Throughput Modelling in LoRaWAN Networks

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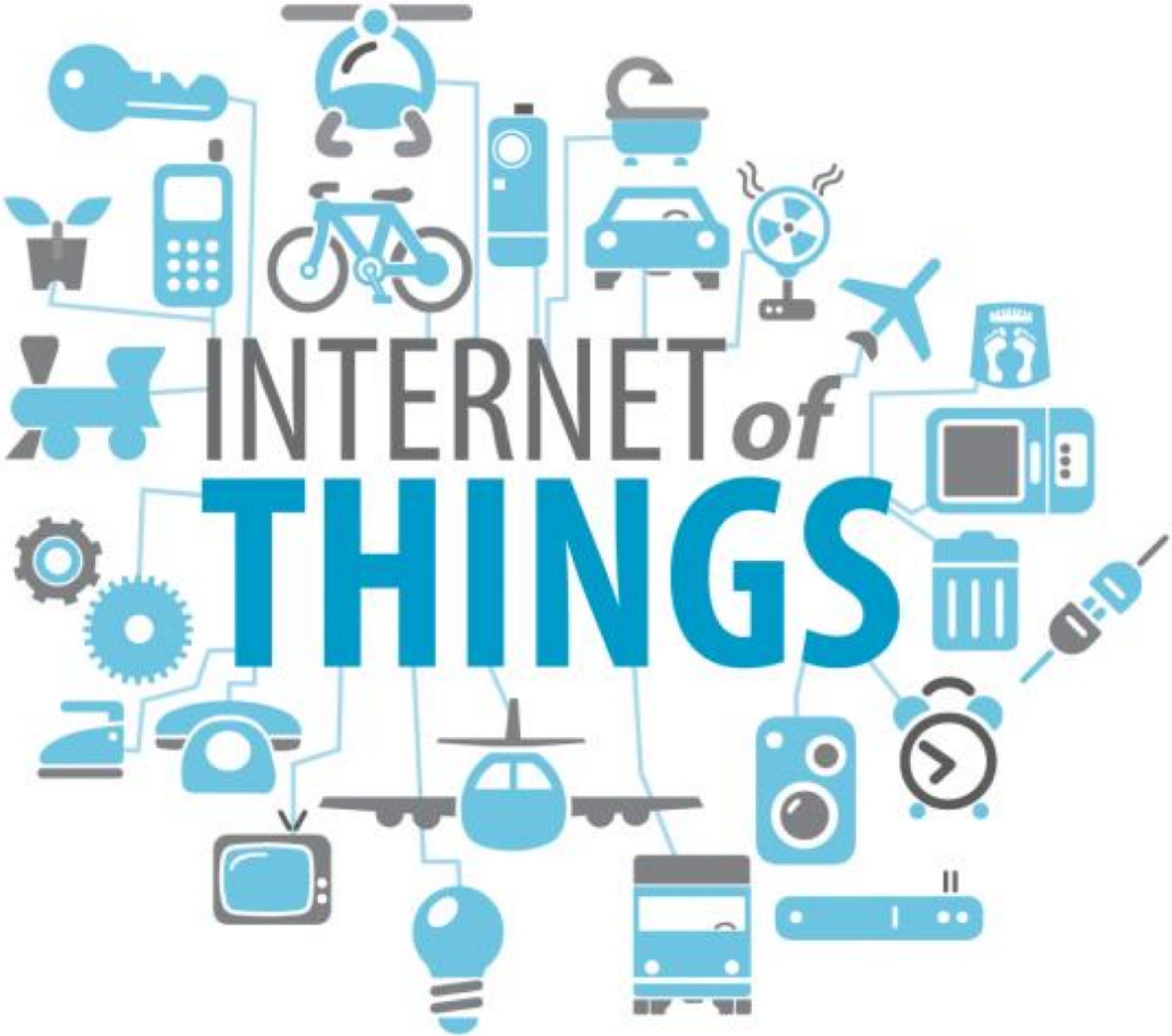
Outline

