Multipath Spatiotemporal SIMO Wireless Systems

Coursework Part-A

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EE401: Advanced Comm. Theory

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1 Task-1

Figure 1: Original Image transmitted to three Users

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The problem considered here is to transmitting 3 digital photos (shown in Figure 1) to three users , at the same time, on the same frequency band. The bit-streams of these image are firstly modulated by DS-QPSK Modulation using following special balanced gold sequence $\{\alpha_1\{k\}\}$ (shown in Table 1).

Table 1: My Balanced Gold Sequence

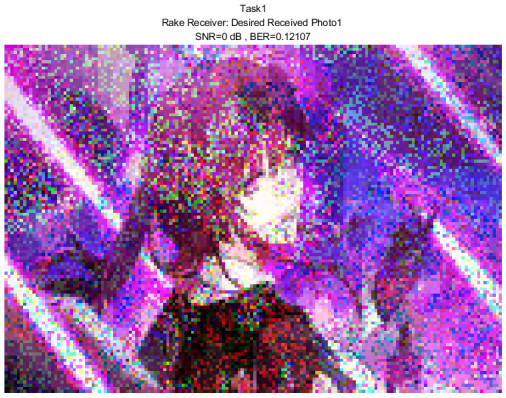
User	Sequence
User1	$[1,-1,-1,1,-1,-1,1,-1,1,1,-1,-1,1,1,-1]^T$
User2	$[-1,1,-1,1,1,-1,1,-1,-1,-1,1,1,1,-1,-1]^T$
User3	$[-1,-1,1,1,1,1,1,-1,-1,1,-1,-1,-1,-1,1]^T$

These signals are transmitted through the simulated channel (fchannel function in my code). It is designed a RAKE receiver to estimate the delay of desired user using corrector. This is benefited from the gold sequence's correlation property, which helps identify the signal closest to the desired one and remove other interfering signals.The simulated numeric results are summarized in Table 2.

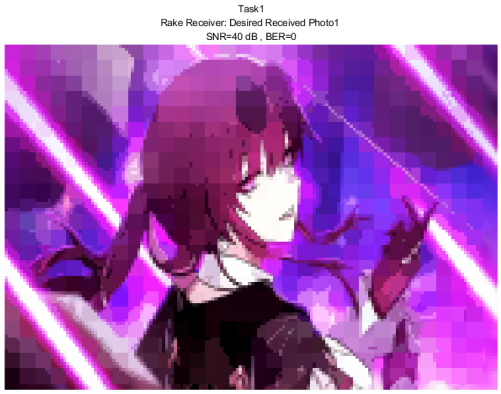
Table 2: Task1-Numeric Results Summary

Metrics	SNR(dB)	Ground-truth	Results
TOA	0	5	5
	40	5	5
BER	0	N/A	0.1213
	40	N/A	0

The photo received by the desired user (User1) is shown in Figure 2. It can be observed that the Bit Error Rate (BER) varies as a function of the Signal-to-Noise Ratio (SNR). A higher SNR leads to a lower BER.



