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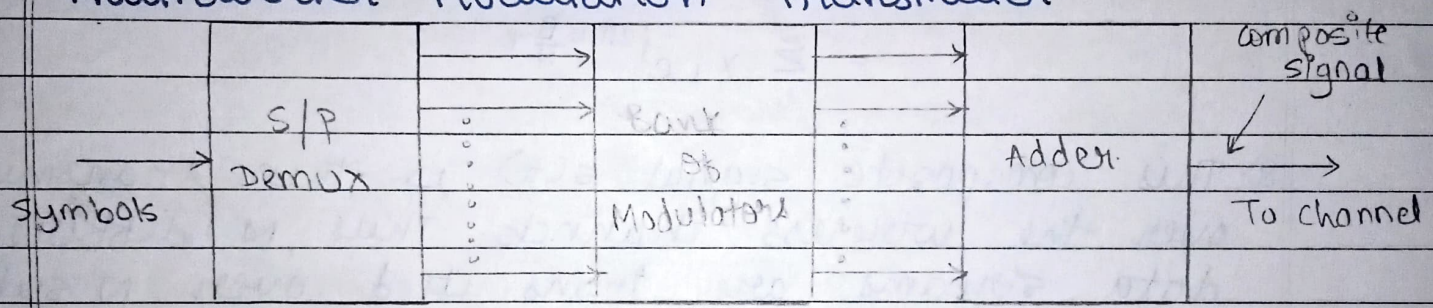
CLASS :- TE B (ENTC)
SUBJECT :- Cellular Networks (CNW)

* Unit 2 - Assignment 2 *

Q2) Draw block diagram to describe each component of Multicarrier Modulation transmitter & receiver.

Ans :- Multicarrier Modulation Transmitter.



1) ~~MCM~~ Multicarrier Modulation of a serial to Parallel converter, Bank of modulators and an adder.
2) Serial to parallel conversion is used to transmit n - information symbols in parallel. Thus there are n - numbers of data streams.
3) The modulator modulates i^{th} data stream onto i^{th} subcarrier.
4) Adder will make the sum all the modulated subcarriers.
5) sum of all such subcarriers forms a composite signal which ~~when~~ then would be transmitted on a channel.

6) Consider the different modulated signals $s_i(t)$ corresponding to the N different subcarriers.

7) The signal $s(t)$ is formed by superposing modulated signals at the transmitter & is given by.

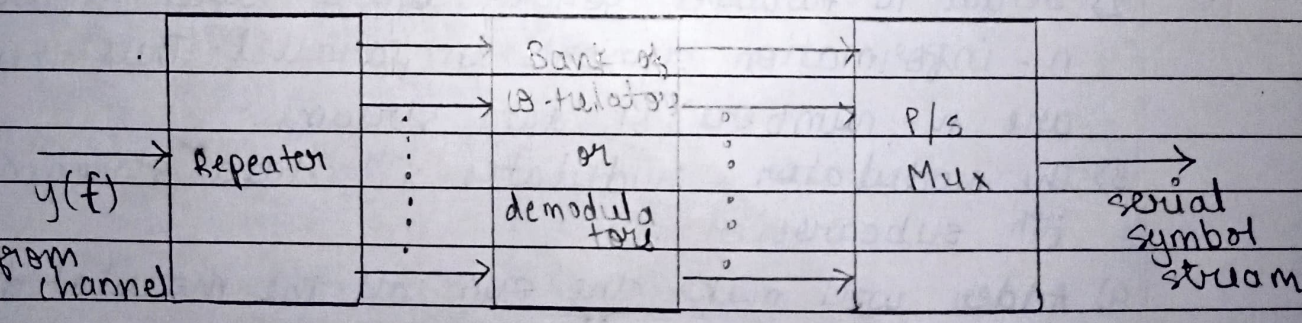
$$s(t) = \sum_i s_i(t) \longrightarrow (1)$$

$$s(t) = \sum_i x_i e^{j2\pi f_i t}$$

$$= \sum_i x_i e^{j2\pi i \frac{B}{N} t}$$

8) This composite signal $s(t)$ is then transmitted over the wireless channels. Thus, N different data streams are transmitted over N sub-carriers in parallel. ~~At the~~

* Multicarrier Modulation Receiver.



1) It consists of a repeator, bank of demodulators & parallel to serial converter. The received signal $y(t)$ is applied to a repeater stage.

2) At the receiver end composite signals are amplified first.

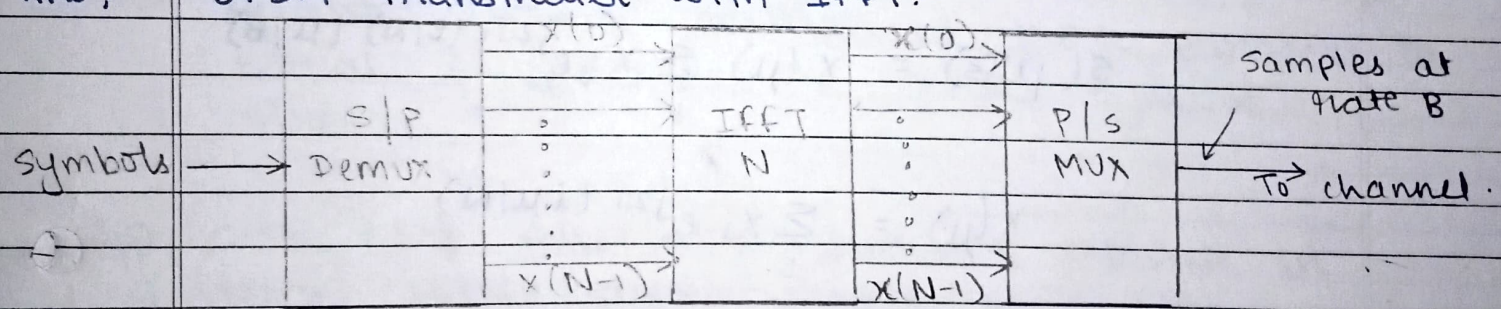
3) At the receiver end composite signals are amplified first.
4) Repeater is an antenna that simultaneously receives, amplifies & transmits a signal.
5) It is passed on to the bank of demodulators & the data is converted back to serial from parallel, forming a symbol stream.