1. Context and motivations
2. Overview of LoRaWAN technology
3. Density-based throughput in Aloha networks
4. Throughput in LoRaWAN networks
5. Simulation results

CONTEXT AND MOTIVATIONS


INTERNET of
THINGS

IoT Communications in ISM bands

Short range

- Typically 2.4 GHz
- Interference from WLANs
- Long range through relaying
- Low traffic

Long range

- EU 863-870 MHz
- Duty-cycle limitation
- Single hop
- Very low traffic

Low Power Wide Area Networks

- Novel technologies
- IETF LPWAN
- LoRaWAN the most promising
  - Unlicenced band
  - Bidirectional communications
  - Open specification
  - Roaming

SEMTECH

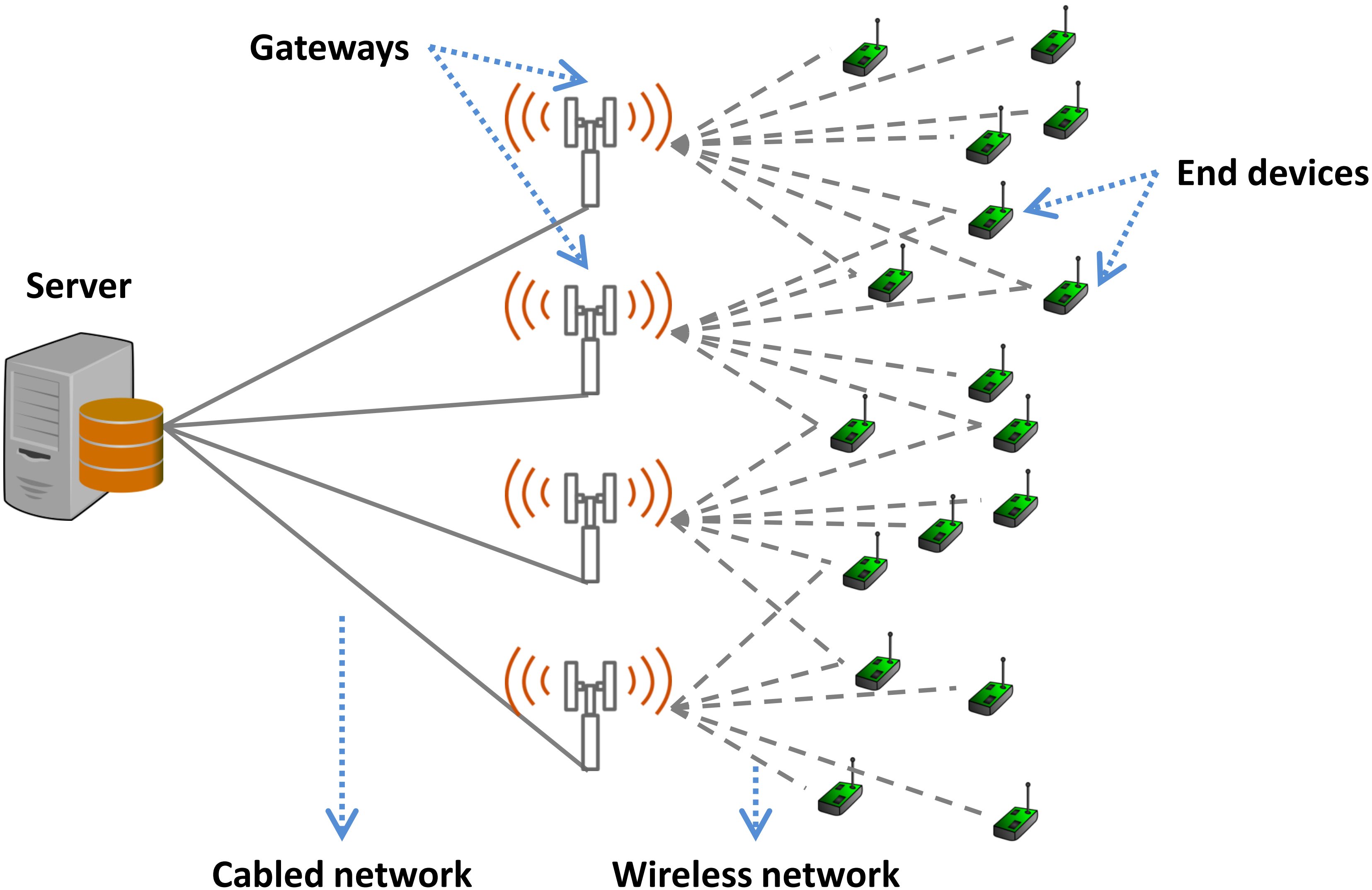
actility
Making Things Smart

IBM

LoRa Alliance™
Wide Area Networks for IoT

OVERVIEW OF LORAWAN TECHNOLOGY

