Master Thesis Defense

A Two-Level Enhancement for Spread Spectrum Based Hidden Aerial Acoustic Communications and Its Applications

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Outline

- Introduction
- Related Works

- Channel Investigation
- Modulation Level Enhancement
- Data Level Enhancement

- Experimental Results
- Conclusions and Future Work
INTRODUCTION

- Hidden Aerial Acoustic Comm.
- Application Scenarios
- System Requirements
Under the original music, the hidden aerial acoustic channel is transmitting information at the same time.

Ideal situation
- People
  - Only notice original music
- Mobile
  - Only get signal from the hidden channel

Messages
Hidden Channel
Application Scenario I

Stores

Consumers

Hidden Message

dress 10% off
dog biscuit 20% off
Application Scenario II

Zhongshan Highway Taoyuan congestion
System Requirements

- Transmission stability
  - Robustness (low error rate) and Distance
  - Embedding Strength, Transmission Stability

- Throughput rate
  - Bits per second / Words per minute
  - #Embedded Symbols, Throughput Rate

  but ... Transmission Stability

- Fidelity
  - Interference / Audio quality
  - Embedding Strength, Fidelity

  but ... Transmission Stability, Throughput Rate
Hidden Acoustic Communication Systems

- System Overview
- SS-based System
- Acoustic OFDM System
System Overview
SS-based System (1/2)

- **Audio preprocess**
  - DCT domain

- **Data preprocess**
  - Reed–Solomon
  - Diagonal Interleaver
  - Escaping symbol for frame header

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SS-based System (2/2)

Embedding
- Codebook
  - Get the code corresponding to the symbol from codebook
- Audio Part
  - Frequency Domain Signal
  - Embed into original signal
  - Output

Data Part
- Frame Symbols
- Masking Threshold

Audio Part
- Control embedding strength according to masking threshold

Extraction
- Audio Part
  - Frequency Domain Signal
  - Correlation calculation to every codewords in the codebook
  - symbol has maximal correlation
- Codebook
Audio preprocess
- DFT domain

Data preprocess
- Convolutional Codes
- Random Interleaver
- Symbols of 1\textsuperscript{st} time slot and 31\textsuperscript{st} (last) time slot are the same

State-of-the-art

- Spread spectrum based (SS-based) method [1]
  - Audio watermarking
- Acoustic OFDM [2]
  - Communication


Channel Determination

- Channel Overview
- Channel Response
Factors:
- Sound Card
  - Digital → Analog
  - Analog → Digital
- Loudspeaker
  - Analog → Sound wave
- Microphone
  - Sound wave → Analog
- Aerial Acoustic Channel
Channel Response (Config I)

- **Loudspeaker**: KINYO PS-205 2.0 Multimedia Speaker
- **Microphone**: Philips SHM1000/97
- **DA/AD**: in Lenovo ThinkPad X61

<table>
<thead>
<tr>
<th>Configuration I</th>
<th>Acoustic OFDM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loudspeaker</td>
<td>Fujitsu-Ten Eclipse TD508</td>
</tr>
<tr>
<td>Microphone</td>
<td>Sony ECM-360</td>
</tr>
<tr>
<td>DA/AD</td>
<td>in Dell Inspiron 5150</td>
</tr>
</tbody>
</table>
Sound Card Response

IBM X61 built-in

Asus Xonar U1
Channel Response (Config II)

<table>
<thead>
<tr>
<th></th>
<th>Configuration II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loudspeaker</td>
<td>Fujitsu-Ten Eclipse TD508 II</td>
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</table>

Frequency: 14000 Hz
Possibility of SS–based method Enhancement

- SS–based method [1] is still workable, when the configuration I is used.

<table>
<thead>
<tr>
<th>Band1</th>
<th>Band2</th>
<th>Band3</th>
<th>Band4</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0–127)</td>
<td>(128–255)</td>
<td>(256–383)</td>
<td>(384–511)</td>
</tr>
<tr>
<td>[0] to</td>
<td>[5512.5] to</td>
<td>[11025] to</td>
<td>[16537.5] to</td>
</tr>
<tr>
<td>[5512.5]</td>
<td>[11025]</td>
<td>[16537.5]</td>
<td>[22050]</td>
</tr>
</tbody>
</table>

Used in [1]:
- Preserve for Audio quality
- Reliable
- Only Reliable in Config. II
- Not Reliable

7200 Hz  14000 Hz

Modulation-Level Enhancement

- Increasing Codebook Size
- Frequency Division
- Adaptive Frequency Division
Increasing Codebook Size

- 4 bits per window (SS-based method [1])
  - 0010 1111 0010

- bits per window codebook size
  - 2X → Size = 256
  - 3X → Size = 4096
  - 4X → Size = 65536

