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UNIT 1 :- INTRODUCTION OF WIRELESS CHANNEL

Lecture 1 :- Free space Propagation Model :

* Free-space propagation model :-

Friiss free space equation is given by

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \quad \text{--- (1)}$$

if $d_0 \Rightarrow P_0$

$$\therefore \quad P_r(d_0) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d_0^2 L} \quad \text{--- (2)}$$

$$P_r(d_0) \cdot d_0^2 = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 L}$$

Dividing by d^2

$$\frac{P_r(d_0) \cdot d_0^2}{d^2} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 \cdot L \cdot d^2} \quad \text{--- (3)}$$

From eqn (1) & (3)

$$\frac{P_r(d_0) \cdot d_0^2}{d^2} = P_r(d)$$

$$\boxed{P_r(d) = P_r(d_o) \cdot \left(\frac{d_o}{d}\right)^2} \quad \text{--- (3)}$$

$P_r(d)$ in decibels. (dB)

$$P_r(d)_{dB} = 10 \log_{10} \left[P_r(d_o) \cdot \left(\frac{d_o}{d}\right)^2 \right]$$

$$= 10 \log_{10} [P_r(d_o)] + 10 \log_{10} \left(\frac{d_o}{d}\right)^2$$

$$= 10 \log_{10} [P_r(d_o)] + 20 \log_{10} \left(\frac{d_o}{d}\right)$$

$$\boxed{P_r(d)_{dB} = 10 \log_{10} [P_r(d_o)] - 20 \log_{10} \left(\frac{d}{d_o}\right)} \quad \text{--- (4)}$$

* **Path loss:-** The free space path loss is defined as the loss of energy when EM wave propagates in a straight line through a vacuum with no absorption or reflection of energy.

$$P_L = -10 \log_{10} \left(\frac{P_r}{P_t}\right)$$

but $P_r = \dfrac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$

$$\boxed{P_L(dB) = -10 \log_{10} \left(\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2 L}\right)}$$

* Fraun-hofer region:-

$d_F = \dfrac{2D^2}{\lambda}$, D = Largest physical dimension of the antenna

Note:- should be written in free-space propagation model after equation (1)

$P_r(d)$ => Received power

P_t => Transmitted power

G_t => Transmitted antenna gain

G_r => Received antenna gain

L => $L \geq 1$ => system Loss factor.

λ => wavelength of Transmitted signal. $= \frac{c}{f_0}$

* Numericals:-

Q:-1 Find received power in free space for a distance of 1km if $P_t = 10W$, $G_t = 0$, $G_r = 0$, $f = 900$ MHz

→ $d = 1000m$ $f = 900 \times 10^6$ Hz

if G_r & $G_t = 0$ then it is in dB so convert it into normal units. by taking antilog of 0

Antilog (0) = 1 = G_r & G_t

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} = \frac{P_t G_t G_r c^2}{(4\pi)^2 d^2 L F^2}$$

$$P_r(d) = \frac{10 \times 1 \times 1 \times (3 \times 10^8)^2}{(4\pi)^2 (1000)^2 \times 1 \times (900 \times 10^6)^2} \quad L = 1$$

$$\boxed{P_r(d) = 7.0361 \times 10^{-9} \text{ W}}$$

$$P_r(d)_{dB} = 10\log_{10}(7.0361 \times 10^{-9})$$

$$\boxed{P_r(d)_{dB} = -81.5266 \text{ dB}}$$

Q:2 If transmitter produces 50W of power express it in dBm & dB W. If 50W is applied to unity gain antenna with 900 MHz. Find received power in dBm at distance of 100 m from antenna.

→ $P_t = 50W = 10\log_{10}(50) = 16.98$ dB W

$P_t\,(dBm) = 10\log_{10}\left(\frac{P_t}{1mW}\right) = 10\log_{10}\left(\frac{50}{1\times10^{-3}}\right)$

$P_t\,(dBm) = 46.98$ dBm

$G_t = G_r = 1$, $f = 900\times10^6$ Hz, $d = 100m$

$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} = \frac{50\times1\times1\times(3\times10^8)^2}{(4\pi)^2(100)^2\times1\times(900\times10^6)}$

$\boxed{P_r(d) = 3.5180\times10^{-6}\ W}$

$P_r(d)\,dBm = 10\log_{10}\left(\frac{3.5180\times10^{-6}}{1\times10^{-3}}\right)$

$\boxed{P_r(d) = -24.5370\ dbm}$

Q:3 Calculate of Fraun-hofer distance for an antenna with maximum dimension of 1m & operating frequency of 900 MHz. If antenna has unity gain, calculate the path loss.

→ $D = 1m$ $f = 900\times10^6$, $G_r = G_t = 1$

Fraun-Hofer

$d_f = \frac{2D^2}{\lambda} = \frac{2D^2}{c/f} = \frac{2D^2 f}{c} = \frac{2\times(1)^2\times 900\times10^6}{3\times10^8}$

$d_f = \frac{600}{100}$ $\boxed{d_f = 6\ m}$

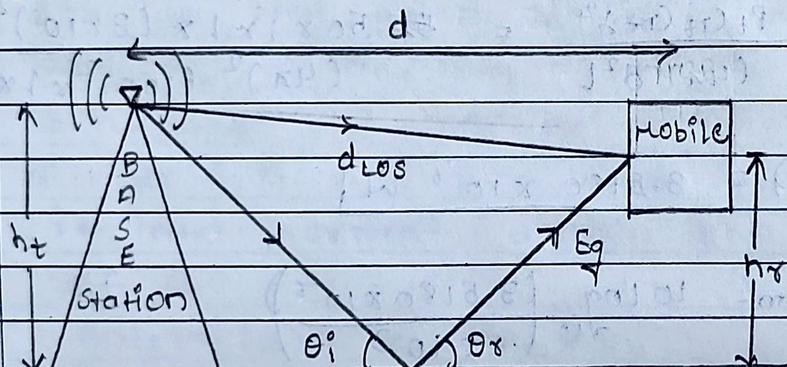
$$P_L = -10\log_{10}\left[\frac{G_t G_r \lambda^2}{(4\pi)^2 L d^2}\right]$$

$$P_L = -10\log_{10}\left[\frac{1\times 1\times(3\times10^8)^2}{(4\pi)^2\times 1\times(1)^2\times(6)^2\,(900\times10^6)^2}\right]$$

$$\boxed{P_L = 47.0896\ dB}$$

Lecture 2:- Ground Reflection Model

* Ground reflection model or Two ray model :-



LOS is Line of sight

Assumptions from book (V Imp)

