

# Coursework EE401: Advanced Comm. Theory

## "Multipath Spatiotemporal SIMO Wireless Systems"

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### 1 Aims

- The main objective of this assignment-study is to simulate a QPSK-DS-CDMA communication system and design space-time array receivers to handle multipaths, suppress MAI (multiple access interference) and improve the overall capacity of the system.

### 2 Equipment and Software

- PC (operating system Windows 10 or Mac OS)
- MATLAB, Visual C++, Labview, or any other suitable language.
- Three digital photos (size: smaller than, or equal to,  $160 \times 112$ ).
- The MATLAB functions given with AM1 experiment (to be downloaded).
- There are four task in this assignment and, for the 4th task, there is your personal data file that should be downloaded from the course-website.

### 3 Definitions

- $\mathcal{X} \triangleq$  alphabetical order of the 1st letter of your surname
- $\mathcal{Y} \triangleq$  alphabetical order of the 1st letter of your formal firstname.

### 4 Tasks

#### Task-1

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- With reference to Figure 1, consider three users with each user transmitting a digital photo, at the same time, on the same frequency band.

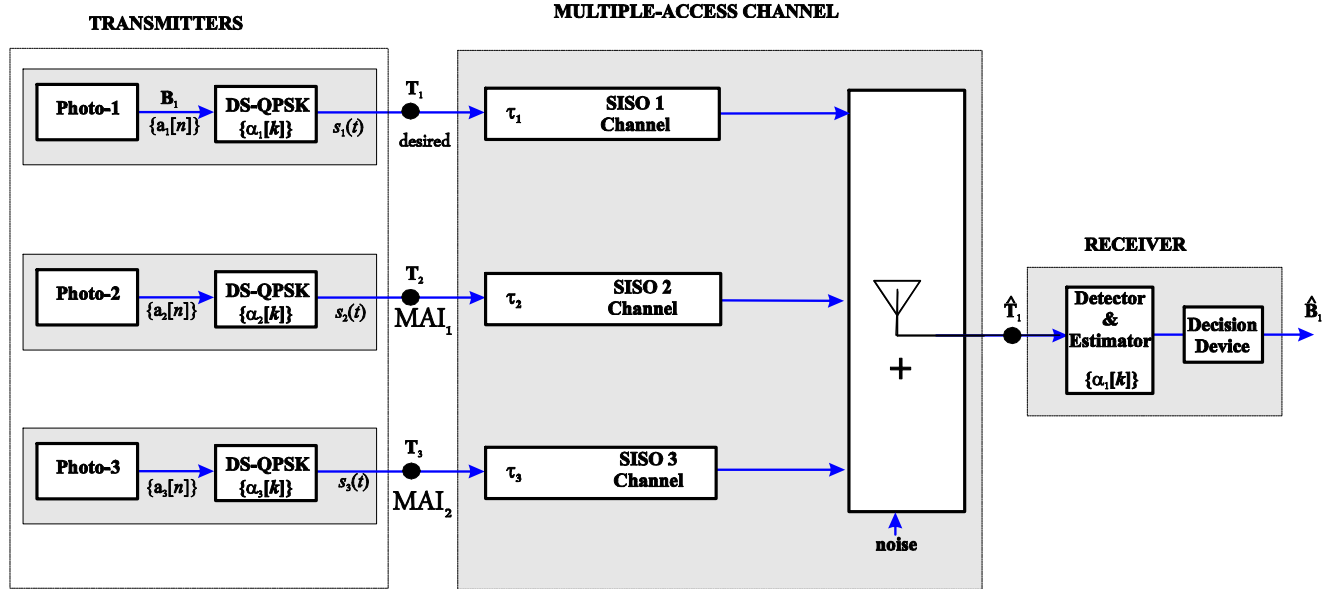


Figure 1: System Architecture for Tasks 1 and 2.

- **Modulation:** All three users use the same constellation diagram given in Figure 2, where the angle  $\phi$  is given in degrees according to the following expression

$$\phi \triangleq \mathcal{X} + 2\mathcal{Y} \quad (1)$$

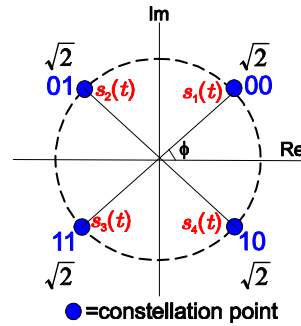


Figure 2: QPSK constellation diagram.

