Low Power Wide Area Networks for the Internet of Things

Framework, Performance Evaluation, and Challenges of LoRaWAN and NB-IoT

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Tutorial Outcomes

- How do LPWAN complement traditional cellular and short-range wireless technologies?
- What are the fundamental mechanisms that enable to meet the LPWAN requirements?
- What are the major design choices made in the LoRaWAN and NB-IoT specifications?
- How do we evaluate the performance of a LoRaWAN and NB-IoT deployment in terms of coverage and capacity?
- What are the recent research directions for radio resource management in LoRaWAN and NB-IoT?

Feedback and Material

- Feedback form
- Presentation slides are available

Outline

Link Budget

Enhanced Network Capacity

- LoRa employs orthogonal spreading factors which enables multiple spread signals to be transmitted at the same time and on the same channel
- Modulated signals at different spreading factors appear as noise to the target receiver
- The equivalent capacity of a single 125 kHz LoRa channel is:

$$SF12 + SF11 + SF10 + SF9 + SF8 + SF7 + SF6$$

$$= 293 + 537 + 976 + 1757 + 3125 + 5468 + 9375$$

$$= 21531 \text{ b/s} = 21.321 \text{ kb/s}$$

Link Budget

- The link budget is a measure of all the gains and losses from the transmitter, through the propagation channel, to the target receiver
- The link budget of a network wireless link can be expressed as:

$$P_{Rx} = P_{Tx} + G_{System} - L_{System} - L_{Channel} - M$$

where:

