* ~~Error~~ ~~corr~~ detectⁿ & correctⁿ:

- Equalizer
- Diversity
- channel coding

} techniques to ↓ error

* Equalizer:
  - at the receiver end
  - compensates the delay characteristics (ISI).

* Diversity:
  - improves signal impairment due to channel fading.
  - at the BS/receiver/both.
  - ~~either by adding an antenna / adding redundant bits in xmitted signal. (error correctⁿ)~~

* channel coding:
  - adding redundant bits in xmitted signal.

* Equalizer should track the time varying nature of the channel & implement the correction to reduce ISI.

* Diversity is based on the fact that individual channels experience independent fading events.

This can be compensated by providing multiple logical channels in b/w xmitter & Receiver & sending part of the signal over each channel.

It does not eliminate errors, but reduces the error rate.

* channel coding
  - error detectⁿ (after detectⁿ, retransmission is read.)
    - Parity check
    - CRC
  - error correctⁿ
    - Block codes
      - Hamming code
      - cyclic codes
        - BCH
        - Reed solomon codes
    - convolution codes

(A) Sums based on Lower radio transmission power & free path loss (Free space loss):

* Lower Radio Transmission power:

- Mobile units are compact in size & work on battery with scarce energy resources.
- The mobile nodes limit transmission power to avoid interference.
- Signal strength decreases with inverse square of distance.
- Higher frequency (3-5 GHz) ~~over~~ usage increases attenuation & decreases range of communicatⁿ.
- At the receiver side, $P_r$ - capture power depends on size & orientatⁿ of the antenna w.r.t. the transmitter.

$$\boxed{P_r = P_t / (4\pi d/\lambda)^2} \qquad \lambda = c/f$$

where, $P_t$ → transmitter power
$d$ → dist. b/w transmitter & receiver
$\lambda$ → wavelength of the signal.

* Path loss:

- b/w transmitter & receiver.
- provide valuable information when determining requirements for transmit power levels, receiver sensitivity & SNR (signal-to-noise) ratio.

- $\boxed{SNR = P_r / P_n}$

where, $P_n$ → avg noise power at the receiver
$P_r$ ⇒ captured power

∴ The path loss, $\boxed{L_p = (4\pi d/\lambda)^2}$

- Actual path loss depends on the transmit frequency & it grows exponentially as range increases b/w the transmitter & the receiver.
- indoor applicatⁿs → path loss ↑ at approx. 20 dB every 100 ft.
- Multipath propagatⁿ $\xrightarrow{\text{leads to}}$ signal fading → ↑ path loss.
- to ↓ effect → utilize additional Access points in a wireless n/w — to provide adequate coverage.

---

Ex ①: Find the transmitted power, if a transmitting node is operating at a frequency of 90 MHz & a mobile phone receiver at a dist. of 650 m establishes the commⁿ with the transmitting node. Assume the captured power at the mobile phone is $1 \times 10^{-6}$ W.

→ $f = 90$ MHz — operating freq. $= 90 \times 10^6$ Hz

$d = 650$ m — dist.

$P_r = 1 \times 10^{-6}$ W — receiver power

$P_t = ?$ — transmitted power

$$P_r = P_t / (4\pi d/\lambda)^2$$

$$\therefore P_t = P_r \cdot (4\pi d/\lambda)^2$$

{speed of light}

$$\lambda = c/f = \frac{3 \times 10^8 \text{ m/s}}{90 \times 10^6 \text{ Hz}} = 3.33$$

$$P_t = 1 \times 10^{-6} \cdot (4 \times 3.14 \times 650 / 3.33)^2$$

$$\boxed{P_t \approx 6 \text{ W}}$$

Ex. 2: The transmitted power of a transmitter is 10 mW, operating at a frequency of 85 MHz. A receiver captures data with the power, 0.1 μW. Find the dist. b/w transmitter & receiver.

