Scalable and Energy Efficient LoRa Networks

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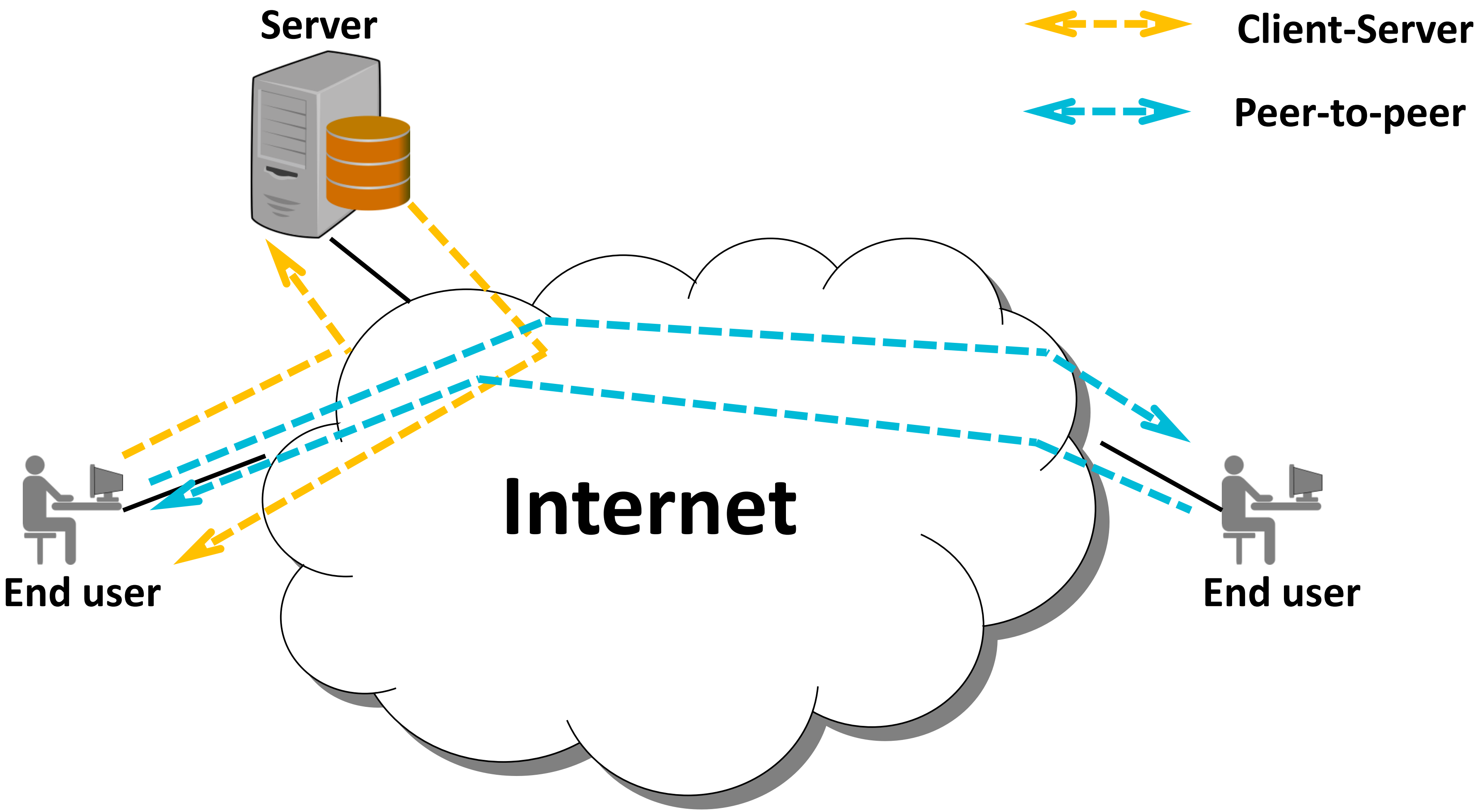
11/7/2019

Outline

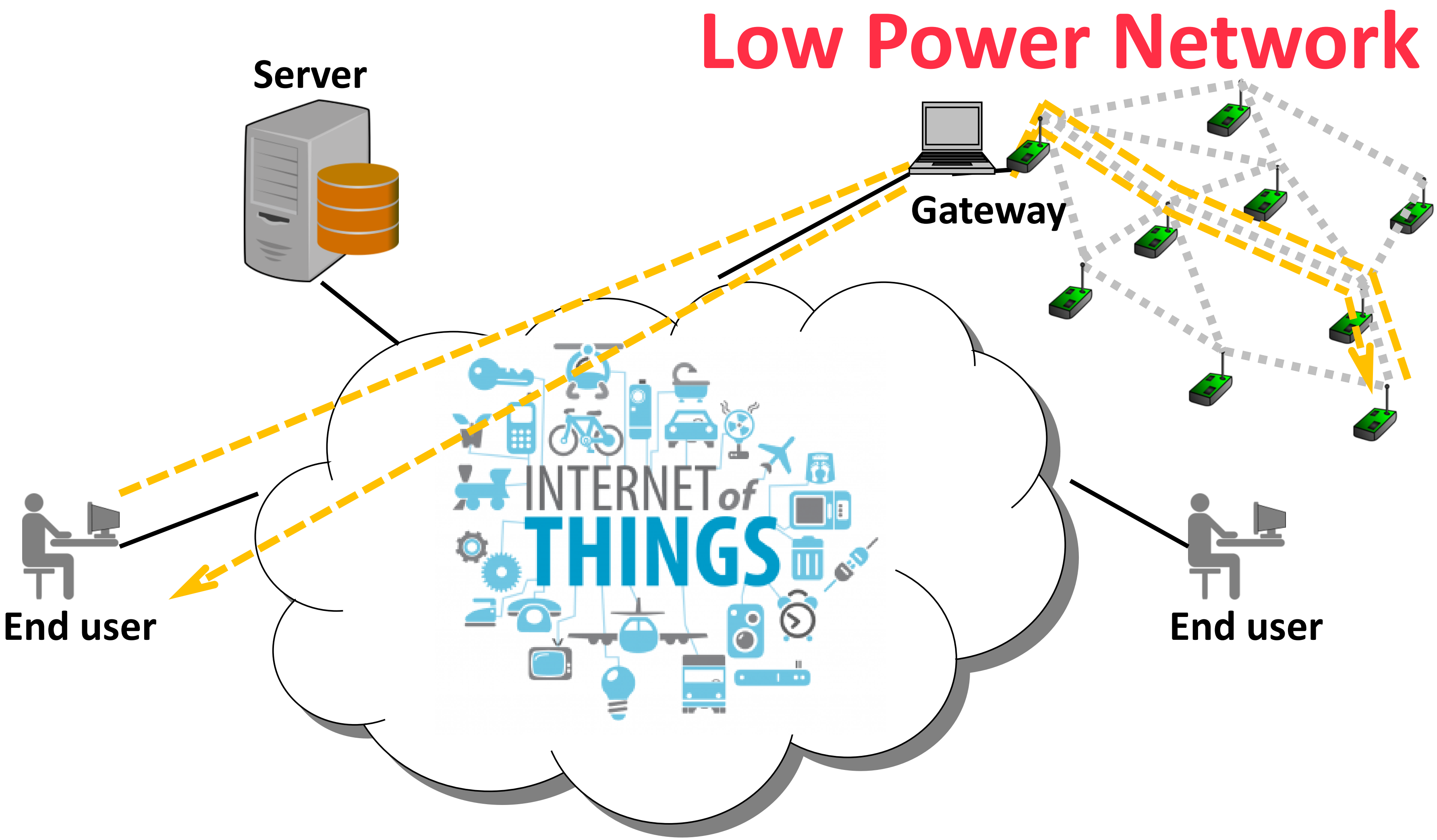
- > Context and motivations
- > Ongoing research and future directions

