BEAM FORMING – TRANSMITTER, RECEIVER DIVERSITY

Beam Forming

In multiple antenna technique beam forming is applied. It is interpreted as linear filtering in the spatial domain. The goal of beam forming is to improve Signal to Noise Ratio (SNR) value. An antenna array geometry is considered and hence the RF signal that impinges reaches the element at different time period. Beam forming is performed is baseband domain when the channel is known at T_r and R_r.

The phases of RF signal is adjusted for achieving superposition. Also antenna steering is done towards the desired direction. Then to shape the antenna pattern, additional weighting of RF signals is also applied.

For improving SNR focussing antenna patterns on required angles of T_r or R_r is done. It will improve the antenna gain. To improve SINR steering of nulls pattern towards the co-channel subscribers. (Co-channels are channels that use same frequency in the system).

Beamforming or smart antenna technique enables Space-Division Multiple Access (SDMA). The SNR, SINR gains can be made use of in reducing error rates. This impliesan increase in data rates. In practical scenario directions of scatterers should be estimated in beam forming procedures.

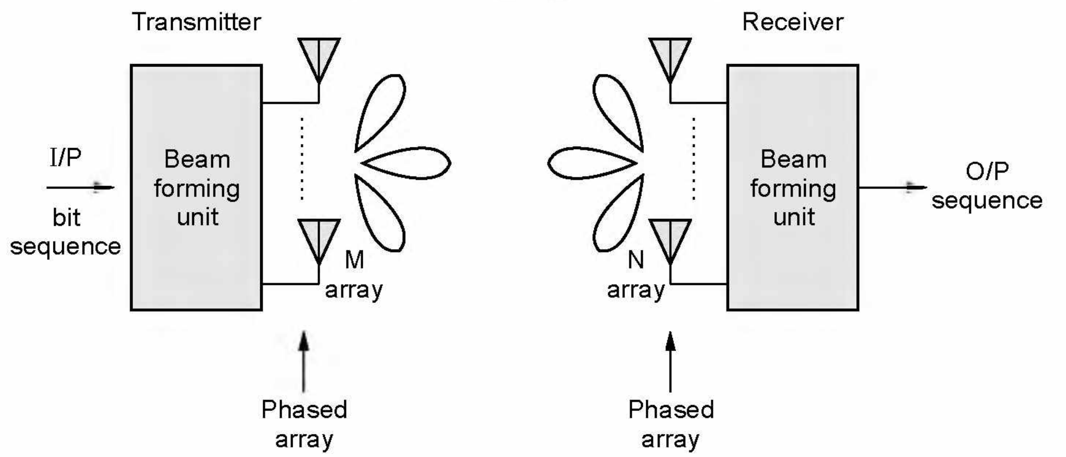

Figure - Beam forming method

TRANSMITTER DIVERSITY

The two main cases considered under transmit diversity are ;

i) Transmitter diversity with the channel-state information and

ii) Transmitter diversity without the channel-state information.

In the first case the transmitter knows about the channel clearly. The information is obtained from feedback from receiver unit. A complete equivalence between transmit diversity and receive diversity is found. On the other hand an optimum transmission scheme weights signals sent from various antenna elements to the receive antenna. This method is known as maximum ratio transmission technique.

In the second case, the transmission of signals from various antenna elements should be done in a way that it will allow receiver to segregate different transmitted signal components. One method is delay diversity. Here the effective impulse response is delay-dispersive even in case if the channel is flat-fading. In this scheme we send data streams with one symbol duration delay from transmit antennas.

To achieve transmit diversity space-time coding can be used.

Consider a Multi-Input-Single-Output (MISO) system with 'A_T' transmitting antennas. The channel matrix is known at the receiver end and not at the transmitting end. For performing coherent combining at the receiver suitable pre-processing of data sequence has to be done at the transmitter side.

Space-Time Coding

An optimal receiver technique is maximal-ratio combing technique. It matches the receive weights to the radio channel. Consider that the signal transmitted is M_{S_o} u(t) in a symbol time period T_s and 's_o' is the transmitted symbol, u(t) is the symbol waveform, then the received signal and combined signal is given expressed as,

$$x = g s_o + n$$
$$= \sqrt{E_s}\, v\, s_o + n$$
$$y = v^H x$$
$$= \sqrt{E_s} \left[\sum_{n=0}^{N-1} |v_n|^2 \right] s_o + \text{Noise signal}$$

where 'v_n' is fading term. If $v_n = 1$, then $E\{|v_n|^2\} = 1$.

Thus in maximum-ratio combining the signal that is multiplied by the summation of the powers in the wireless channels.

In the transmit diversity scheme, an array of 'A_T' elements is used at transmitter. If a similar received signal is achieved then it would have an optimal maximal ratio transmission at the other end. Considering a system with 'A_t' transmit antennas with a single receive A_r antenna.

Let receive be a channel-state information equipped receiver. In a simple diversity technique, there will be an repeatation of transmission of same message symbol (s_o) over the N symbol time periods and one element at a time in procesing. At the receiving end the data from all (A_r) receiving signals from N symbol period is taken as vector x with length N and

$$x = \sqrt{E_s}\, v\, s_o + n$$

It is same form when compared to receiver diversity. This 'x' is the vector received signal at one element over the 'N' symbol intervals. Thus the message vector x is processed and expressed as,

$$y = v^H x$$
$$y = \sqrt{E_s} \left[\sum_{n=0}^{N-1} |v_n|^2 \right] s_o + \text{Noise signal}$$

This transmit diversity will be of order 'N, if the N channels are independent. This transmit scheme is inefficient, due to expensive bandwidth. Because only a signal element is made use of within any symbol time period.

