Coursework EE401: Advanced Comm. Theory
Part-A
“Multipath Spatiotemporal SIMO Wireless Systems”

Professor A. Manikas
Chair of Communications and Array Processing
Department of Electrical & Electronic Engineering
Imperial College London

v14.21

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, 160×112).
- 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 [20%]

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

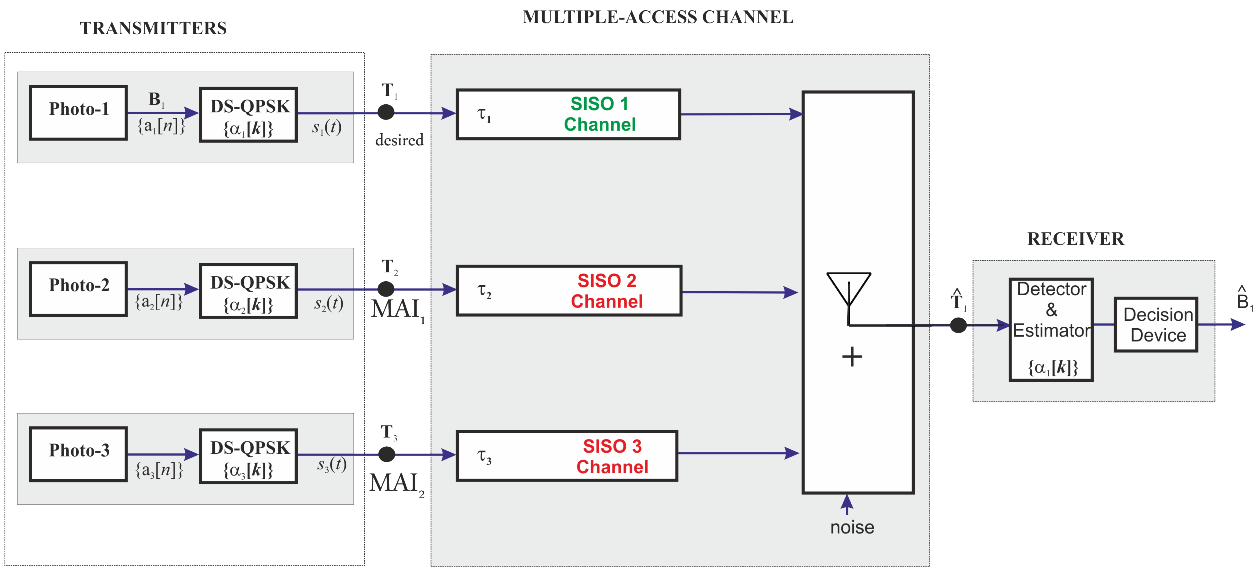

Figure 1: System Architecture for Tasks 1 and 2.

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

$$\phi \triangleq \mathcal{X} + 2\mathcal{Y} \tag{1}$$

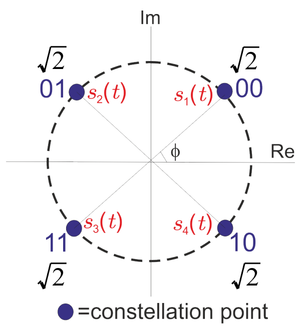

Figure 2: QPSK constellation diagram.

- **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:

$$d \geqq 1 + (\mathcal{X} + \mathcal{Y}) \bmod 12 \tag{2}$$

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 $\widehat{\mathrm{T}}_1$) according to the parameters given in Table-1. The point $\widehat{\mathrm{T}}_1$ 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 $s_1(t)$	$(\tau_1 \bmod 15) = 5$	$\beta_1 = 0.4$	$(30°, 0°)$
one path of $s_2(t)$	$(\tau_2 \bmod 15) = 7$	$\beta_2 = 0.7$	$(90°, 0°)$
one path of $s_3(t)$	$(\tau_3 \bmod 15) = 12$	$\beta_3 = 0.2$	$(150°, 0°)$

- **Noise**: The noise at point $\widehat{\mathrm{T}}_1$ is assumed to be additive white Gaussian noise of zero mean and power

   i. 0dB, and
   ii. 40dB

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

Task-1a: Using the above description, simulate the system up to the receiver's input (point $\widehat{\mathrm{T}}_1$). 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. { $\mathrm{a}_1[n]$}) and remove the other 2 signals as unwanted multiple-access interference (MAI). Make a comparison at different levels of noise (0dB and 40dB)

[20%]

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 $\widehat{\mathrm{T}}_1$ 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 $s_1(t)$	$(\mathcal{X} + \mathcal{Y}) \bmod 4$	$\beta_{11} = 0.8$	$(30°, 0°)$
2nd path of $s_1(t)$	$4 + (\mathcal{X} + \mathcal{Y}) \bmod 5$	$\beta_{12} = 0.4 \exp(-\mathrm{j}40°)$	$(45°, 0°)$
3rd path of $s_1(t)$	$9 + (\mathcal{X} + \mathcal{Y}) \bmod 6$	$\beta_{13} = 0.8 \exp(+\mathrm{j}80°)$	$(20°, 0°)$
$s_2(t)$	8	$\beta_2 = 0.5$	$(80°, 0°)$
$s_3(t)$	13	$\beta_3 = 0.2$	$(150°, 0°)$