CONTEXT END MOTIVATIONS

Traditional communications over Internet



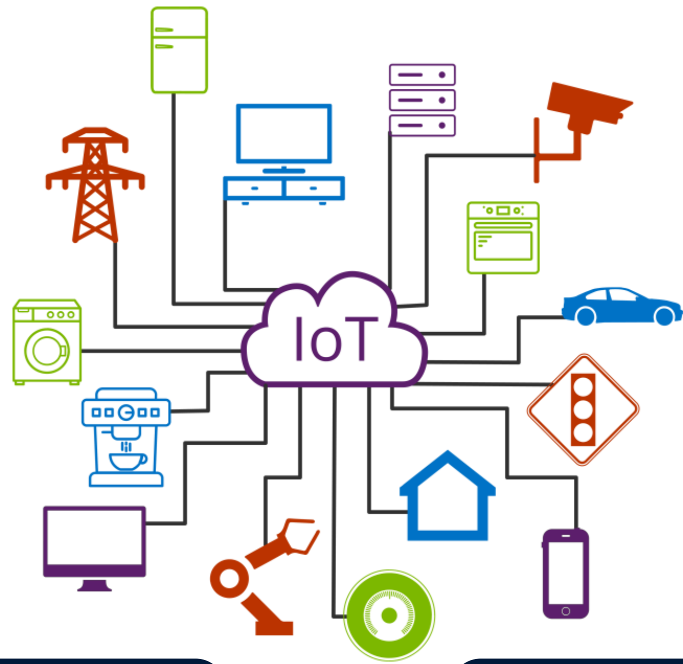
Evolution toward the Internet of Things



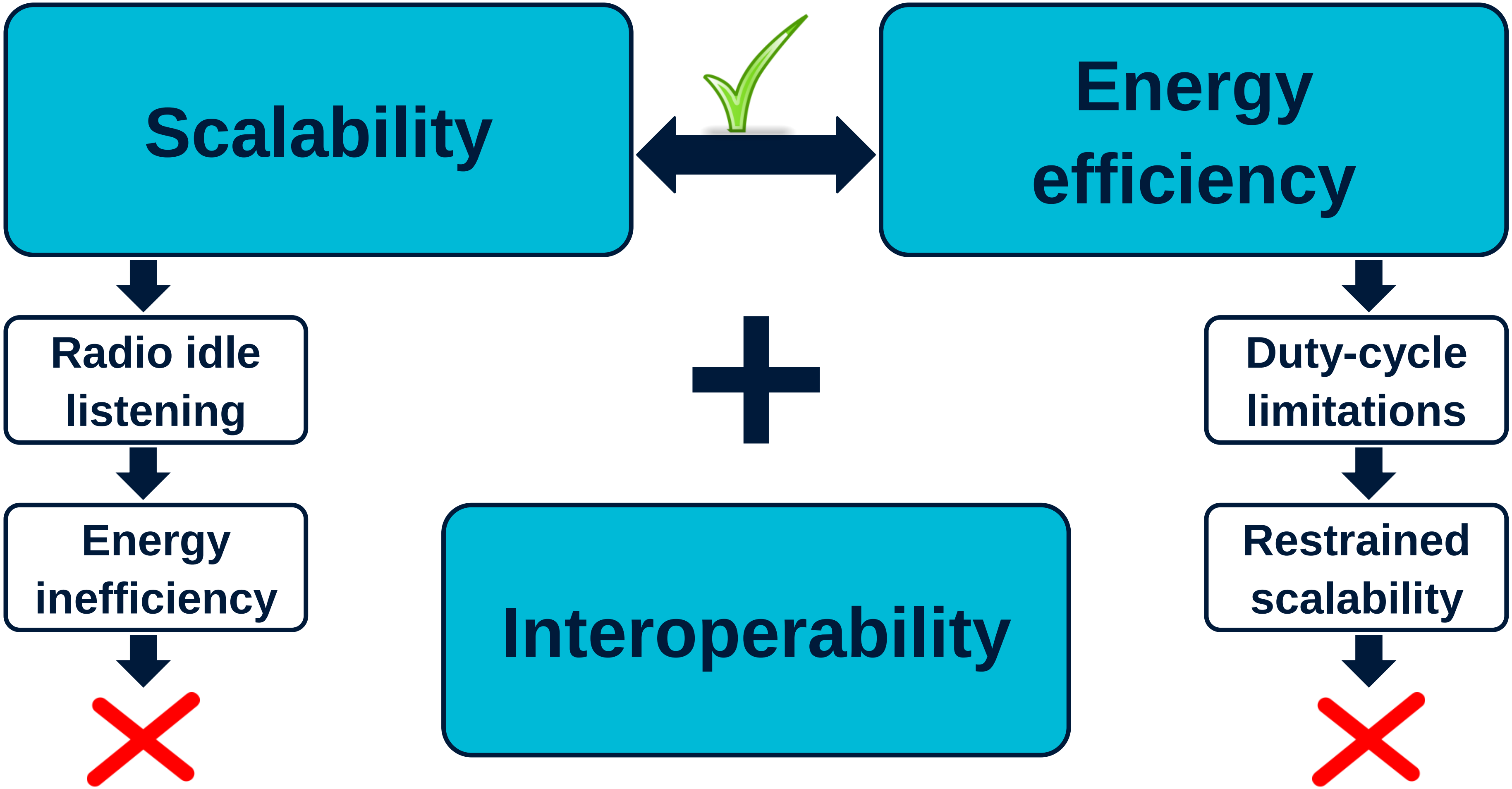
New communication challenges

Pervasive computing

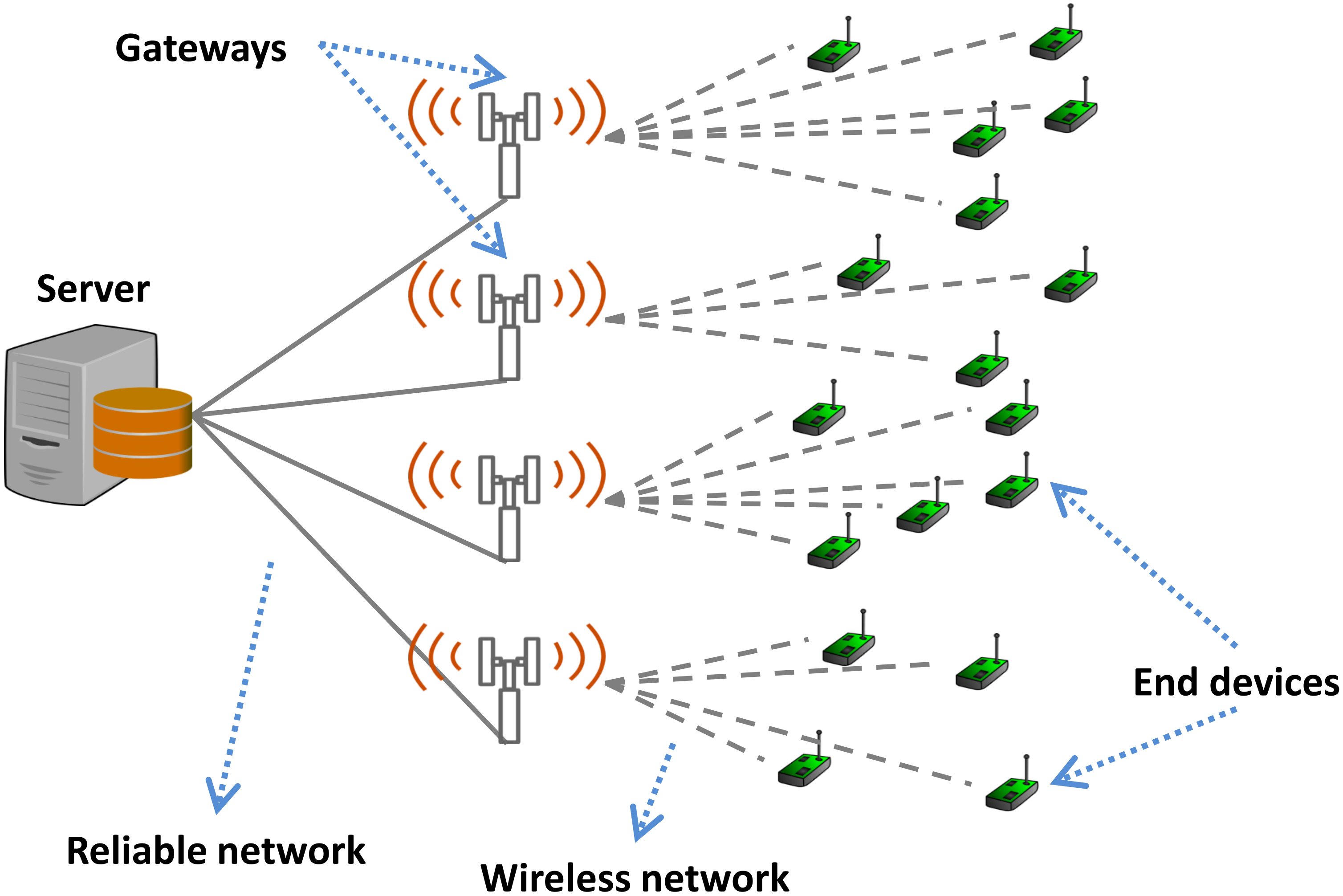
- → **Numerous devices** → **Cheap circuitry** → **Limited memory & limited processing** → **Scalability**
- → **Wireless connectivity** → **Battery or harvesting** → **Limited energy** → **Energy-efficiency**