- **PN-codes:** The three PN-code sequences  $\{\alpha_1[k]\}$ ,  $\{\alpha_2[k]\}$  and  $\{\alpha_3[k]\}$  are gold-sequences produced using the following two primitive polynomials:

1st polynomial (m-sequence)	2nd polynomial (m-sequence)
$D^4 + D + 1$	$D^4 + D^3 + 1$

The desired user's gold-sequence  $\{\alpha_1[k]\}$  is produced by adding (modulo-2) a delayed version ( $d$ -bits) of the 2nd m-sequence to the 1st m-sequence where  $d$  is the smallest integer that:

- gives a "balanced" gold-sequence and

– satisfies the inequality:

$$d \geq 1 + (\mathcal{X} + \mathcal{Y}) \bmod 12 \quad (2)$$

The gold-sequences of the remaining two users  $\{\alpha_2[k]\}$  and  $\{\alpha_3[k]\}$  are produced with delays  $d + 1$  and  $d + 2$  respectively.

- **Channel:** the three transmitted signals  $s_1(t)$ ,  $s_2(t)$  and  $s_3(t)$  arrive at the input of the receiver (point  $\hat{T}_1$ ) according to the parameters given in Table-1. The point  $\hat{T}_1$  is taken as the origin (0,0,0) of the 3-dim real space.

Table-1: Channel Parameters (there are no multipath effects)			
signal-paths arriving at the receiver	relative delay	fading coeff.	(azimuth, elevation) ( $\theta, \phi$ )
one path of $s_1(t)$	$(\tau_1 \bmod 15) = 5$	$\beta_1 = 0.4$	$(30^\circ, 0^\circ)$
one path of $s_2(t)$	$(\tau_2 \bmod 15) = 7$	$\beta_2 = 0.7$	$(90^\circ, 0^\circ)$
one path of $s_3(t)$	$(\tau_3 \bmod 15) = 12$	$\beta_3 = 0.2$	$(150^\circ, 0^\circ)$

- **Noise:** The noise at point  $\hat{T}_1$  is assumed to be additive white Gaussian noise of zero mean and power
  - 0dB, and
  - 40dB

below the power level of the desired signal at point  $\hat{T}_1$ .

Task-1a: Using the above description, simulate the system up to the receiver's input (point  $\hat{T}_1$ ). No MATLAB buildin functions should be used for generating noise and modulation/demodulation.

Task-1b: Considering all the channel parameters unknown, design a receiver to receive "photo-1" (i.e.  $\{a_1[n]\}$ ) and remove the other 2 signals as unwanted multiple-access interference (MAI). Make a comparison at different levels of noise (0dB and 40dB)

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## Task-2

- As in Task-1 but replacing the channel described by Table-1 with the multipath channel of Table 2 where the desired user's signal is received at point  $\hat{T}_1$  via three paths (multipaths).

Table-2: Channel Parameters (with multipath effects)			
signals arriving at the Receiver	relative delay in $T_c$	fading coeff.	(azimuth, elevation) ( $\theta, \phi$ )
1st path of $s_1(t)$	$(\mathcal{X} + \mathcal{Y}) \bmod 4$	$\beta_{11} = 0.8$	$(30^\circ, 0^\circ)$
2nd path of $s_1(t)$	$4 + (\mathcal{X} + \mathcal{Y}) \bmod 5$	$\beta_{12} = 0.4 \exp(-j40^\circ)$	$(45^\circ, 0^\circ)$
3rd path of $s_1(t)$	$9 + (\mathcal{X} + \mathcal{Y}) \bmod 6$	$\beta_{13} = 0.8 \exp(+j80^\circ)$	$(20^\circ, 0^\circ)$
$s_2(t)$	8	$\beta_2 = 0.5$	$(80^\circ, 0^\circ)$
$s_3(t)$	13	$\beta_3 = 0.2$	$(150^\circ, 0^\circ)$

Design the best receiver for this environment. Note: the fading coefficients may be assumed known.

