Braidio: An Integrated Active-Passive Radio for Mobile Devices with Asymmetric Energy Budgets

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Variability in battery capacity

Three orders of magnitude variation in battery capacity
Asymmetric battery lifetime

Devices with smaller batteries deplete far ahead of those with larger batteries.
Symmetric power consumption

Bluetooth

<table>
<thead>
<tr>
<th>Mode</th>
<th>TX</th>
<th>RX</th>
<th>TX/RX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>55~60mW</td>
<td>59~67mW</td>
<td>0.82~1.0</td>
</tr>
</tbody>
</table>

BLE

<table>
<thead>
<tr>
<th>Mode</th>
<th>TX</th>
<th>RX</th>
<th>TX/RX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>21~30mW</td>
<td>19mW</td>
<td>1.1~1.6</td>
</tr>
</tbody>
</table>
Can we design a power proportional radio?

Can we create a radio which consumes power proportional to battery size?
Diversity of radio architectures

Active: Symmetric Radio

WiFi/ Bluetooth

Backscatter: Low power transmitter

RFID Tag

Passive: Low power receiver

AM receiver
Diversity of radio architectures

**Active:**
Symmetric Radio

**Backscatter:**
Low power transmitter

**Passive:**
Low power receiver

- WiFi/Bluetooth
- RFID Tag
- AM receiver
Symmetric active radio architecture

Active TX

Active RX

Baseband

Mixer

Antenna

Amplifier

2.4GHz Carrier

Baseband

Mixer

Antenna

Amplifier

2.4GHz Carrier

Similar power consumption at TX and RX
Diversity of radio architectures

Active: Symmetric Radio

Backscatter: Low power transmitter

Passive: Low power receiver

WiFi/Bluetooth

RFID Tag

AM receiver
Backscatter reader architecture

Backscatter transmitter

Antenna

Baseband
Backscatter reader architecture

Backscatter reader

- Baseband
- Mixer
- Amplifier
- 2.4GHz Carrier
- Antenna 1
- Antenna 2

Backscatter transmitter

- Antenna
- Baseband

Much less power at TX but reduced range
Diversity of radio architectures

- **Active:** Symmetric Radio
  - WiFi/Bluetooth

- **Backscatter:** Low power transmitter
  - RFID Tag

- **Passive:** Low power receiver
  - AM receiver
Passive receiver architecture

Active TX

Passive RX

Much less power at RX but reduced range
Power consumption of radios

<table>
<thead>
<tr>
<th>Radio type</th>
<th>TX</th>
<th>RX</th>
<th>TX/RX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td>20mW</td>
<td>20mW</td>
<td>1</td>
</tr>
<tr>
<td>Backscatter</td>
<td>20mW</td>
<td>0.02mW</td>
<td>1000:1</td>
</tr>
<tr>
<td>Passive</td>
<td>0.02mW</td>
<td>20mW</td>
<td>1:1000</td>
</tr>
</tbody>
</table>
Architecture of radios

Achievable region

- TX/RX = 1:1000
- TX/RX = 1:1
- TX/RX = 1000:1

Any ratio in between 1:1000 to 1000:1

Available radio

Radio type  TX/RX
Active  1

RX power

TX Power
Challenges in combining three modes

Backscatter RX consumes excessive power

Different types of radios have different working ranges
Why is a Backscatter reader power hungry?

Self-interference cancellation

Active IQ Receiver

2.4GHz Carrier

Baseband

Mixer

Est. of interference

Antenna 1

Amplifier

Leakage

Antenna 2

2.4GHz Carrier

Baseband

Mixer

Est. of interference

Antenna 1

Amplifier

Leakage

Antenna 2

In-phase

Quadrature

0

1

Active IQ Receiver

Self-interference cancellation
Reducing power of Backscatter reader

Passive receiver with SAW filter

Antenna diversity
Bradio Backscatter RX: Design Tradeoffs

- Passive receiver with SAW filter
  - Reduced sensitivity
  - Reduced robustness
  - Reduced range

- Antenna diversity
Active radio as a safety net

What if the Braidio backscatter mode fails?
Challenge #2: different working ranges

- **Regime A**: Backscatter link
- **Regime B**: Passive link
- **Regime C**: Active link

Distance vs TX Power graph showing
- RX power vs TX Power
Challenge #2: different working ranges

Braidio multiplexes across modes based on SNR of each link and battery levels to achieve desired power ratio.
Implementation of Braidio

Top Layer

- Receive Ant + SAW filter
- Ant. Switch
- Amp + Comparator
- Passive Receiver
- Carrier Emitter
- TX Ant

Bottom Layer

- Active Radio
- UFL Connector + RF Cable
- Micro-controller

Dimensions:
- 47mm/1.85in
Braidio: Achievable power ratios

![Graph showing achievable power ratios]

A: Active
B: Passive @ 1M
C: Backscatter @ 1M

- 1:2546
- 0.9524:1
- 3546:1
Braidio: Operating distance
Braidio: Performance gain over active radio

300x improvement when fitness band transmits to laptop
Conclusion

Braidio: A novel power-proportional radio that can deal with asymmetric energy budgets on mobile devices.

Thank you
Braidio: A novel power-proportional radio that can deal with asymmetric energy budgets on mobile devices.

Thank you
Performance gain (TX/RX) vs Distance/m

- iPhone 6s to Apple Watch
- Apple Watch to iPhone 6s
- SurfaceBook to Nexus 6P
- Nexus 6P to SurfaceBook
- iPhone 6s to Fuel Band
- Fuel Band to iPhone 6s