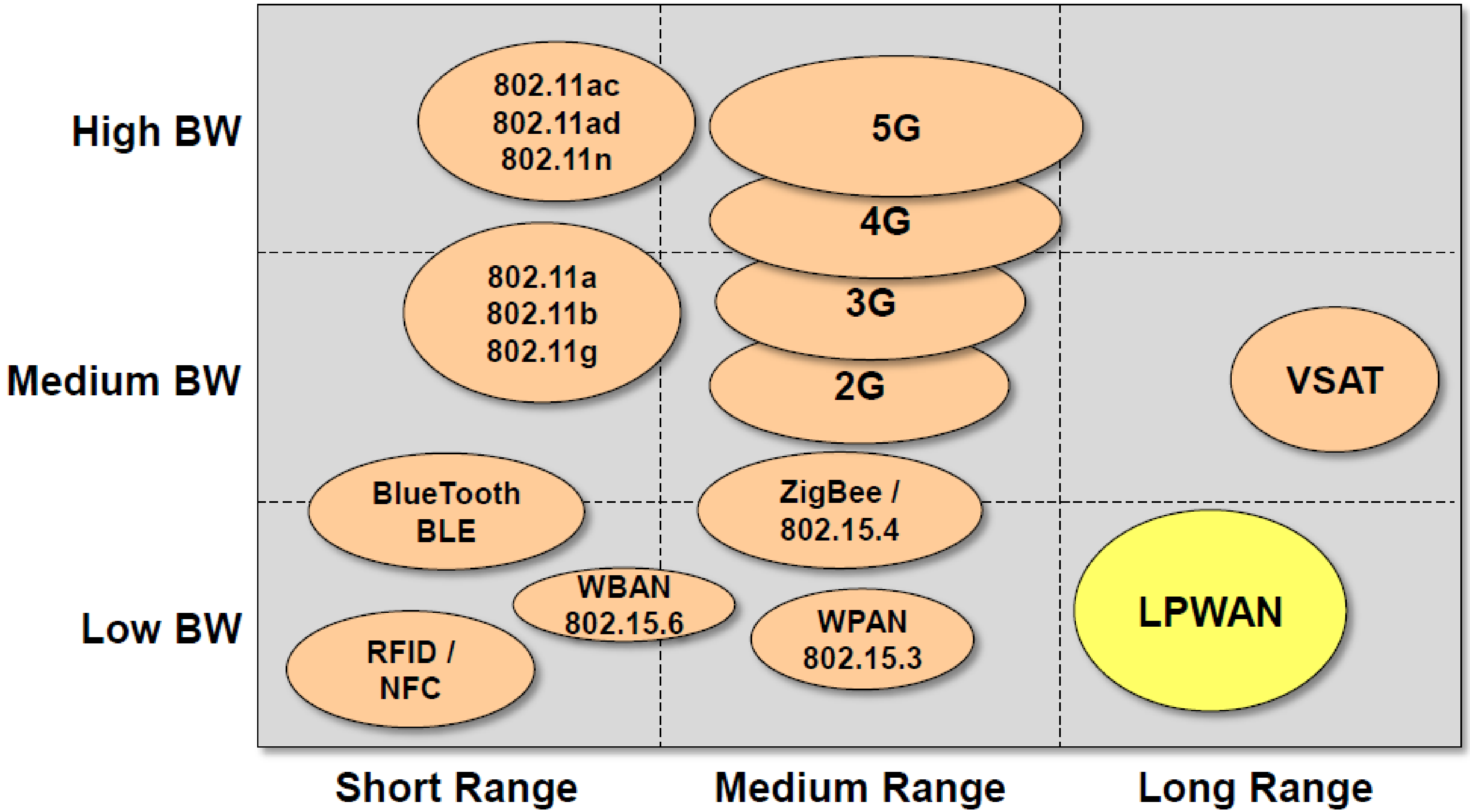
Design constraints for IoT communications



Low Power Wide Area Networks (LPWAN)



LPWAN and other wireless technologies



High-level comparison among Low Power Networks

Short range		Long range
Single hop	Multi-hop/mesh	Single hop
Low energy TX	Low energy TX	Energy expensive TX
Limited scope	Big scope	Wide scope
Small delay	Increased delay	Small delay

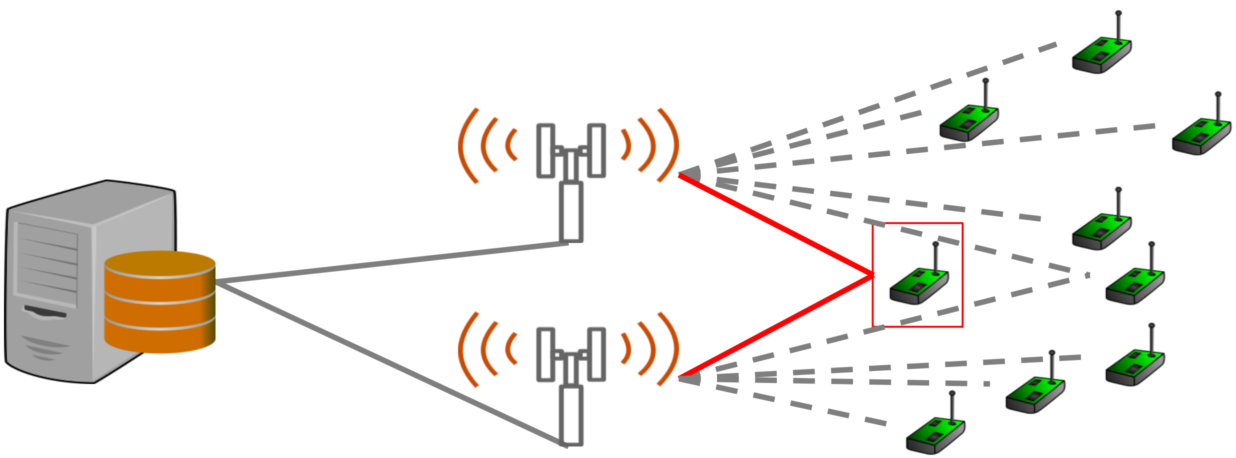
ZigBee® 6TiSCH LoRaWAN sigfox

NB-IOT

Long Range WAN

LoRaWAN

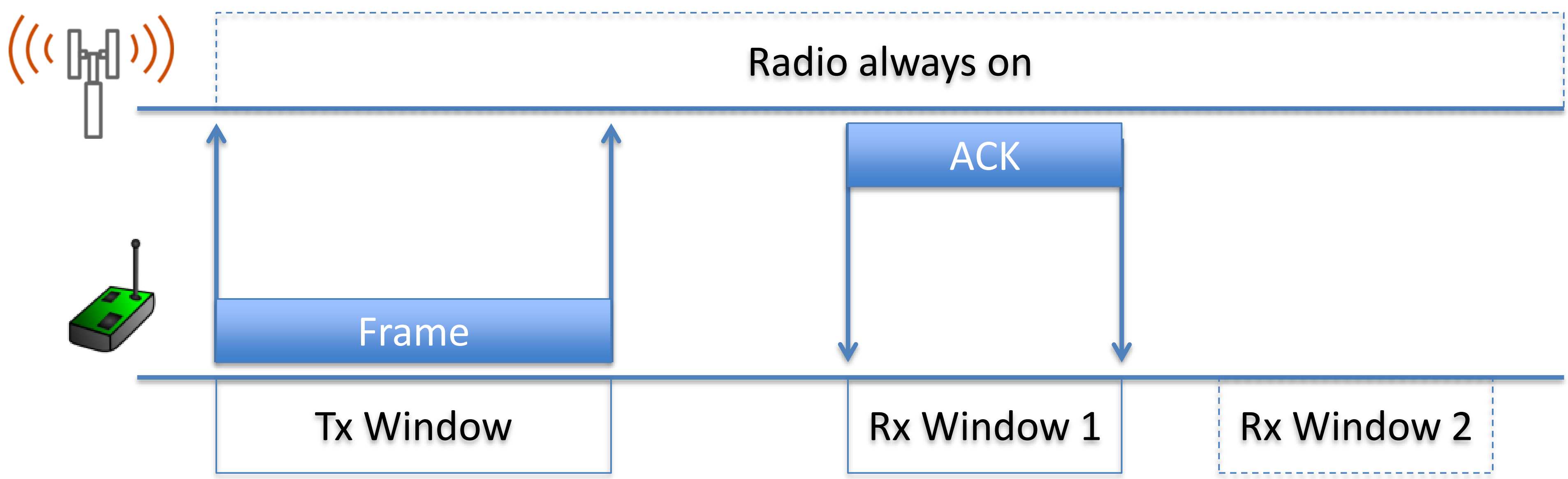
- Unlicenced band
- Bidirectional communications
- Open specification
- Roaming



LoRaWAN modes (1/3)