Q3) Draw neat diagram & explain the working operation of OFDM transmitter & receiver with FFT.

OR

Q 8) Draw with neat Block diagram OFDM transmitter with IFFT.

Ans :- OFDM Transmitter with IFFT :-



1) The Bank of Modulators in Multicarrier Modulation is replaced by IFFT block in OFDM.
2) The information symbols at the input are converted from serial stream into parallel.
3) The serial to parallel converter takes the serial stream of input bits & outputs N parallel streams.
4) The N-point IFFT modulates parallel streams in a baseband manner.

5) The output of IFFT ~~modulates parallel streams~~ is the applied to parallel to serial convertor to produce the OFDM signal.

6) Let $s(t)$ is the MCM transmit signal. It is band-limited to the total Bandwidth B.

$$\therefore \text{Nyquist sampling Rate} = B$$
$$\text{sampling time } T_s = \frac{1}{B}$$

7) consider the composite MCM signal.

$$\sum_i x_i e^{j2\pi i (B/N) t}$$

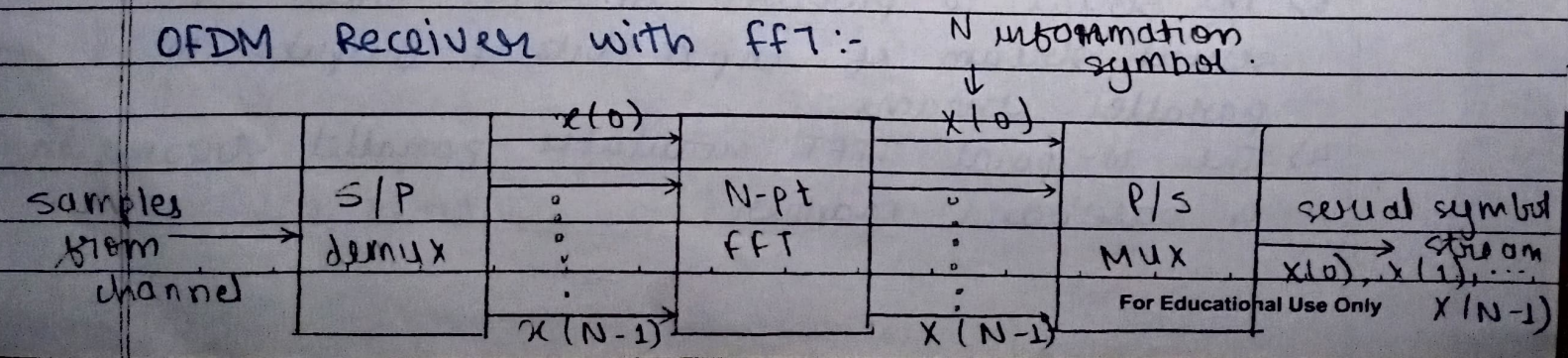
8) The μth sample at time instant $\mu T_s = \mu / B$ is given as,

$$s(\mu T_s) = x(\mu) \sum_i x_i e^{j2\pi i (B/N)(\mu/B)}$$

$$x(\mu) = \sum_i x_i e^{j2\pi (i\mu/N)}$$

The above equation shows that the sample $x(\mu)$ is basically the Inverse Direct fourier Transform co-ettient of the information symbol $X(0), X(1) \ldots X(N-1)$ at μ^{th} time point.

OFDM Receiver with FFT :-



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1) The OFDM receiver performs inverse process of the transmitter.
2) In order to recover the information ~~sysbo~~ symbols an, FFT operation is used at the receiver.
3) A fast fourier Transform (FFT) is performed on samples received from channel to produce the series of symbols
4) FFT block in OFDM Receiver replaces the bank of modulators in Multicarrier Modulation.
5) The samples from channel is given to the serial to parallel convertor, the output parallel bits are given to N-point FFT to demodulate symbol on each subcarrier.
6) The output of N-pnt FFT is N-information symbols which multiplexed from parallel to serial & generates a serial symbol stream.