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

$$E_{total} = E_{LOS} + E_{gr}$$

$$P_{tot} \propto \frac{1}{d^n} \quad [n = 2\ [\text{Two ray model}]]$$

$$P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4} = \frac{E_g}{\eta}\left[\frac{G_r \lambda^2}{4\pi}\right]^2, \quad \eta = 377$$

$$E_r = \frac{2E_0 d_0}{d} \times \frac{2\pi h_t h_r}{\lambda d}\ \text{v/m} \qquad d >> \sqrt{h_t h_r}$$

$$P_L(dB) = 40\log_{10}(d) - [10\log_{10}(G_t) + 10\log_{10}(G_r) + 20\log_{10}(h_t) + 20\log_{10}(h_r)]$$

Numericals:-

Q:-1 Check whether 2-ray model is applicable or not

i) $h_t = 35m$, $h_r = 3m$, $d = 250m$

ii) $h_t = 30m$, $h_r = 1.5m$, $d = 450m$

→ i) if $d > 10(h_t + h_r)$ then 2-ray model is applicable

i) $10(h_t + h_r) = 10(35 + 3) = 380$

As $d < 10(h_t+h_r)$ so Two Ray Model is ~~not applicable~~. not applicable

ii) $10(h_t + h_r) = 10(30 + 1.5) = 315m$

As $d < 10(h_t+h_r)$ so Two-ray model is ~~not~~ applicable.

Q:-2 A mobile is located 5km from base station & uses an antenna with gain 2.55 dB. E-field at 1 km from transmitter is 10^{-3} V/m. The carrier frequency is 900 MHz. Find E-Field at mobile. Given $h_t = 50m$, $h_r = 1.5m$.

→ $d = 5km = 5000m$, $G_t = 2.55\,dB$, $d_0 = 1km = 1000m$

$E_0 = 10^{-3}$ V/m, $f = 900MHz = 900 \times 10^6$ Hz

$d > 10(h_t + h_r)$ check this condition is satisfied or not in every numerical

$10(h_t + h_r) = 10(50 + 1.5) = 515m$

As $d > 10(h_t + h_r)$ so 2-ray model is satisfied.

$$E_R(d) = \frac{2E_0 d_0}{d} \cdot \frac{2\pi h_t \cdot h_r}{\lambda d}$$

$\cancel{E_r = 2\pi \; \lambda = \frac{c}{f}}$ $\quad \lambda = \frac{C}{F}$

$$E_R(d) = \frac{2 \times 10^{-3} \times 1000 \times 2\pi \times 50 \times 1.5}{\frac{3 \times 10^8}{900 \times 10^6} \times (5000) \times (5000)}$$

$$\boxed{E_R(d) = 113.0973 \times 10^{-6} \; v/m}$$

Q:3 A receiver is located at 10 km from 50W transmitter. The carrier frequency is ~~1400~~ 1900 MHz, $G_t = 1$, $G_r = 2$, Find

i) Received power ii) Magnitude of Electric field at receiver

Assume $h_t = 50m$, $h_r = 15m$.

→ $d = 10\,km = 10000\,m$, $P_t = 50\,W$, $f_c = 1900 \times 10^6\,Hz$

$G_t = 1$, $G_r = 2$

i) $$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} = \frac{50 \times 1 \times 2 \times (3 \times 10^8)^2}{(4\pi)^2 \times (10000)^2 \times (1900 \times 10^6)^2}$$

~~$P_r(d) = 78.9379 \times 10^{-12}\,W$.~~

$$P_r = \frac{|E_r^2|}{\eta} \frac{G_r \lambda^2}{4\pi}$$

$$78.9379 \times 10^{-12} = \frac{|E_r^2|}{377} \cdot \frac{1 \times (3 \times 10^8)^2}{(4\pi) \times (1900 \times 10^6)^2}$$

$$|E_r^2| = \frac{78.9379 \times 10^{-12} \times 377 \times (4\pi) \times (1900 \times 10^6)^2}{1 \times (3 \times 10^8)^2}$$

$|E_r^2| =$

$$\boxed{P_r(d) = 1.5787 \times 10^{-10}\ W}$$

$$P_r(d)_{dB} = 10\log_{10}(1.5787 \times 10^{-10}) = -98.0168\ dB$$

~~Pr~~ = TE $\boxed{P_r(d)_{dB} = -98.0168\ dB}$

$$P_r(d) = \frac{|E^2|}{\eta} \frac{G_r \lambda^2}{4\pi} \quad \eta = 377 \text{ or } 120\pi$$

$$|E^2| = \frac{P_r(d) \times \eta \times 4\pi}{G_r \lambda^2} =$$

$$|E| = \sqrt{\frac{1.5787 \times 10^{-10} \times 377 \times 4\pi}{2 \times \left(\frac{3 \times 10^8}{1900 \times 10^6}\right)^2}}$$

$$\boxed{|E| = 3.8729 \times 10^{-3}\ V/m}$$

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Lecture 3:- Channel estimation & diversity

