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

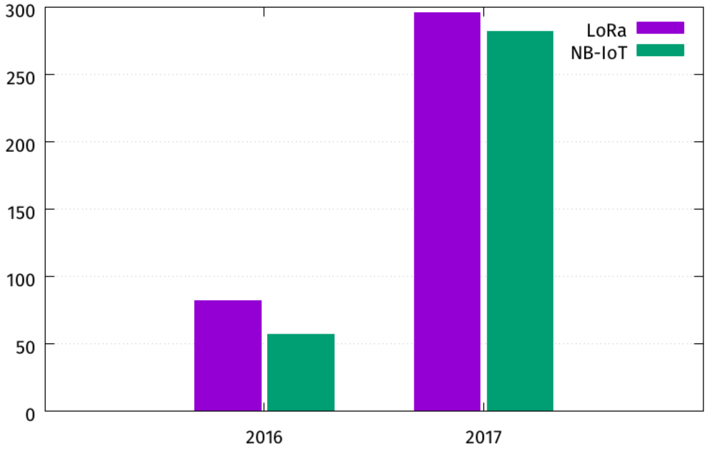
- How do LPWAN complement traditional cellular and short-range wireless technologies?
- What are the fundamental mechanisms that enable to meet the LPWAN requirements?
- What are the major design choices made in the LoRaWAN and NB-IoT specifications?
- How do we evaluate the performance of a LoRaWAN 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

Interest of the Scientific Community



LoRa and NB-IoT in titles of scientific publications. Source: Google scholar, 2018

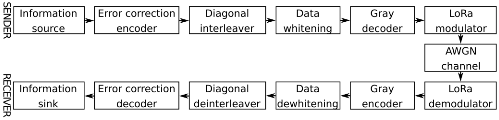
Analyzing the Limits of LoRaWAN

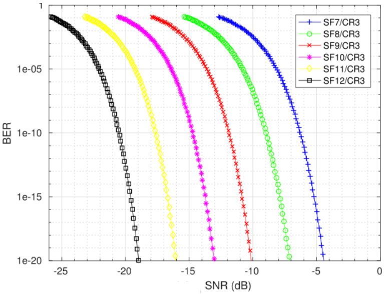
Research Approaches for Analyzing LoRaWAN

- The research studies analyze the performance of LoRaWAN networks considering different criteria:
  - Capacity
  - Coverage
  - Energy
  - Delay
  - Fairness
- The research studies use different methods to obtain the performance results:
  - Simulation
  - Mathematical modeling
  - Measurement campaigns

Simulation of the LoRa Bit Error Rate[1]

- Implementation of the LoRa physical layer in ns-3
- Simulation of the Bit Error Rate (BER): $\log_{10}(BER(SNR)) = \alpha \exp(\beta SNR)$

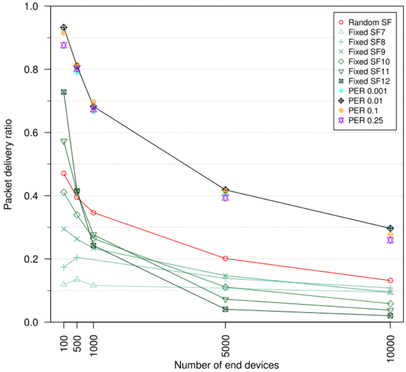




[1] Van den Abeele, Floris, et al. "Scalability analysis of large-scale LoRaWAN networks in ns-3." IEEE Internet of Things Journal 4.6 (2017)

Basic Assignment of Spreading Factors[2]

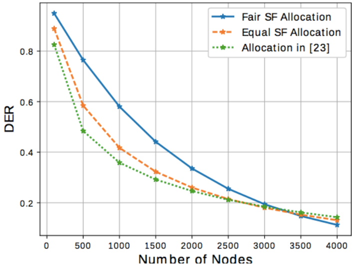
- Assigning spreading factors based on a packet error ratio threshold gives the highest Packet Delivery Ratio (PDR)
- However, this basic assignment leads to unfairness between end-devices using different spreading factors