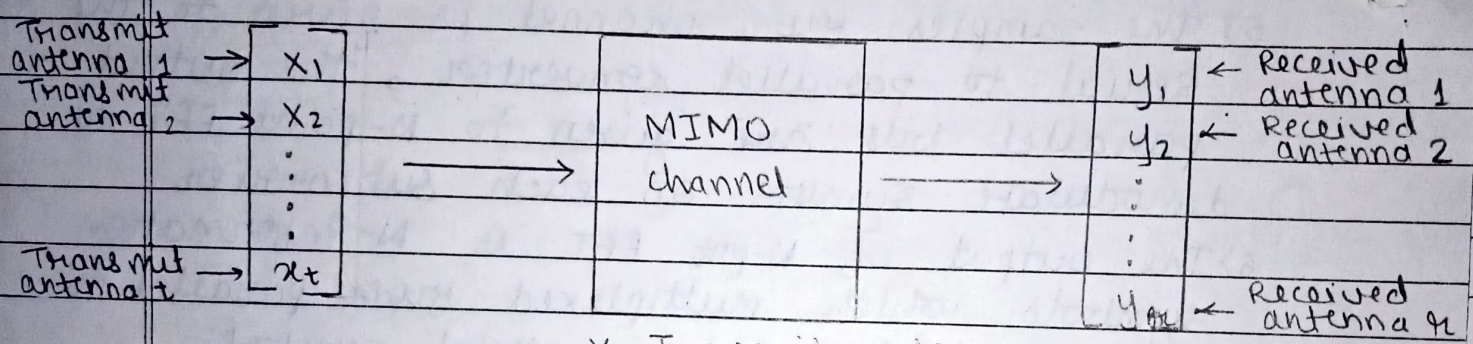
Q4) With neat schematic, draw & explain in detail MIMO system model.

Ans :- Consider a MIMO wireless system with t transmit antennas & r receive antennas. Let $x_1, x_2, \ldots x_t$ denote t symbols transmitted from the t transmit antennas in the MIMO system. The transmit symbols can be stacked to form a vector, termed as transmit vector.

$$X = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_t \end{bmatrix}$$

corresponding to transmission let $y_1, y_2, \ldots y_r$ denote the r received symbols across the r received antennas in the MIMO system.

$$y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ \vdots \\ y_r \end{bmatrix}$$



X = Transmit vector
Y = Receive vector.

Let the complex co-efficient h_{ij} represent the fading channel co-efficient between ith receive antenna & j^{th} transmit antenna.

$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1t} \\ h_{21} & h_{22} & \cdots & h_{2t} \\ \vdots & \vdots & & \vdots \\ h_{r1} & h_{r2} & \cdots & h_{rt} \end{bmatrix}$$

where the r x t dimensional matrix H is termed the MIMO channel matrix. Let the additive

noise at the received antenna i be denoted by n_i i.e $n_1, n_2, \ldots n_r$ denote the additive noise at the receive antenna. Thus the net MIMO input output system model can be represented in vector form as.

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

This matrix can be represented as.

$$y = Hx + n$$

The received symbol y_1 is given as.

$$y_1 = h_{11}x_1 + h_{12}x_2 + \cdots h_{1t}x_t + n_1$$

For the special case of $t = 1$ i.e single-Input Multipule-Output (SIMO), the matrix can be modeled as.

$$\underbrace{\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_r \end{bmatrix}}_{y} = \underbrace{\begin{bmatrix} h_1 \\ h_2 \\ \vdots \\ h_r \end{bmatrix}}_{h} x + \underbrace{\begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_r \end{bmatrix}}_{n}$$

similarly for one receive antenna i.e $r = 1$, it is termed as Multiple-Input single output (MISO) system model is given as.

$$y = \begin{bmatrix} h_1 & h_1 & \cdots & h_t \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_t \end{bmatrix} + n$$

For $t = r = 1$, i.e for single receive & transmit antenna, it reduces to single-input single-output (SISO) system modelled as.

$$y = hx + n.$$

The co-variance matrix of the noise R_n of noise vector n is defined as.

$$R_n = E\{nn^H\}$$

$$= E\left\{ \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_L \end{bmatrix} \begin{bmatrix} n_1^* & n_2^* & \cdots & n_L^* \end{bmatrix} \right\}$$

$$= \begin{bmatrix} E\{|n_1|^2\} & \cdots\cdots & E\{n_1 n_n^*\} \\ E\{n_2 n_1^*\} & & E\{n_2 n_n^*\} \\ \vdots & & \vdots \\ E\{n_n n_1^*\} & & E\{|n_n|^2\} \end{bmatrix}$$

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$$= \begin{bmatrix} \sigma_n^2 & 0 & 0 & \cdots & 0 \\ 0 & \sigma_n^2 & 0 & & 0 \\ \vdots & \vdots & \vdots & & \vdots \\ 0 & 0 & 0 & \cdots & \sigma_n^2 \end{bmatrix}$$

$$= \sigma_n^2 I_n$$

The noise vector n with co-variance structure is termed spatially uncorrelated additive noise, since the noise samples at the different antennas i, j are independent i.e $E\{n_i n_j^*\} = 0$

MIMO system model across different time instants can be denoted as.

$$\underbrace{\begin{bmatrix} y_1(k) \\ y_2(k) \\ \vdots \\ y_n(k) \end{bmatrix}}_{y(k)} = \underbrace{\begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1t} \\ h_{21} & h_{22} & & h_{2t} \\ \vdots & \vdots & & \vdots \\ h_{n1} & h_{n2} & & h_{nt} \end{bmatrix}}_{H} \underbrace{\begin{bmatrix} x_1(k) \\ x_2(k) \\ \vdots \\ x_t(k) \end{bmatrix}}_{x(k)} + \underbrace{\begin{bmatrix} n_1(k) \\ n_2(k) \\ \vdots \\ n_n(k) \end{bmatrix}}_{n(k)}$$

Q6) Explain multicarrier transmitter & Receiver & what are its advantages.