* HATA model:-
1. Imperical formation of graphical path loss derived by Okumura model.
2. valid for 150 MHz to 1500 MHz.
3. It gives propagation loss in urban area in the form of standard formula.
4. $$\boxed{L(dB) = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_{te}) - a(h_{re}) + [44.9 - 6.55\log_{10}(h_{te})]\,d}$$

f_c => Frequency in (MHz) from 150 MHz to 1500 MHz

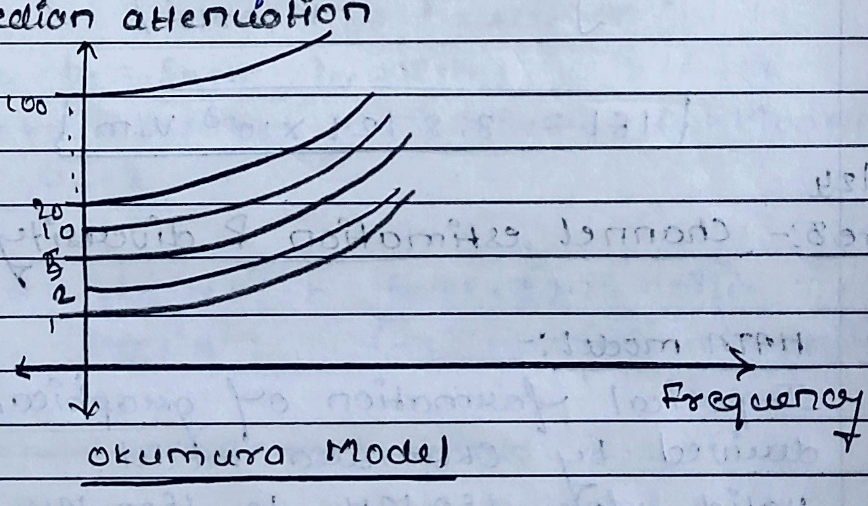
h_{te} => Effective transmitter (base station) antenna height

h_{re} => Effective receiver (mobile) antenna height.

d => Tx - Rx separation distance in km.

$a(h_{re})$ = correction factor for effective mobile antenna height.

5. No path specific corrections.
6. Well suited if $d > 1$ km.
7. Works well for larged sized cells.
8. Not suitable for PCS.



Okumura Model

* **Receiver noise computation:-**

i) Noise power $(n_0) = KTF$

K => Boltzman's constant $= 1.38 \times 10^{-23}$

T => kelvin ~~B => B.W~~ F => noise figure

$n_p = n_0 B$, $n_p = \sigma_n^2 = n_0 B$

Numericals :-

Q:1 Compute noise power at $T = 293\,K$, noise figure $(F) = 5\,dB$ & Bandwidth $(B.W) = 30\,kHz$.

→ $5\,dB = 10\log_{10} F \Rightarrow \log_{10} F = 0.5$

$F = 10^{0.5} \Rightarrow \boxed{F = 3.1622}$

$n_0 = KTB = 1.38\times10^{-23} \times 293 \times \cancel{30\times10^3}\ 3.1622$

$\boxed{n_0 = 1.27862\times10^{-20}}$

$n_0(dB) = 10\log_{10} \cancel{(1.28302\times10^{-16})}\ (1.02786\times10^{-20})$

$\boxed{\cancel{n_0 = -159.1613\,dB}}$, $\boxed{n_0 = -199\,dB}$

$n_p = \sigma_n^2 = n_0 B = 1.21302\times10^{-16} \times 30\times10^3$

$\boxed{\cancel{n_p = 3.83906\times10^{-12}}}$ $\boxed{n_p = 3.8358\times10^{-16}}$

$n_p(dB) = \cancel{10\log_{10}(3.63906\times10^{-12})}\ 10\log_{10}(3.8358\times10^{-16})$

$\boxed{\cancel{n_p = -114.3901\,dB}}$ $\boxed{n_p = -154.1614\,dB}$

★ **Channel estimation :-**

The wireless channel model is given as

$y(k) = h x(k) + n(k)$ —— ①

The estimate of the received symbol corresponds to $x(t)$ is given as

$\hat{x}(k) = \frac{1}{h} y(k)$ [Called as zero forcing receiver.]

—— ②

consider transmission of L pilot symbols then received

$$y^{(P)}k = hx^{(P)}k + n(k) \quad \text{(3)}$$

Due to presence of noise in a system $y(k) \neq x(k)$ for any value of k, so h can be estimated as a minimum value of cost function.

$$\hat{h} = \arg\min_{h} \{ (y^{(P)}(1) - hx^{(P)}(1))^2 + (y^{(P)}(2) - hx^{(P)}(2))^2 \}$$

$$\cancel{\hat{h} = \sum_{K=1}^{L} y^{(P)}(k) - hx^{(P)}(k)}$$

$$\hat{h} = \underbrace{\sum_{K=1}^{L} (y^{(P)}(k) - hx^{(P)}(k))^2}_{\xi(h)} \quad \text{(4)}$$

This estimate of h gives min. value of error function so called as square equivalent

To minimize the error function differentiate the same & set equal to zero.

$$\frac{d\,\xi(h)}{dh} = \sum_{K=1}^{L} 2(y^{(P)}(k) - hx^{(P)}(k)) (x^{(P)}(k))$$

$$0 = \sum_{K=1}^{L} x^{(P)}(k) (y^{(P)}(k) - \hat{h}x^{(P)}(k))$$

$$\boxed{\hat{h} = \frac{\sum_{K=1}^{L} y^{(P)}(k) x^{(P)}(k)}{\sum_{K=1}^{L} (x^{(P)}(k))^2}} \quad \text{(5)}$$

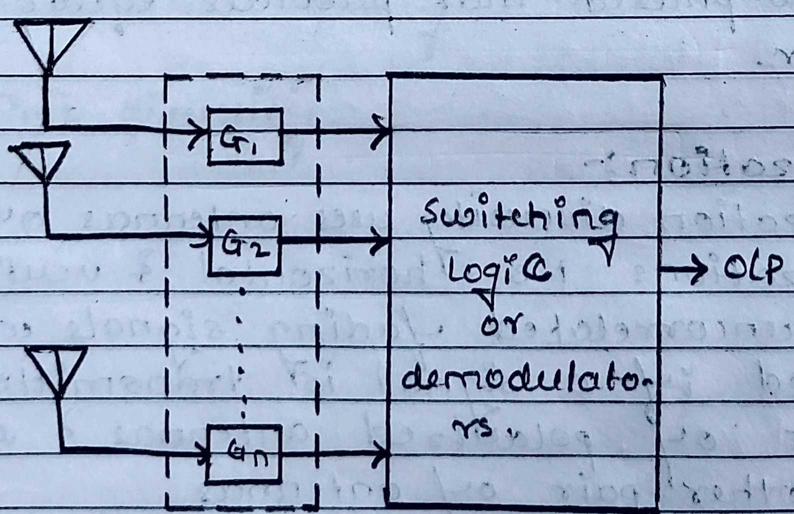
$$\boxed{\hat{h} = \frac{(x^{(P)})^H y^{(P)}}{(x^{(P)})^H x^{(P)}} = \frac{(x^{(P)})^H y^{(P)}}{|x^{(P)}[k]|^2}} \quad (6)$$

* **Diversity :-** ~~Dt~~ It is a technique that provide wireless link improvement at low ~~&~~ cost.
2. It is a powerful communication receiver technique.
3. Diversity reception is used in order to minimize the effects of fading.
4. Types of diversity

Diversity
- Polarization
- Frequency
- Time
- Space
  - Selective
  - Feedback
  - Maximal to ratio combining
  - Equal gain

1. ~~Polarization:-~~ Space diversity :-

Block diagram :-



* **Space diversity reception methods :-**
1. Selection diversity :- In this method the branches having the strongest received signal will be selected.