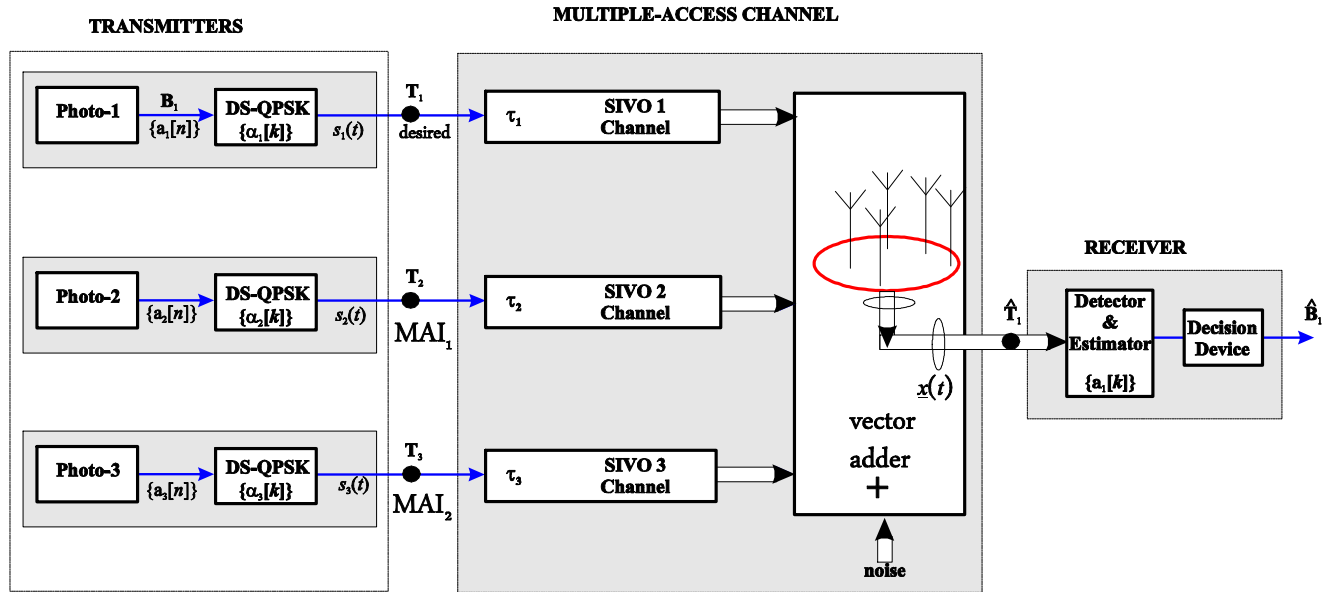


Figure 3: System Architecture for Task 3.

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**Task-3**

- As in Task-1 but by employing at point  $\hat{T}_1$  (see Figure 3) a uniform circular array of 5 isotropic elements (antennas) with half-wavelength inter-antenna spacing (1st element:  $30^\circ$  anticlockwise with respect to the x-axis). Design the best possible receiver for this environment.

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**Task-4**

- Personal data file:** For this task please download your personal data file from

<http://skynet.ee.imperial.ac.uk/notes/notes.html>

- PN-codes:** With reference to Figure 4, each of the three users is transmitting a text message of sixty 8-bit characters. The desired-user uses a gold-sequence  $\{\alpha_1[k]\}$  that is generated based on the following two primitive polynomials:

	1st polynomial (m-sequence)	2nd polynomial (m-sequence)
1st user:	$D^5 + D^2 + 1$	$D^5 + D^3 + D^2 + D + 1$

by adding (modulo-2) a delayed version ( $d$ -bits) of the 2nd m-sequence to the 1st m-sequence where

$$d \triangleq \text{the parameter "phase\_shift" in your personal file} \quad (3)$$

No information is provided about the PN-codes of the other two users.

**Modulation:** The desired user uses the constellation diagram shown in Figure 2, where the angle  $\phi$  is given in degrees by the parameter “phi\_mod”. That is

$$\phi \triangleq \text{"phi\_mod" in your personal file} \quad (4)$$

- **Channel:** The channel parameters are unknown to the receiver - except the fading coefficients of the multipaths of the desired user  $\beta_{1,1}$ ,  $\beta_{1,2}$  and  $\beta_{1,3}$  which have been already estimated using another approach. These are given by the elements of the  $(3 \times 1)$  complex vector "Beta\_1" in your personal file,

i.e.

$$[\beta_{1,1}, \beta_{1,2}, \beta_{1,3}]^T = \text{"Beta\_1"} \text{ in your personal file} \quad (5)$$

- **Channel output:** The complex received array signal-vector  $\underline{x}(t)$  at output of the antenna array is given in your personal data file by the parameter "Xmatrix". That is, it is given in the form of  $L$  snapshots (i.e. the vectors  $\underline{x}(t_\ell)$  for  $\ell = 1, 2, 3, \dots, L$ ) forming the matrix  $\mathbb{X} \in \mathbb{C}^{N \times L}$ , where  $N$  is the number of array elements, i.e.

$$\mathbb{X} = \text{"Xmatrix"} \text{ in your personal file} \quad (6)$$

Note that the system is asynchronous with unknown time delays with respect to the receiver's clock.

