\right) = 10 \log_{10} \left(\frac{P_t}{P_r}\right.$$

<u>isotropic</u>

$$\frac{P_t}{P_r} = \left(\frac{4\pi R}{\lambda}\right)^2$$

<u>Others</u>

$$\frac{P_t}{P_r} = \left(\frac{4\pi R}{\lambda}\right)^2 \frac{1}{G_t G_r} = \frac{(CR)^2}{f^2 A_r A}$$

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2$$

$$P_r(dB) = P_t(dB) + \underbrace{G_t(dB) + G_r(dB) - PL(dB)}$$

for isotropic antena free space loss

$$P_r = \frac{P_t G_t}{4\pi R^2} A_{eff}$$

Optical LOS : $d = 3.57\sqrt{h}$

Radio LOS to horizon: $d = 3.57\sqrt{Kh}$

$K = 4/3$

$d = 3.57\sqrt{Kh_1} + \sqrt{Kh_2}$

heigth of Tx   height of Rx

ASK	FSK	PSK
$B_T = (1+r)R$	$B_T = \left[\frac{(1+r)M}{\log_2 M}\right]R$	$B_T = \left(\frac{1+r}{\log_2 M}\right)R$

ERROR DETECTION

$P_1 = (1 - P_b)^F$: Probability that a frame arrives with NO bit errors

$P_b \to$ BER

$F \to$ # of bits per frame

$P_2 = 1 - P_1$: Probability that a frame arrives with one OR more undetected errors

Bit stuffing $\underbrace{11111}$ "0"

Ex) to be transmitted : 0110110 111111 00110

transmitted : 0110110 11111 0 00110

Ex) 0110111011111111111100110

011011101111101111101 00110

Parity checking : 1001101 → 10011010

10011010 → 10011000 → 11011000
transmitted received received
✓✓ XX
cannot detect

Two dimensional Parity :

Data blocks

1	0	0	1	1	0	0	1
1	0	1	1	1	0	0	0
0	1	0	0	1	1	1	0
0	1	1	1	0	1	0	0
0	0	0	1	1	0	1	1

Row Parities

Column Parities

1 parity of parities

Cyclic Redundancy Checking

110101 | 1010001101 00000

```
110101 | 101000110100000
         110101
          111011
          110101
            111010
            110101
               111110
               110101
                 101100
                 110101
                  110010
                  110101
                     01110
```

ilk 1 indir
diğerleri 2 indir
Sonuncusu 1 indir
Son indirince XOR YOK

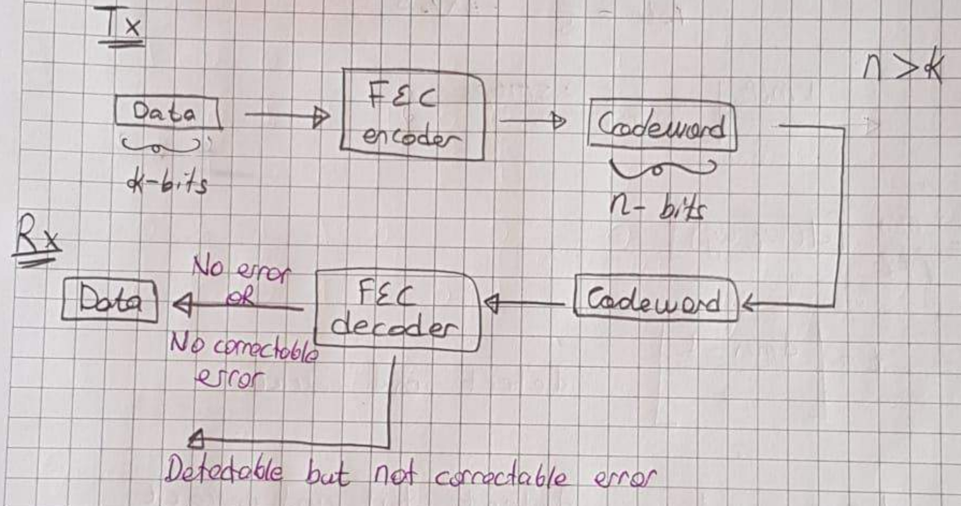
101000110101110

Yeni konular

Forward Error Correction (FEC)

① BER on wireless link can be high. → large # of retransmissions

② Propagation delay ↑ → inefficient system



Hamming distance

$d(v_1, v_2) = 3$

$v_1 = 011011$

$v_2 = 110001$

✓ ✓ ✓

Ex	Data block	codeword
①	00	00000
②	01	00111
③	10	11001
④	11	11110

Suppose → $\underbrace{00100}$ Received

$d(r,1) = 1$ → "00" error-correction in terms of Hamming distance.