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

[30%]

Task-3

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

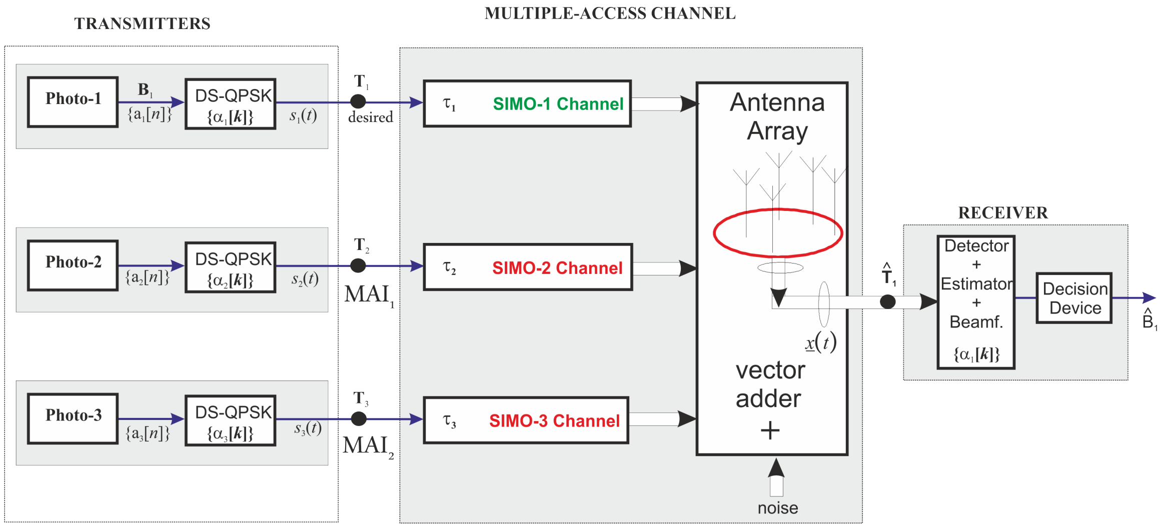

Figure 3: System Architecture for Task-3

[30%]

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

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

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 ϕ is given in degrees by the parameter "phi_mod". That is

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

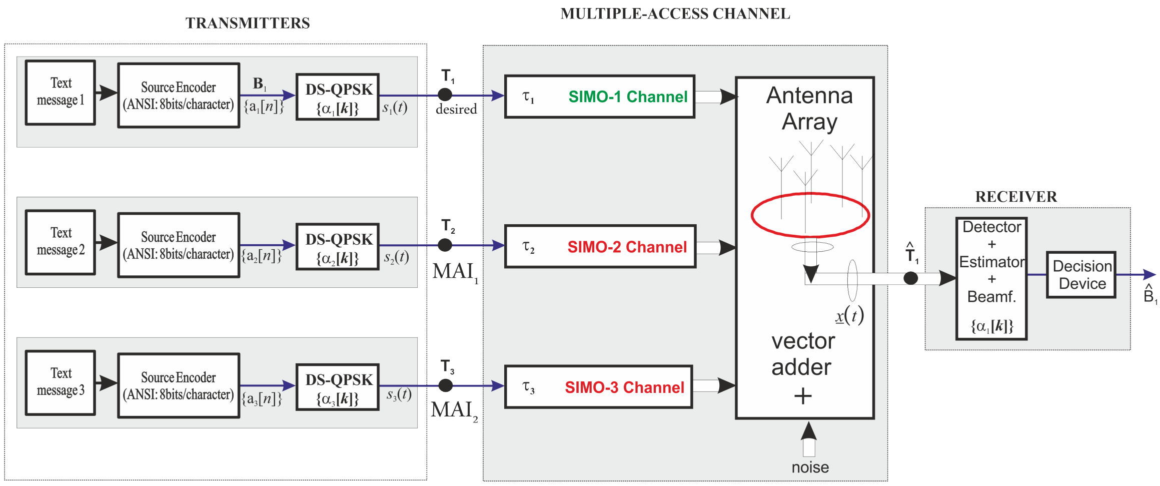

Figure 4: System Architecture for Task-4

- **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 (3×1) complex vector "Beta_1" in your personal file,

  i.e.
$$\left[\beta_{1,1},\quad \beta_{1,2},\quad \beta_{1,3}\right]^T = \text{"Beta\_1" in your personal file} \tag{5}$$

- **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 $\ell = 1, 2, 3, .., L$) forming the matrix $\mathbb{X} \in C^{N\times L}$, where N is the number of array elements, i.e.
$$\mathbb{X} = \text{"Xmatrix" in your personal file} \tag{6}$$

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

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 seeting 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:

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

   in which $\underline{x}(i)$,$i = 1, .., L$ 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.