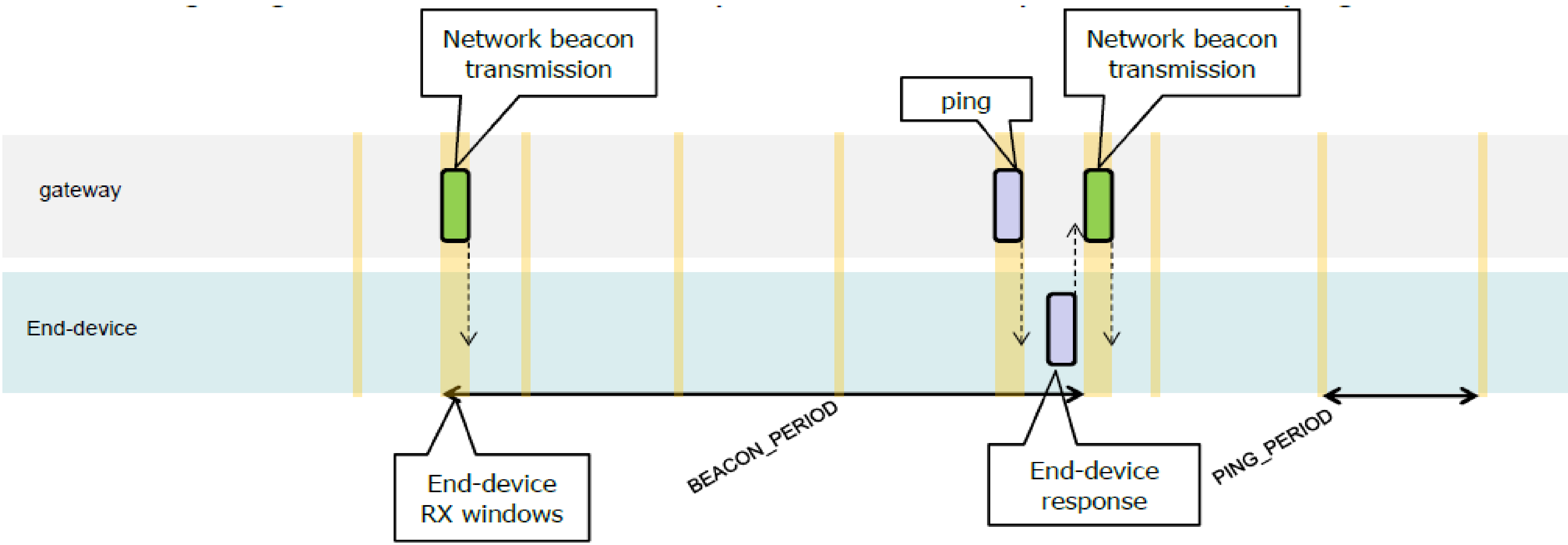
Mode A: All end-devices

RX idle listening BUT on gateways (mains powered)