2. Feedback or scanning diversity :- In this method 'n' signals are scanned in a proper sequence & monitored to pick up a signal in the sequence that is above the predetermined threshold value.

3. Maximal Ratio combining :-

i) In this method, the signals from all of the 'n' branches are weighted.

ii) The signals are weighted according to their individual signal voltage to noise power ratios & then the signals are combined.

4. Equal gain combining :-

i) In this method, all the diversity branches are added with the same weighing factor.

ii) The signals from each diversity branches are co-phased that provides equal gain factor.

2. Polarization :-

i) Polarization diversity uses antennas of different polarizations i.e horizontal & vertical.

ii) Two uncorrelated fading signals will be received if a signal is transmitted by a pair of polarized antennas & received by another pair of antennas.

iii) This is due to fading ~~techniques~~ variations by horizontal & vertical polarizations & different reflection coefficient values of the tall building walls.

Advantages:- i) No need of additional space & bandwidth.

Disadvantages:-

i) Polarization diversity required 3dB extra power.

ii) Only two diversity branches are allowed.

3. Frequency diversity:- i) It refers to the use of multiple frequency bands or channels within the radio spectrum to transmit & receive signals between mobile devices & the base stations.

ii) ~~1. Minimizing~~ This approach is employed to improved the reliability & performance of wireless communication systems.

Key points about frequency diversity in CN:-

~~4. Time diversity:-~~ a) Minimizing interference

b) Fading mitigation.

c) Increased capacity

d) Improved reliability

e) Load balancing

4. Time diversity:-

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Lecture 4 :- Okamura & Hata Models :-

* Relation for least square estimate or Channel estimation :-

The process of calculating channel coefficient (h) at wireless receiver.

⇒ Pilot or training symbols ⇒ Estimate channel coefficients.

Transmitted symbols ⇒ $x^{(P)}(1), x^{(P)}(2), \ldots, x^{(P)}(L^{P})$

Received symbols are $y^{(P)}(1), y^{(P)}(2), \ldots, y^{(P)}(L^{P})$

General equation ⇒ $\underset{O/P}{Y(k)} = \underset{\text{channel coefficient}}{h}\,\underset{I/P}{x(k)} + \underset{\text{Noise}}{n(k)}$

$\therefore \quad Y^{P}(k) = h x^{(P)}(k) + n(k)$

$\hat{h}$ of h is derived as minimizer of cost function.

$$\hat{h} = \underbrace{\sum_{K=1}^{L}\left[Y^{(P)}(k) - h x^{(P)}(k)\right]^2}$$

$\xi(h)$ ⇒ observation error.

$$\frac{d\,\xi(h)}{dh} = \sum_{K=1}^{L} 2\left[Y^{(P)}(k) - h x^{(P)}(k)\right].\,x^{(P)}(k) = 0$$

$$\sum_{K_1}^{L} 2\left[Y^{(P)}(k) - \hat{h} x^{(P)}(k)\right].\,x^{(P)}(k) = 0$$

$$\sum_{K_1}^{L}\left[Y^{(P)}(k).\,x^{(P)}(k)\right] - \hat{h}\left[x^{(P)}(k)\right]^2 = 0$$

$$\boxed{\hat{h} = \frac{\sum_{K=1}^{L}\left[Y^{(P)}(k) - x^{(P)}(k)\right]}{\sum_{K=1}^{L}\left[x^{(P)}(k)\right]^2}} \quad (1)$$

Formulae :- (Okumura model) :-

1. Free space path loss :- $L_F = -10\log_{10}\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right]$

2. B.S antenna gain :- $G(h_{te}) = 20\log_{10}\left(\frac{h_{te}}{200}\right)$

3. Mobile antenna height gain :- $G(h_{re}) = 20\log_{10}\left(\frac{h_{re}}{3}\right)$

4. Total path loss :- $L_{50} = L_F + A_{mu} - G(h_{te}) - G(h_{re}) - G_{Area}$

5. Median Received power :- $P_r(d) = EIRP - L_{50}$ &

$EIRP = 20\log_{10}[P_{in}(W)]$ → watts.

Numericals :-

Q:-1 Find total path loss & median received power using Okumura model for d = 40 km, A_{mu} = 41 dB, h_{te} = 100m, h_{re} = 10m. If EIRP for base station is 1 kW at 900 MHz, G_{Area} = 9 dB.

→ $L_{50} = L_F + A_{mu} - G(h_{te}) - G(h_{re}) - G_{Area}$

$\lambda = \frac{c}{f}$

$\therefore L_F = -10\log\left[\frac{c^2}{(4\pi)^2 d^2 \cdot f^2}\right] = -10\log\left[\frac{(3\times10^8)^2}{(4\pi)^2 \cdot (40\times10^3)^2 \cdot (900\times10^6)^2}\right]$

$\boxed{L_F = 123.5678 \text{ dB}}$

$G(h_{te}) = 20\log\left(\frac{h_{te}}{200}\right) = 20\log\left(\frac{100}{200}\right) = -6.0205 \text{ dB}$

$G(h_{re}) = 20\log\left(\frac{h_{re}}{3}\right) = 20\log\left(\frac{10}{3}\right) = 10.4575 \text{ dB}$

$L_{50} = 123.5618 + 41 + 6.0205 - 10.4575 - 9$

$$\boxed{L_{50} = 151.1308 \text{ dB}}$$

~~EIRP =~~ $P_r(d) = EIRP - L_{50}$

$EIRP = 20\log(1\times10^3) = 60$

$P_r(d) = 60 - 151.1308$

$$\boxed{P_r(d) = \cancel{90} - 91.1308 \text{ dB}}$$

Numericals (HATA Model) :-

1. Correction factor ($f_c > 300$ MHz)

$$a(h_{re}) = 3.2(\log 11.75 h_{re})^2 - 4.97$$

2. $L_{(URBAN)} = 69.55 + 26.16 \log(f_c) - 13.82 \log(h_{te}) - a(h_{re}) + [44.9 - 6.55 \log(h_{te})] . \log(d)$

in HATA model convert f_c into MHz

Q:- Compute median loss for large city by considering HATA model at a distance of 3km with carrier frequency of 2.1 GHz with transmitting & receiving antenna gain 20m & 2m respectively.