P_{Rx} = the expected received power

P_{Tx} = the transmitted power

G_{System} = system gains such as antenna gains

L_{System} = system losses such as feed-line losses

$L_{Channel}$ = losses due to the propagation channel

M = fading margin and protection margin

Coverage of LoRaWAN

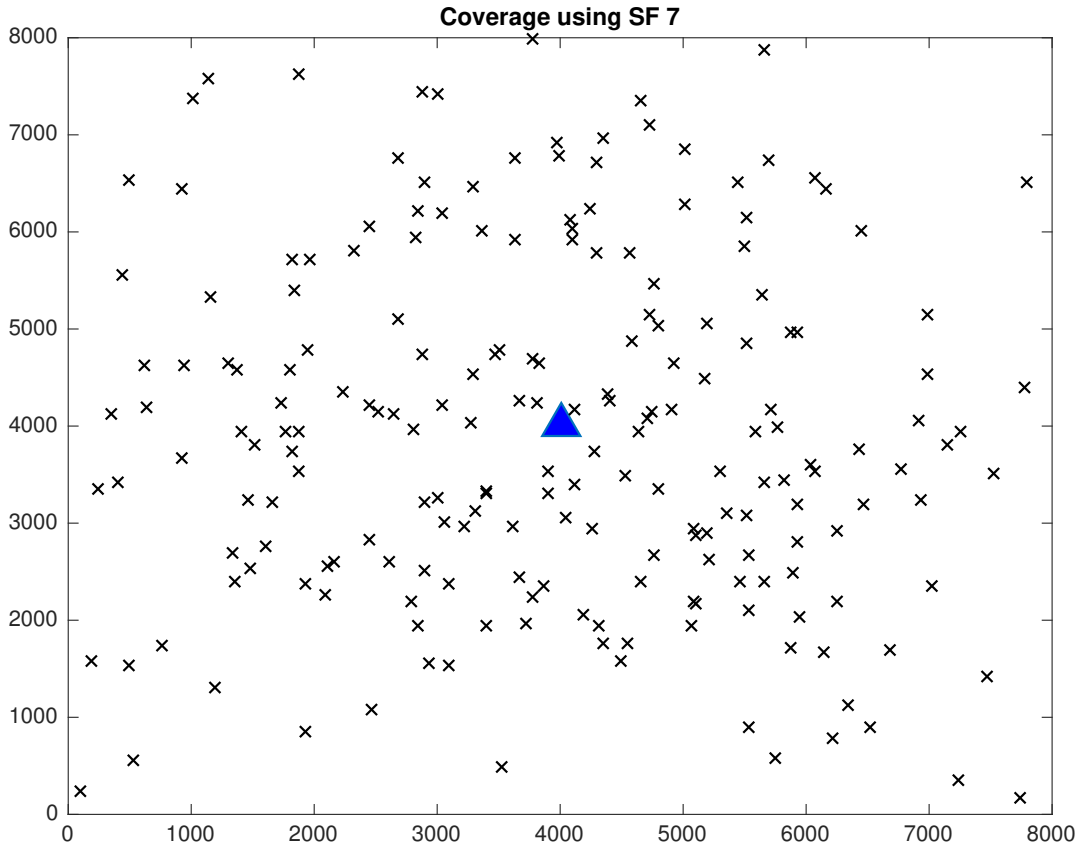
Scenario of Study

- Geographic area
  - Square area of 16.000 sqm
  - 1000 end-devices uniformly distributed
- Link budget
  - Transmit power: 14 dBm
  - Okumura-Hata pathloss in urban area
  - Shadow fading: $\mathcal{N}(0, 8dB)$
  - Gateway height: 30 m
  - End-device height: 1.5 m
  - Bandwidth: 125 kHz
  - Antenna gains: 3 dBi

SNR-SF Mapping

```
if SNR_margin(i) <= -20 node_SF(i) = 0; elseif SNR_margin(i) <= -17.5 node_SF(i) = 12;
elseif SNR_margin(i) <= -15 node_SF(i) = 11; elseif SNR_margin(i) <= -12.5 node_SF(i)
= 10; elseif SNR_margin(i) <= -10 node_SF(i) = 9; elseif SNR_margin(i) <= -7.5
node_SF(i) = 8; elseif SNR_margin(i) <= +Inf node_SF(i) = 7; end
```

Coverage Study



Spreading Factor	7	8	9	10	11	12
Cumulative coverage (%)	40.50	51.60	61.60	70.40	77.70	86.10

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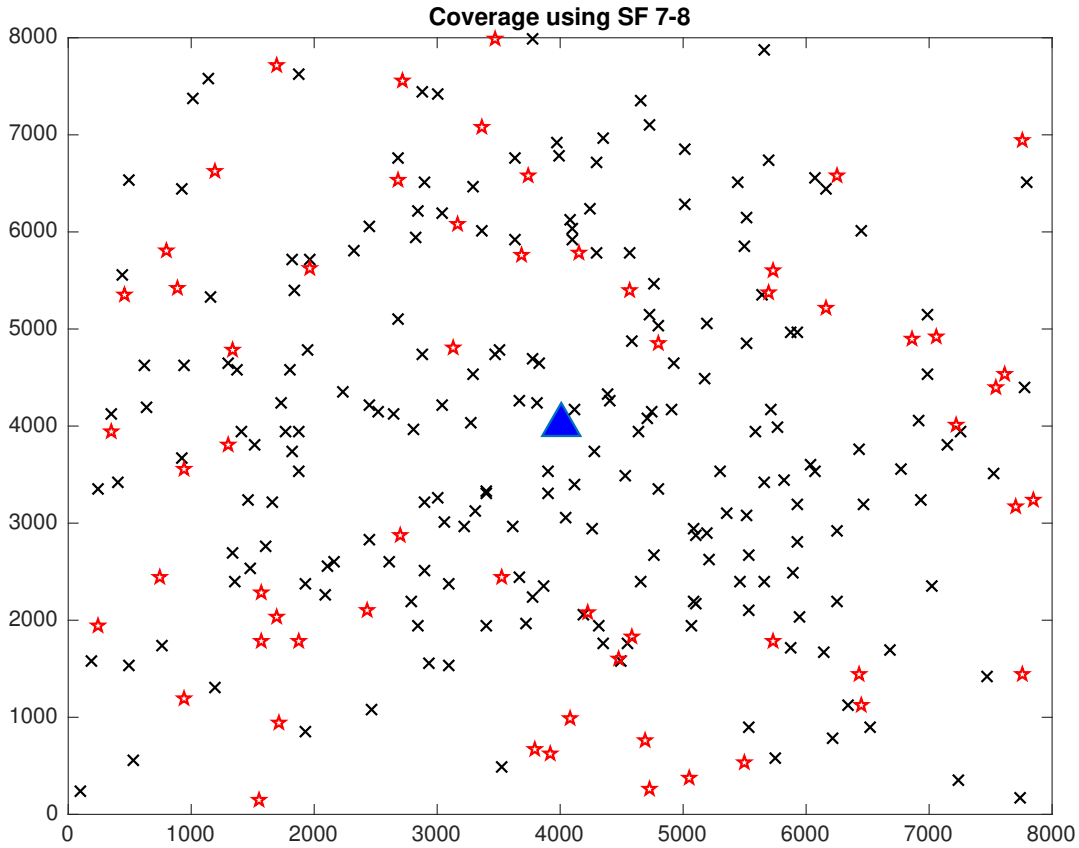