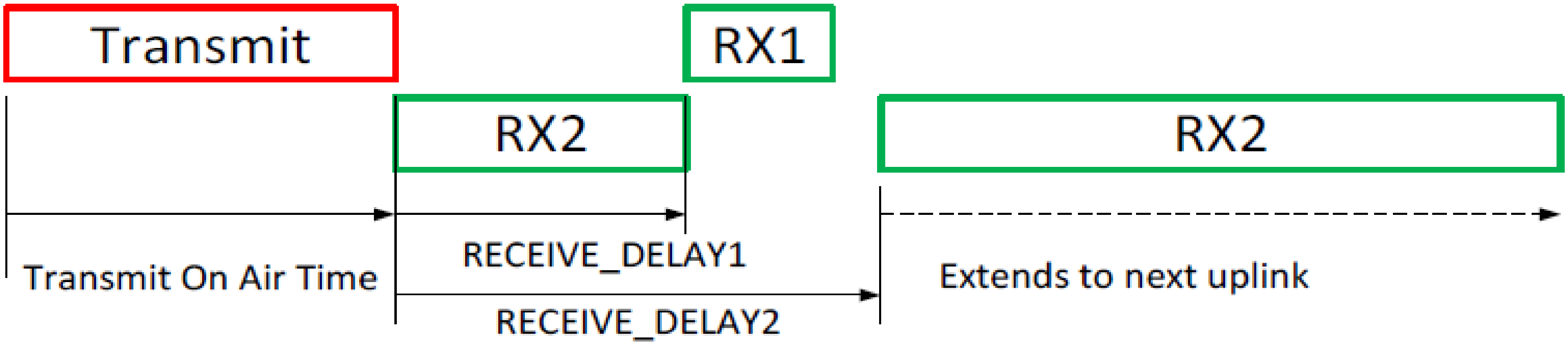
Mode B: Beacon

Synchronization of RX and TX

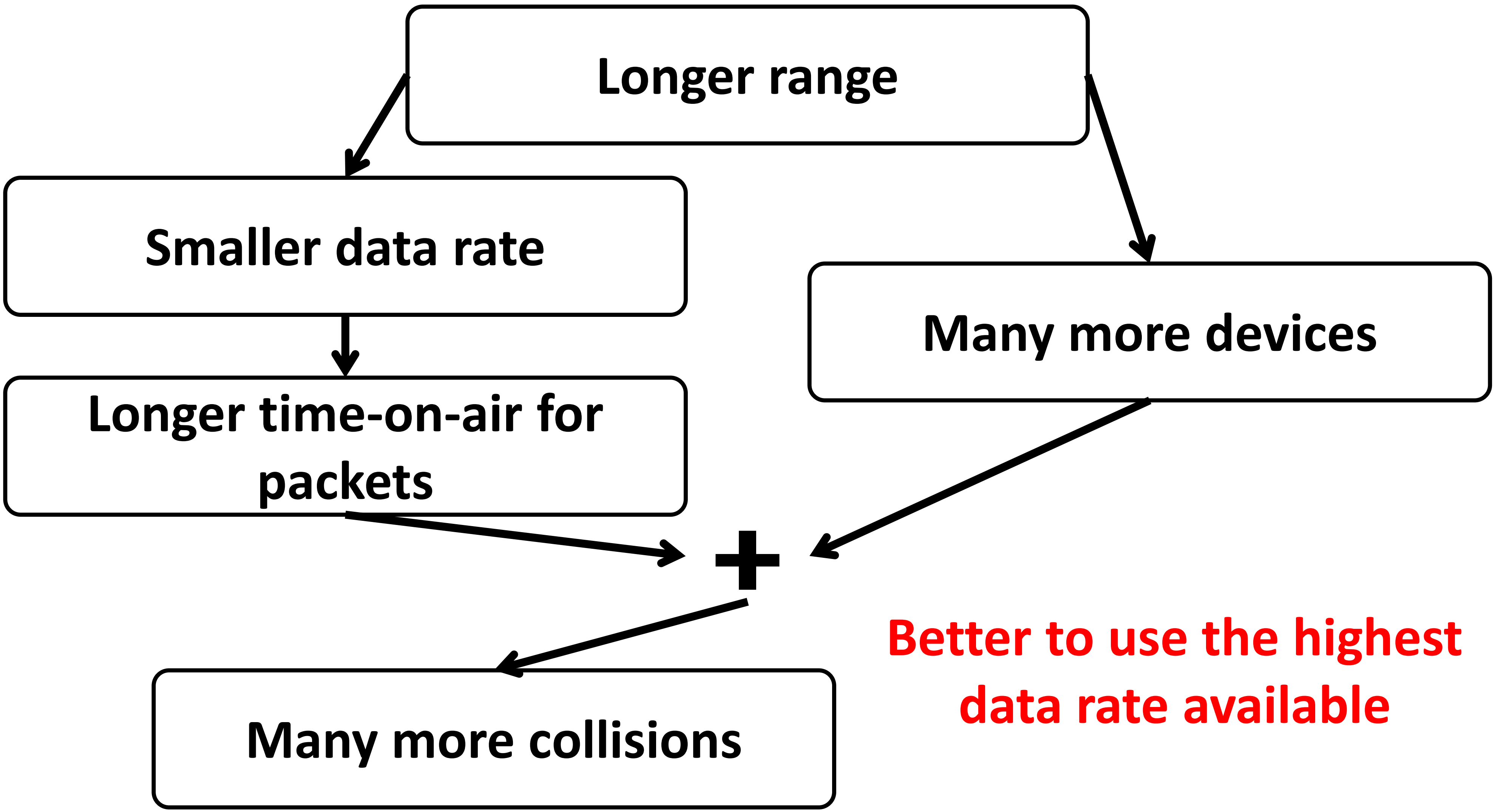


Mode C: Continuously listening

End-devices idle listening



Consideration about datarates



Better to use the highest data rate available

ONGOING RESEARCH AND FUTURE DIRECTIONS

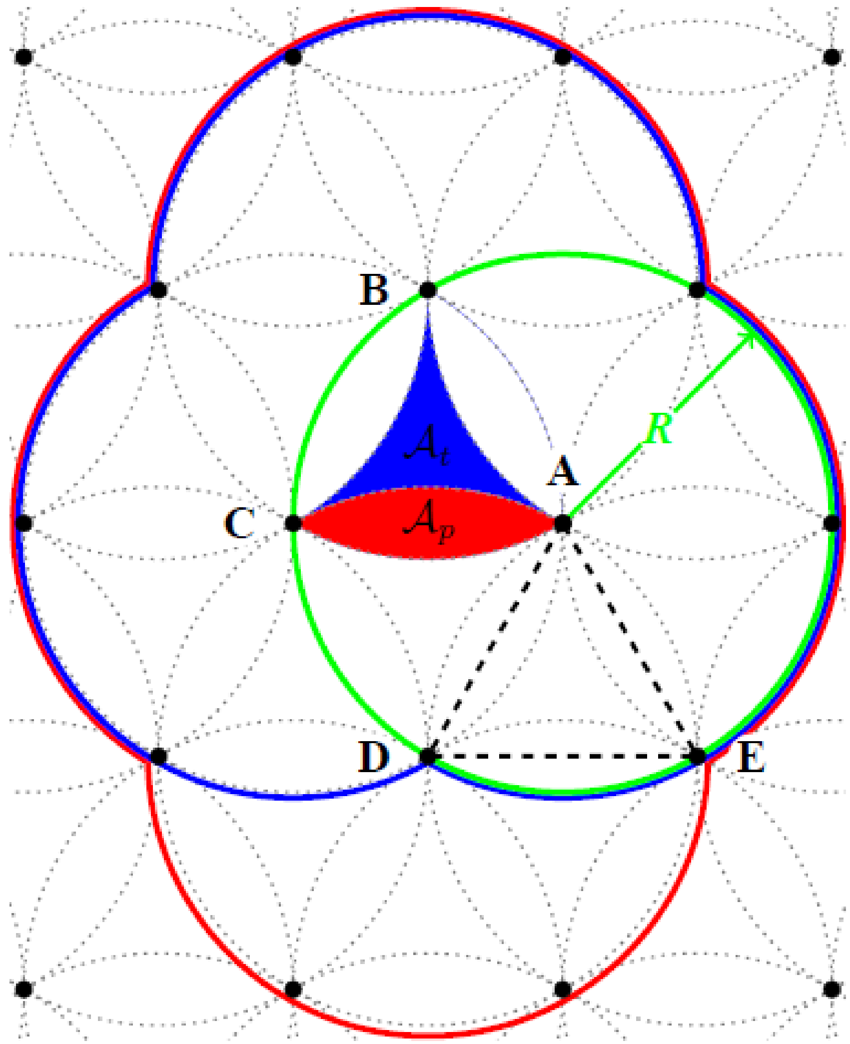
Research directions

- Performance evaluation of LoRa networks
- Design of efficient LoRa MAC protocols
- Applications on LoRa networks
- Backhauling LoRaWANs with satellites
- Comparison between LoRa and 6TiSCH networks

Accettura N, Alata E, Berthou P, Dragomirescu D, Monteil T. Addressing scalable, optimal and secure communications over LoRa networks: challenges and research directions. Wiley Internet Technology Letters, 2018.

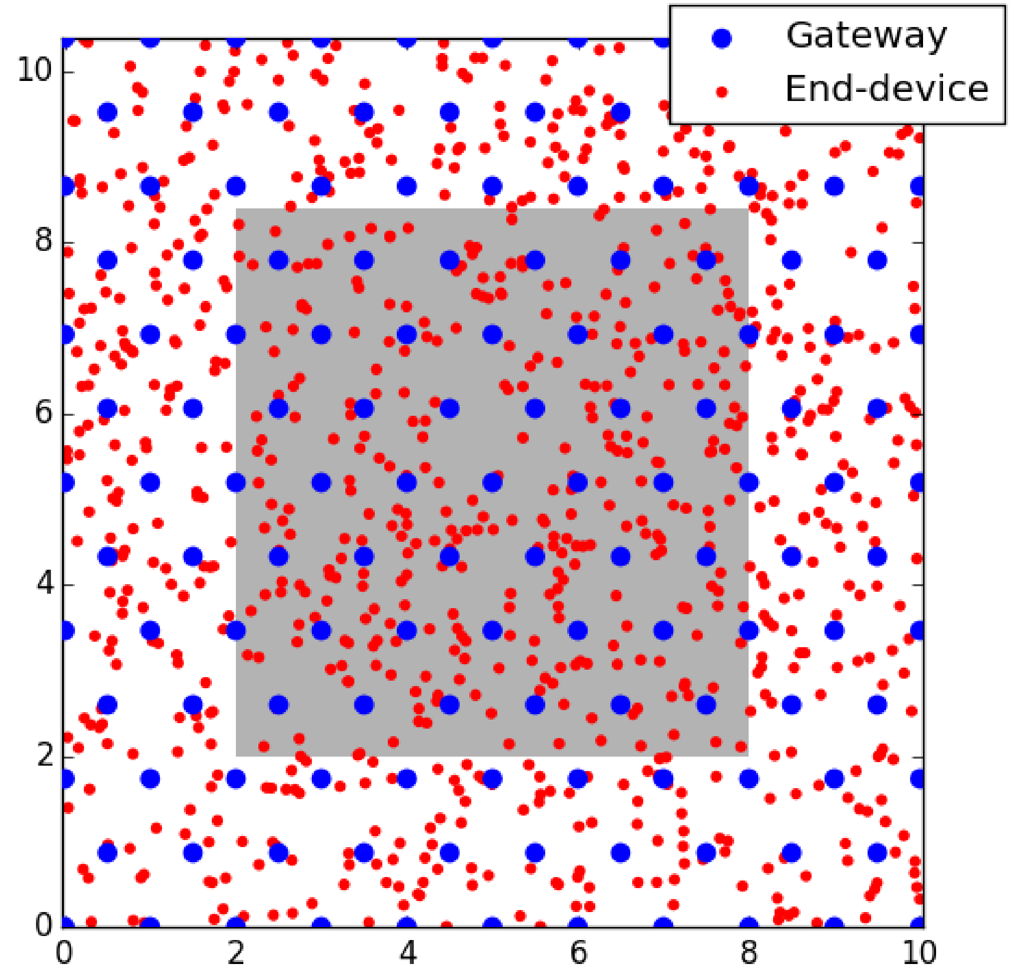
Performance evaluation of LoRa networks (1/6)

- Honecomb deployment as in cellular networks
  - City scaled scenarios
- Each point covered by 3 or 4 gateways



Performance evaluation of LoRa networks (2/6)

What is the **throughput** as function of the **density** of end-devices over a disk of radius R centered **anywhere** onto the honeycomb deployment?



Performance evaluation of LoRa networks (3/6)