Hence a better transmit diversity cannot be achieved by focusing only on a single symbol period. For space-time coding time dimensions has to considered. Redundancy in both time and space dimensions has to be introduced.

Diversity with Bandwidth Efficiency

Transmit diversity without loss of bandwidth is very important. Consider two symbols are transmitted over say two time periods. Let these symbols be s_0 and s_1.

Transmit So from antenna element a_o and s_i from antenna element a_i- N_o wastage of bandwidth efficient and this method is known as Alamouti's transmit diversity technique. In this above example two symbols are transmitted over two symbol time intervals order-2 diversity is achieved and bandwidth efficiency is maintained.

The only bottle neck observed is that transmitted energy E_s is halfed for each symbol sent. Also in this scheme it requires proper arrangement of data over both time and space with transmission redundancy. For reliable transmission controlled redundancy would help.Consider Rayleigh fading phenomena. A MIMO system has 'A_T' transmit and 'A_r' receive antennas. Let space-time code spans with K symbols. Considering M x N channel matrix H as, H = [v_{mn}] is taken as constant for 'k' symbols.

In next symbol interval ($-s_1^*$) from element a_0 and (s_o^*) from element a_1 where '*' is used for conjugation. The channel from these two elements is constant in both time intervals (2 T_s). Then the transmit antenna posses an energy of E_s and hence each symbol is sent with half the energy. The signal received over the symbol intervals say y_0 and y_1 is expressed as,

$$y_0 = \sqrt{\frac{E_2}{2}}\,[v_0 s_0 + v_1 s_1 + n_0],$$

and

$$y_1 = \sqrt{\frac{E_2}{2}}\,[-v_0 s_1^* + v_1 s_0^* + n_1],$$

From the $\begin{bmatrix} y_0 \\ y_1^* \end{bmatrix}$ will be like,

$$\begin{bmatrix} y_0 \\ y_1^* \end{bmatrix} = \sqrt{\frac{E_2}{2}} \begin{bmatrix} v_0 & v_1 \\ v_1^* & -v_0^* \end{bmatrix} \begin{bmatrix} s_0 \\ s_1 \end{bmatrix} + \begin{bmatrix} n_0 \\ n_1^* \end{bmatrix}$$

$$\mathbf{y} = H \begin{bmatrix} s_0 \\ s_1 \end{bmatrix} + n$$

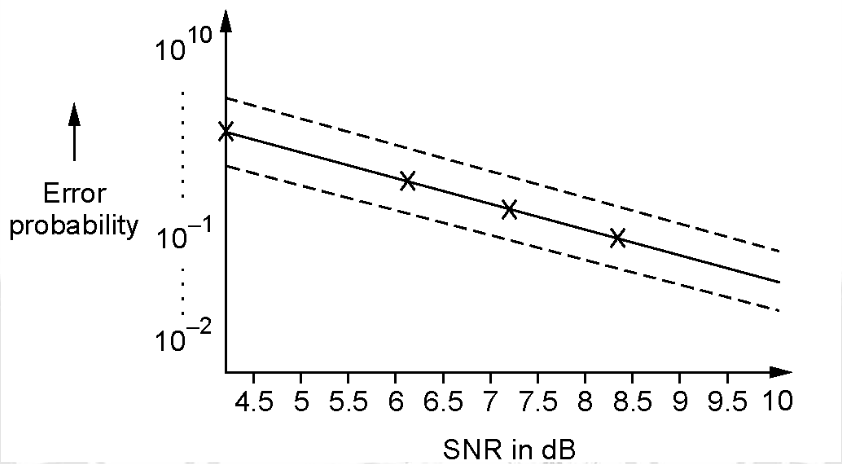

Figure - Example of space-time trellis code for 4-PSK consetellation
i)-----4 states ii) X X 8 states

Considering all the three codes for 4-PSK, constellation achieves a data rate of 2 bits/sec/Hz for two-element array for consideration the first trellis code consists of 4 states (0 - 3). The data input is such as 4 PSK symbols (0 - 3). In the condition of code available in state 0, input is 1, a 0 will be transmitted from antenna 'a_o'.

Then 'a_1' is transmitted from antenna 'a_1' and so on. A better coding gain is achieved with space time coding but with coding complexities. The transmit diversity with space-time coding desired performance is obtained with improved coding gain.

Receiver Diversity

In large-scale fading scenario in wireless radio and macro diversity technique is applied to compensate this fading effects. The maximal-ratio combiner is one of the macro diversity technique which can combine the received signals and detect them efficiency.

For diversity reception or combining there are three popular combining techniques used, namely

- **Selection combining,**
- **Maximal-ratio combining and**
- **Equal gain combining**

Each method set the weight vector value and they also find solution for interference cancellations. This loads to minimize the fading impacts. But it is assumed that the channel fading vector 'v' is known in all the three techniques.

Combination of Signals

A simple technique applied for reception is to allow combination of signals from various antenna signals at receiver end. Two methods of exploiting different signals from multiple diversity branches. They are ;

a) **Selection diversity** - Best signal copy is selected and detected where all other copy of signals are discarded.

b) **Combining diversity** - All the copies of signals are combined and decoded.

The method of combining diversity leads to a good performance. It requires complex receiver than the selection diversity. In most receivers demodulation / decoding is done in the baseband. Appropriate number of antenna elements and down conversion methods are applied. It is assumed that different signal copies undergoes independent fading.

Also in these considerations gain of multiple antennas has two effects namely,

a) **Diversity gain** - Shows that many antenna elements are in fading dip at a time.

b) **Beamforming gain** - It reflects that for the combining diversity the combiner generally performs an averaging over noise at the different antennas.

Selection Diversity