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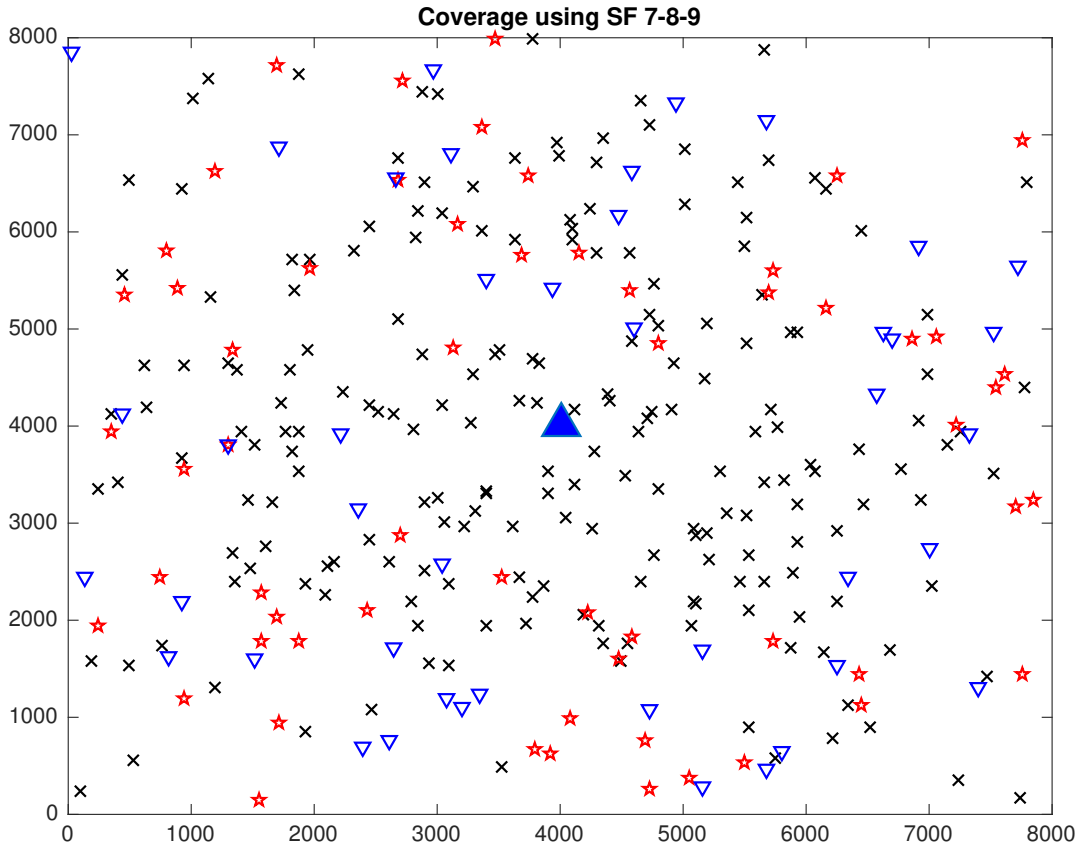