Traffic portion correctly dispatched to at least 1 gateway

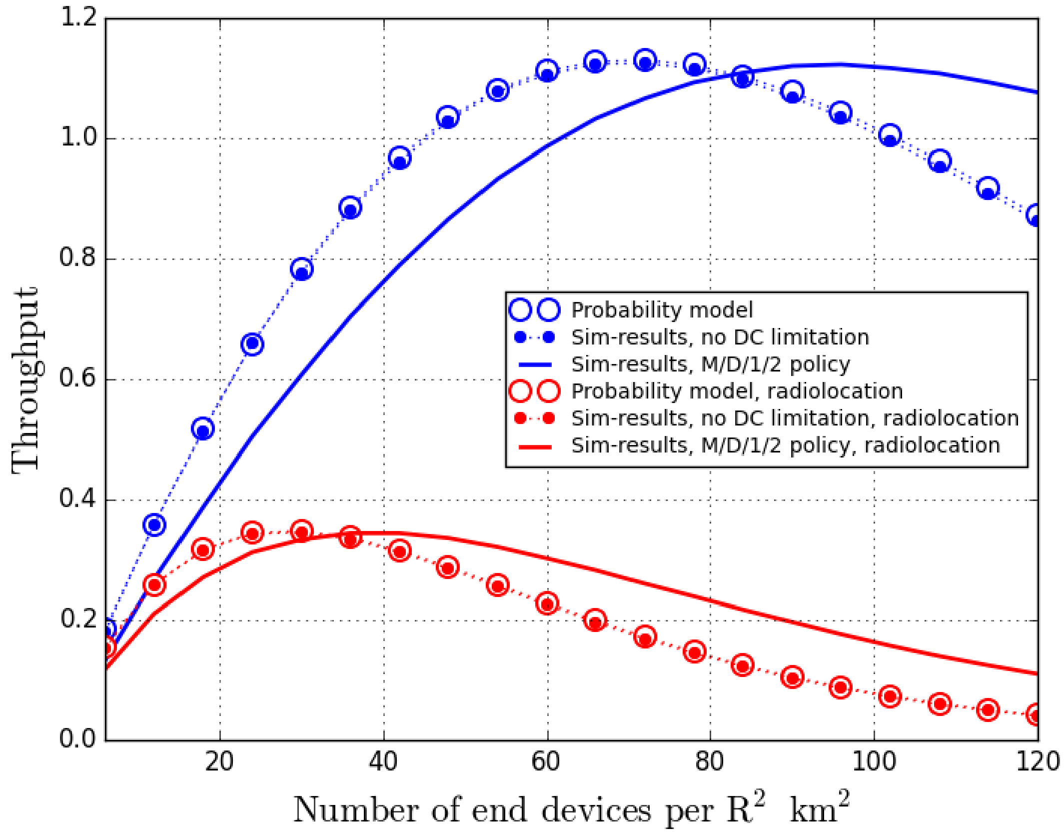
$$\Gamma = p\mu\pi \cdot \Bigg[\frac{2\pi}{\sqrt{3}} e^{-\frac{(2-p)p\mu\pi}{n}} + \left(-\frac{4\pi}{\sqrt{3}} + 3\right) e^{-\frac{(2-p)p\mu\pi}{n}\left(\frac{4}{3}+\frac{\sqrt{3}}{2\pi}\right)} + \left(-\frac{2\pi}{\sqrt{3}} + 3\right) e^{-\frac{(2-p)p\mu\pi}{n}\left(\frac{5}{3}+\frac{\sqrt{3}}{2\pi}\right)} + \left(\frac{2\pi}{\sqrt{3}} - 2\right) e^{-\frac{(2-p)p\mu\pi}{n}\left(\frac{3}{2}+\frac{\sqrt{3}}{\pi}\right)} + \left(\frac{4\pi}{\sqrt{3}} - 6\right) e^{-\frac{(2-p)p\mu\pi}{n}\left(\frac{5}{3}+\frac{\sqrt{3}}{\pi}\right)} + \left(-\frac{2\pi}{\sqrt{3}} + 3\right) e^{-\frac{(2-p)p\mu\pi}{n}\left(\frac{5}{3}+\frac{3\sqrt{3}}{2\pi}\right)} \Bigg],$$

Traffic portion correctly dispatched to at least 3 gateways

$$\Gamma^r = p\mu\pi \cdot \Bigg[\left(\frac{2\pi}{\sqrt{3}} - 2\right) e^{-\frac{(2-p)p\mu\pi}{n}\left(\frac{3}{2}+\frac{\sqrt{3}}{\pi}\right)} + \left(\frac{4\pi}{\sqrt{3}} - 6\right) e^{-\frac{(2-p)p\mu\pi}{n}\left(\frac{5}{3}+\frac{\sqrt{3}}{\pi}\right)} + \left(-\frac{6\pi}{\sqrt{3}} + 9\right) e^{-\frac{(2-p)p\mu\pi}{n}\left(\frac{5}{3}+\frac{3\sqrt{3}}{2\pi}\right)} \Bigg].$$

Accettura N, Medjiah S, Prabhu B, Monteil T. Low power radiolocation through long range wide area networks: A performance study. In: Proceedings of IEEE WiMob '17; 2017; Rome, Italy.

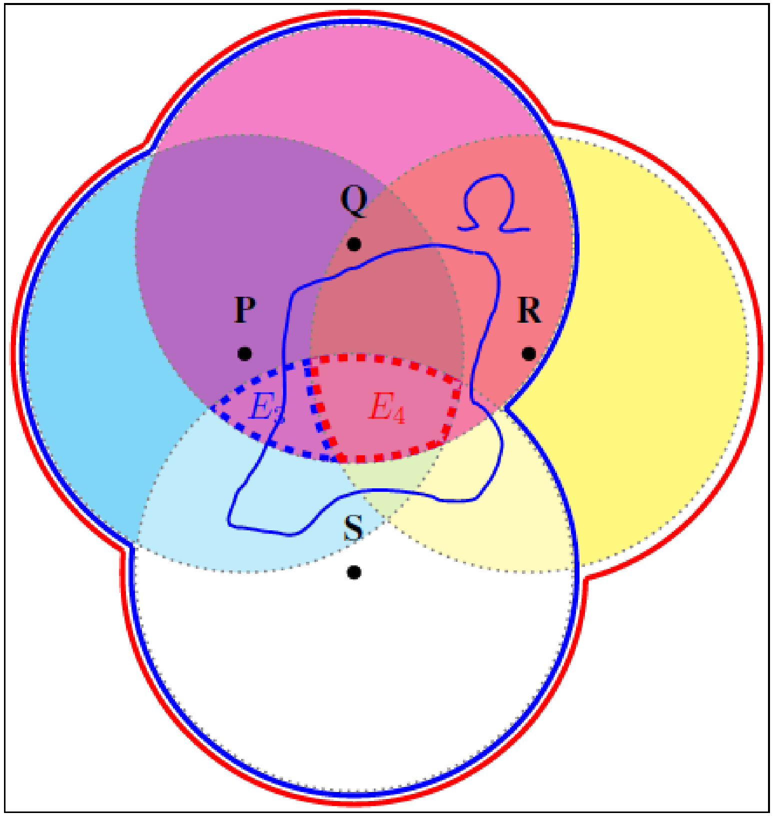
Performance evaluation of LoRa networks (4/6)



- 3 channels
- Model validated!!!
- Stretch along abscissa due to frame dropped

Accettura N, Prabhu B, Monteil T. Simulating scalable Long Range Wide Area Networks for very low power monitoring applications. In: Proceedings of MSSANZ MODSIM '17; 2017; Hobart, Australia.

Performance evaluation of LoRa networks (5/6)



Rate of successful transmissions $S_L(\Omega)$ from end devices on any compact subset of the plane to at least L gateways among the ones reachable by each end device ∈ Ω

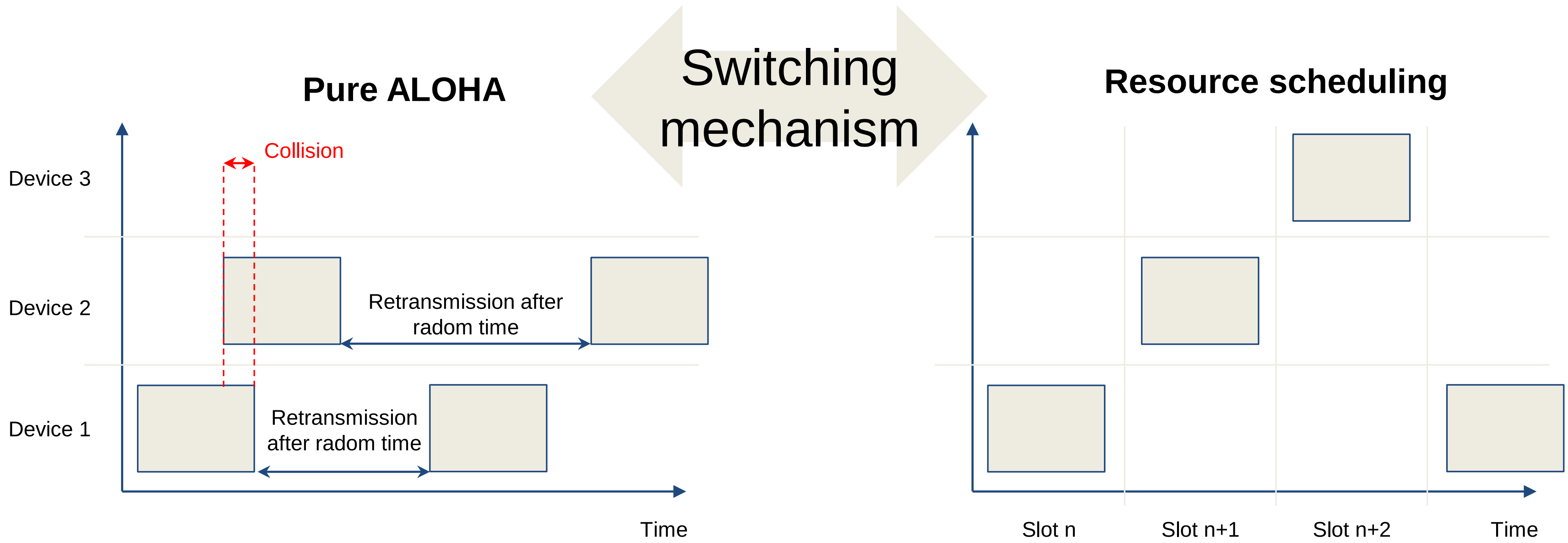
$$\mathcal{S}_L(\Omega) = p\mu \sum_{\substack{\Gamma \subset \Gamma^* \\ |\Gamma| \geqslant L \\ \Delta_\Gamma \cap \Omega \neq \varnothing}} \mathcal{A}(\Delta_\Gamma \cap \Omega) \sum_{l=L}^{|\Gamma|} (-1)^{l-L} \binom{l-1}{L-1} \sum_{\substack{\Phi \subseteq \Gamma \\ |\Phi| = l}} \mathcal{Q}(\mathcal{U}_\Phi), \qquad \text{if} \quad \forall \alpha \in \Omega : |\sigma(\alpha)| \geqslant L$$

