Ripple II

Roy and Choudhury, USENIX NSDI ‘16

Design

- Vibra-motor: *Linear Resonant Actuator* (LRA) driven by a waveform generator.
  - Input signal to the LRA: OFDM(!)

2.2 Microphone as vibration receiver

- Mic: Sound pushes diaphragm, diaphragm vibrates, produces electrical signal, amplified.
  - Bigger frequency range
- Ripple II: Notice mic is sensitive to **contact** vibrations
- Problem: Interference from **air vibrations**

Interference Cancellation (Sect. 3.1)

- Cover sound hole: Figure 5: SINR was -10 dB (@ 10 KHz), increases to +25 dB (@ 10 KHz). Generally better at higher frequencies.
- V (contact vibration), S (interference sound), E (electric noise)
  - E comes from common electric supply voltage of mics.
  - Goal: Interference Cancellation (subtract S)
  - System model shown in Figure 6
  - Possible weakness: Physical interfering vibration (i.e. riding in a Jeep off-road, would it work?)

Failed Attempts (Sect. 3.1)

- E has a spatial signature across mics, MIMO! But, can’t estimate spatial signature for interference sound.

Symbol Selective Adaptive Noise Filtering

- See slides: https://www.usenix.org/sites/default/files/conference/protected-files/nsdi16*slides*roy.pdf
- Slide 24: Sound interference affects only certain subcarriers
- V*1, S*1, S_2 not defined
- Personal comm. w/authors:
    - V1 = V(t)H_{V1}, S1 = S(t)H_{S1}, and so on.
    - As vibration from the primary microphone leaks to the secondary microphone, they model the secondary microphone's signal as a filtered version of the primary.
    - If not affected by ambient sound, this channel gain is entirely the function of the solid medium (e.g. the circuit board where these microphones are mounted) and hence it is static.
    - Primary and secondary symbols are from Mic1 and Mic2 respectively.

- Avoid lower frequency band interference by starting above 500 Hz

OFDM (Sect. 3.2)

- Characterize the channel in Figure 9
    - Multipath components weak, and from motor mass
    - 10 dB max excess delay of 400 us, conservative CP of 1 ms
    - Coherence B/W 480 Hz, subcarrier chosen 40 Hz (conservative)

MAC Layer (Sect. 4)

- **Cool idea:** Back EMF lets transmitter sense receiver interference like the Ethernet

    - Interference sound induces a tiny current
    - Measure that induced current to motor by voltage drop across series resistor
    - Results in Figure 11 are pretty convincing

- But why 7 KHz interference and a 3 KHz transmission? What mechanism would separate those in the real world?

Proactive Symbol Recovery (4.3, 4.4)

- Transmitter has better estimate of errored symbols than receiver (see Figure 14).
- Idea: Transmitter sends on every other OFDM subcarrier, more power.
    - Better SNR, half rate, essentially a bit rate adaptation
    - Estimates start and end (Fig 14) of interference by Back-EMF sensing.

- Convolutional coding atop everything adds fall-back layer

Performance Evaluation (S. 5)

- Fig. 17(a) CDF across all noise environments
  - PSR retrasnmits erroneous symbols and improves throughput
  - Recall is weak, so it misses many symbols that should have been retransmitted
    - Expected/desirable? b/c of coding?

Applications

- Finger Ring
- Tabletop comms
- P2P money transfer