Soln:

$P_t = 10 \text{ mW} = 10\times10^{-3}\text{ W}$, $f = 85 \text{ MHz} = 85\times10^{6}\text{ Hz}$

$P_r = 0.1\ \mu\text{W} = 0.1\times10^{-6}\text{ W}$, $d = ?$

$$P_r = (P_t)/(4\pi d/\lambda)^2$$

$$\lambda = c/f = \frac{3\times10^{8}}{85\times10^{6}} = 3.5$$

$$0.1\times10^{-6} = 10\times10^{-3}/(4\times3.14\times d/3.5)^2$$

$$\boxed{d \approx 88\text{ m}}$$

Ex. 3: The transmitted power of a transmitter is 20 mW operating at a frequency of 75 MHz. At a distance of 500 m, a mobile phone establishes the communicatn with this transmitter. Find the captured power.

Soln:

$P_t = 20 \text{ mW} = 20\times10^{-3}\text{ W}$

$f = 75 \text{ MHz} = 75\times10^{6}\text{ Hz}$

$d = 500\text{ m}$

$P_r = ?$

$$\lambda = c/f = \frac{3\times10^{8}}{75\times10^{6}} = 4$$

$$P_r = \frac{P_t}{(4\pi d/\lambda)^2} = \frac{20\times10^{-3}}{(4\times3.14\times500/4)^2}$$

$$\boxed{P_r = 0.01\ \mu\text{W}}$$

(4): For a mobile communication system, it is given that average noise power at the receiver is 25 uW & the captured power is 100 mW. Calculate SNR in dB.

Soln:

Avg. noise power, $P_n = 25\ \mu W = 25 \times 10^{-6}\ W$

Received power, $P_r = 100\ mW = 100 \times 10^{-3}\ W$

SNR = ?

$$SNR = \frac{P_r}{P_n} = \frac{100 \times 10^{-3}}{25 \times 10^{-6}}$$

$$SNR = 4000$$

$$SNR\ (dB) = 10 \cdot \log_{10} (4000)$$

$$\boxed{SNR \simeq 36\ dB}$$

---

Ex (5): A mobile receiver communicates at a distance of 5 km with the transmitter which is having the operating frequency of 750 MHz. Calculate the path loss in the system.

Soln:

Transmitter operating freq → $f = 750\ MHz = 750 \times 10^{6}\ Hz$.

$d = 5\ km = 5 \times 10^{3}\ m$

path loss, $L_p = ?$

$$L_p = \left(\frac{4\pi d}{\lambda}\right)^2$$

$$\lambda = c/f = \frac{3 \times 10^{8}}{750 \times 10^{6}} = 0.4$$

$$L_p = \frac{4 \times 3.14 \times 5 \times 10^{3}}{0.4}$$

$$\boxed{L_p = 2.46 \times 10^{8}}$$

Q: In a mobile commⁿ systems, path loss is $10^9$. the dist. b/w the transmitter & the receiver is 3 km. Find the transmitter operating freq.

Solⁿ: path loss, $L_p = 10^9$

$d = 3\ km = 3 \times 10^3\ m$

$f = ?$

Now, $L_p = \left(\frac{4\pi d}{\lambda}\right)^2$ & $\lambda = c/f$

$\therefore\ 10^9 = \frac{4 \times 3.14 \times 3 \times 10^3 \times f}{c}$

$10^9 = \frac{4 \times 3.14 \times 3 \times 10^3 \times f}{3 \times 10^8}$

$\therefore\ f = 251.6 \times 10^6$ $\therefore\ \boxed{f = 251.6\ MHz}$

---

Ex (7): For a given communication system, transmitter operates at a freq. of 850 MHz with a power of 125 mW. This transmitter communicates with the receiver having the received power of 1 μW. What is the dist. b/w transmitter & receiver?

Solⁿ: $P_t = 125\ mW = 125 \times 10^{-3}\ W$

$f = 850\ MHz = 850 \times 10^6\ Hz$

$P_r = 1\ \mu W = 1 \times 10^{-6}\ W$

Now, path loss, $L_p = \frac{P_t}{P_r} = \frac{125 \times 10^{-3}}{1 \times 10^{-6}} = 125 \times 10^3$

$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{850 \times 10^6} = 0.3529$

Also, $L_p = \left(\frac{4\pi d}{\lambda}\right)^2$

$125 \times 10^3 = \left(\frac{4 \times 3.14 \times d}{0.3529}\right)^2$

$\therefore\ \boxed{d = 9.93\ m}$

OR find using $P_r = \frac{P_t}{(4\pi d/\lambda)^2}$

## Sums based on Antenna gain

**Antenna gain:**

- measure of directionality of antenna.
- defined as the power o/p in a particular direction as compared to that produced in any direction by a perfect omnidirectional antenna.