Ans:- Advantages of Multicarrier Transmitter:-

1. Each OFDM subcarrier experiences flat fading.

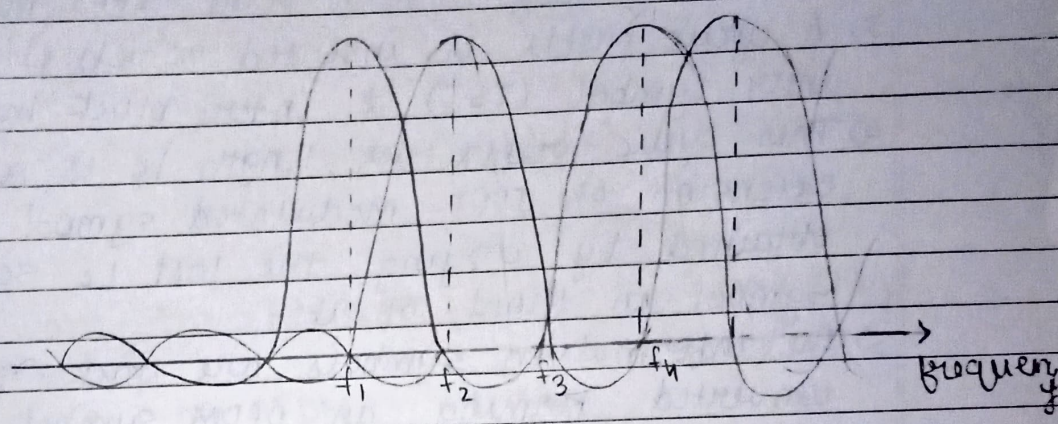
2) There is no inter-symbol interference in the data transmitted on any of the sub-carriers in OFDM.
3) Multicarrier Modulation eliminates the Inter Symbol Interference (ISI) through parallel transmission by using multiple narrowband subcarries.
4) Signal distorion of the received symbols is avoided in Multicarrier Modulation.
5) Multicarrier modulation makes efficient use of the spectrum by allowing overlap.

Q7) Explain Orthogonality in OFDM.

Ans:- 1) Two signals are said to be orthogonal if they are independent of each other in a specified time interval & do not interact with each other.
2) We can transmit a number of orthogonal signals over a common channel without interface & detect them on the receiving end without interference.
3) In FDM we have different channels (signals) occupying different frequency bands with a guard band in between to avoid any interference between the adjacent channels. But this makes FDM a B.W inefficient system.
4) The Bandwidth effiency improves considerably if we use OFDM technique instead of the simple FDM.

5) In the othogonal FDM (OFDM) the subcarriers $f_1, f_2, f_3 \ldots$ etc.

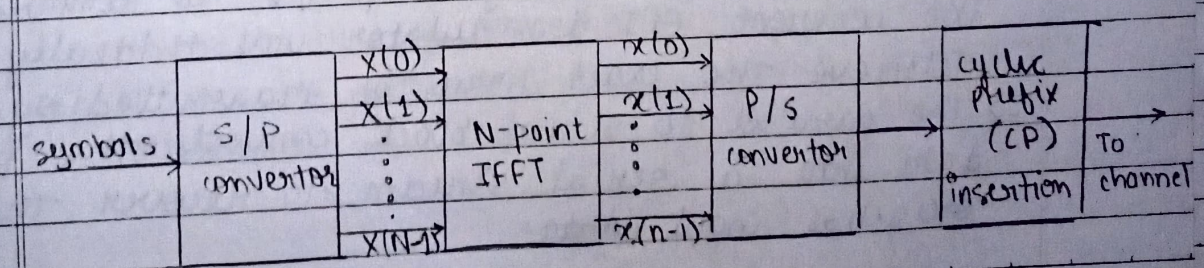
6) Are placed as close as they can be placed theoretically in the frequency domain.



7) The subcarriers $f_1, f_2 \ldots$ etc are placed at the null points of all the other subcarriers. This automatically eliminates the interference among the adjacent subcarriers.

8) Due to this type of subcarriers, the total bandwidth of OFDM system is much less than that of conventional FDM system & we can accommodate more number of users.

89) Explain OFDM transmitter & Receiver with cyclic prefix.



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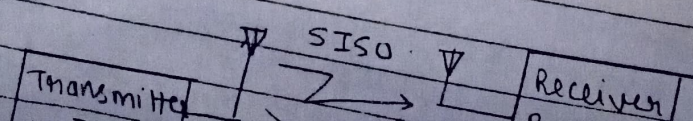
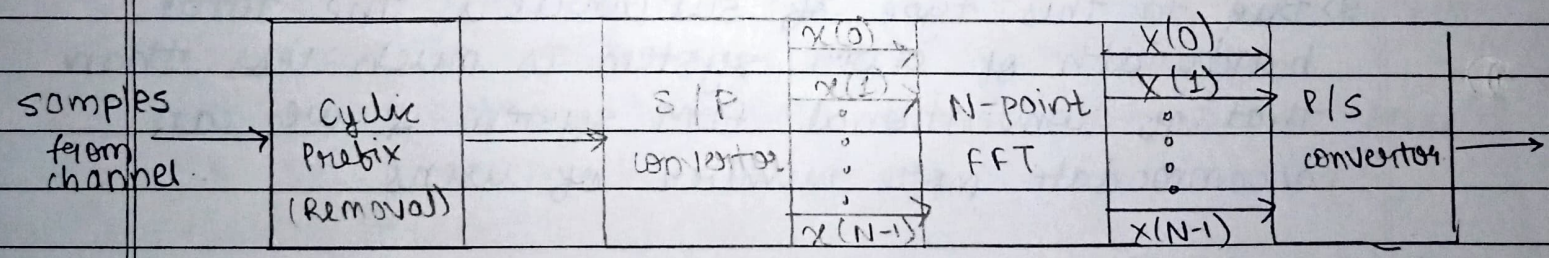