Performance evaluation of LoRa networks (6/6)

Future works:

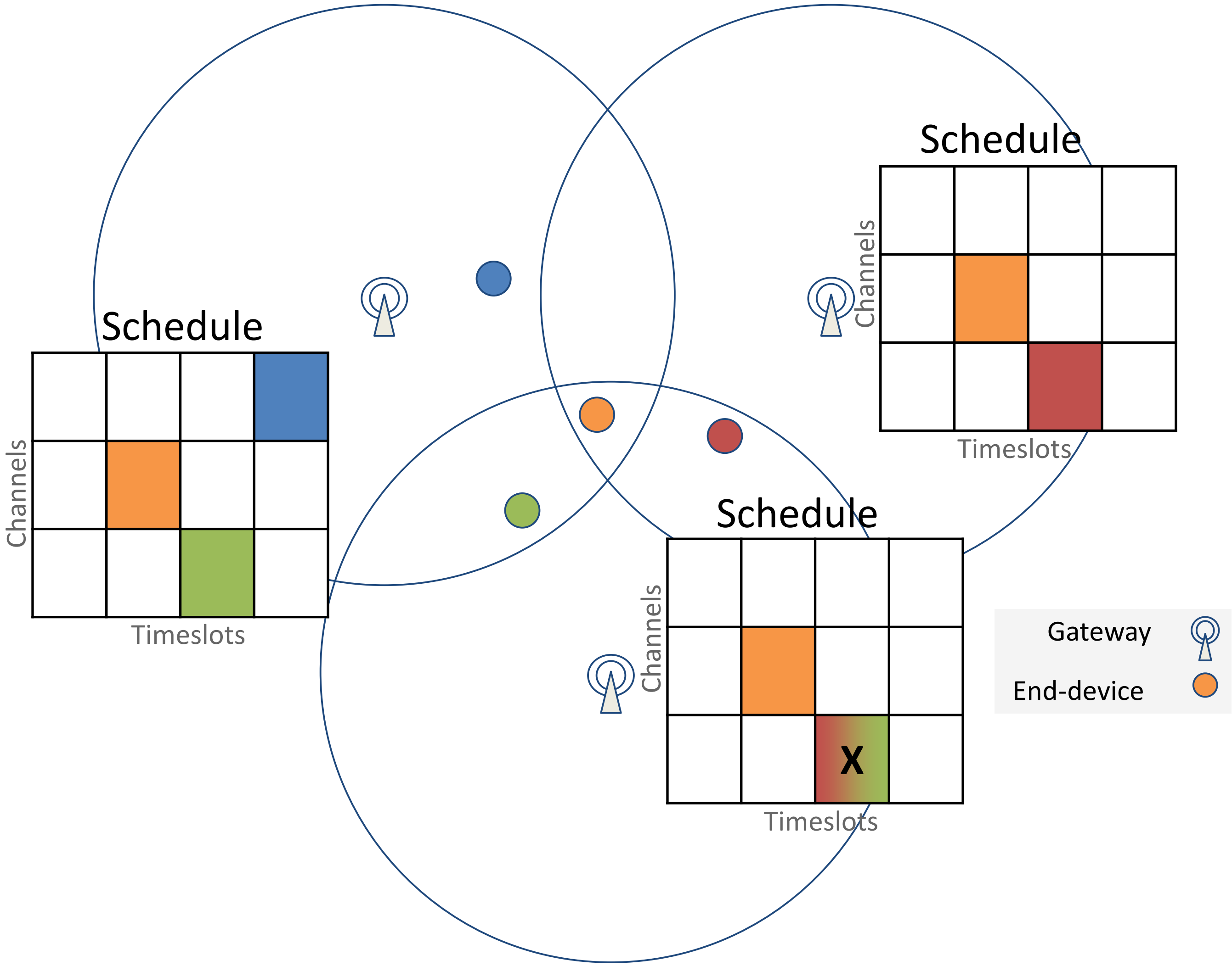
- Different size of packets simultaneously
- Several data rates (QoS)
- Which gateway will send the ACK?
- Real throughput (taking into account ACKs)
- Latency evaluation
- Round trip delay in bidirectional communications

Design of efficient LoRa MAC protocols (1/2)

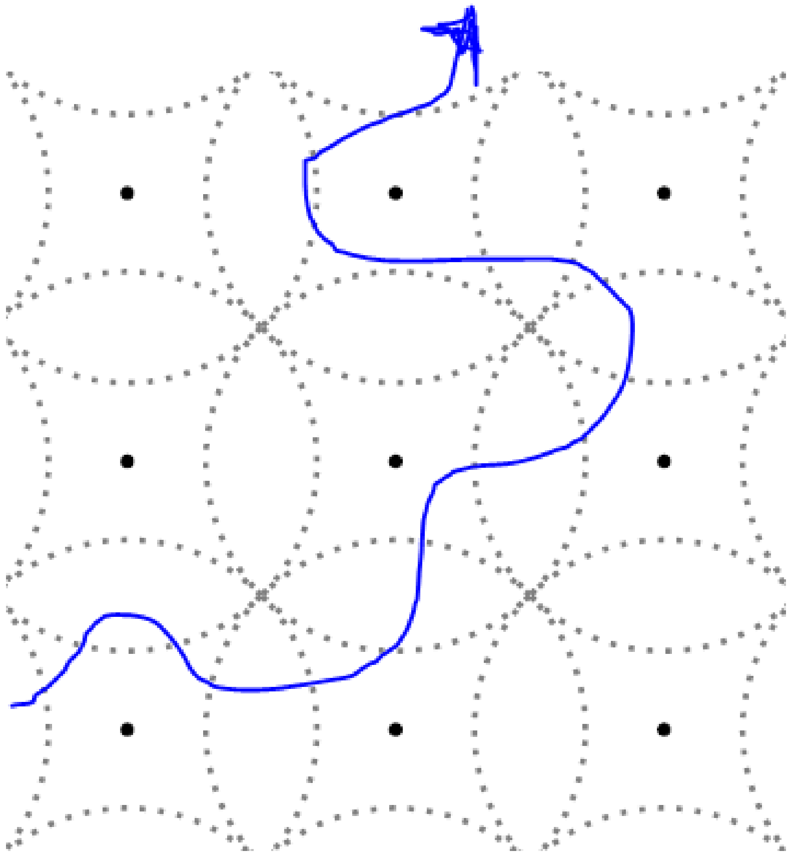


Design of efficient LoRa MAC protocols (2/2)

- > How to maximize the number of devices
- > How to handle moving objects
- > How to insure different class of services



Applications on LoRa networks (1/2)



- Low power radiolocation
- Low power tracking
- Instruments:
  - Capture-Recapture techniques for detecting which gw received the packet
  - Operational Reasearch to handle bidirectional communications
  - Machine learning to predict trajectory

