Multiple Antenna Transmission & Reception

- Multicarrier modulation enables richer, more efficient use of multiple antennas & receivers in wideband channels.

- Multiple antenna techniques can be grouped into 3 different categories.

  (1) Diversity

  (2) Interference Suppression

  (3) Spatial Multiplexing.

-(1) Spatial Diversity.

It allows a number of different versions of the signal to be transmitted and/or received, and provides considerable resilience against fading.

-(2) Interference Suppression

It uses the spatial dimensions to reject interference from other users, either through the physical antenna gain pattern or through other forms of array processing such as linear precoding, post coding or interference cancellation.

-(3) Spatial Multiplexing

It allows two or more independent streams of data to be sent simultaneously in the same bandwidth, and hence is useful primarily for increasing the data rate.

All 3 of these different approaches are often collectively referred to as multiple input-multiple output (MIMO) communication.

Spatial Diversity

- Spatial diversity is more essential for reliable wireless systems.
- The advantage of spatial diversity is that no additional bandwidth or power is needed.

Instead, it is exploited through two or more antennas, which are separated by enough distance so that the fading is approximately decorrelated between them.

- When multiple antennas are used, there are two forms of gain available.

(i) Diversity Gain → Because of multiple independent channels b/w Tx^r. & Rx^r. It depends on product of statistical characteristics of those channels.

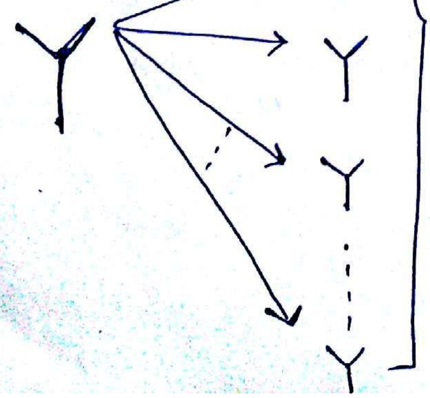
(ii) Array Gain.

↓

It does not rely on statistical diversity b/w the different channels. Instead, it depends on combined energy of each of the antennas.

Due to array gain, even if the channels are completely correlated, the received SNR increases linearly with the number of receive antennas.

Eg: Consider a $1 \times N_r$ system.



Perfectly Correlated.
$\therefore h_i = h$.

In correlated flat fading, each antenna $i \in (1, N_r)$ receives a signal that can be characterized as

$$y_i = h_i x + n_i$$
$$= h x + n_i$$

SNR on a single antenna is $\gamma_i = \frac{|h_i \mathcal{E}_x|^2}{\sigma^2}$

$$\gamma_i = \frac{|h|^2}{\sigma^2},$$

where σ^2 is the noise power & we assume the signal energy as 1. ie, $\mathcal{E}_x = E|x|^2 = 1$.

If all the receive antenna paths are added, the resulting signal is

$$y = \sum_{i=1}^{N_r} y_i = N_r \cdot h x + \sum_{i=1}^{N_r} n_i$$

and the combined SNR, assuming that just the noise on each branch is uncorrelated, is given by

$$\gamma_\Sigma = \frac{|N_r h|^2}{N_r \cdot \sigma^2} = \frac{N_r^2 \cdot |h|^2}{N_r \cdot \sigma^2} = \frac{N_r \cdot |h|^2}{\sigma^2}.$$

$$\Rightarrow \gamma_\Sigma \propto N_r$$

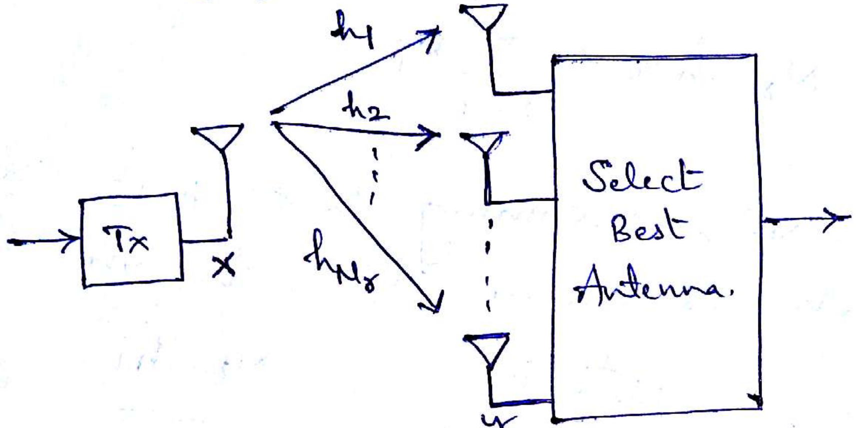
Hence, the received SNR also increases linearly with the number of receive antennas, even if those antennas are correlated.