1) The information symbols are parallelized in N different sub-streams by using serial to parallel converter.
2) Each sub-stream will modulate a seperate carrier through the N-point IFFT modulation block.
3) A cyclic prefix is inserted which eliminates the inter-symbol (ISI) & inter-block interference (IBI).
4) This cyclic prefix of length Lc is a circular extension of IFFT-modulated symbol & it is obtained by copying the last Lc samples of 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.

OFDM Receiver with cyclic Prefix.



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

3) considering the noise at the receiver, the received symbol $Y(K)$ can be expressed as,

$$Y(K) = H(K) \cdot X(K) + N(K).$$

- $N(K)$ is the noise across the Kth subcarrier.

4) The zero-forcing detector for subcarrier is a simple detection scheme for $X(K)$ & is given by,

$$\hat{X}(K) = \frac{1}{H(K)} Y(K) = X(K) + \frac{N(K)}{H(K)}.$$

Q10) What are the Advantages & Disadvantages of OFDM?

Ans:- Advantages of OFDM :-

1) OFDM makes efficient use of the spectrum by allowing overlap.
2) OFDM divides the channel into narrowband flat fading sub-channel, it is more resistant to frequency selective fading as compared to single carrier system.
3) OFDM eliminates ISI & IFI with the use of a cyclic prefix.
4) channel equlization in OFDM becomes simpler as compared to single carrier systems that uses adaptive equalization techniques.
5) As compared to single carrier system, OFDM is less sensitive to sample timing offsets.
6) It provides good protection against co-channel interference & impulsive parasitic noise.

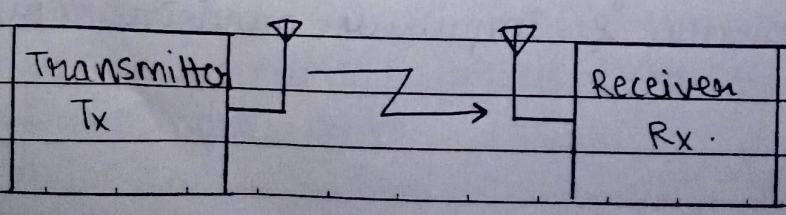
Disadvantages of OFDM :-

1. OFDM requires RF power amplifier with a high peak to average power ratio because it has a noise like amplitude with a very large dynamic range.
2. OFDM system is more sensitive to carrier frequency offset & drift due to leakage of the DFT.
3. It is sensitive to Doppler shift.
4. It needs linear transmitter circuitry, which suffers from poor power efficiency.
5. It suffers loss of efficiency caused due to cyclic prefix.

Q11) Explain different types of multiantenna systems.

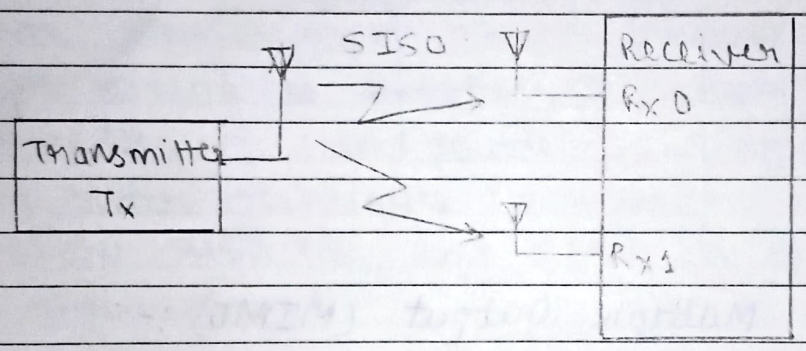
Ans :- Following are the types of Multi-antennas :-
1. SISO (Single-Input Single output)
2. SIMO (single-Input Multiple output)
3. MISO (Multiple-Input single Output)
4. MIMO (Multiple-Input Multiple-Output).

I] Single Input Single Output (SISO) :-
SISO stands for Single Input & Single Output. It consists of one antenna for transmission & one for reception.



- SISO is a conventional radio system where neither the transmitter nor receiver has multiple antenna.

II] Single Input Multiple output (SIMO) :-
- SIMO stands for single Input & multiple outputs. It consists of one antenna for transmission and multiple antennas for reception.
- Here one signal is transmitted & two or more are received.