$d(r,2) = 2$

$d(r,3) = 4$

$d(r,4) = 3$

eğer 2 yada daha fazla olabilir codeword var ise

"error can be detected but not corrected

$(n,k) \Rightarrow$ redundancy $\rightarrow \dfrac{(n-k)}{k}$

code rate $\rightarrow \dfrac{k}{n}$

in example $\begin{matrix} n=5 \\ k=2 \end{matrix} > \dfrac{3}{2} = 1.5$

rate $= \dfrac{2}{5} \rightarrow \times 2.5$

$$\xrightarrow{1\,\text{mbps}} \boxed{\text{encode}} \xrightarrow{2.5\,\text{mbps}}$$

$$d_{min} = \min_{j \neq i} \left[d(w_i, w_j) \right]$$

$$t = \left\lfloor \frac{d_{min} - 1}{2} \right\rfloor$$ detect and correct

$$t = d_{min} - 1$$ detect but not correct

Coding can be used to the required E_b/N_o value to achieve a given bit error rate.

Flow Control

→ Stop-and-Wait flow control

Bit length of a link:

$$B = R \times \frac{d}{v}$$

- B: (bits)
- R: data rate (bps)
- d: distance
- v: velocity of propagation (m/s)

L : frame length

$a = \frac{B}{L}$

- $a > 1$: insufficient, higher data rate, longer distance
- $a < 1$: the propagation time is less then the transmission time.

Ex)

$R = 1\,Gbps$

$d = 200\,m$

$v = 2 \times 10^8\,m/s$

$B = 1000$ bits $\Rightarrow a = \frac{1}{8} = 0.125$

Assume $L = 1000$ octets $= 8000$ bits

if 1st bit of frame arrives $1\mu s$

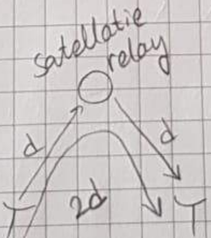
Transmission time $8\mu s$

Ex)

$R = 1\,Mbps$

$d = 36000\,km$

$v = 3 \times 10^8\,m/s$



$B = 240000$ bits

$L = 8000$ bits

$a = 30$

1st bit 240 ms

transmission time 8 ms

Sliding-window Flow Control

max window size $= 2^k - 1$

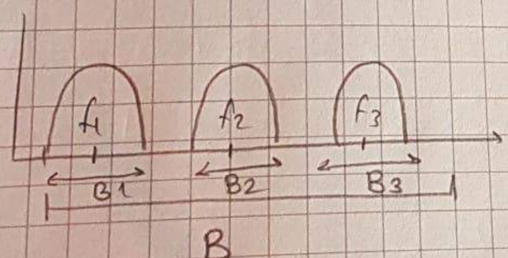
Error Control

ARQ : Automatic repeat request

- Stop-and-wait
- Go-back-N
- Selective-reject.

Multiplexing

FDM



Multiple Channel Access

Frequency Division Duplex

Time Division Duplex:

$(T_b + T_p + T_g)$

$$R = \frac{B}{2(T_b + T_g + T_p)}$$

B → the size of block in bits

R → effective data rate OR effective # of bits transmitted per second

actual data rate

$$A = \frac{B}{T_b}$$

$$A = 2R\left(1 + \frac{T_p + T_g}{T_b}\right)$$

Ex)

$R = 192$ kbps

$B = 48$ bits

$T_g = 10\,\mu s$

$d = 1$ km $\longrightarrow$ $c = 3 \times 10^8$ m/s

$$T_p = \frac{10^3}{3 \times 10^8} = 3.33\,\mu s$$

propagation time hız ve mesafe arasındaki ~~arasından~~ ilişkiden bulunur

hava olduğundan dolayı $\boxed{v = c = 3 \times 10^8 \text{ m/s}}$

$$T_b = \frac{B}{2R} - T_g - T_p$$

$T_b = 111.67\,\mu s$ $\Rightarrow$ $A = \frac{B}{T_b} = 429.83$ kbps $\approx$ **430 kbps**

Frequency Division Multiple Access

Time Division Multiple Access