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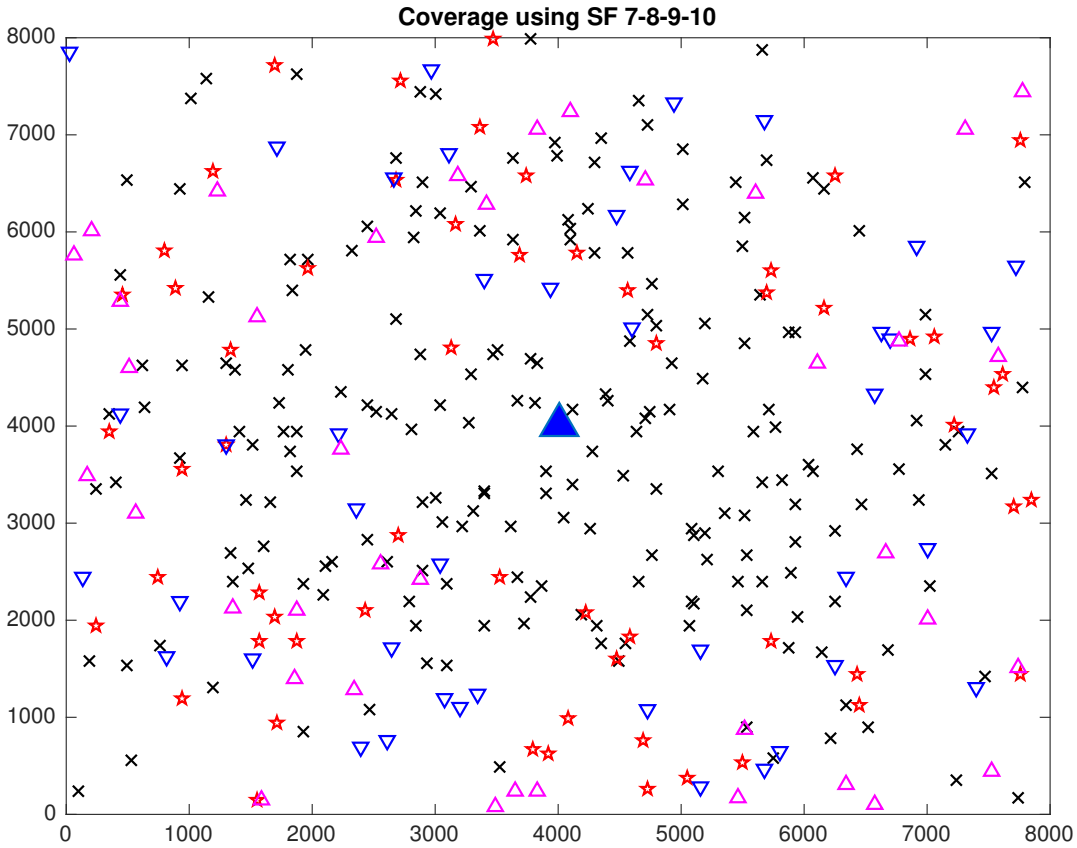