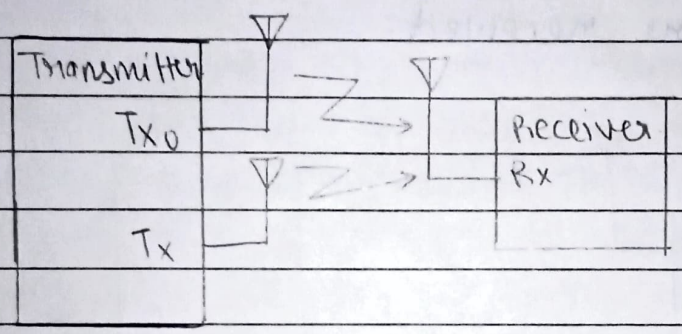


- Receive antenna diversity is used in SIMO antenna technique.
- While receiving a signal, the antenna can either select the strongest signal or can join all the signals received in different antenna is known as receive diversity.
- As compared to SISO system SIMO systems provide more Throughput with micro-diversity.

III] Multiple Input single output (MISO):-
- In the MISO (Multiple - input single -output) antenna technique, multiple antennas are used in

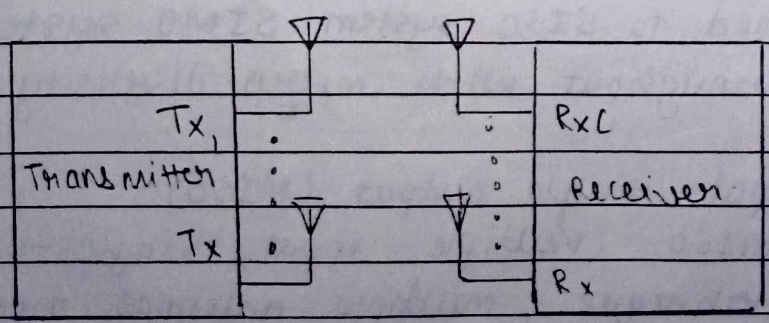
the transmitter while a single antenna is used in the receiver.

- Transmit diversity is used in MISO antenna technique.
- Transmit antenna diversity is a controlled diversity technique which provides spatial repeation of transmitted signals through different antennas.



IV] Multi Input Multiple Output (MIMO) :-

- MIMO consists of multiple antennas in both the transmitter & receiver.
- They have capability of combining the SIMO & MISO technologies. MIMO increase capacity by using spatial Multiplexing (SM).



Q12) What is principle of MIMO ? Explain with block diagram MIMO system ?

Ans:- Principle :-

1) The ~~MIM~~ Multiple-Input Multiple-Output (MIMO) system uses multiple antennas on both the transmitter and receiver.

2) They have dual capability of combining the SIMO & MISO technologies.

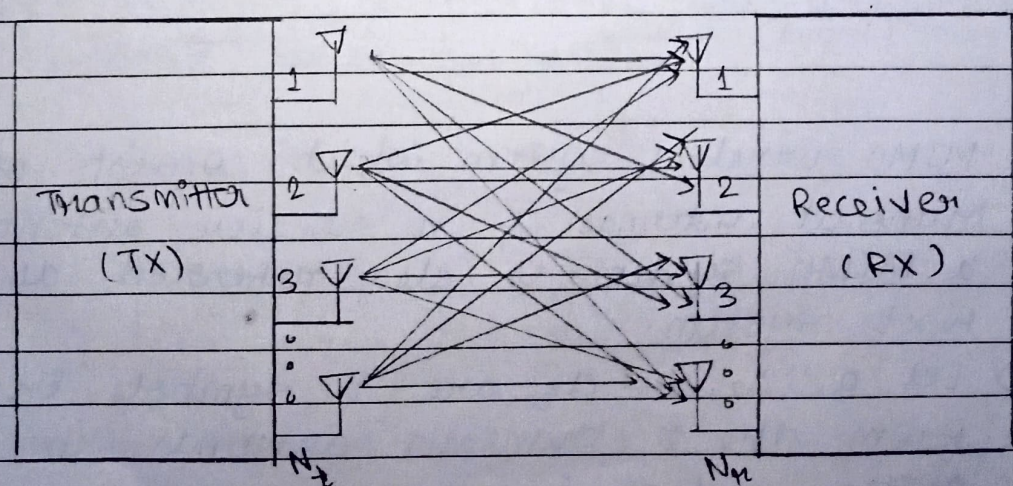
3) They also increase capacity by using spatial Multiplexing (SM).

4) The MIMO method has some clear advantages over Single-Input Single-Output (SISO) methods.

5) The fading is greatly eliminated by spatial diversity & low power is required as compared to other techniques in MIMO.

6) MIMO systems are used to obtain high speeds & throughput.

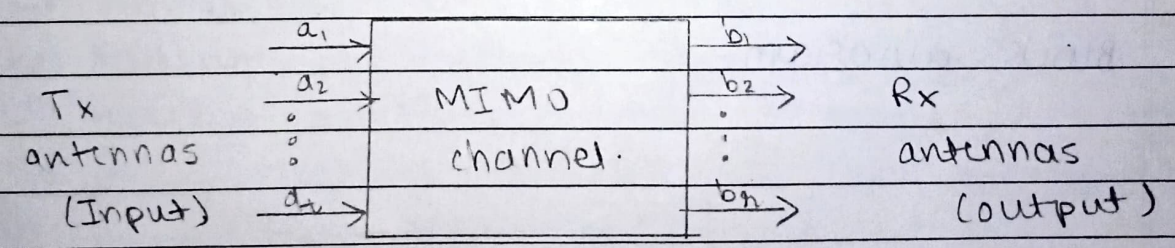
Block diagram.



