Multichannel Communication based on Adaptive Equalization in Very Shallow Water Acoustic Channels

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INTRODUCTION

Range (80m)  
Receiver Array  
Ship B

Receiver Depth 5m

Weight

Projector

Depth (10m)

Bottom Depth (16m)

TIME VARYING MULTIPATH FADING

Beamformed Multipath Intensity Profiles 18.5kHz 54m 22 Nov 05

Data

Average Multipath Intensity Profile (10dB margin)

-20  -15  -10  -5  0  5  10  15  20

Time Delay (Seconds)

-20  -15  -10  -5  0  5  10  15  20

Time Delay (Seconds)

-20  -15  -10  -5  0  5  10  15  20

Time Delay (Seconds)
CHANNEL MODEL

- Ray Model
- Rayleigh Fading on individual arrivals
- Fading is time correlated, Doppler spread
- Alpha-Stable noise

![Graphs showing measured and simulated multipath power delay and intensity profiles](image)

**measured**

**simulated**
Single Carrier Differential Phase Shift Keying

**DBPSK Frame**

<table>
<thead>
<tr>
<th>Sync / Training Preamble</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>127 or 511 bits ML sequence</td>
<td>900 bits Pseudo Random Sequence</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre Frequency</td>
<td>18.5kHz</td>
</tr>
<tr>
<td>Symbol Rate</td>
<td>9250sym/s</td>
</tr>
<tr>
<td>Raised Cosine Filter Alpha</td>
<td>0.25</td>
</tr>
<tr>
<td>Over sampling</td>
<td>16</td>
</tr>
<tr>
<td>Arbitrary Start Bit</td>
<td>‘1’</td>
</tr>
</tbody>
</table>
Comparing BERs for same channel parameters (80m to 2740m)

![Comparing Bit Error Rates](image-url)
EXPERIMENTAL DESCRIPTION

SEA TRIAL SETUP

- **Ship A**: Projector
  - Bottom Depth (15m – 30m)
  - Depth (5m – 10m)
- **Ship A**: Receiver Array
  - Range (80m – 2740m)
- **Ship B**: Receiver Depth 5m
  - Receiver Depth 5m
- **Weight**
  - Weight
EXPERIMENTAL DESCRIPTION

SHALLOW WATER CHANNEL

Sea trial analysis results to set channel model and modem simulation

**Projector**
12.7 kHz – 24.3 kHz

**Front-end Receiver**
Nested Hydrophone Array

**Signal Conditioning Boards**

![Image of projector](image1.png)

![Image of front-end receiver](image2.png)
EXPERIMENTAL DESCRIPTION

PC with PCI NI DAQ
(Transmitter/Receiver)

National Instruments Multi-function DAQ Card
## CHANNEL MEASUREMENTS

<table>
<thead>
<tr>
<th>Range (m)</th>
<th>Root Mean Square (RMS) Delay Spread (ms)</th>
<th>Doppler Spread, $W_d$ (Hz)</th>
<th>Doppler Shift (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>1.2</td>
<td>9</td>
<td>-1,+2</td>
</tr>
<tr>
<td>130</td>
<td>1.9</td>
<td>8</td>
<td>-1</td>
</tr>
<tr>
<td>600</td>
<td>0.85</td>
<td>4</td>
<td>-2</td>
</tr>
<tr>
<td>1030</td>
<td>0.85</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>1510</td>
<td>0.38</td>
<td>2</td>
<td>-1</td>
</tr>
<tr>
<td>1740</td>
<td>0.13</td>
<td>2</td>
<td>+1</td>
</tr>
<tr>
<td>2740</td>
<td>0.10</td>
<td>3</td>
<td>+2</td>
</tr>
</tbody>
</table>
ADAPTIVE EQUALIZATION

LINEAR EQUALIZER

\[ r(2k) \rightarrow f_f \rightarrow y(k) \rightarrow z(k) \rightarrow \ddot{a}(k) \]

\[ \mu_{ff} \rightarrow - \rightarrow b(k) \rightarrow e(k) \]

\[ T_s/2 \text{ spaced feedforward filter} \]

Connects during tracking mode

Connects during training mode

Linear Equalizer

Differential Decoding & Decision

Training Sequence
ADAPTIVE EQUALIZATION

- DECISION FEEDBACK EQUALIZER

\begin{align*}
&\text{Decision Feedback Equalizer} \\
&\text{Differential Decoding & Decision}
\end{align*}
ADAPTIVE EQUALIZATION

- Comparing LE in simulation and trial
- Least Mean Square (LMS) Adaptation

Comparing Bit Error Rates

![Graph comparing simulated BER and trial BER with and without equalization](image-url)

- BER w/o EQ
- BER after EQ
Comparing LE-LMS and DFE-LMS from trial data

Equalizer Output BER Performance

- w/o processing
- DFE-LMS
- LE-LMS
Multichannel Combining

- Short Range: Main improvement from automatic beamforming.
- Long Range: Main improvement from increased SNR.

```
\[ r_1(2k), r_2(2k), r_3(2k), r_4(2k), r_5(2k) \rightarrow LE/DFE \]
```

Multichannel Combining

```
\[ LE/DFE \]
```

Differential Decoding & Decision

```
\[ T_s, * \]
```

\[ z(k), y^*(k-1) \rightarrow \hat{a}(k) \]
MULTICHLANNEL COMBINING

2740m Trial Data

Mean Square Error

Differentially Decoded Input Symbols Constellation Plots

Differentially Decoded Output Symbols Constellation Plots

Multiple Output Combined Differentially Decoded Symbols Constellation Plots
MULTICHLANEL COMBINING

Performance from trial data

Multichannel Combining Output BER Performance

Test Range (m)

BER

- w/o processing
- LE-LMS
- LE-LMS+MC
Turbo Product Codes

- Code Rate ~ 0.75
CHANNEL CODING

- Turbo Product Codes performance from trial data
Turbo Product Codes performance from trial data

Percentage of Error Free Frames

Test Range (m)

% Error Free Frames

w/o processing
LE-LMS+MC
LE-LMS+MC+TPC
CONCLUSION

- Channel model results are adequately close to real data
- DPSK-LE-LMS is generally better than DPSK-DFE-LMS for shorter distances
- Multichannel combining and TPC improves BER performance
- Overall the packets recovered are over 80% except at 130m and 1510m. The channel is probably varying too fast for the LMS adaptation
- Faster adaptation algorithms will work better but at expense of increased computational complexity.
THAT’S ALL FOLKS!

- Questions and Answers
- Have a pleasant day ahead!