**Effective Area:**

- related to the physical size & shape of an antenna.

**Reln b/w gain & area:**

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi f^2 A_e}{c^2} \quad (\because \lambda = c/f)$$

where, $G \rightarrow$ antenna gain
$A_e \rightarrow$ effective area
$f \rightarrow$ carrier frequency
$c \rightarrow$ speed of light $= 3 \times 10^8$ m/s
$\lambda \rightarrow$ carrier wavelength

---

Ex. ① : ~~For a parabolic reflective antenna with a diameter of 2 m, operating at 12 GHz,~~ what is the effective area & ~~the~~ antenna gain?

~~$A_e = \pi r^2 = \pi = 3.14$~~ $d = 2m \quad \therefore r = 1m$ (radius)

Area $= A = \pi r^2 = \pi \times 1 = \pi$

$A_e = 0.56 \times A$ (given in table)

$$\boxed{A_e = 0.56 \times \pi}$$

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi \times 0.56}{(0.025)^2} = 35186$$

$$\left\{ \lambda = \frac{c}{f} = \frac{3 \times 10^8}{12 \times 10^9} = 0.025 \text{ m} \right\}$$

for a parabolic reflective antenna with a diameter of 2m, operating at 12 GHz, what is the effective area & the antenna gain.?

Soln : for a, parabolic reflective antenna,

$$\left.\begin{aligned} A_e &= 0.56\,A \; m^2 \\ \text{power gain} &= 7A/\lambda^2 \end{aligned}\right\} \text{ already defined.}$$

Now, diameter = 2 m $\therefore$ radius = 1 m.

$A = \pi r^2 = \pi \times (1)^2 = \pi$

$\therefore \boxed{A_e = 0.56\,\pi \; m^2}$

$A \rightarrow$ area of the antenna aperture (i.e. circular $\therefore A = \pi r^2$)

Now, $\lambda = \dfrac{c}{f} = \dfrac{3\times10^8 \; m/s}{12\times10^9 \; Hz}$

$\lambda = 0.025$ m

Now, $G = \dfrac{4\pi A_e}{\lambda^2}$

$= \dfrac{4\times\pi\times0.56\times\pi}{(0.025)^2}$

$\cong 35,336.80$

$G(dB) = 10 \times \log_{10}(35,336.80)$

$\boxed{G \cong 45.48 \, dB}$

OR

$G = \dfrac{7A}{\lambda^2} = \dfrac{7\times\pi}{(0.025)^2} = 35,168$

$G(dB) = 10 \times \log_{10}(35,168) = 45.46$

$\boxed{G \cong 45.46 \; dB}$

## Sums based on frequency reuse (For cellular n/ws).

* **Frequency Reuse:**
 a technique of reusing frequencies & channels within a cellular n/w to improve the n/w capacity. (avoiding interference).

---

Ex. ①: A cellular n/w has a total BW of 56 MHz. If two 35 kHz simplex channels are used to provide full-duplex voice & control channels, compute the no. of channels available per cell if a system uses (a) 4 cell reuse (b) 7 cell reuse & (c) 12-cell reuse.

$\xrightarrow{\text{soln:}}$ Total available BW = 56 MHz = 56,000 kHz

channel BW = 35 kHz × 2 simplex channels
= 70 kHz / duplex channel

∴ Total available channels = $\frac{56000}{70}$ = 800 channels.

N → frequency (cell) reuse,

(a) $\underline{N = 4}$, total no. of channels available per cell

$= \frac{800}{4} = \underline{200}$ channels.

(b) for $\underline{N = 7}$, no. of channels available per cell

$= \frac{800}{7} \approx \underline{115}$ channels

(c) for $\underline{N = 12}$, no. of channels available per cell

$= \frac{800}{12} \approx \underline{67}$ channels.