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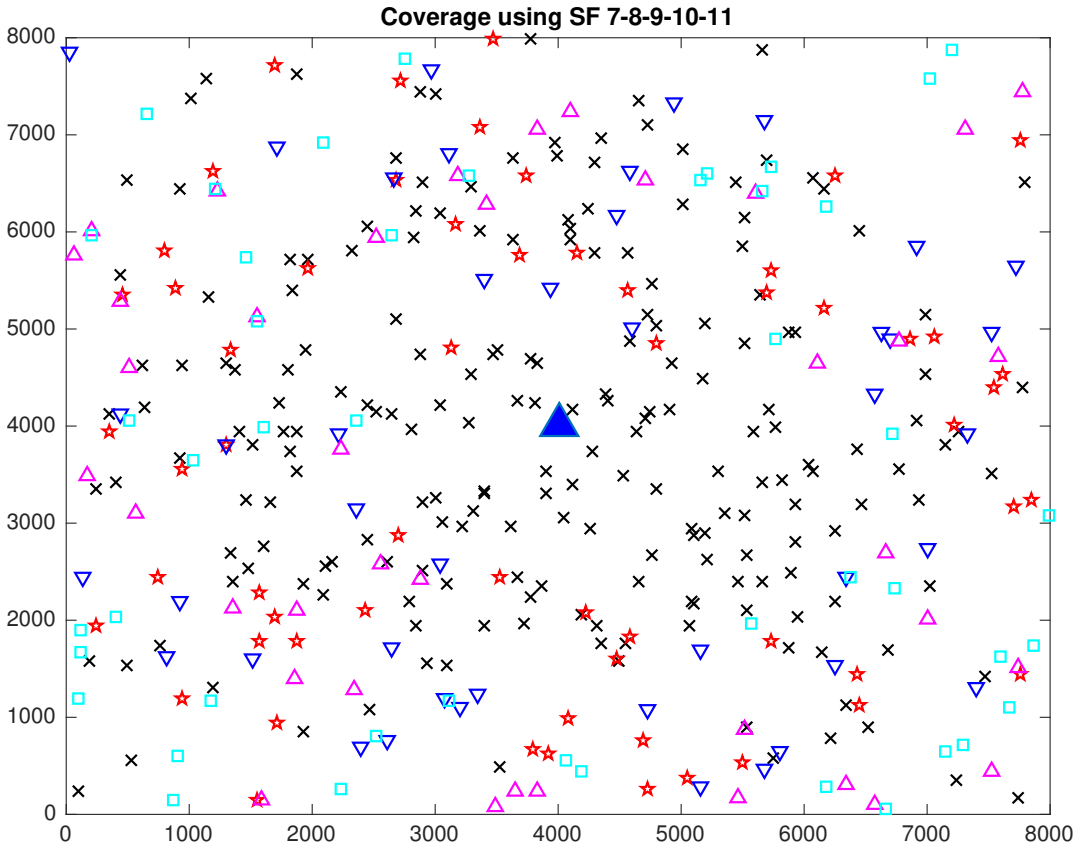

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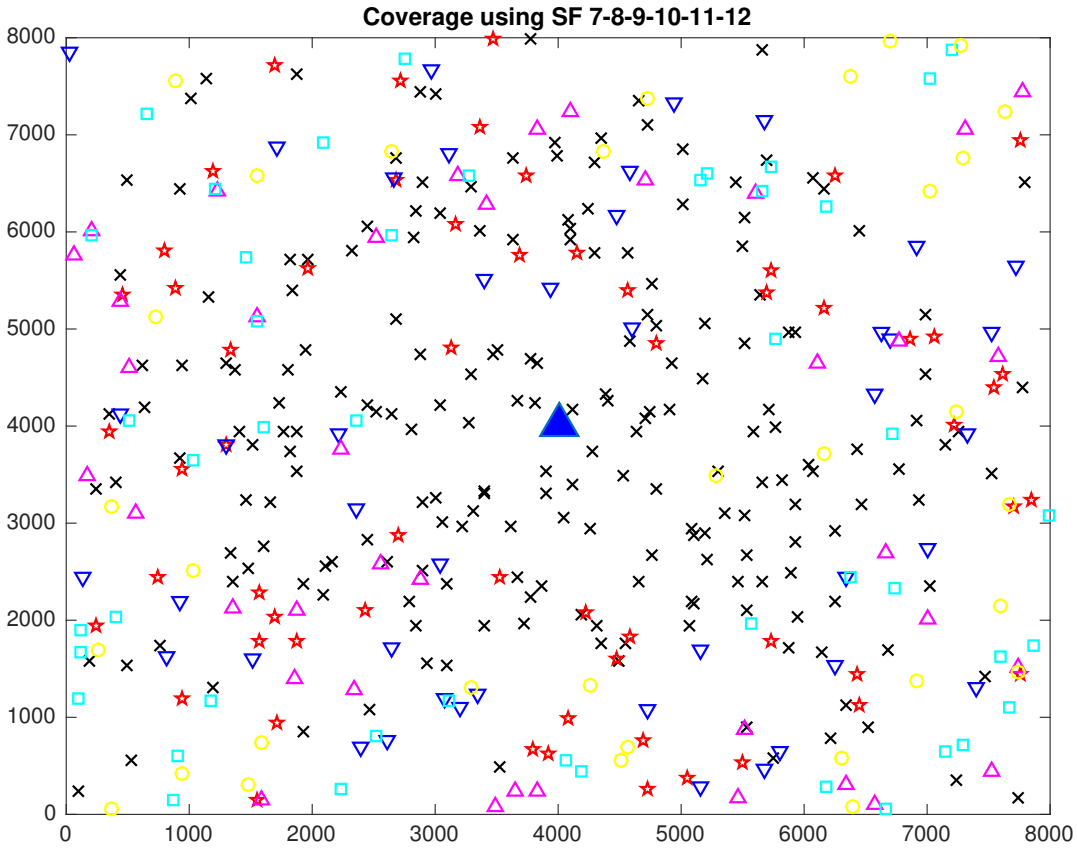