→ Given $d = 3$km, $f_c = 2.1\times10^9$ Hz, $h_{te} = 20$m, $h_{re} = 2$m, $f_c = 2.1\times10^3$ MHz $= 2100$ MHz

Applicable when? Here $f_c > 300$ MHz

$a(h_{re}) = 3.2[\log(11.75 h_{re})]^2 - 4.97$

$a(h_{re}) = 3.2[\log(11.75\times2)]^2 - 4.97$

$$\boxed{a(h_{re}) = 1.0454 \text{ dB}}$$

keep in MHz

$$L(URBAN) = 69.55 + 26.16 \log(2100) - 13.82 \log(20) - 1.0454 + [44.9 - 6.55 \log(20)] \cdot \log(3)$$

keep in km

$$\boxed{L(URBAN) = 154.7904 \text{ dB}}$$

11/02/24

UNIT 2 :- ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

Lecture 1: Orthogonal frequency division multiplexing (OFDM) :-

* **Motivation & multicarrier basics :-**

Single - carrier communication system :-

1. In a single-carrier communication system, a single radio frequency carrier is used to carry the information. Hence information in the form of bits is carried by only one single RF carrier.
2. This system uses a single carrier for the entire baseband bandwidth of B.
3. Therefore the symbols are transmitted as
   $x(0) \Rightarrow 0$ to T
   $x(1) \Rightarrow T$ to $2T$
   i.e a single symbol transmitted every $T = 1/B$ seconds.

Symbol Time :

if $B = 2W$, $W \Rightarrow$ one sided B.W

Then symbol time is given by

$$T = \frac{1}{B}$$

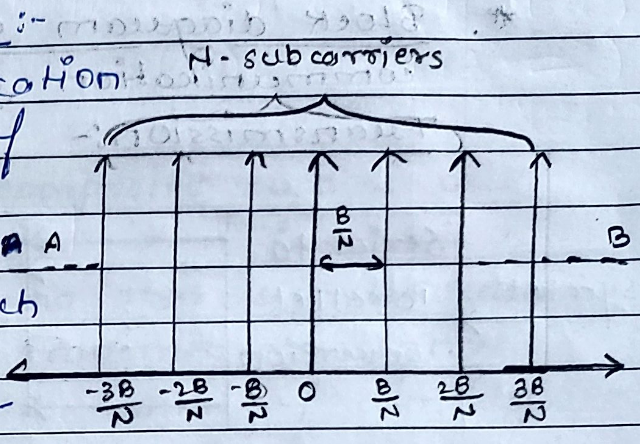
symbol rate :- $\Rightarrow \frac{1}{T} = \frac{1}{1/B} \Rightarrow \frac{1}{T} = B$

Symbol rate = B

such systems are called single-carrier communication system

Multi-carrier system :-

1. Multi-carrier communication system is a method of transmitting data by splitting it into several components & sending each of these components over separate carrier signals.



2. Thus this system uses more than one carriers.
3. The total bandwidth B is divided into N sub-bands each of B.W B/N.
4. Each sub-band is represented by a subcarrier.
5. ~~As shown in fig~~ The subcarriers are placed at frequencies (. . . , -B/N, 0, B/N . .)

consider frequency of ith subcarrier

$$f_i = i\left(\frac{B}{N}\right)$$

if x_i is the data transmitted on ith sub-carrier

then $s_i = x_i e^{j2\pi f_i t}$

$$\boxed{s_i = x_i e^{j2\pi i\left(\frac{B}{N}\right)t}}$$

$s_i(t) \Rightarrow$ ith subcarrier signal.

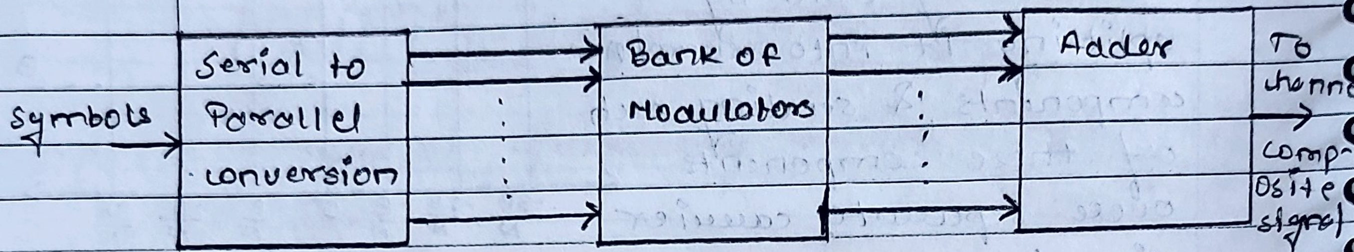
$x_i(t) \Rightarrow$ Data transmitted on the ith subcarrier

f_i = ith subcarrier centre frequency

$e^{j2\pi f_i t} \Rightarrow$ ith subcarrier.