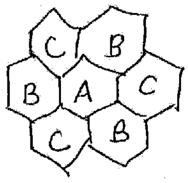
Q: In a cellular n/w with hexagonal cells, it is forbidden to reuse a frequency band in an adajacent cell. If 915 frequencies are available, how many can be used in a given cell.

Soln:

cell shape → hexagonal

∴ has 6 neighbhours

neighbhours can be :




i.e. only 3 unique cells are needed

∴ Each cell can have $\frac{915}{3} = 305$ freq.

---

Ex-③: Consider a cellular n/w with 64 cells, Each hexagonal cell has an approx. area of 10 km², The total no. of radio channels allotted for the n/w is 336. Find the total no. of channels of the n/w, if (a) N = 4, (b) N = 7, (c) N = 12, where N = cell reuse.

Soln: no. of cells = 64, each cell area = 10 km²

∴ total area covered by n/w = 64 × 10 = 640 km²

total available channels = 336

(a) N = 4: available channels in a cell = 336/4 = 84

total channels = 84 × 64 = 5376

(b) N = 7: available channels in a cell = 336/7 = 48

total channels = 48 × 64 = 3072

(c) N = 12: available channels in a cell = 336/12 = 28

total channels = 28 × 64 = 1792.

## Convolution codes:

- Error correcting codes
- defined by 3 parameters n, k, K

  where n → o/p bits

  k → i/p bits

  K → constraint factor (memory bits)

- It processes i/p data 'k' bits at a time & produces an o/p of 'n' bits for each incoming 'k' bits.
- current 'n' bit o/p depends not only on the value of current 'k' i/p bits but also on previous 'K−1' blocks of 'k' i/p bits.
- It can be represented by an encoder shift register, state diagram & code trellis.

  ↓

  useful in decoding process.

- Initially, register is initialized to all zeros.
- The encoder produces 'n' o/p bits after which the oldest 'k' bits from the register are discarded & 'k' new bits are shifted in.
- It can be represented by using a finite state ~~mtc~~. machine.
- The machine has $2^{k(K-1)}$ states & the transition from one state to another is determined by the most recent 'k' bits of i/ps & produces 'n' o/p bits.

* Diversity :
  - impro
  fadin

Q: Draw (2,1,3) shift register with all possible values, Also draw state chart diagram & code trellis.

Soln: Here,

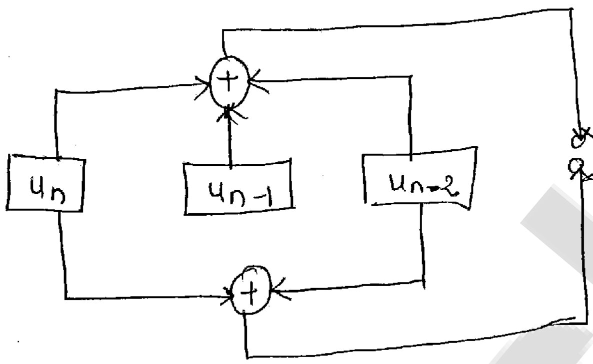
$n = 2$ (no. of o/p bits)

$k = 1$ (no. of i/p bits)

$K = 3$ (constraint factor)

$\therefore$ memory bits $= K-1 = 3-1 = 2$

* Convolution encoder with $(n,k,K) = (2,1,3)$




$vn_1 = u_n \oplus u_{n-1} \oplus u_{n-2}$

o/p bits →

$vn_2 = u_n \oplus u_{n-2}$

Here, memory bits = 2

$\therefore$ no. of possible states = 4

state table:

| $u_{n-1}$ | $u_{n-2}$ | state |
|---|---|---|
| 0 | 0 | a |
| 0 | 1 | b |
| 1 | 0 | c |
| 1 | 1 | d |

EX-OR table:

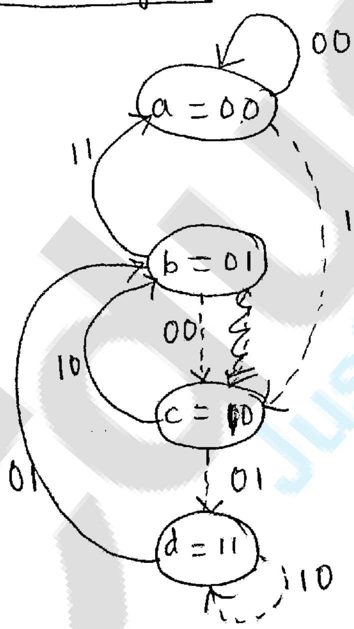
| a | b | $a \oplus b$ |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