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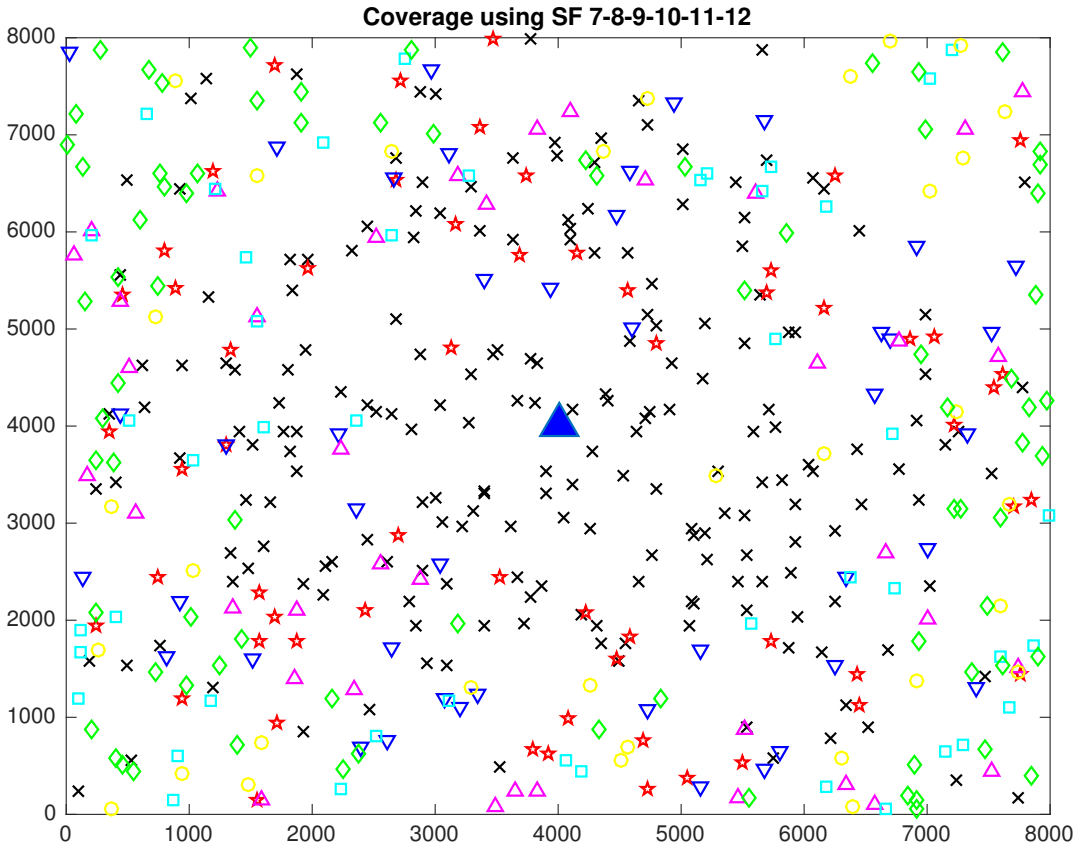