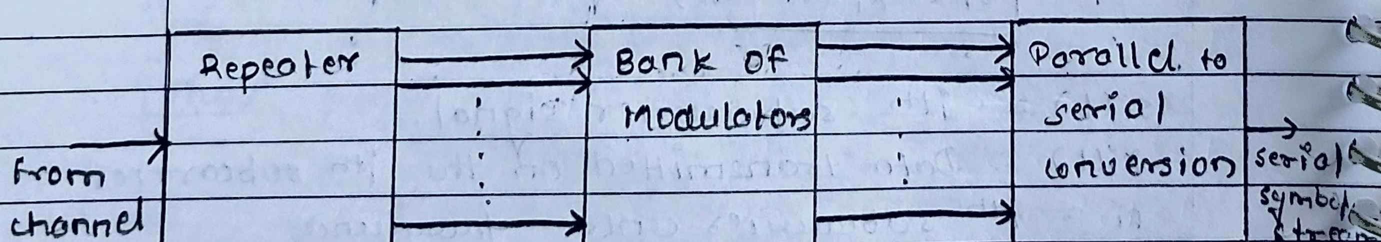
*. **Block diagram of Multi-carrier communication system :-**

Transmission:-



1. MCM transmitter consists of a serial to parallel converter, bank of modulators & an adder.
2. Serial to parallel converter is used to transmit N information symbols in parallel. Thus there are N no. of data streams.
3. The modulator modulates i^{th} data stream onto the i^{th} subcarrier.
4. Adder will make the sum all the modulated ~~carriers~~. subcarriers.
5. Sum of all such subcarriers forms a composite signal which then would be transmitted on a channel.

~~Reception (Receiver)~~ :- Receiver:-



1. It consists of a repeater, bank of modulators & parallel to serial converter. The received signal r(t) is applied to a repeater stage.
2. At the receiver end composite signals are amplified first.
3. Repeater is an antenna that simultaneously receives, amplifies & transmits a signal.
4. It is passed on to the bank of demodulators or correlators & the data is converted back to serial from parallel forming a symbol stream.

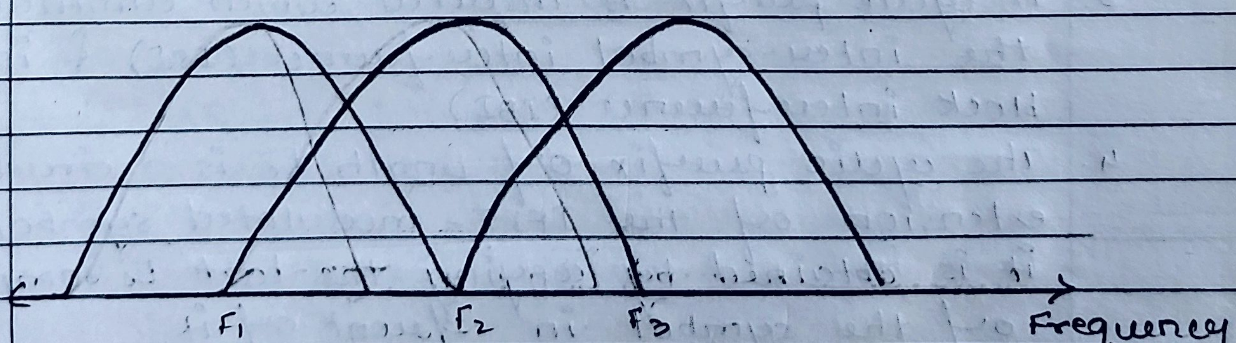
Advantages :-

1. NO ISI
2. Flat fading
3. Signal distortion is avoided.

Disadvantages :-

1. complex system.

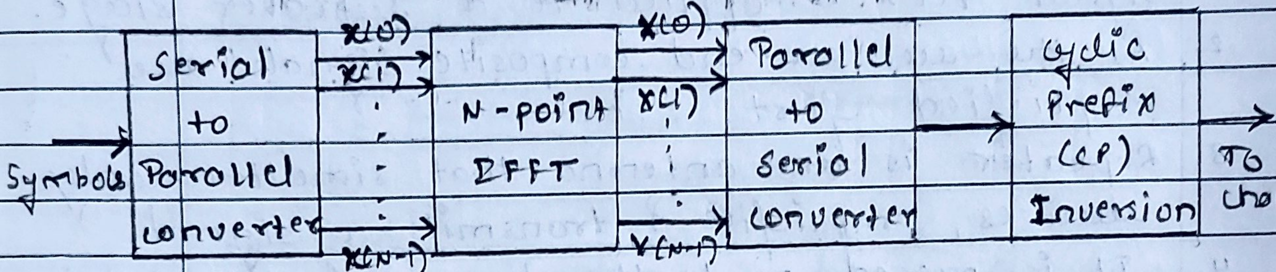
* ~~OFDM :~~ Concept of OFDM :-



Signals are orthogonal if they are mutually independent of each other in a specific time & do not interact with each other.

* Block diagram of OFDM :-

Transmitter :-

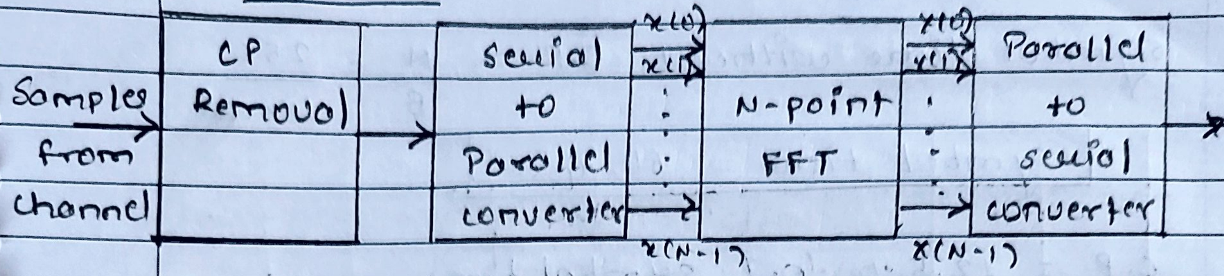


1. ~~Serial to parallel conversion :- The symbols (bits) which are in serial form are converted into parallel format.~~

2. ~~N point IFFT :-~~

1. The information symbols are parallelized in N different sub-streams by using serial to parallel converter.
2. Each sub stream will modulate a separate carrier through the N-point IFFT modulation block.
3. A cyclic prefix is inserted which eliminates the inter-symbol interference (ISI) & inter-block interference (IBI).
4. The cyclic prefix of length L_c is a circular extension of the IFFT-modulated symbol & it is obtained by copying the last L_c samples of the symbol in front of it.
5. The information symbols are back serial converted, forming an OFDM symbol that will modulate a high-frequency carrier before its transmission through the channel.