1) It consists of a transmitter with N_t number of transmitting and a receiver with N_r number of receiving antennas.
2) The data stream at the transmitter (Tx) enters an encoder & the encoded outputs are applied to N_t transmitting antennas.
3) Multiple transmitting antennas transmit the signal through the wireless propogation channel which is assumed to be quasi-static & frequency-flat.
4) Term quasi-static means ~~it~~ the coherence time of channel is extremely long due to which "a large number" of bits can be transmitted within this time.

Q13) What is MIMO system model? What are advantages of MIMO?

Ans:-



1) MIMO wireless system which consists of t transmit antennas & r receive antennas. Such a MIMO system is also referred as an r x t system.
2) Let $a_1, a_2, \ldots a_t$ are t symbols transmitted from the t transmit antennas in the MIMO system i.e a_i

3) The a_i denotes the symbol transmitted from i^{th} transmit antenna with $1 \leq i \leq t$.

4) The t-dimensional vector is formed by stacking of transmit symbols. It is also called as transmit vector & is given by,

$$a = \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_t \end{bmatrix}$$

5) Let $b_1, b_2, \ldots b_r$ are the r received symbols across the r receive antennas which can be stacked as r-dimensional receive symbol vector & is given by,

$$b = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_r \end{bmatrix}$$

6) Let h_{ij} is the complex co-efficient representing the fading channel co-efficient between the ith receive antenna & the jth transmit antenna.

7) The $r \times t$ channel co-efficients are arranged in a matrix form as follows.

$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1t} \\ h_{21} & h_{22} & \cdots & h_{2t} \\ \vdots & \vdots & & \vdots \\ h_{r1} & h_{r2} & & h_{rt} \end{bmatrix}$$

8) The vector form of net MIMO input output system model is :

$$\begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1t} \\ h_{21} & h_{22} & & h_{2t} \\ \vdots & \vdots & & \vdots \\ h_{n1} & h_{n2} & & h_{nt} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_t \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_n \end{bmatrix}$$

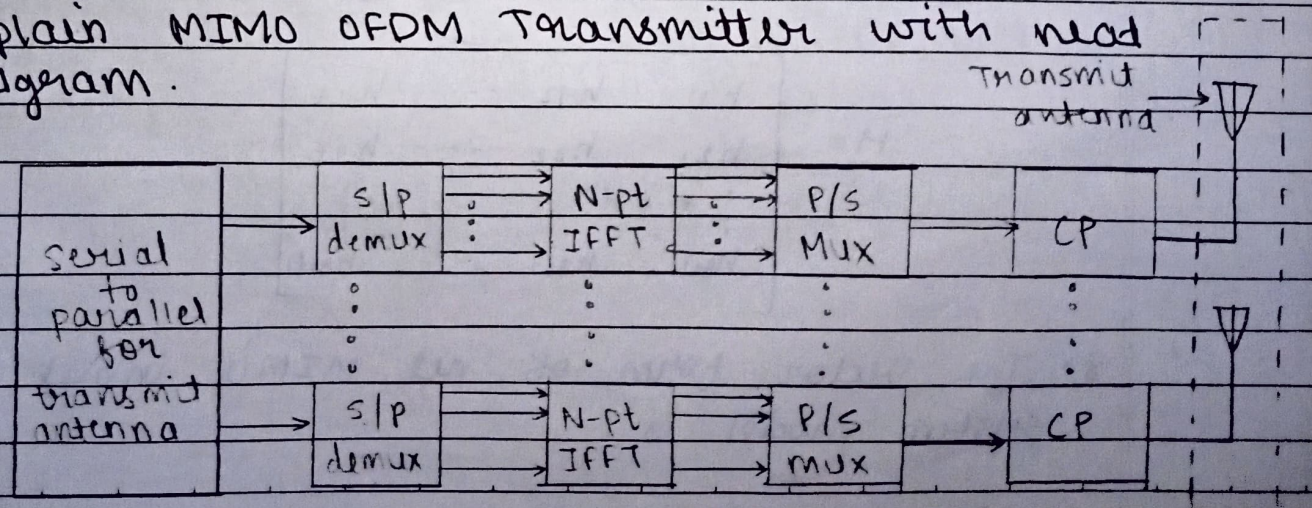
This can be represented using matrix as,

$$b = H \cdot a + n.$$

Advantages of MIMO :-

1) Increased uplink / downlink throughput.
2) High Quality of service with increased spectral efficiency.
3) Increases the spatial diversity & multiplexing gain.
4) Minimizes the fading effects on the transmitted signal traveling to receive antenna.
5) Better signal to Noise Ratio (SNR)
6) Reduction in BER (Bit Error Rate)
7) Higher speed and throughput.

Q14) Explain MIMO OFDM Transmitter with neat diagram.



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 serial to parallel convertor & becomes parallel data.

4) on the parallel data, IFFT operation is performed.

5) ~~CP is added~~ Time domain symbols are parallel to serial convertor & then a cyclic prefix is added.

6) CP is added to eliminate ISC & ICI.

7) Finally, the amplified modulated signals are transmitted.

Q1) consider the MIMO channel matrix as,

$$H = \begin{bmatrix} 2 & -6 & 0 \\ 3 & 4 & 0 \\ 0 & 0 & 2 \end{bmatrix}$$

considering a transmit power of $P = -1.25\,dB$ & noise power $\sigma_n^2 = 3dB$, compute the MIMO capacity & optimal Power allocation.