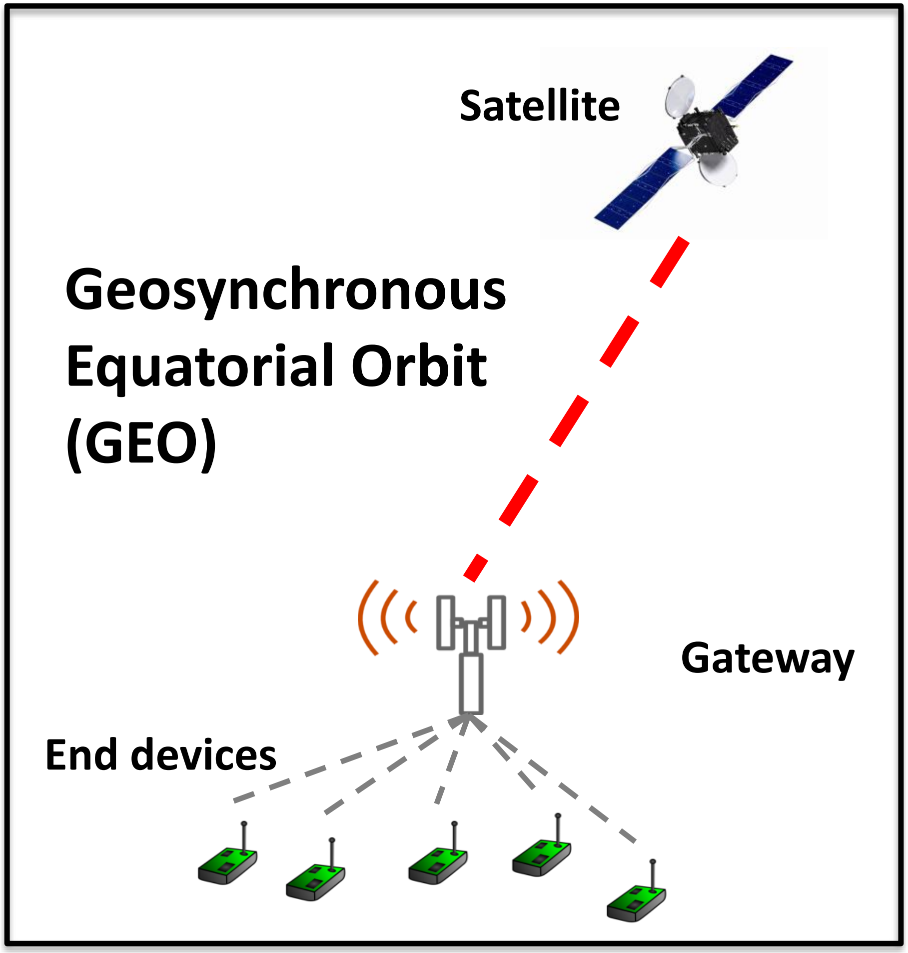
Accettura N, Medjiah S, Prabhu B, Monteil T. Low power radiolocation through long range wide area networks: A performance study. In: Proceedings of IEEE WiMob ’17; 2017; Rome, Italy.

Applications on LoRa networks (2/2)

E-healt:

> Which kind of body measurements?
> Which rate?
> How many people?
> Which automated service can be built on top?
> How to manage secure communications (sensitive data)?

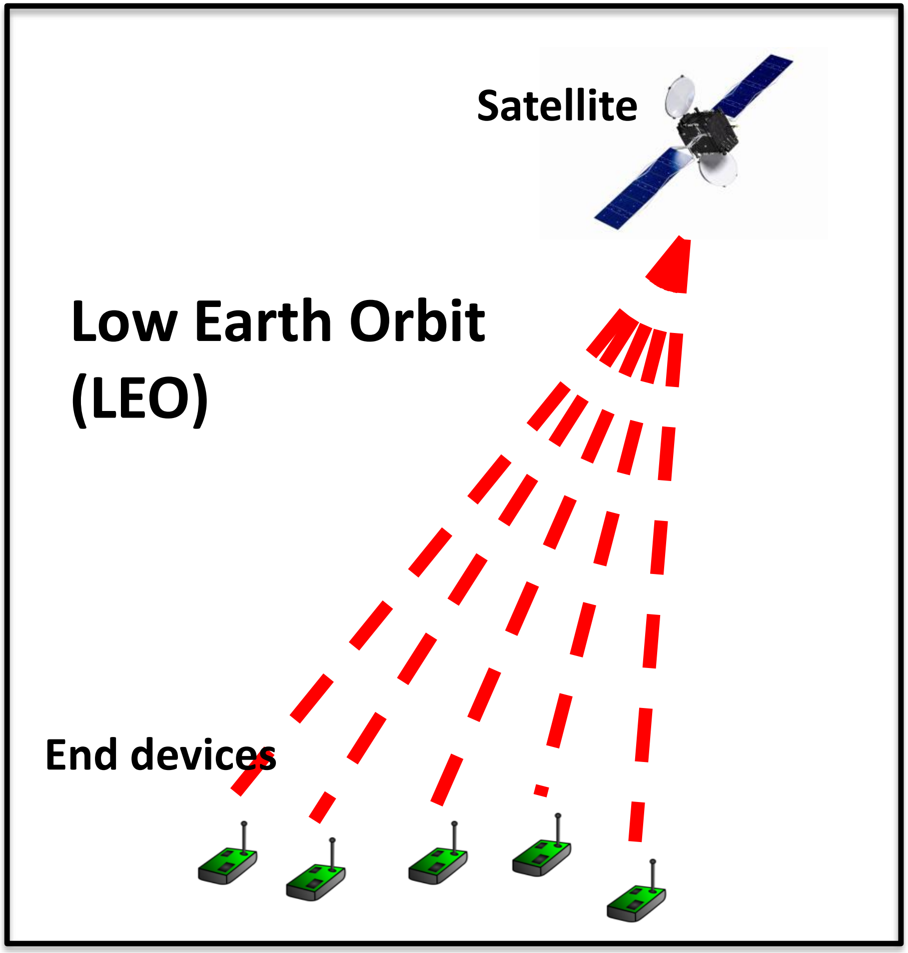
Backhauling LoRaWANs with satellites (1/2)



- Synchronization between LoRa communications and schedule of transmissions on the satellite link
- Replicas cancellation
- Cross-layer optimization

Palattella MR, Accettura N. “Enabling Internet of Everything Everywhere: LPWAN with satellite backhaul”. In: Proceedings of the Global Information Infrastructure and Networking Symposium (GIIS 2018). Oct. 2018, pp. 1–5.

Backhauling LoRaWANs with satellites (2/2)

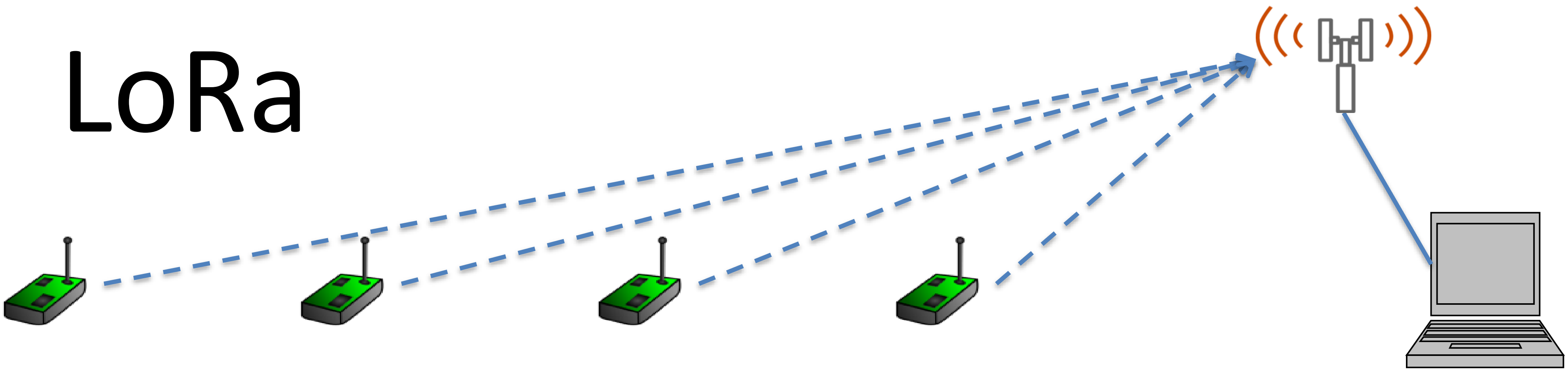


- Difficulties:
  - Low data rates
  - How the satellite channel affects the behavior of the technology
  - Proprietary technology at the PHY layer
- To be done:
  - New MAC protocols
  - How to get rid of the dependency of the network server for both data and control planes?
  - IP support according to current (and future) architectures
  - Application layer protocols (CoAP and MQTT) performance

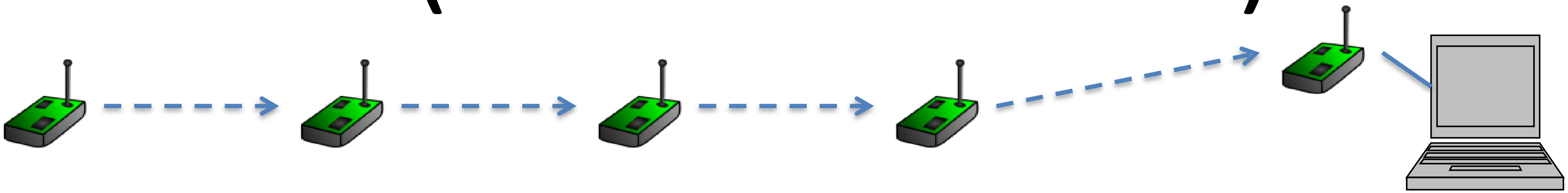
Fraire JA, Céspedes S, Accettura N. Direct-To-Satellite IoT - A Survey of the State of the Art and future research perspectives. (under review)

Comparison between LoRa and 6TiSCH networks

LoRa



6TiSCH (mesh networks)



Make dialogue happen

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QUESTIONS?