An academic perspective on LoRaWAN

Fernando Kuipers
Feb. 2\textsuperscript{nd}, 2018
https://fernandokuipers.nl
Objective

• Highlights from the scientific literature
  – Performance
  – Collisions
  – Simulators
  – Improvements

• No details, but pointers
Performance
Spin the wheel!

- Doppler effect
  - Frequency shift
  - Possible effect for SF12 at 38 km/h (doubles when SF is lowered)

- Corroborated by angular (rotating disk) and linear (car/boat) velocity experiments
  - Coverage up to 30 km at sea

From the city to the mountains…

• Vegetation matters
  – 50-90m coverage in the forest

• Temperature matters
  – High temperature has detrimental impact

• Antenna matters

Source: [2].

Measurements at TU Delft, performed by my students Lichen Yao, Lu Liu, Xin Liu, and Minfeng Li.

LoRaWAN in the wild

- **Generic devices**
  - Use default keys
  - Do not need to registered device id or associated application
  - Sent packets that are typically not encrypted

- **Dec. 2015 – July 2016, all TTN data from nodes using generic key 2B7E151628AED2A6ABF7158809CF4F3C**
  - Received frames 17,467,312
  - Unique frames 16,228,814
  - Unique device ids 1,618
  - Gateways 691

Results from the wild [4]

1618 device id’s

Spreading Factor

Frequency usage EU
Coffee time? [4]

<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>comma separated decimals</td>
<td>ca. 5.54 million</td>
</tr>
<tr>
<td>temperature readings</td>
<td>ca. 1.3 million</td>
</tr>
<tr>
<td>various other strings</td>
<td>ca. 1 million</td>
</tr>
<tr>
<td>string: foo...</td>
<td>974,634</td>
</tr>
<tr>
<td>string: hello</td>
<td>733,724</td>
</tr>
<tr>
<td>humidity measurements:</td>
<td>666,609</td>
</tr>
<tr>
<td>GPS locations</td>
<td>320,391</td>
</tr>
<tr>
<td>battery level</td>
<td>140,450</td>
</tr>
<tr>
<td>light sensor (brightness)</td>
<td>ca. 45,000</td>
</tr>
<tr>
<td>string: test</td>
<td>42,336</td>
</tr>
<tr>
<td>distance measures:</td>
<td>ca. 2,500</td>
</tr>
<tr>
<td>string: coffee</td>
<td>172</td>
</tr>
</tbody>
</table>

10,104,330 readable strings
Collisions
Capture effect

- Depending on power & timing, one of multiple concurrent signals is received

Our additional experiments*

<table>
<thead>
<tr>
<th>Objective</th>
<th>Scenario</th>
<th>Evaluation Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame collision characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single gateway</td>
<td>Equal received power</td>
<td>Line-of-sight (LOS)</td>
</tr>
<tr>
<td></td>
<td>Different transmission powers</td>
<td>Non-line-of-sight (NLOS)</td>
</tr>
<tr>
<td>Multiple gateways</td>
<td>Same Network</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Different Networks</td>
<td></td>
</tr>
</tbody>
</table>

* Experiments performed by my MSc student Andri Rahmadhani.
Frame loss conditions

- Both frames get destroyed (preamble lock)

- Weaker frame gets destroyed, stronger frame survives (LoRa header of the weaker frame gets destroyed, receiver immediately starts reading new frame)

- Both frames get destroyed (LoRa header of the weaker frame OK, keeps lock)

- Both frames get destroyed (MIC/Payload CRC error)
Simulators
Simulating growth

  - Log-distance path loss model
  - Parameters from small-scale experiments
  - Capture effect & collision conditions
  - LoRaSim extended with LoRaWAN
  - Up- and downlink traffic

- All conclude that scalability is an issue!
Improvements
ACKs and retransmissions are costly.

Encoding is more efficient.

Application-layer coding

Chirp Spread Spectrum (CSS)

- One chirp = 1 symbol = SF bits
- One chirp covers entire BW
- Frequency offset (+ wrap-around) determines symbol

Disentangling collisions

Hardware imperfections cause frequency offsets.

The offset allows to separate the chirps.

Source: [10].

Range extension [10]

• Correlate sensor data

LoRa backscatter

- 9.25 $\mu$W (1000x lower than LoRa chipsets)
- Up to 2.8 km away
- Multiple backscatter devices on 1 tone

Source: [11].

(My) Research continues!

More pointers will be placed at:
www.thethingsnetwork.org/wiki/External/Research