SNR = 0 dB



SNR = 40 dB

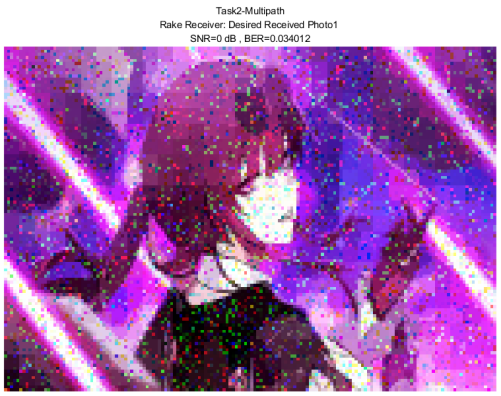
Figure 2: Task1-Received Photo By User1

2 Task-2

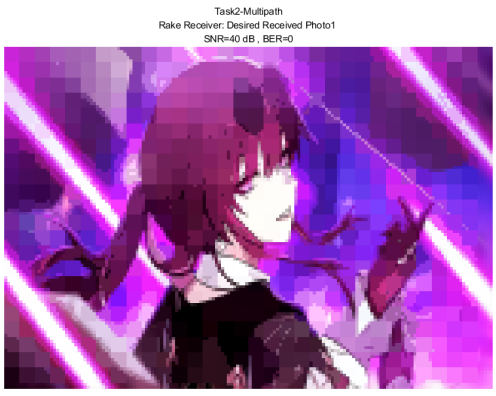
In this task, we consider to add the multi-path channel to the User1, The simulated numeric results are summarized in Table 3, and the photo received by the desired user (User1) is shown in Figure 3.

Table 3: Task2-Numeric Results Summary

Metrics	SNR(dB)	Ground-truth	Results
TOA	0	0, 5, 13	0, 5, 13
	40	0, 5, 13	0, 5, 13
BER	0	N/A	0.034012
	40	N/A	0



SNR = 0 dB



SNR = 40 dB

Figure 3: Task2-Received Photo By User1

Here,the Maximum Ratio Combining (MRC) rules are introduced at the receiver, which is designed to maximize the output Signal-to-Noise Ratio ($SNR_{out,div}$). Consequently, this approach exploits multipath diversity to enhance the BER performance, offering a significant improvement over single path scenarios. This can be verified by comparing the BER and quality in Figure 3 with that in Figure 2 when SNR = 0.

3 Task-3

In this task, we consider to add the uniform circular antenna array (UCA) at the receiver. The geometry of UCA are shown in Figure 4.

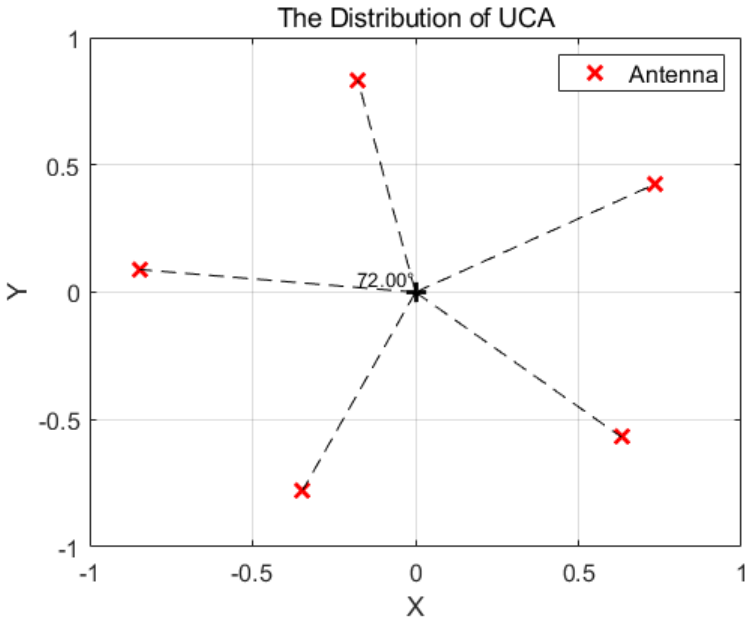
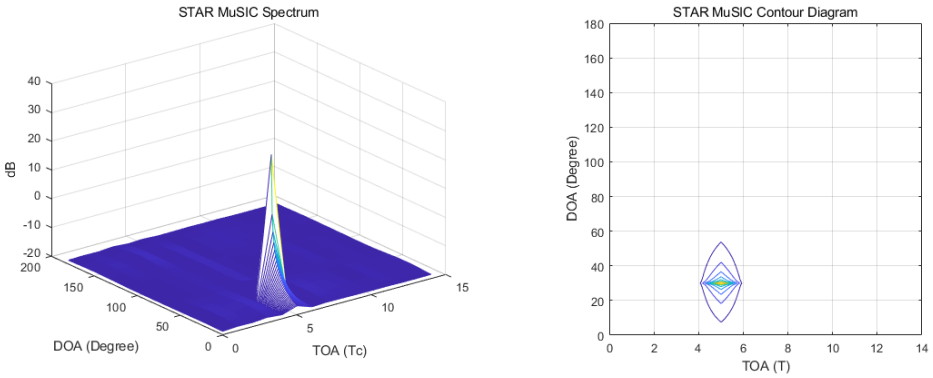