Receive Diversity

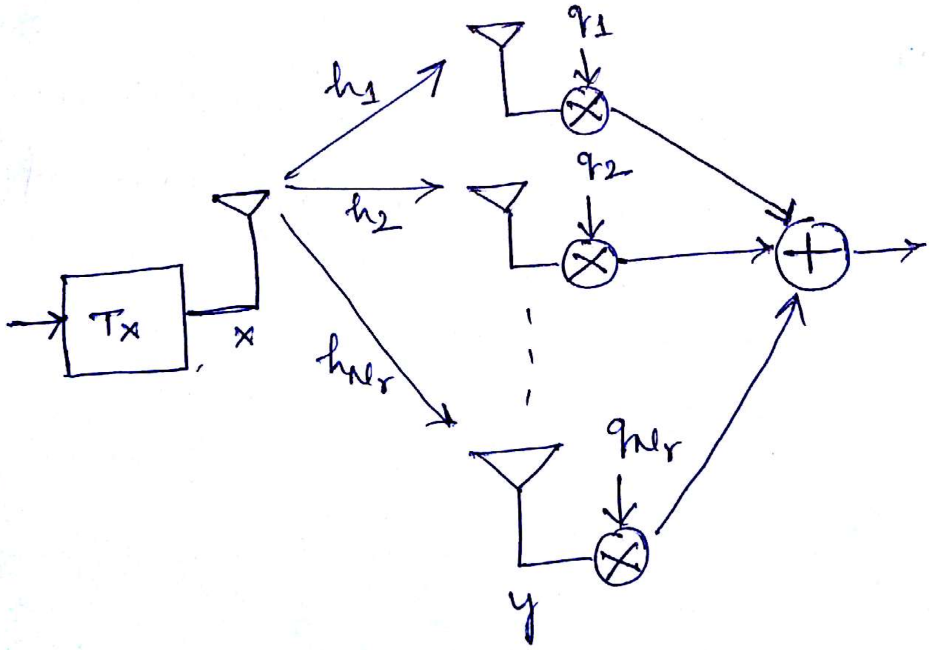
- The most common form of spatial diversity is receive diversity, often with just two Rx antennas. ($N_r = 2$).

- In this section, we will overview two of the widely used combining algorithms.

(1) Selection Combining (SC) (2) Maximal Ratio Combining (MRC)



Selection Combining (SC)



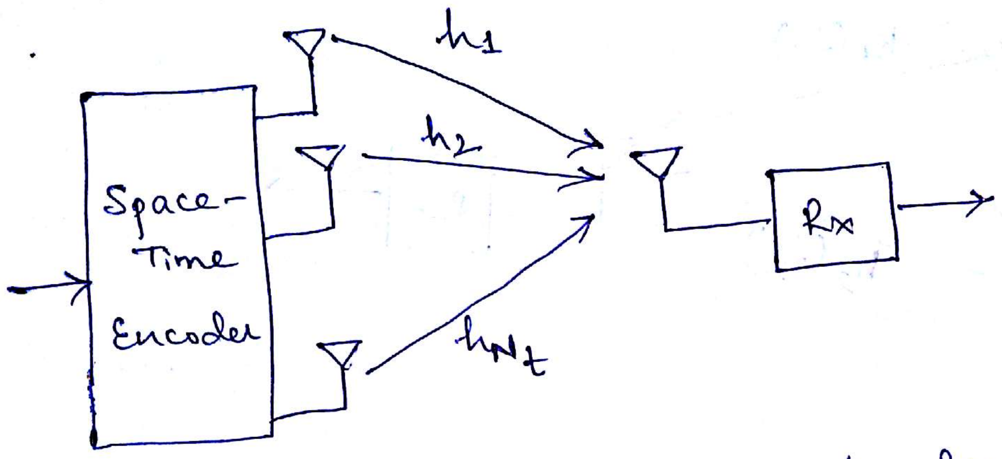
Maximal Ratio Combining (MRC)

Here $q_i = |q_i| e^{j\phi_i}$ is a complex factor.