Ans:- MIMO channel matrix is 3x3

$\therefore$ $n = t = 3$ antennas

$\sigma_n^2 = 3dB$

$P = -1.25\,dB = 0.75$

$$C_1^H C_2 = 2 \times (-6) + (3) \times (4) = 0$$

Hence SVD of the channel matrix H is given as

$$H = \begin{bmatrix} 2 & -6 & 0 \\ 3 & 4 & 0 \\ 0 & 0 & 2 \end{bmatrix}$$

$$= \begin{bmatrix} \frac{2}{\sqrt{13}} & \frac{-6}{\sqrt{52}} & 0 \\ \frac{3}{\sqrt{13}} & \frac{4}{\sqrt{52}} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= \underbrace{\begin{bmatrix} \frac{-6}{\sqrt{13}} & \frac{2}{\sqrt{13}} & 0 \\ \frac{24}{\sqrt{13}} & \frac{3}{\sqrt{13}} & 0 \\ 0 & 0 & 1 \end{bmatrix}}_{U} \underbrace{\begin{bmatrix} \sqrt{52} & 0 & 0 \\ 0 & \sqrt{13} & 0 \\ 0 & 0 & 2 \end{bmatrix}}_{\Sigma} \underbrace{\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}}_{V^H}$$

$\therefore \sigma_1 = \sqrt{52} \Rightarrow \sigma_1^2 = 52$
$\sigma_2 = \sqrt{13} \Rightarrow \sigma_2^2 = 13$
$\sigma_3 = 2 \Rightarrow \sigma_3^2 = 4$

The channel capacity C in terms of P_1, P_2, P_3 assigned to different channels singular mode is given as,

$$C = \log_2\left(1 + \frac{P_1\sigma_1^2}{\sigma_n^2}\right) + \log_2\left(1 + \frac{P_2\sigma_2^2}{\sigma_n^2}\right) + \log_2\left(1 + \frac{P_3\sigma_3^2}{\sigma_n^2}\right)$$

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$$= \log_2\left(1+\frac{P_1 \times 52}{2}\right) + \log_2\left(1+\frac{P_2 \times 13}{2}\right) + \log_2\left(1+\frac{P_3 \times 4}{2}\right)$$

capacity has to be maximized for total power
$P_1 + P_2 + P_3 = 0.75.$

For $N = t = 3.$

Using Lagrangian equation.

$$\left(\frac{1}{\lambda} - \frac{1}{26}\right) + \left(\frac{1}{\lambda} - \frac{2}{13}\right) + \left(\frac{1}{\lambda} - \frac{1}{2}\right) = 0.75$$

$$\therefore \frac{1}{\lambda} = \frac{0.75 + \frac{1}{26} + \frac{2}{23} + \frac{1}{2}}{3}$$

$$\therefore \frac{1}{\lambda} = 0.48$$

For $N = 2$

$$\left(\frac{1}{\lambda} - \frac{1}{26}\right) + \left(\frac{1}{\lambda} - \frac{2}{13}\right) = 0.75$$

$$\therefore \frac{1}{\lambda} = \frac{0.75 + \frac{1}{26} + \frac{2}{13}}{2}$$

$$\therefore \frac{1}{\lambda} = 0.4712$$

$$\therefore P_1 = \left(\frac{1}{\lambda} - \frac{1}{26}\right) = 0.4712 - \frac{1}{26} = 0.4327 > 0$$

$$P_2 = \left(\frac{1}{\lambda} - \frac{2}{13}\right) = 0.4712 - \frac{2}{13} = 0.3174 > 0$$

Since P_1 & $P_2 > 0$ this is feasible power allocation.

$P_1 = 0.4327 = -3.63$ dB
$P_2 = 0.3174 = -4.98$ dB.
$P_3 = 0$

Capacity c,

$$C_{max} = \log_2\left(1 + \frac{52 \times 0.4327}{2}\right) + \log_2\left(1 + \frac{13 \times 0.3174}{2}\right)$$
$$= 5.23 \text{ b/s Hz}$$

The transmit vector x is given as.

$$x = \begin{bmatrix} v_1 & v_2 & v_3 \end{bmatrix} \begin{bmatrix} \tilde{x}_1 \\ \tilde{x}_2 \\ \tilde{x}_3 \end{bmatrix}$$
$$= v_1 \tilde{x}_1 + v_2 \tilde{x}_2$$

$\tilde{x}_3 = 0$ because $P_3 = 0$.

$\sqrt{P_1} = 0.66$
$\sqrt{P_2} = 0.56$

$$\therefore \quad x = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \tilde{x}_1 + \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \tilde{x}_2$$

$\tilde{x}_1 = \sqrt{P_1}\, b_1$ & $\tilde{x}_2 = \sqrt{P_2}\, b_2$

$$x = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} 0.66\, b_1 + \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} 0.56\, b_2$$

Q5) Define spectral efficiency and Derive an expression for loss in efficiency.

Ans:- The loss in efficiency can be calculated as.

$$\text{loss in efficiency} = \frac{\text{cyclic Prefix}}{\text{Total OFDM symbol length}}$$

$$= \frac{L-1}{N+L-1}$$

As the block length N becomes very large,

$$\lim_{N \to \infty} \frac{L-1}{N+L-1} \to 0$$