Acoustic Communication

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Motivation
Background
Sound
Capturing Sound

![Diagram of sound capturing process]

- Sound
- Voltage signal
- Amplified signal
- Band-limited signal
- Digital samples

Image: BackDoor - Roy et al.
Human Auditory System
Frequency Masking

Audible up to 20 kHz
Interference
\sin(x)

\sin(2x)
\[ \sin(x) \]
\[ \sin(2x) \]
\[ \sin(x) + \sin(2x) \]
Embedding Data
Amplitude Modulation
Phase Modulation

Binary code PRN

Carrier wave

BPSK modulated signal

Image: https://commons.wikimedia.org/wiki/File:Phase_modulation_BPSK_GPS.svg
Binary Phase-Shift Keying (BPSK)

Quadrature Phase-Shift Keying (QPSK)

Frequency Modulation
Orthogonal Frequency Division Multiplexing (OFDM)

- Multiple Sub-Carriers
- Compensate severe Channel Conditions

Ambient Noise

![Graph showing received SNR vs frequency for different environments: in a square, in a cafe, and in an office.](Image: Message Behind the Sound - Wang et al.)
Human Voice

Soft Music

Rock Music

Image: Message Behind the Sound - Wang et al.
Messages Behind the Sound: Real-Time Hidden Acoustic Signal Capture with Smartphones

Qian Wang, Kai Ren, Man Zhou, Tao Lei, Dimitrios Koutsonikolas, Lu Su
Wuhan University & The State University of New York at Buffalo
Image: Message Behind the Sound - Wang et al.
On-Off Keying

Magnitude

Frequency (KHz)

Magnitude

Frequency (KHz)
Energy Difference Keying (EDK)
Error Correction

- Intra Symbol
- Inter Symbol
Results

![Graph showing the decoding rate (%) against distance (m) for two different sound levels (80dB and 77dB)].

- **80dB**
- **77dB**
BackDoor: Making Microphones Hear Inaudible Sounds

Nirupam Roy, Haytham Hassanieh, Romit Roy Choudhury
University of Illinois at Urbana-Champaign
Creating a shadow

Inaudible tone pair

Amplitude

Frequency

Signal inside microphone

Microphone filter

10K  20K  24K  40K  50K

Audible sound  Near ultrasound  Ultrasound
Perfect Pre-Amplifier

\[ S = \sin(\omega_1 t) + \sin(\omega_2 t) \]

\[ \omega_1 = 2\pi \times 40\text{kHz} \]

\[ \omega_2 = 2\pi \times 50\text{kHz} \]

Amplified Signal = \( A_1 S \)
Non-Linearities

\[ S = \sin(\omega_1 t) + \sin(\omega_2 t) \]
\[ \omega_1 = 2\pi \times 40\text{kHz} \]
\[ \omega_2 = 2\pi \times 50\text{kHz} \]

Amplified Signal = \( A_1 S + A_2 S^2 + A_3 S^3 + \ldots \)
Non-Linearitys

\[ A_1S = A_1(\sin(\omega_1t) + \sin(\omega_2t)) \]

\[ \omega_1 = 2\pi \times 40\text{kHz} \]
\[ \omega_2 = 2\pi \times 50\text{kHz} \]
Non-Linearities

\[ A_1 S = A_1 (\sin(\omega_1 t) + \sin(\omega_2 t)) \]

\[ A_2 S^2 = 1 + \cos(\omega_1 t - \omega_2 t) - \frac{1}{2}\cos(2\omega_2 t) - \cos(\omega_1 t + \omega_2 t) - \frac{1}{2}\cos(2\omega_1 t) \]

\(\omega_1 = 2\pi \cdot 40\text{kHz}\)
\(\omega_2 = 2\pi \cdot 50\text{kHz}\)
Non-Linearities

Image: BackDoor - Roy et al.
Non-Linearitys

Image: BackDoor - Roy et al.
Results

![Graph showing throughput vs distance]

- Coding rate: 3/4
- Coding rate: 1/2

Image: BackDoor - Roy et al.
Jamming

- White Noise as ‘Data’
- Noise at [0,12]kHz at Eavesdropper
Dhwani:
Secure Peer-to-Peer
Acoustic NFC

Rajalakshmi Nandakumar, Krishna Kant Chintalapudi, Venkata N. Padmanabhan,
Ramarathnam Venkatesan
Microsoft Research India
NFC

- Slow Adoption
- Specialized Hardware
- Man-in-the-Middle Attacks
JamSecure

SNR = \( P_A - P_B + IC \) dB

SNR = \( P_A - P_B \) dB

Image: Dhwani - Nandakumar et al.
Information-Theoretic Security

- Shannon’s One-Time Pad Encryption
- Wyner’s Wiretap Model

Image: Dhwani - Nandakumar et al.
Results

![Graph showing packet success rate vs distance with four lines representing different conditions: No Jamming BPSK, No Jamming QPSK, Jamming BPSK, Jamming QPSK. The graph indicates a decrease in packet success rate as distance increases.]
Attacks

Prevents

• Man-in-the-Middle

• Placement Attacks

Affected by

• DOS

• Shielding
## Conclusions

<table>
<thead>
<tr>
<th>Description</th>
<th>Dolphin</th>
<th>Backdoor</th>
<th>Dhwani</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hide Data in Audible Range</td>
<td>Non-Linearities High Frequencies</td>
<td>Acoustic NFC</td>
<td></td>
</tr>
<tr>
<td>Receiver</td>
<td>Smartphone Microphone</td>
<td>Smartphone Microphone</td>
<td>Smartphone Microphone &amp; Speaker</td>
</tr>
<tr>
<td>Sender</td>
<td>Speaker</td>
<td>2 Ultrasound Speakers</td>
<td>Smartphone Microphone &amp; Speaker</td>
</tr>
<tr>
<td>Throughput</td>
<td>500bps (at 1m)</td>
<td>4kbps</td>
<td>2.4kbps</td>
</tr>
<tr>
<td>Range</td>
<td>up to 10m</td>
<td>1m</td>
<td>20cm</td>
</tr>
<tr>
<td>Operating Frequencies</td>
<td>8-20kHz</td>
<td>40 &amp; 50kHz</td>
<td>6-7kHz</td>
</tr>
<tr>
<td>Inaudible</td>
<td>Yes, but requires Sound</td>
<td>Yes</td>
<td>No (up to 1.5m)</td>
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</tbody>
</table>