← NOTE

| i/p bit $u_n$ | memory bits $u_{n-1}$ | $u_{n-2}$ | o/p bits $v_{n_1}$ | $v_{n_2}$ | current state | Next state |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 00 | 00 |
| 1 | 0 | 0 | 1 | 1 | 00 | 10 |
| 0 | 0 | 1 | 1 | 1 | 01 | 00 |
| 1 | 0 | 1 | 0 | 0 | 01 | 10 |
| 0 | 1 | 0 | 1 | 0 | 10 | 01 |
| 1 | 1 | 0 | 0 | 1 | 10 | 11 |
| 0 | 1 | 1 | 0 | 1 | 11 | 01 |
| 1 | 1 | 1 | 1 | 0 | 11 | 11 |

state chart diagram:

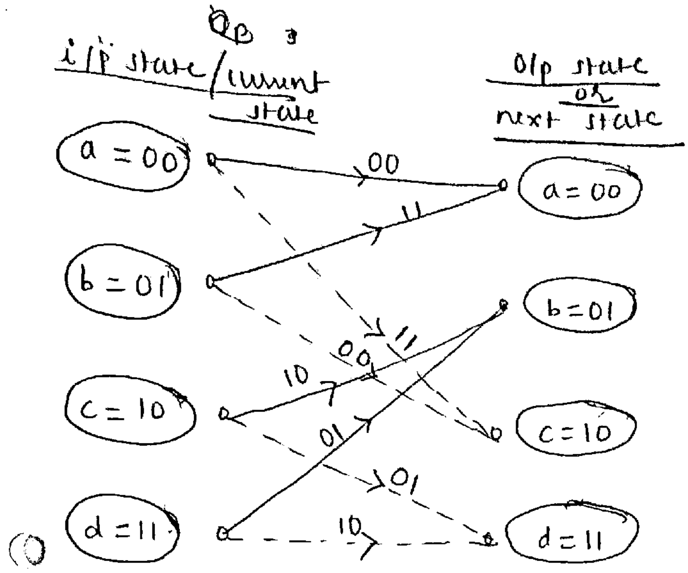
let ⟶ : i/p bit '0'
- - -> : i/p bit '1'



code trellis:

→ : i/p bit '0'

- - -> : i/p bit '1'



Draw state chart for i/p string: 1011001

soln:

| i/p $u_n$ | $u_{n-1}$ | $u_{n-2}$ | next | o/p $v_{n_1}$ | $v_{n_2}$ |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 10 | 1 | 1 |
| 0 | 1 | 0 | 01 | 1 | 0 |
| 0 | 0 | 1 | 00 | 1 | 1 |
| 1 | 0 | 0 | 10 | 1 | 1 |
| 1 | 1 | 0 | 11 | 0 | 1 |
| 0 | 1 | 1 | 01 | 0 | 1 |
| 1 | 0 | 1 | 10 | 0 | 0 |

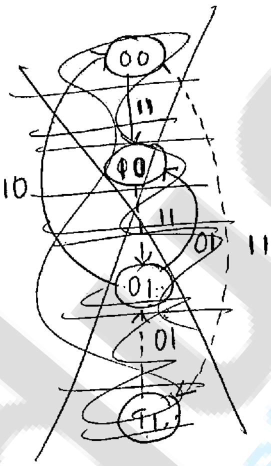
Ex-OR table

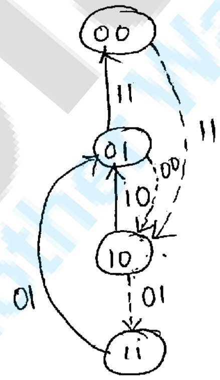
| a | b | a ⊕ b |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

statechart:

——— : 0

- - - : 1






NOTE: 4 states are possible

∵ No. of states $= 2^{k(K-1)}$

$= 2^{1(3-1)} = 2^2 = 4$ combinations