Downlink Transmit Beamforming

Single-Carrier Acoustic Communication in a Simulated Noisy Environment

Nolan Pearce

Northeastern University

December 2023

Outline

Context

- Link Architecture from Stojanovic et. al, "Phase Coherent Digital Communications for Underwater Acoustic Channels" (IEEE Journal of Oceanic Engineering, 1994) [2]
- User with 1 TX/RX node transmits to Base Station with M TX/RX nodes
- MSE and feedforward filter-based algorithim used for base station DFE receiver
  - Complex filter with $N_{FF}, N_{FB} = [30, 2]$ taps
  - RRC Pulse Shaping with roll-off factor 0.5
  - Channel-based angle estimation
- Uplink-only implementation; relatively simple transmitters but hardware-intensive receiver base station

Motivation

- Implement transmit downlink beamformer dependent on underwater channel geometry
- More complex base station will allow for linear equalizer at user receiver
- Savings on processing time, hardware, costs, etc.

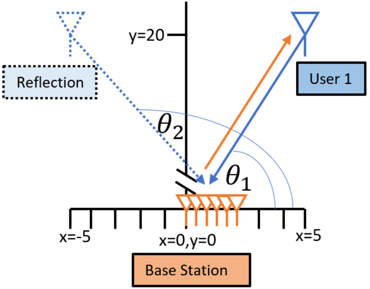


Figure: Simulation diagram for reflected underwater channel

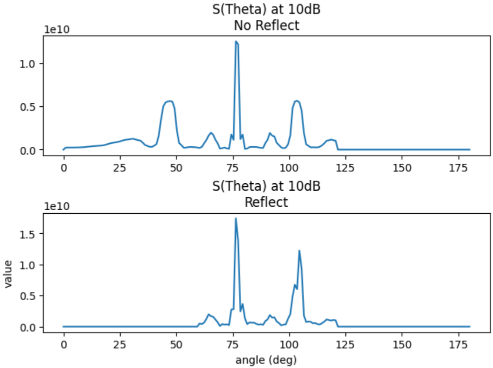
Communication System

BPSK Transmitter/Receiver initialized with following parameters:

Parameter	**Symbol**	**Value**
Center Frequency	f_c	15 kHz
Sampling Frequency	f_s	48 kHz
Symbol Rate	R	3000 Symbols/s
Samples per Symbol	N_s	16
# of Array Elements	M	16
Wavespeed	v	343 m/s
Element Spacing	d	$\approx 0.5\lambda_c$
True User Angle	θ	76°

Channel

- Channel is AWGN with euclidean distance-based time delay τ (860 symbols)
- Reflected transmitter simulated with second coordinate set reflected across $y = 0$; reflection surface along y-axis to the right of base station array
- Uplink SNR=10 dB; User identified at 76°; Reflection identified at local maximum near 104°



Cross-Correlation

- Cross-Correlation between upsampled LMS preamble and received baseband signal for array elements $M = [4, 6, 8, 10]$
- Distance-based sample delay and reflected transmitted signal identifiable
- Less delay from base station elements closer to user

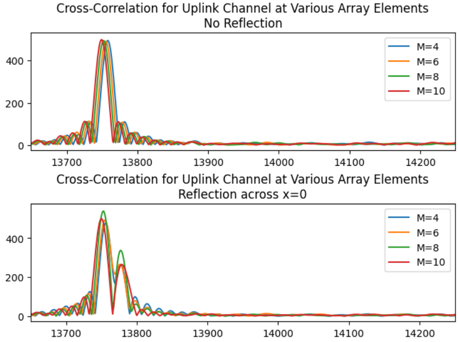


Figure: Cross-Correlation for Uplink Signal for single array element

Without Beamforming

- Received signal formed by delay-and-sum method
- Assumed same transmitter position and channel response

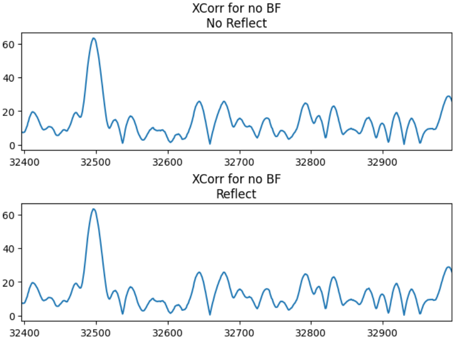


Figure: Cross-Correlation for Downlink Signal for single user

With Beamforming

- User angle applied via steering vector for reflected and non-reflected channel
- Eliminates many multipath effects including reflection

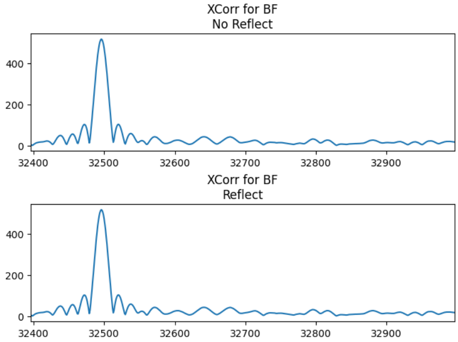


Figure: Cross-Correlation for Downlink Signal for single user

Next Steps

- Implement Linear Equalizer from Chapter 10 of *Digital Communications* [1]
- Obtain constellation diagram and MSE for downlink signal
- Prepare for open-air test on acoustic testbed
- Test using underwater metrics (v, λ_c)

P. Massoud Salehi and J. Proakis.
Digital Communications.
McGraw-Hill Education, 2007.

M. Stojanovic, J.A. Catipovic, and J.G. Proakis.
Phase-coherent digital communications for underwater acoustic channels.
IEEE Journal of Oceanic Engineering, 19(1):100–111, 1994.