Figure 4: The geometry of UCA (Z=0)

Here, the STAR (Spatio-Temporal ARray) manifold vector are implemented using manifold extender. This extended manifold can be used to estimated TOA and DOA using STAR MuSIC algorithm. The simulated numeric results are summarized in Table 3

Table 4: Task3-Numeric Results Summary

Metrics	SNR(dB)	Ground-truth	Results
TOA	0	5	5
	40	5	5
DOA	0	$(30°, 0°)$	$(30°, 0°)$
	40	$(30°, 0°)$	$(30°, 0°)$
BER	0	N/A	0
	40	N/A	0



Spectrum Contour Diagram

Figure 5: Task3-Two-dimensional STAR-MuSIC Spectrum and Contour Diagram(SNR=0)

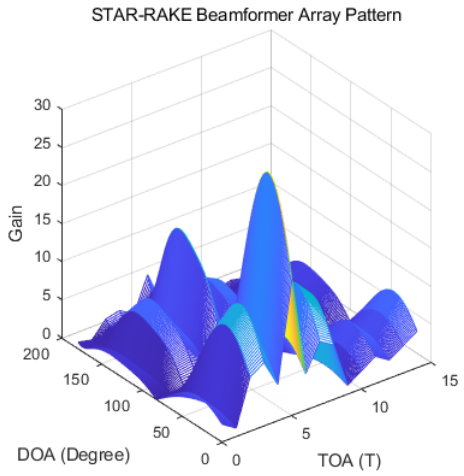
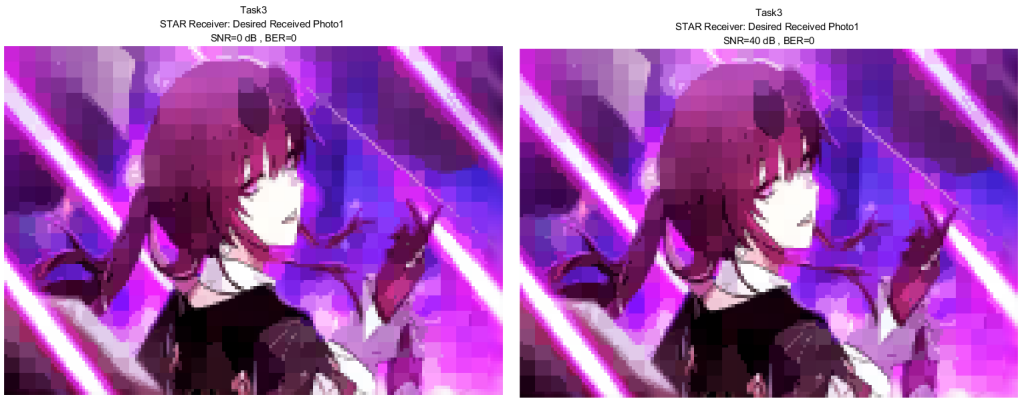


Figure 6: Task3-STAR-RAKE Beamformer Array Pattern(SNR=0)



