A Real-Time Coded OFDM Acoustic Modem in Very Shallow Underwater Communications

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INTRODUCTION

OBJECTIVES

TRIAL SETUP

COMMUNICATION SCHEME

PERFORMANCE

FUTURE WORK

SUMMARY
INTRODUCTION

- Typical COTS modems performed at 200-300bps @ BER ~ $10^{-7} - 10^{-6}$ for distances up to 2400m (Actual shallow water performance evaluated by DSO)

- July 2004 – assembled a team of acoustics and communication engineers
OBJECTIVES

- Study of local shallow waters
  - Measurements / Develop channel model
- Developed a versatile and reconfigurable underwater acoustic communications test bed
- Investigate and evaluate communications processing techniques
  - OFDM
  - Turbo Product Codes
COMMUNICATION SCHEME

- Orthogonal Frequency Division Multiplexing

[Diagram showing frequency and time domains with labeled tones and symmetrical period]
COMMUNICATION SCHEME

- Orthogonal Frequency Division Multiplexing
COMMUNICATION SCHEME

Why OFDM?
- Easy to combat multipaths by cyclic extension.
- Robust against impulsive shrimp noise.
- Mild channel Doppler spread – OFDM not suffer severe inter-carrier interference (ICI).

Why DPSK on each sub-carrier
- Slow channel fading allows time-domain DPSK.
- Simplified receiver design – no channel estimation.
Waveform Structure

- Transmit in bursts, 12 frames in one burst, each burst starts with an Automatic Gain Control (AGC) preamble.

<table>
<thead>
<tr>
<th>AGC</th>
<th>OFDM Frame 1</th>
<th>OFDM Frame ...</th>
<th>OFDM Frame 12</th>
</tr>
</thead>
</table>

### Waveform Structure (Cntd.)

- Within one OFDM frame: 2 OFDM training symbols, 18 OFDM data symbols

<table>
<thead>
<tr>
<th>Time Sync Preamble</th>
<th>Guard Bits</th>
<th>OFDM Training Syms</th>
<th>OFDM Data Sym 1</th>
<th>OFDM Data Sym ...</th>
<th>OFDM Data Sym 18</th>
</tr>
</thead>
</table>
### Single-carrier BPSK modulated time sync preamble
- Easy to design time-domain binary sequence with good correlation property for receiver sync.

### Guard bits are actually cyclic extension of the time sync sequence
- Sharper resolution of receiver sync correlator output
Two identical OFDM training symbols for fine frequency offset estimation (FOE)
- FOE using Moore’s method.
- Cyclic extensions surrounding the 2 training symbols and no cyclic extension between them.
- No coarse frequency offset estimation because
  - channel Doppler effect is small
  - transducers introduce little FO
  - frequency up and down conversions are done all digitally with high precision (FO < 10 Hz)
Each data symbol has both cyclic prefix and postfix.

Why postfix?
- Receiver designed to synchronize with the dominant path;
- Dominant path need not be the first-arriving path when range is short;
- In case that dominant path is not the first-arriving path, ISI will occur if no postfix!
Length of cyclic extensions varies according to channel multipath spread at different ranges, thus different data rate between 2 kbps to 10 kbps.
COMMUNICATION SCHEME

Turbo Reed-Solomon Product Code

- Encoder: Product code based on Reed-Solomon code.
- Decoder: Soft-input soft-output iterative decoding, Chase algorithm, and algebraic Reed-Solomon harding decoding.

Benefit

- High code rate (0.75).
- Easy to implement as compared to turbo convolutional code.
- Better performance over multipath fading channels.
COMMUNICATION SCHEME

- Modem Architecture

![Diagram of Communication Scheme]

- FEC Encoder
- Interleaver (Optional)
- GUI
- FEC Decoder
- Deinterleaver (Optional)
- PC-to-FPGA Interface
- FPGA-to-PC Interface
- OFDM Transmitter
- OFDM Receiver
- DAC
- LPF & Amplifier
- LPF & Gain Control
- Projector
- Hydrophone

UW Communications in Shallow Waters
COMMUNICATION SCHEME

OFDM Transmitter

- Modem Controller
- Time Sync Sequence
- AGC Sequence
- DPSK MOD
- FFT/Cyclic Extend
- Digital Up Converter
- RRC Filter
- DAC

Module on PC
Module on FPGA
COMMUNICATION SCHEME

OFDM Receiver

AGC → DDC → Frame Synchronization → FOC → FFT → DPSK DEMOD
PERFORMANCE

AGC Performance

![AGC Performance Graph](image-url)
## OFDM Performance

<table>
<thead>
<tr>
<th>Category</th>
<th>Dist (m)</th>
<th>Mod</th>
<th>FEC</th>
<th># of Rx frames in error</th>
<th>BER: 0.04 to 0.1 (Uncoded only: – conditions not good enough to switch on channel coding)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Range</td>
<td>80</td>
<td>DB/QPSK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>140</td>
<td>DB/QPSK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium Range</td>
<td>400</td>
<td>DBPSK (2.08kbps)</td>
<td>TRSPC</td>
<td>1</td>
<td>5e-5</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>DBPSK (2.08kbps)</td>
<td>TRSPC</td>
<td>0</td>
<td>&lt;4e-6</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>DQPSK (4.16kbps)</td>
<td>TRSPC</td>
<td>0</td>
<td>&lt;4e-6</td>
</tr>
<tr>
<td></td>
<td>1700</td>
<td>DBPSK (4.77kbps)</td>
<td>TRSPC</td>
<td>0</td>
<td>&lt;4e-6</td>
</tr>
<tr>
<td></td>
<td>1700</td>
<td>DQPSK (9.54kbps)</td>
<td>TRSPC</td>
<td>0</td>
<td>&lt;4e-6</td>
</tr>
<tr>
<td>Long Range</td>
<td>2500</td>
<td>DQ/BPSK</td>
<td></td>
<td></td>
<td>BER: 0.04 to 0.1</td>
</tr>
</tbody>
</table>
PERFORMANCE

“Medium Range” Performance
PERFORMANCE

"Near/Far Range" Performance

Ambient Noise Floor
FUTURE WORK

- Rectify “Near” Range Problems
  - Inter Channel Interference
    - Sub-Channel Equalization
  - Time Synchronization
    - Frame and Symbol Level Synchronisation

- Rectify “Far” Range Problem
  - Improve the Peak to Average Power Ratio (PAR≈1) of OFDM Signal
SUMMARY

- Developed a versatile and reconfigurable underwater acoustic communication test bed
- Accumulated at-sea data for communication channel characterizations and communication signals
- Implemented a real time OFDM communication modem in FPGA
- Successful application advanced channel coding methods (TRSPC) to underwater communications
- The OFDM DB/QPSK (2.08-9.54kbps) BER performance of $< 4 \times 10^{-6}$ was achieved at the ranges from 400m to 1700m.
- However, for ranges less than 400m and above 2500m, our OFDM modem did not perform well. We have identified the problems and recommendations were made to overcome them
THAT’S ALL FOLKS!

• Have a pleasant day ahead!