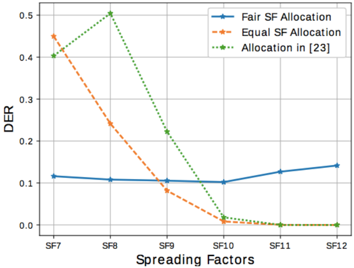


[2] Van den Abeele, Floris, et al. "Scalability analysis of large-scale LoRaWAN networks in ns-3." IEEE Internet of Things Journal 4.6 (2017)

Fair Assignment of Spreading Factors[3]

- Fairness is achieved by minimizing the maximum collision on spreading factors: $\min_s \max p_{coll,s}$
  - The minimum is reached for a fraction p_s of end-devices using spreading factor s given by $p_s = \frac{s}{2^s} / \sum_{i=7}^{12} \frac{i}{2i}$
- Fairness does not hinder the data extraction rate DER (the ratio of received packets to transmitted packets over a period of time)





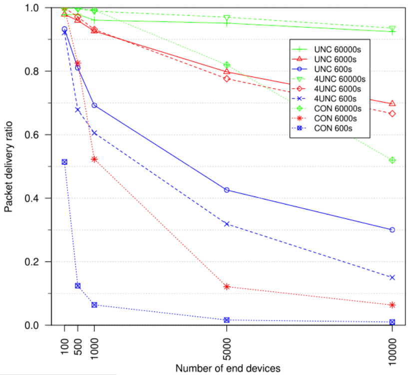
[3] Reynders, Brecht, Wannes Meert, and Sofie Pollin. "Power and spreading factor control in low power wide area networks." 2017 IEEE International Conference on Communications (ICC). IEEE, (2017)

Joint Assignment of Transmit Power and Spreading Factors[4]

[4] Abdelfadeel, Khaled Q., Victor Cionca, and Dirk Pesch. "Fair Adaptive Data Rate Allocation and Power Control in LoRaWAN." IEEE 19th International Symposium on A World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2018.

Impact of Confirmed Messages[5]

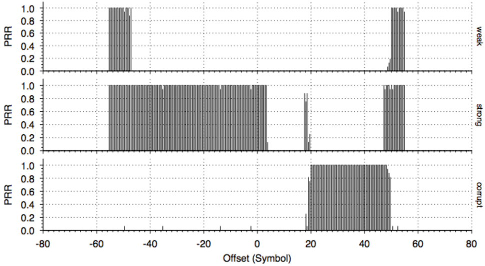
- Repeating the messages or using confirmed mode increases the PDR only when the traffic load is very low
- For high traffic load, the PDR of confirmed mode is limited by the duty cycle and half-duplex transmission



[5] Van den Abeele, Floris, et al. "Scalability analysis of large-scale LoRaWAN networks in ns-3." IEEE Internet of Things Journal 4.6 (2017)

Measurement of the Capture Effect[6]

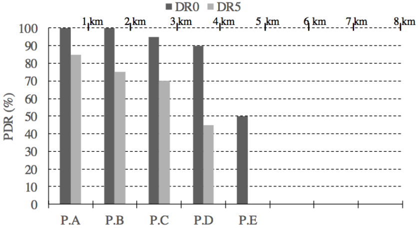
- Experimentation (55.25 symbols packet length) shows the packet reception rate as function of transmission offset relative to the weak node in symbols
- A strong transmission can be successfully decoded when it arrives one packet time early up to at most 3 symbols late
- Capture model integrated in a discrete-event simulator (LoRaSim)

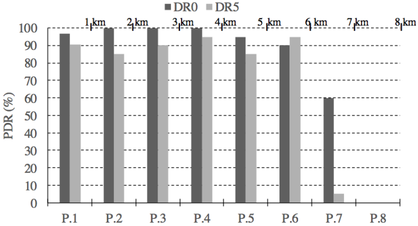


[6] Bor, Martin C., et al. "Do LoRa low-power wide-area networks scale?." Proceedings of the 19th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems. ACM, 2016.

Experimental Study of Coverage[7]

- PDR in a nomadic test for urban (top) and suburban (bottom) scenarios near Murcia





[7] Sanchez-Iborra, Ramon, et al. "Performance Evaluation of LoRa Considering Scenario Conditions." Sensors 18.3 (2018)

Energy

- Modeling the Energy Performance of LoRaWAN

Going Beyond LoRaWAN

Research Approaches for Improving LoRaWAN

- physical Layer
- mac Layer : scheduling or learning