Transmit Diversity

- It is a more recent development than receive diversity.
- Multiple antenna transmit schemes are often categorized into two classes:

(1) Open-loop (2) Closed-loop.



Open-loop transmit diversity.

2 × 1 Space-Frequency Block Coding (SFBC)

The simplest SFBC corresponds to two transmit antennas and a single receive antenna.

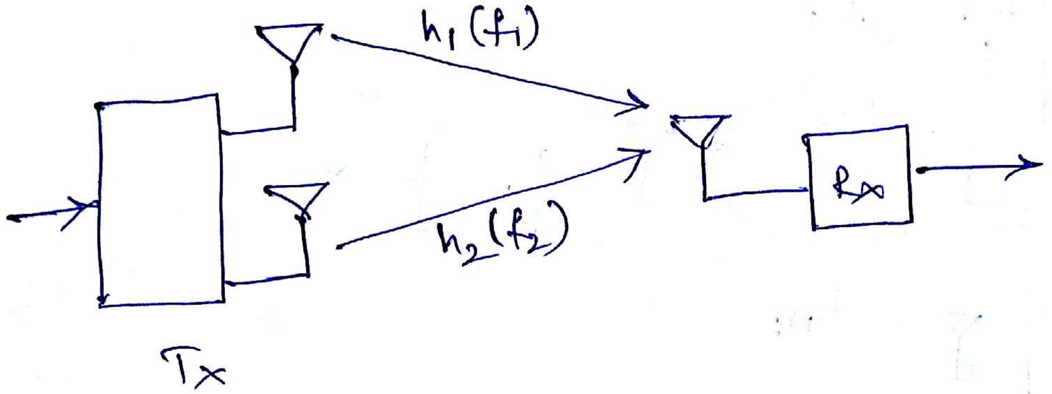
If two symbols to be transmitted are s_1 and s_2, the Alamouti code sends the following over two subcarriers f_1 and f_2.

		Antennas	
		1	2
Sub carrier	f_1	s_1	s_2
	f_2	$-s_2^*$	s_1^*

Assuming a flat fading channel on each subcarrier, then

$h_1(f_1)$ → is the complex channel gain from Tx Antenna 1 to Rx Antenna.

$h_2(f_2)$ ⟶ is the complex channel gain from Tx Antenna 2 to Rx Antenna.



$$r(f_1) = h_1(f_1)\, s_1 + h_2(f_2)\, s_2 + n(f_1)$$

$$r(f_2) = h_1(f_1)\,(-s_2^*) + h_2(f_2)\, s_1^* + n(f_2)$$

Assuming channel is constant over the two adjacent subcarriers, ie,

$$h_1(f_1) = h_1(f_2) = h_1$$

$$h_2(f_1) = h_2(f_2) = h_2$$

$$\therefore\ r(f_1) = h_1 s_1 + h_2 s_2 + n(f_1)$$

$$r(f_2) = h_1(-s_2^*) + h_2 s_1^* + n(f_2)$$

$$= -h_1 s_2^* + h_2 s_1^* + n(f_2)$$

$$y_1 = h_1^* r(f_1) + h_2 r^*(f_2)$$

$$y_2 = h_2^* r(f_1) - h_1 r^*(f_2)$$

} Using diversity combining scheme & assuming channel is known at Rx.

$$\therefore y_1 = h_1^*\left(h_1 s_1 + h_2 s_2 + n(f_1)\right) + h_2\left(-h_1^* s_2 + h_2^* s_1 + n^*(f_2)\right)$$

$$y_1 = \left(|h_1|^2 + |h_2|^2\right) s_1 + h_1^* n(f_1) + h_2 n^*(f_2)$$

|||ly

$$y_2 = \left(|h_1|^2 + |h_2|^2\right) s_2 + h_2^* n(f_1) - h_1 n^*(f_2)$$

Resulting SNR

$$\gamma_\Sigma = \frac{\left(|h_1|^2 + |h_2|^2\right)^2}{|h_1|^2 \sigma^2 + |h_2|^2 \sigma^2} \cdot \frac{E_x}{2}$$

$$= \frac{|h_1|^2 + |h_2|^2}{\sigma^2} \cdot \frac{E_x}{2}$$

$$\gamma_\Sigma = \frac{\sum_{i=1}^{2} |h_i|^2}{\sigma^2} \cdot \frac{E_x}{2}.$$

Here $E|s_1|^2 = E|s_2|^2 = \frac{E_x}{2}$ since each one sent twice.