Spatial Frequency Phase Modulation

The requirements for the work of this group is as follows:

- Describe the spatial frequency phase modulation principle and provide bit error probability results (using simulations) for different modulation methods (MPSK, MFSK, M = 2,3m ...) and different number of antennas (2, 4 antennas). You should compare your results to the reference system. The reference system is a modulation scheme having the same bandwidth efficiency as the combined spatial modulation scheme but using single antenna at the transmitter and single antenna at the receiver!
- What happens to the bit error probability of spatial modulation if channel state information is available at the transmitter. This could provide improved performance and your job is investigate this and compare it to the above case and whether if this could provide better performance than the case of no channel state information at the receiver!

Example

SM PSK Modulation

Consider a BPSK modulation and two transmit antennas (no FSK in this case). In this case BPSK carries 1 bit per waveform and we can another bit to select the transmitted antenna. In this means we will have 2 bits per transmitted symbol $k = 2$)

Assuming a Rayleigh flat fading channel, the received sample can be written as follows

$$r_n = \begin{cases} h_0\sqrt{E_s} + z_n, & \text{bits 00 was transmitted} \\ h_1\sqrt{E_s} + z_n, & \text{bits 01 was transmitted} \\ -h_0\sqrt{E_s} + z_n, & \text{bits 10 was transmitted} \\ -h_1\sqrt{E_s} + z_n, & \text{bits 11 was transmitted} \end{cases}$$

where h_i is complex Gaussian with zero-mean and a unit standard deviation. $E_s = kE_b$ is the average energy per symbol and $z_n = x_n + jy_n$ is the thermal noise which is modeled as complex Gaussian with zero mean and a variance of N_0, i.e. x_n and y_n are independent Gaussian random variables with zero mean and variance of $N_0/2$ each.

The receiver tries to decide on the transmitted bits by computing the quared Euclidean distance between the received signal sample and all possible signal points! This means the receiver coimputes four metrics and choose the set of bits that gives the minimum metric. The four metrics are given by

$$\mathcal{M}(r_n, a_n b_n = 00) = \left| r_n - h_0\sqrt{E_s} \right|^2$$

$$\mathcal{M}(r_n, a_n b_n = 01) = \left| r_n - h_1\sqrt{E_s} \right|^2$$

$$\mathcal{M}(r_n, a_n b_n = 10) = \left| r_n + h_0\sqrt{E_s} \right|^2$$

$$\mathcal{M}(r_n, a_n b_n = 11) = \left| r_n + h_1\sqrt{E_s} \right|^2$$

SM PSK FSK Modulation

Try now the above case but with 2FSK added. Say if we have BPSK, BFSK, and two antenanas. In this case we have three bits per transmitted waveform: One bit to select the BPSK symbol, one bit to select the frequency tone of the BFSK modulation and the third bit to select the antenna. This means we will have 3 bits per transmitted symbol $k = 3$) and the consumed bandwidth is approximatly $B = \Delta f + \frac{1}{2T_s} + \frac{1}{2T_s} = \Delta f + \frac{1}{T_s} \approx \frac{2}{T_s}$

Assuming a Rayleigh flat fading channel, the received sample can be written as follows

BPSK	BFSK	SM	Received Symbol
$\sqrt{E_s}$	$(\sqrt{E_s}, 0)$	Antenna 1	$(r_1 = h_1\sqrt{E_s} + n_1,\ r_2 = n_2)$
$\sqrt{E_s}$	$(\sqrt{E_s}, 0)$	Antenna 2	$(r_1 = h_2\sqrt{E_s} + n_1,\ r_2 = n_2)$
$\sqrt{E_s}$	$(0, \sqrt{E_s}, 0)$	Antenna 1	$(r_1 = n_1,\ r_2 = h_1\sqrt{E_s} + n_2)$
$\sqrt{E_s}$	$(0, \sqrt{E_s}, 0)$	Antenna 2	$(r_1 = n_1,\ r_2 = h_2\sqrt{E_s} + n_2)$
$-\sqrt{E_s}$	$(-\sqrt{E_s}, 0)$	Antenna 1	$(r_1 = -h_1\sqrt{E_s} + n_1,\ r_2 = n_2)$
$-\sqrt{E_s}$	$(-\sqrt{E_s}, 0)$	Antenna 2	$(r_1 = -h_2\sqrt{E_s} + n_1,\ r_2 = n_2)$
$-\sqrt{E_s}$	$(0, -\sqrt{E_s})$	Antenna 1	$(r_1 = n_1,\ r_2 = -h_1\sqrt{E_s} + n_2)$
$-\sqrt{E_s}$	$(0, -\sqrt{E_s})$	Antenna 2	$(r_1 = n_1,\ r_2 = -h_2\sqrt{E_s} + n_2)$

where h_i is complex Gaussian with zero-mean and a unit standard deviation. $E_s = kE_b$ is the average energy per symbol and $n_i = x_i + jy_i$ is the thermal noise which is modeled as complex Gaussian with zero mean and a variance of N_0, i.e. x_i and y_i are independent Gaussian random variables with zero mean and variance of $N_0/2$ each.