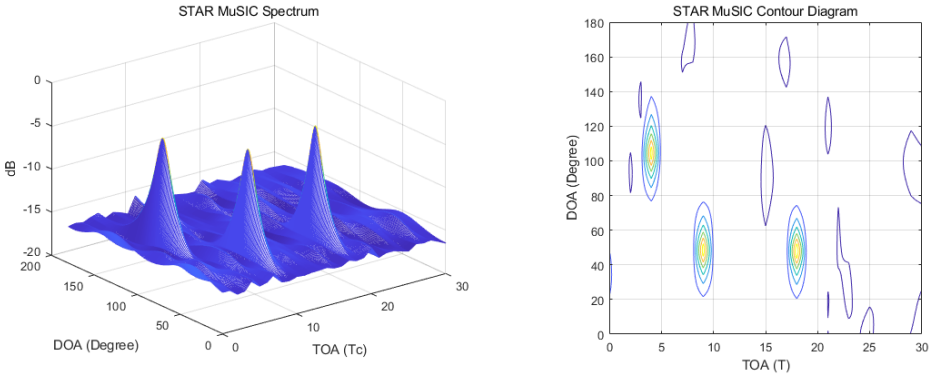
SNR = 0 dB SNR = 40 dB

Figure 7: Task3-Received Photo By User1

When the SNR is set to 0, the STAR MuSIC Spectrum and Contour Diagram are presented in Figure 5. The peak point in Figure 5 indicates the estimated Direction of Arrival (DOA) and Time of Arrival (TOA) as (30, 5), which aligns with the ground truth. Subsequently, the STAR RAKE Beamformer is designed to receive the desired signal, with the array pattern depicted in Figure 6. Figure 7 showcases the received photo at various SNR levels. Notably, even at an SNR of 0, the system demonstrates superior performance with a BER of 0.

4 Task-4

In this task, it is same STAR receiver as Task-3. Loading fast-fading data, the STAR MuSIC algorithm performs as Figure 8.



Spectrum Contour Diagram

Figure 8: Task4-Two-dimensional STAR-MuSIC Spectrum and Contour Diagram

Choosing the source number (detected by MDL) of peak points in Figure 8, we can get the estimated results shown in the Table 5.

Table 5: Task4-Numeric Results Summary

Metrics	Paths	Estimation
TOA	Path1	18
	Path2	9
	Path3	4
DOA	Path1	$(48°, 0°)$
	Path2	$(48°, 0°)$
	Path3	$(104°, 0°)$

Subsequently, the STAR RAKE Beamformer is designed to receive the desired signal, with the array pattern depicted in Figure 9.

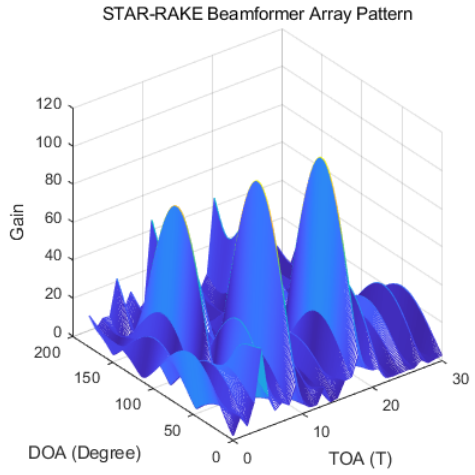


Figure 9: Task4-STAR-RAKE Beamformer Array Pattern

Finally, after transforming the text's bit-stream into a string, the text message we received is displayed below:

```
The received text-message is :
Huang,H., well done!!! Mission accomplished!!!!!!!!!!!!!!!!
```

References

[1] A. Manikas, "Coursework Part-A: Multipath spatiotemporal simo wireless systems," Nov. 2023. Available online: https://skynet.ee.ic.ac.uk/notes/notes.html

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[3] A. Manikas, "Differential geometry in array processing(2004)". Imperial College Press.

[4] G. Efstathopoulos and A. Manikas, "Extended Array Manifolds: Functions of Array Manifolds," in IEEE Transactions on Signal Processing, vol. 59, no. 7, pp. 3272-3287, July 2011, doi: 10.1109/TSP.2011.2132719.

[5] A. Manikas and M. Sethi, "A space-time channel estimator and single-user receiver for code-reuse ds-cdma systems," IEEE transactions on signal processing, vol. 51, no. 1, pp. 39–51, 2003.

[6] A. Manikas and L. Huang, "Star channel estimation in ds-cdma commnication systems," IEE Proceedings-Communications, vol. 151, no. 4, pp.387–393, 2004.