Spread Spectrum Extracting

Original Audio ➔ Output Audio
Frequency Division

The original usage of bands

- Band1: (0-127) [0] to [5512.5]
- Band2: (128-255) [5512.5] to [11025]
- Band3: (256-383) [11025] to [16537.5]
- Band4: (384-511) [16537.5] to [22050]

Not Reliable

The frequency division approach
Embedding and Correlation Calculation

**Embedding**

Symbols to be embedded in current window

**Extraction**

Codebooks

Correlation Calculation

Correlation Calculation

Correlation Calculation

Symbols
Fading
Selective Fading
Influence of Selective Fading

Sent data

Save $1.00 on any Windex Multi-Surface test 1–1
Save $1.00 on any Windex Multi-Surface test 1–2
Save $1.00 on any Windex Multi-Surface test 2–1
Save $1.00 on any Windex Multi-Surface test 2–2
Save $1.00 on any Windex Multi-Surface test 3–1
Save $1.00 on any Windex Multi-Surface test 3–2

Received Data

Save $1.00 on any Windex Multi-Surface test 1–1
Save $1.00 on any Windex Multi-Surface test 1–2
Save $1.00 on any Windex Multi-Surface test 2–1
Save $1.00 on any Windex Multi-Surface test 2–2
Save $1.00 on any Windex Multi-Surface test 3–1
Save $1.00 on any Windex Multi-Surface test 3–2
Adaptive Frequency Division

Band1 (0-127) [0] to [5512.5]

Band2 (128-255) [5512.5] to [11025]

Band3 (256-383) [11025] to [16537.5]

Band4 (384-511) [16537.5] to [22050]

Not Reliable

Band1 (0-127) [0] to [5512.5]

123123123123123123123123123

Band4 (384-511) [16537.5] to [22050]
Comparison
Data-Level Enhancement

- Variable length coding
- Error propagation
- Controlling mechanism
Variable Length Coding (VLC)

- Most applications of the proposed system are in text-based data transmission
  - lossless compression
  - the source symbols are finite
- VLC is suitable for enhancing transmission efficiency
  - Adopt Huffman codes in our system
Error Propagation

- Huffman coding
  - Symbol length is not constant
- If an error occurs, prefix removing may affect the next symbol
- In this situation, errors are propagated to subsequent symbols
Basic Idea for Error Propagation Controlling

Starting point

- HEADER Type I - DATA SECTION
- HEADER Type II - DATA SECTION
- HEADER Type I - DATA SECTION
- HEADER Type II - DATA SECTION

Starting points of segments
Frame Structure in [1]

Diagonal Interleaver

Original symbol order

Out-of-boundary

Diagonal data interleaved ordering
Interleaver in proposed system
Proposed Segment Structure

Segment I

Segment II

The proposed segment structures
Huffman encoding with padding

DATA
Save $1.00 on ONE 64oz. or 96oz. Welch's 100% Juice

Huffman Coding

Embed in next segment

Segment Boundary

padding

1 1
Experimental Results

- Subjective Quality Test
- Transmission Performance
Different audio condition
- The original
- Acoustic OFDM embedded
- SS-based Method embedded with different bandwidth
  - 4134.3 Hz, 5512.5 Hz, 6890.6 Hz, 8268.75 Hz
Subjective Quality Test (1/2)

- Types of music
  - Classic music
  - Pop music
  - Heavy Metal Music
  - Jazz Music

- The results are scored by 20 people
  - 0 ~ 10

- Figure next page
  - Mean
  - 95% Confidence Interval
Subjective Quality Test Result

Classic Music

Pop Music

Heavy Metal Music

Jazz Music
Transmission Performance

- **Factors**
  - **Transmission rate**
    - Number of divisions:
      - 1 (77 bps), 2 (153 bps), 3 (230 bps), 4 (306)
  - **Volume**
    - SL1 Acoustic OFDM = 2 m
    - SL2 Acoustic OFDM = 3 m
  - **Embedding bandwidths**
    - 4134.3 Hz, 5512.5 Hz, 6890.6 Hz, 8268.75 Hz
  - **Error Rate**
    - Precision > 90%
  - **Transmission distance**
    - Measurement, stepping by 0.1 m
Results of Transmission Performance Test (SL1 volume level, Acoustic OFDM 2m)
Results of Transmission Performance Test (SL2 volume level, Acoustic OFDM 3m)
Conclusions

- In this work, we investigate the aerial acoustic channel

- A two-level enhancement of transmission capability over the hidden aerial acoustic channel is proposed
  - Modulation level: Adaptive frequency division
  - Data level: VLC integration
Future Work (1/2)

- Improvement of SS-based embedding is achieved, but the way for improving OFDM still under investigation
Future Work (2/2)

- Applying the system in real applications
  - Finding tradeoff between confliction conditions
    - Ex:
      - Long distance, low error rate,
      - how to achieve the highest transmission rate?
    - Ex:
      - Short distance, low playing volume,
      - how to enhance the robustness of the system?
Questions?
Thanks for your attention