University of KwaZulu Natal

School of Engineering

Selected Topics in Electronic Engineering: ENEL4TBH2

Selected Topics in Computer Engineering: ENEL4STH2

(Advanced Wireless Communication), Oct. 2025

Duration: **2 hours** Marks: 50

Examiners : Prof. H. Xu (Internal)

: Dr. A. Alonge (External)

Question 1: [10 marks] Alamouti Scheme

In the Alamouti scheme it is assumed that $N_r = 1$ receive antenna is employed at the receiver. Under the assumption that fading coefficients are constant over two symbol periods, the received signals r_i for two consecutive time intervals are given

$$r_1 = h_1 x_1 + h_2 x_2 + n_1$$

$$r_2 = -h_1 x_2^* + h_2 x_1^* + n_2$$

where $h_i \in \mathbb{C}^{N_r \times 1}$ is the channel fading coefficient vector, each entry of h_i is distributed with $CN(0,1)$. $n_i \in \mathbb{C}^{N_r \times 1}$ is the additive white Gaussian noise (AWGN) vector, every entry of n_i is distributed with $CN(0,2\varepsilon/\rho), i \in [1:2]$. ρ is the signal-to-noise ratio at each receive antenna and $E[|x_i|^2] = \varepsilon$.

(1.1) [**2 marks**] Explain why the variance of every entry of n_i is $2\varepsilon/\rho$, not ε/ρ.

(1.2) [**8 marks**] Derive the equivalently received signals as

$$z_1 = (|h_1|^2 + |h_2|^2)x_1 + \tilde{n}_1$$
$$z_2 = (|h_1|^2 + |h_2|^2)x_2 + \tilde{n}_2$$

where $\tilde{n}_1 = h_1^* n_1 + n_2^* h_2$ and $\tilde{n}_2 = h_2^* n_1 - n_2^* h_1$

Question 2: (10 marks) Multiple Reception Combining: MRC and SC

In a single-input multiple-output (SIMO) system there are $N_r = 2$ receive antennas at the receiver. It is assumed that the fading channels between the transmitter and the N_r receive antennas are statistically independent each other.

(1) [**2 marks**] Explain why the error performance of a wireless communication system with multiple receiver antennas is better than the system with only one receive antenna.

(2) At each receive antenna the received signal is given by

$$y_i = \sqrt{\rho} h_i x + n_i$$

where $h_i \sim CN(0,1)$. x is an 8QAM symbol with $E[|x|^2] = 1$. ρ is the signal-to-noise ratio at each receive antenna. n_i is the AWGN distributed as $n_i \sim CN(0,1)$.

(2.1) [**2 marks**] Write matlab code to setup 8QAM signal set Ω with $E[|x|^2] = 1$;

[2.2] [**2 marks**] Write matlab code to implement $h_i \sim CN(0,1)$;

[2.3] [**2 marks**] write matlab code to implement $n_i \sim CN(0,1)$;

(2.4) [**2 marks**] Given $\rho = 5\ dB$ and $x = 1 + j$ write matlab code to implement $y_i = \sqrt{\rho} h_i x + n_i$;

Question 3: (10 marks) Spatial Modulation (SM)

(1) [**2 marks**] The key assumption to make the conventional spatial modulation feasible has been explained in the slides. What is the key assumption to make the conventional spatial modulation feasible?

(2) [**8 marks**] In slide 21 of spatial modulation lecture PPT the maximum likelihood (ML) detection is given by

$$[\hat{j}, \hat{x}_q] = \max_{j,q} p_y(\boldsymbol{y}|\boldsymbol{x}_{jq}, \boldsymbol{H}) = \min_{j,q} \left\{ \sqrt{\rho} \left\| \boldsymbol{g}_{jq} \right\|_F^2 - 2Re\left(\boldsymbol{y}^H \boldsymbol{g}_{jq}\right) \right\}$$

where $p_{\boldsymbol{Y}}(\boldsymbol{y}|\boldsymbol{x}_{jq}, \boldsymbol{H}) = \pi^{-N_t} exp\left(-\left\| \boldsymbol{y} - \sqrt{\rho} \boldsymbol{H} \boldsymbol{x}_{\boldsymbol{jq}} \right\|_F^2\right)$, $\boldsymbol{g}_{jq} = \boldsymbol{h}_j x_q, j \in [1{:}N_t]$ is the index of transmit antenna, $\boldsymbol{h}_j$ denotes the j^{th} column of $\boldsymbol{H}$. $\hat{j}$ and $\hat{x}_q$ are the estimated antenna index and the transmitted symbol, respectively. ρ is the signal-to-noise ratio. $Re(\cdot)$ stands for taking real part of a complex symbol.

Prove: $\max_{j,q} p_y(\boldsymbol{y}|\boldsymbol{x}_{jq}, \boldsymbol{H}) = \min_{j,q} \left\{ \sqrt{\rho} \left\| \boldsymbol{g}_{jq} \right\|_F^2 - 2Re\left(\boldsymbol{y}^H \boldsymbol{g}_{jq}\right) \right\}$

Question 4: (10 marks) Generalised Spatial Modulation (GSM)

There are two systems, the conventional SM and the GSM in this question.

In the conventional SM system there are four transmit antennas and N_r receive antennas at the receiver. The received signal is given by

$$\boldsymbol{y}_{SM} = \sqrt{\rho}\boldsymbol{h}_i x + \boldsymbol{n}$$

where $E[|x|^2] = 1$. ρ is the signal-to-noise ratio. $\boldsymbol{h}_i = \left[h_{i1}\ h_{i2}\ \cdots h_{iN_r}\right]^{\boldsymbol{T}}, i \in [1:4]$, is the channel fading coefficient vector, each $h_{ik}, k \in [1:N_r]$, is distributed with $CN(0,1)$. $E\left[h_{ik}^* h_{ij}\right] = 0, k \neq j$. $\boldsymbol{n}$ is the additive white Gaussian noise vector, every entry of $\boldsymbol{n}$ is distributed with $CN(0,1)$.

In the generalized SM (GSM) system there are four transmit antennas and N_r receive antennas at the receiver. In the GSM system we use $(1,3), (1,4), (2,3)$ and $(2,4)$ to transmit symbols. The received signal is given by

$$\boldsymbol{y}_{GSM} = \sqrt{\rho/2}\boldsymbol{h}_i x + \sqrt{\rho/2}\boldsymbol{h}_j x + \boldsymbol{n}$$

where $i \in [1:2]$ and $j \in [3:4]$. All ρ, $\boldsymbol{h}_i$ and $\boldsymbol{n}$ are the same as SM system.

Mathematically prove both of the above systems have the same error performance.

Question 5: (10 marks) Space-time line codes

Appendix is a space-time line code (STLC) journal paper. Please refer to the Appendix to write your understanding of 1×2 space-time line code in terms of:

(1) (**3 marks**) 1×2 STLC system model;

(2) (**3 marks**) General 1×2 STLC system description;

(3) (**4 marks**) Encoding of 1×2 STLC;

The transmitted signals, the fading coefficients and noises are all random variables. You **MUST** use mean and variance to describe each random variable in your understanding.