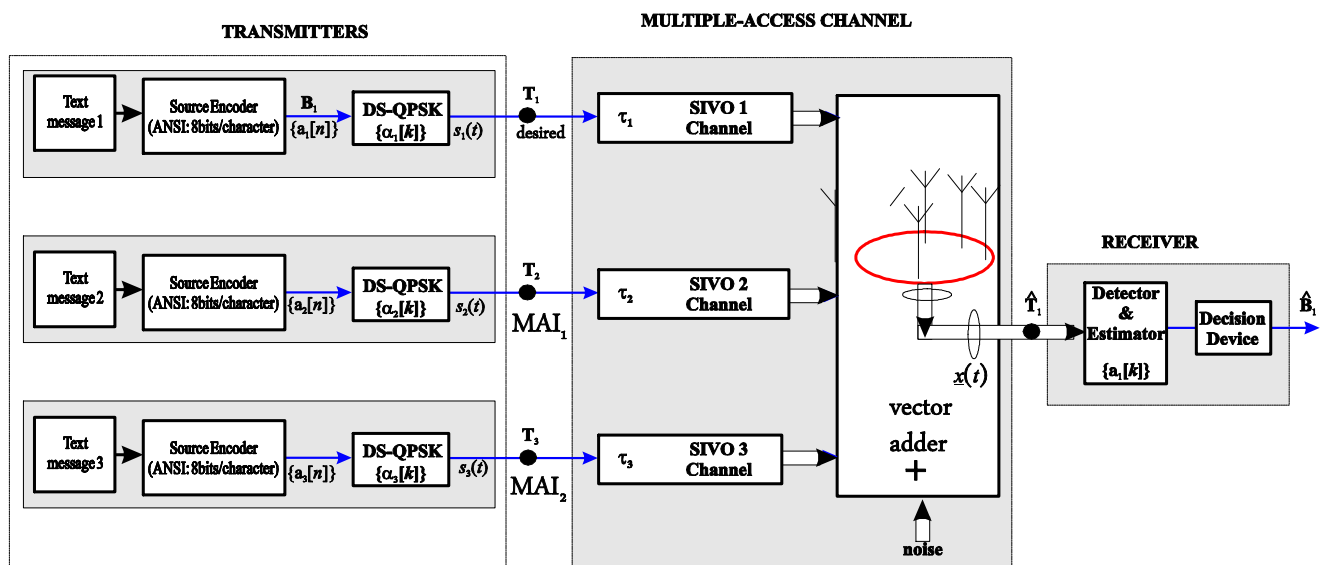


Figure 4: System Architecture for Task 4

- Task-4a: Estimate the various channel parameters associated with the desired user's paths.
- Task-4b: Design a receiver (preferably a spatiotemporal beamformer) to receive the 60-character desired text-message.

## 5 Deliverable

- MATLAB/C file(s) - with brief comments. That is four MATLAB script files (one per task) where the system parameters are defined and a number of MATLAB functions (with comments) are called.
- A pdf file with the results of the above four tasks (photos/messages) supported by 2-5 lines of some brief comments per task.

- Comments, if any, of how to run the programs to observe the results of the four tasks.
- A user interface may be useful - but not essential.
- Please upload a zip file (including all the files) named by your login name (eg. kl209.zip)

## 6 Some Notes

1. The messages are first modulated using QPSK, then spread by the gold sequences.
2. The PN-codes are generated by setting the initial state of the shift register be all ones (i.e.  $[1 \ 1 \ 1 \ 1 \ 1]$ );
3. The Xmatrix in your "mat" file contains the received signals which has the form:

$$[\underline{x}(1), \underline{x}(2), \dots, \underline{x}(L)] \quad (N \times L \text{ matrix})$$

in which  $\underline{x}(i), i = 1, \dots, L$  is a  $N \times 1$  vector. Note that  $\underline{x}(1)$  is the first snapshot of the signal-vector received and  $\underline{x}(L)$  is the last snapshot of the signal-vector received.

4. Please download and use the "Matlab Wrappers" from

<http://skynet.ee.imperial.ac.uk/notes/notes.html>

## 7 References

- [1] Lecture Notes on Advanced Communication Theory
- [2] your own references.