Communication through Physical Vibration

Nirupam Roy

ECE598HH Guest Lecture
UIUC, October 4, 2016
Short range communication:
a new need of this decade
Short range communication: a new need of this decade
Emerging technologies for short range

Capacity

Driving forces of short range communication research
Emerging technologies for short range communication research

Driving forces of short range communication research:

- Convenience
- Availability
- Health
- Energy
- Capacity
- Security / Privacy
Emerging technologies for short range

Visible Light Communication

Acoustic NFC

bytelight

Zoosh
Physical vibration:
a new mode of communication
Vibration Motor

Accelerometer
Morse Code Key

Vibration Motor

On   On   On

Modulated vibration

Accelerometer
Applications: Mobile Money Transfer
Applications: Mobile Money Transfer
Applications: Authentication with Ring

Enter Passcode
Applications: Authentication with Ring

Vibratory Passcode Detected
Applications: Authentication with Ring
Applications: Body-Area Network
Or...may be you can come up with a better one
Morse-code  Single-Carrier  Multi-Carrier  Multi-dimension  Phy-Security

Single-Carrier  Multi-Carrier
Morse-code
Single-Carrier
Multi-Carrier
Multi-dimension
Phy-Security

0 30 60 90 120 ms

100 Hz
200 Hz
300 Hz
Morse-code  Single-Carrier  Multi-Carrier  Multi-dimension  Phy-Security

Filtering

Envelope Detection
Demo
Search for a better Ripple

| 0.2K | Ripple - I |
| 0.3K | Ultrasound  |
| 1.0K | Visible Light |
| 9.6K | Infrared |
|   | Ripple - II 32K |
|   | NFC 106K |

(bits-per-second, entry level versions)
Hardware front-end

Vibration recovery at the receiver

Transmitter side rate control
Hardware front-end

Vibration recovery at the receiver

Transmitter side rate control
A better sensor for physical vibration

The transmitter:

Driving voltage
A better sensor for physical vibration

The receiver:

Accelarometer

Vibration
A better sensor for physical vibration

The receiver:

- **Accelerometer**
  - Vibration

- **Microphone**
  - Vibration
  - + Sound
A better sensor for physical vibration

The receiver:

- **Accelerometer**: Vibration
- **Microphone**: Vibration + Sound

![Graph]

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1K</td>
<td></td>
</tr>
<tr>
<td>5K</td>
<td></td>
</tr>
<tr>
<td>10K</td>
<td></td>
</tr>
<tr>
<td>15K</td>
<td></td>
</tr>
</tbody>
</table>
A better sensor for physical vibration

The receiver:

- **Accelerometer**
  - Vibration

- **Microphone**
  - Vibration
  - Sound

**OFDM**

![Graph showing amplitude across frequency bands](image)

```
Amplitude
1K  5K  10K  15K
```
A better sensor for physical vibration

The receiver:

But wait…
A better sensor for physical vibration

The receiver:

Ambient sound

Microphone

Vibration + Sound

OFDM

Amplitude

Frequency

+ 1K 5K 10K 15K
Hardware front-end

Vibration recovery at the receiver

Transmitter side rate control
Vibration recovery at receiver
Vibration recovery at receiver

Vibration → V → Primary mic. → V+S → Receiver

Sound → S
Vibration recovery at receiver
Vibration recovery at receiver

Vibration -> Primary mic. -> V+S -> - -> V

Sound -> Secondary mic. -> S
Vibration recovery at receiver

Vibration

Primary mic.

Secondary mic.

Sound

Adaptive Filter
Vibration recovery at receiver

Vibration

Primary mic.

Sound

Secondary mic.

Adaptive Filter

V vibration recovery at receiver
Vibration recovery at receiver

Signal sources are correlated
Vibration recovery at receiver

Symbol Selective Adaptive Filtering

Signal sources are correlated
Vibration recovery at receiver

Noise is sparse in frequency
Vibration recovery at receiver

Noise is sparse in frequency

Static channel between the sensors

Ambient sound

Vibration frequency bins

Primary mic.

Secondary mic.
Vibration recovery at receiver

Static channel between the sensors

Relative estimate of the channel
Vibration recovery at receiver

Selected bins (primary mic.)

Selected bins (secondary mic.)

Adaptive Filter

Corrected bins
Hardware front-end

Vibration recovery at the receiver

Transmitter side rate control
MAC layer rate control

1. Transmitter side
   - Symbol 07
   - Symbol 06
   - Symbol 05
   - Symbol 04
   - Symbol 03
   - Symbol 02
   - Symbol 01

2. Receiver side
   - Packet 02
   - Packet 01

- Symbol: A signal sent from the transmitter to the receiver.
- Packet: A group of symbols sent from the transmitter to the receiver.

Transmitter side and Receiver side are connected through a series of symbols and packets.
MAC layer rate control

Transmitter side

Interference sensing

Receiver side

Symbols:
- Symbol 07
- Symbol 06
- Symbol 05
- Symbol 04
- Symbol 03
- Symbol 02
- Symbol 01

Packets:
- Packet 02
- Packet 01

ACK
MAC layer rate control

Transmitter side

Receiver side

Interference sensing
MAC layer rate control
MAC layer rate control
MAC layer rate control
MAC layer rate control
MAC layer rate control
MAC layer rate control

Low “Signal to Interference and Noise Ratio” (SINR)
MAC layer rate control

OFDM symbols

Corrupted symbols
MAC layer rate control

OFDM symbols

Corrupted symbols

Symbol retransmission
MAC layer rate control

What is the data-rate of the duplicate symbol?
How can the receiver detect a duplicate symbol?

OFDM symbols
Corrupted symbols
Symbol retransmission
MAC layer rate control

Half of the symbol per retransmission

Symbol 01

Symb 01

Doubles the energy per bit
MAC layer rate control

Half of the symbol per retransmission

Data in alternate frequency bins

Doubles per bit energy
MAC layer rate control

Half of the symbol per retransmission

Data in alternate frequency bins

Identical halves in the time domain signal

Doubles per bit energy
MAC layer rate control

Half of the symbol per retransmission

Data in alternate frequency bins

Identical halves in the time domain signal

Algorithm detects this special symbol at the receiver

Doubles per bit energy

Schmidl-Cox sync. algo.
Demo

Receiver Side

Transmitter Side
Applications

Vibrations do not **tether**

Vibrations do not **broadcast**

Vibratory communication