Rc. Receiver:-



1. The information symbols are down-converted to the baseband & the cyclic prefix is removed.
2. The symbols are converted into parallel form by serial to parallel converter.
3. The coherent FFT demodulator will ideally retrieve the exact form of transmitted symbols.
4. Finally, the parallel to serial block converts this parallel data into a serial stream to recover the original input data.

Lecture 2:- MIMO wireless communication:-

Roll NO :- 36

* Design example of OFDM:-
Wi-Max (Wireless Interoperability for microwave access :-

$N = 256$ & B.W/sub $= 15.625$ kHz / sub

$\frac{B}{N} = 15.625$ kHz

$B = 15.625 \times 256 = 4 \times 10^6$

$\boxed{B = 4\text{MHz}}$

Coherent Bandwidth $(B_c) = 250$ kHz

As B.W/sub $< B_c$ → Flat fading.

Roll NO:- 86

symbol time without C.P is $\frac{N}{B} = \frac{256}{4 \times 10^6}$

$\boxed{\text{symbol time} = 64\ \mu sec}$

C.P = 12.5 % of symbol time

$C.P = \frac{12.5 \times 64 \times 10^{-6}}{100}$

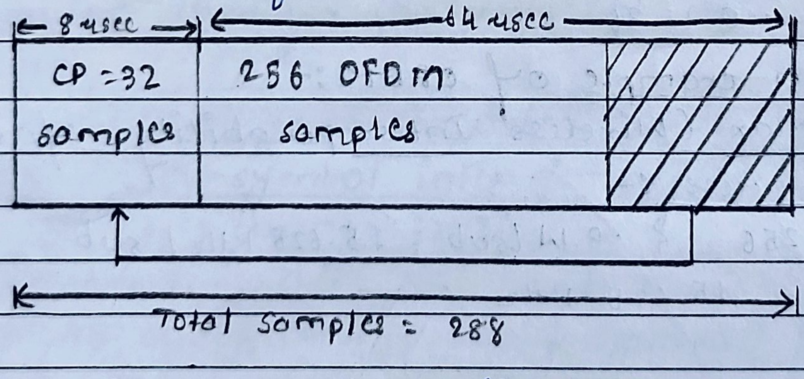
$\boxed{C.P = 8\ \mu sec}$

No. of samples in C.P = $\frac{8\ \mu sec}{\text{Sample time}} = \frac{8 \times 10^{-6}}{1/B}$

$= 8 \times 10^{-6} \times B = 8 \times \cancel{10^{-6}} \times 4 \times \cancel{10^{6}}$

$\boxed{\text{No. of samples} = \cancel{32}\ 32}$

Total no. of samples = 256 + 32 = 288

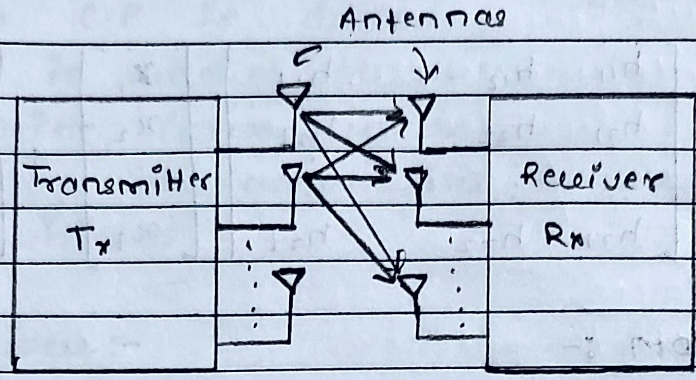


Loss in spectral efficiency :-

Loss = $\frac{\text{length of cyclic prefix } L_c}{\text{Total No. of samples}} = \frac{32}{288}$

$\boxed{\text{Loss} = 11.1\ \%}$

* How MIMO works ?



1. STTP :- i) It stands for Space Time Transmit diversity.
ii) Same data is transmitted & coded through different antennas.
iii) As power ↑ses, SNR also ↑ses.

2. SM :- i) It stands for spatial multiplexing.
ii) It delievers parallel data to receivers by using multipaths.
iii) As capacity ↑ses, O/p ↑ses.

3. Uplink collaborative MIMO link :- Two devices can collaboratively transmit data on same subchannel, which ↑ses uplink capacity.

* MIMO system model :-

$$x = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_t \end{bmatrix} \quad y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_t \end{bmatrix} \quad H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1t} \\ h_{21} & h_{22} & \cdots & h_{2t} \\ \vdots & & & \vdots \\ h_{r1} & h_{r2} & \cdots & h_{rt} \end{bmatrix}$$

't' 'r'

