Charm: Exploiting Geographical Diversity Through Coherent Combining in LPWANs
OR
When They Go Low, We Go Lower (Power)

*IPSN 2018, Porto*

**Adwait Dongare**, Revathy Narayanan, Akshay Gadre, Anh Luong, Artur Balanuta, Swarun Kumar, Bob Iannucci, Anthony Rowe

Electrical And Computer Engineering
Carnegie Mellon University, Pittsburgh PA and Silicon Valley CA
Low-Power Wide-Area Networking (LPWAN)
LPWAN’s potential

- Sub-GHz ISM band
- chirp spread-spectrum (CSS)
- 10km range in line-of-sight
- Low data rate (0.25 kbps – 27 kbps)
- 5+ year battery life
- Thousands of devices per gateway
OpenChirp In Pittsburgh

- **openchirp.io**
  CMU’s LoRaWAN network in Pittsburgh

- 4 outdoor gateways + multiple indoor gateways
Coverage
Penetration Inside Buildings

Bi-directional packet success rate

Gateway RSSI for successful packets:

-150 dBm
-105 dBm
-60 dBm
Client Device Battery Life

- Wireless transmissions dominate energy usage
- Increasing data rate and reducing retransmissions significantly improves battery life
LPWANs have lots of gateways.....

Can we use them to improve network performance?
Coherent Combining

• Multiple gateways hear the same weak transmission
• Coherent combining in the cloud
• e.g. Cloud Radio Access Networks (C-RAN) in cellular communication
Challenges

• High bandwidth connectivity to the cloud

• Nanosecond-scale synchronization

• Expensive computing resources for large number of streams

• Latency
Charm

- **Practical coherent combining**
  Leverage diversity from multiple gateway receivers

- **Software architecture**
  - Scaleable two-phase protocol
  - Local packet detection

- **Hardware platform**
  Auxiliary low-cost SDR-like platform for gateways
LoRaWAN
Charm: Two-Phase Protocol
Charm: Local Packet Detection

Uses only the preamble and sync header
Charm: Enhanced Packet Detection

- Uses the entire packet

Diagram:
- Chirp spread-spectrum packet
- Subsample (folding)
- Matched filtering
- Known signal pattern
- Threshold
Charm: Gateway Hardware

- Semtech SX1257 frontend with MicroSemi IGLOO FPGA

- Outputs radio I/Q stream like an SDR

- Auxiliary hardware for existing gateways and interfaces with raspberry Pi
Practical Coherent Combining With Charm

- High bandwidth connectivity to the cloud
  - upload samples on request

- Nanosecond-scale synchronization
  - local packet detection simplifies synchronization

- Expensive computing resources for large number of streams
  - selective combination of sample streams

- Latency
  - LoRaWAN ~1 sec to ACK
Benchmark: Packet Detection

![Bar chart showing signal-to-noise ratio vs spreading factor for different detection methods.]

- Charm enhanced detection
- Charm local detection
- LoRaWAN

Signal-to-noise ratio (dB)

Spreading factor

-70 -60 -50 -40 -30 -20 -10 0
Benchmark: Improved Network And Device Performance

Combined signal SNR increases logarithmically

Results into improved battery life on client devices
Simulation: Dense Deployment

LoRaWAN

Charm

Improvements

Increase in coverage area: 46.60%

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>Battery Life</th>
<th>Improved region (by area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x</td>
<td>2x</td>
<td>35.33%</td>
</tr>
<tr>
<td>4x</td>
<td>4x</td>
<td>22.30%</td>
</tr>
<tr>
<td>8x</td>
<td>8x</td>
<td>2.26%</td>
</tr>
</tbody>
</table>
Simulation: Random Deployment

Improvements

Increase in coverage area: 74.59%

<table>
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<th>Data Rate</th>
<th>Battery Life</th>
<th>Improved region (by area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x</td>
<td>2x</td>
<td>33.70%</td>
</tr>
<tr>
<td>4x</td>
<td>4x</td>
<td>25.82%</td>
</tr>
<tr>
<td>8x</td>
<td>8x</td>
<td>3.48%</td>
</tr>
</tbody>
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Future Work

• **Collisions:** can we decode collisions?

• **Scalability:** can we avoid continuously streaming to the cloud?

• **Hardware Architecture:** how can we leverage new radio front-ends

Analog Devices ADALM-Pluto
Conclusions

- Decode weak transmissions through coherent combining
  - Charm’s two-phase protocol
  - On-demand upload - save bandwidth
  - Local packet detection - simplify synchronization requirements and computation
  - Selective combination - better scalability
- SDR-like auxiliary hardware to capture I/Q streams
- Performance
  - Improve coverage up to 98%
  - Improve battery life up to 8x
  - Effectively reduce coverage holes
  - No changes on low-power devices
Thank you!

Q&A

Adwait Dongare (adongare@cmu.edu)