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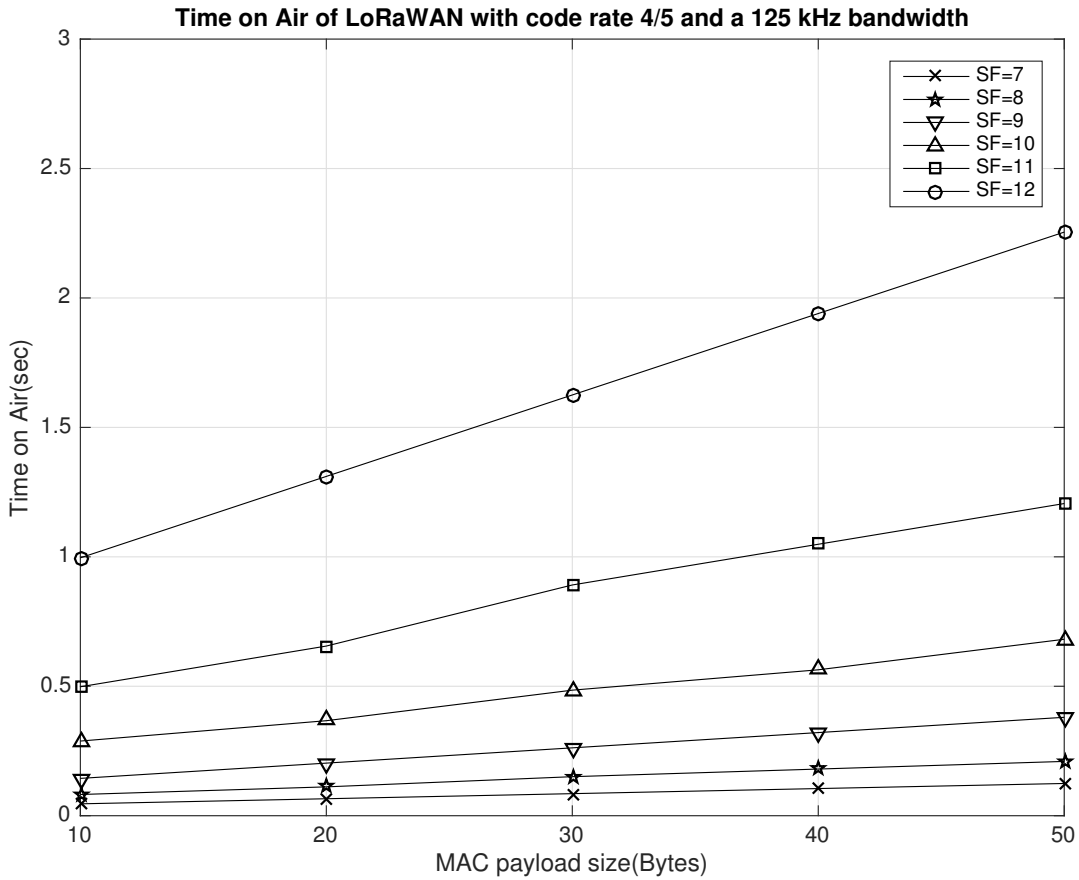
Spreading Factor and Time on Air



Energy

Multiple Gateways

Capacity of LoRaWAN

ALOHA Model

- ALOHA with duty cycle

$$\frac{\delta}{\tau} N \exp\left(-2N\frac{\delta}{\tau}\right)$$

- ALOHA with multiple receivers and perfect packet capture

$$\frac{\delta}{\tau} N \exp\left(-2N\frac{\delta}{\tau}\right)\left(1+\sum_{n=2}^{N}\frac{\left(2N\frac{\delta}{\tau}\right)^n}{n!}\left(1-\left(1-\frac{1}{n}\right)^r\right)\right)$$

- ALOHA with multiple receivers and realistic packet capture

$$\frac{\delta}{\tau} N \exp\left(-2N\frac{\delta}{\tau}\right)\left(1+\sum_{n=2}^{N}\frac{\left(2N\frac{\delta}{\tau}\right)^n}{n!}\left(1-\left(1-\frac{K^{n-1}}{n}\right)^r\right)\right)$$

with

$$K = \frac{1}{2}10^{-\frac{\Delta}{10\alpha}}$$