$$n = \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_r \end{bmatrix}$$

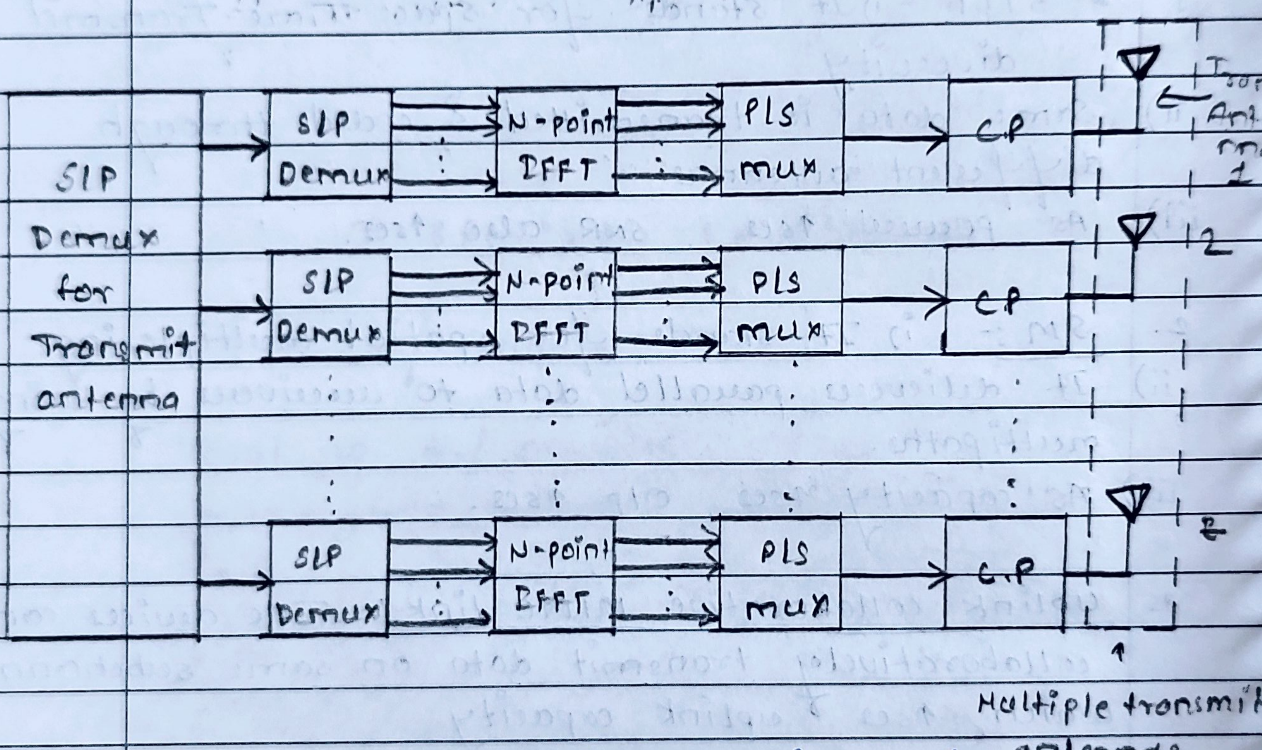
P/S → Parallel to serial
S/P → serial to parallel
C.P → cyclic Prefix.

$$y = Hx + n$$

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_r \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1t} \\ h_{21} & h_{22} & \cdots & h_{2t} \\ \vdots & \vdots & & \vdots \\ h_{r1} & h_{r2} & & h_{rt} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_t \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_r \end{bmatrix}$$

* **MIMO – OFDM :-**

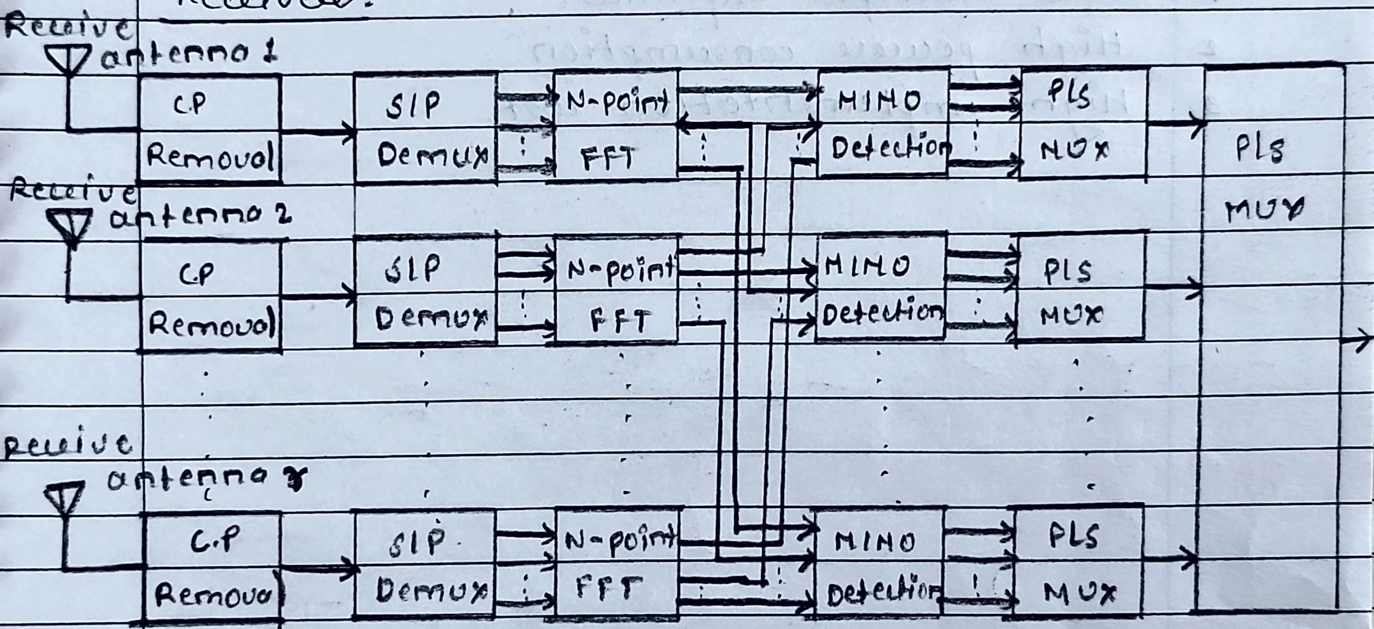
Transmitter :-



1. MIMO-OFDM transmitter consists of serial to parallel demux block for transmit antennas, N-point IFFT, parallel to serial mux & cyclic prefix (CP).
2. On each transmit antenna again S/P demux operation is performed.
3. Each information symbol is passed through a S/P converter & becomes parallel data.
4. On the parallel data, the IFFT operation is performed.

5. Time domain symbols are P/S converted & then C.P is added.
6. C.P is added to eliminate ISI & ICI (Inter-carrier interference).
7. Finally, the amplified modulated signals are transmitted.

Receiver :-



1. At receiver, C.P & IFFT is removed at each receive antenna.
2. MIMO detection is performed across each subcarrier
3. For the first sub-carrier take the output from the first subcarrier at every received antenna.
4. For the second subcarrier take the O/P from the second subcarrier at every receive antenna & perform the MIMO detection for all subcarriers
5. After MIMO detection of all subcarriers, convert these subcarriers from P/S.
6. Again all these parallel streams are converted into serial streams by using parallel to serial mux.

Advantages:-

1. Bandwidth increases.
2. Data rate increases.
3. Spatial efficiency increases.
4. Reliability of link increases.

Disadvantages:-

1. Need multiple antennas.
2. High power consumption.
3. High implementation cost.