[7] Tse D, Viswanath P. "Fundamentals of wireless communication[M]". Cambridge university press, 2005.

APPENDIX: CMD Log Output and User Interface

4.1 Task-1&Task-2

```
........Initization: 3 Co-channel Transmiter.........
Load three Images for three Users
Start DS-QPSK Modulation
................................................

..............Task-1a (SNR = 0 dB)..................
..............Task-1a Channel Parameters.............
SNR = 0
Delay = 5,7,12
Beta = 0.4,0.7,0.2
................................................
Transmit the images through this channel

..............Task-1b Rake Receiver.................
Start Channel Estimation
The estimated photo-1 transmition delay is: 5
Start DSSS-QPSK Demodulation
BER = 0.12104
................................................

..............Task-1a (SNR = 40 dB)..................
..............Task-1a Channel Parameters.............
SNR = 40
Delay = 5,7,12
Beta = 0.4,0.7,0.2
................................................
Transmit the images through this channel

..............Task-1b Rake Receiver.................
Start Channel Estimation
The estimated photo-1 transmition delay is: 5
Start DS-QPSK Demodulation
BER = 0
................................................
```

Task1

```
........Initization: 3 Co-channel Transmiter.........
Load three Images for three Users
Start DS-QPSK Modulation
................................................

..............Task-2a (SNR = 0 dB)..................
..............Task-2a Channel Parameters.............
SNR = 0
Delay = 0, 5, 13, 8, 13
Beta = 0.8, 0.30642-0.25712i, 0.13892+0.78785i, 0.5, 0.2
................................................
Transmit the images through this channel

..............Task-1b Rake Receiver.................
Start Channel Estimation
The estimated photo-1 transmition delay is: 0   5  13
Start DSSS-QPSK Demodulation
BER = 0.034254
................................................

..............Task-2b (SNR = 40 dB)..................
..............Task-2b Channel Parameters.............
SNR = 40
Delay = 0, 5, 13, 8, 13
Beta = 0.8, 0.30642-0.25712i, 0.13892+0.78785i, 0.5, 0.2
................................................
Transmit the images through this channel

..............Task-1b Rake Receiver.................
Start Channel Estimation
The estimated photo-1 transmition delay is: 0   5  13
Start DSSS-QPSK Demodulation
BER = 0
................................................
```

Task2

Figure 10: Task-1&Task-2 CMD Log Output

4.2 Task-3&Task-4

```
First, please set your desired SNR (dB).
You can enter any non-numeric value to defaultly set SNR to 0 dB
Enter SNR (dB) value:
SNR is set to: 0 dB
........Initization: 3 Co-channel Transmiter.........
Load three Images for three Users
Start DS-QPSK Modulation
................................................

..............Task-3 (SNR = 0 dB)..................
.............Task-3 Channel Parameters..........
SNR = 0
Delay = 5, 7, 12
Beta = 0.4, 0.7, 0.2
DOAs (Theta) = 30, 90, 150
................................................

.............Task-3 UCA STAR Receiver.................
Deploy Uniform Circular Array (UCA)
Transmit the images through this channel
Start Discretiser and Manifold Extender
Start STAR Channel Estimation
The estimated Photo-1 delay are : 5
The estimated Photo-1 DOAs (theta, phi) are : 30   0
Start STAR Beamformer
Start DS-QPSK Demodulation
BER = 0
................................................
```

Task3

```
..........Task4 UCA STAR Receiver with Personal data.............
Deploy Uniform Circular Array (UCA)
Start Discretiser and Manifold Extender
Start STAR Channel Estimation
The estimated delay are : 18   9   4
The estimated DOAs (theta, phi) are : 48    0   48    0  104    0
Start STAR Beamformer
Start DS-QPSK Demodulation
The received text-message is :
Huang,H., well done!!! Mission accomplished!!!!!!!!!!!!!!!!
```

Task4

Figure 11: Task-3&Task-4 CMD Log Output