Network architecture

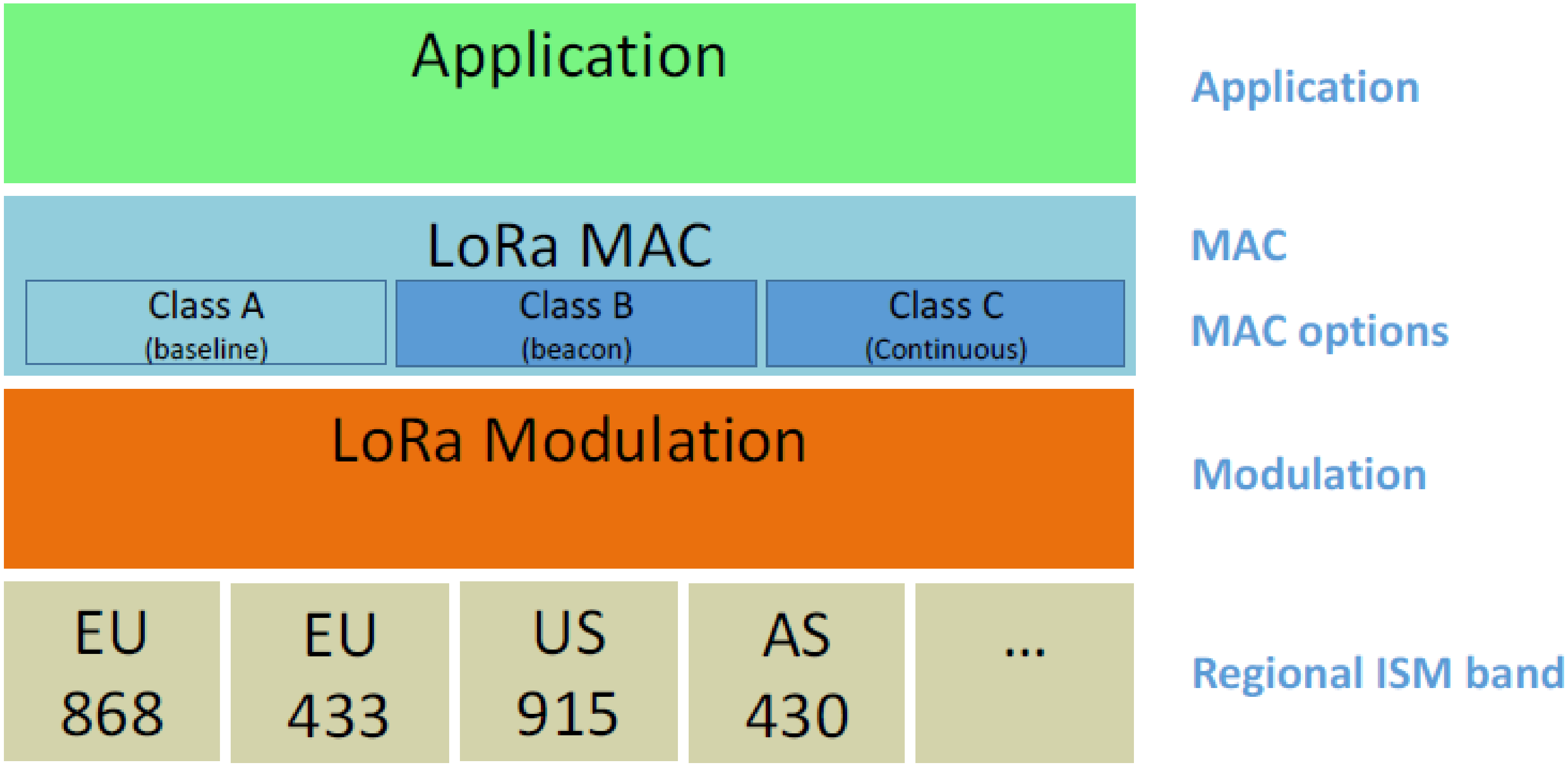


Communication

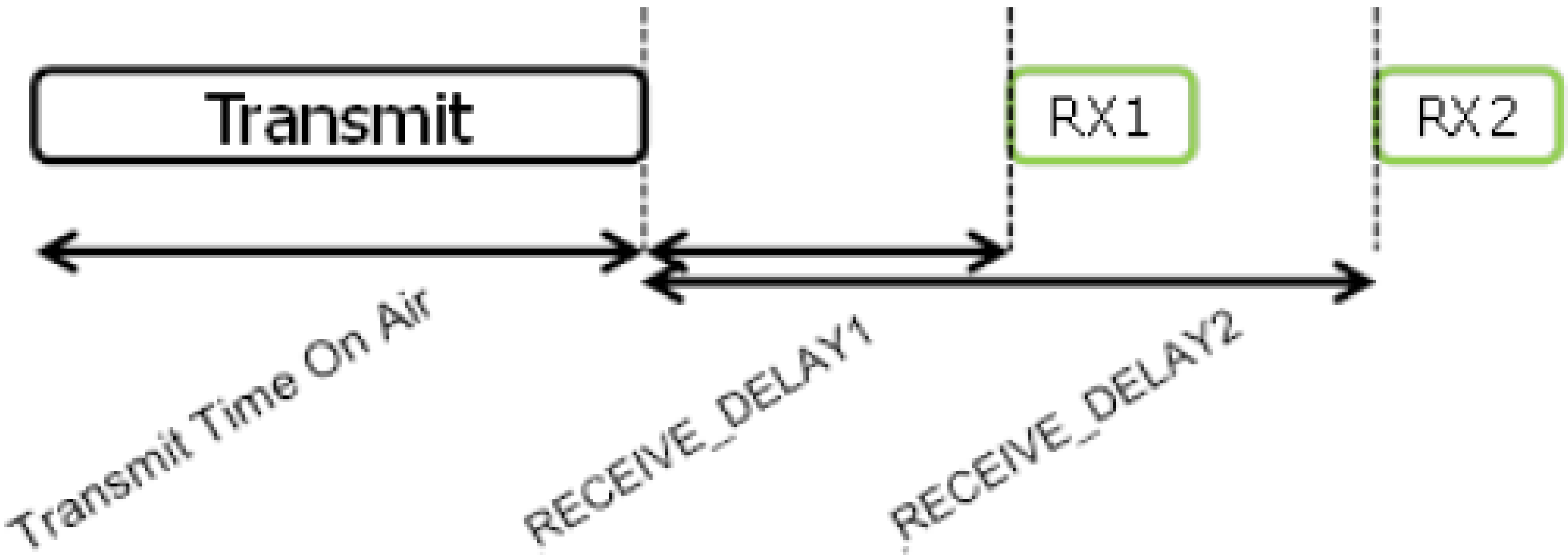
Concurrent multi-channel transmissions with several datarates

DataRate	Configuration	Indicative physical bit rate [bit/s]
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa: SF7 / 125 kHz	5470
6	LoRa: SF7 / 250 kHz	11000
7	FSK: 50 kbps	50000
8..15	RFU	

Protocol stack

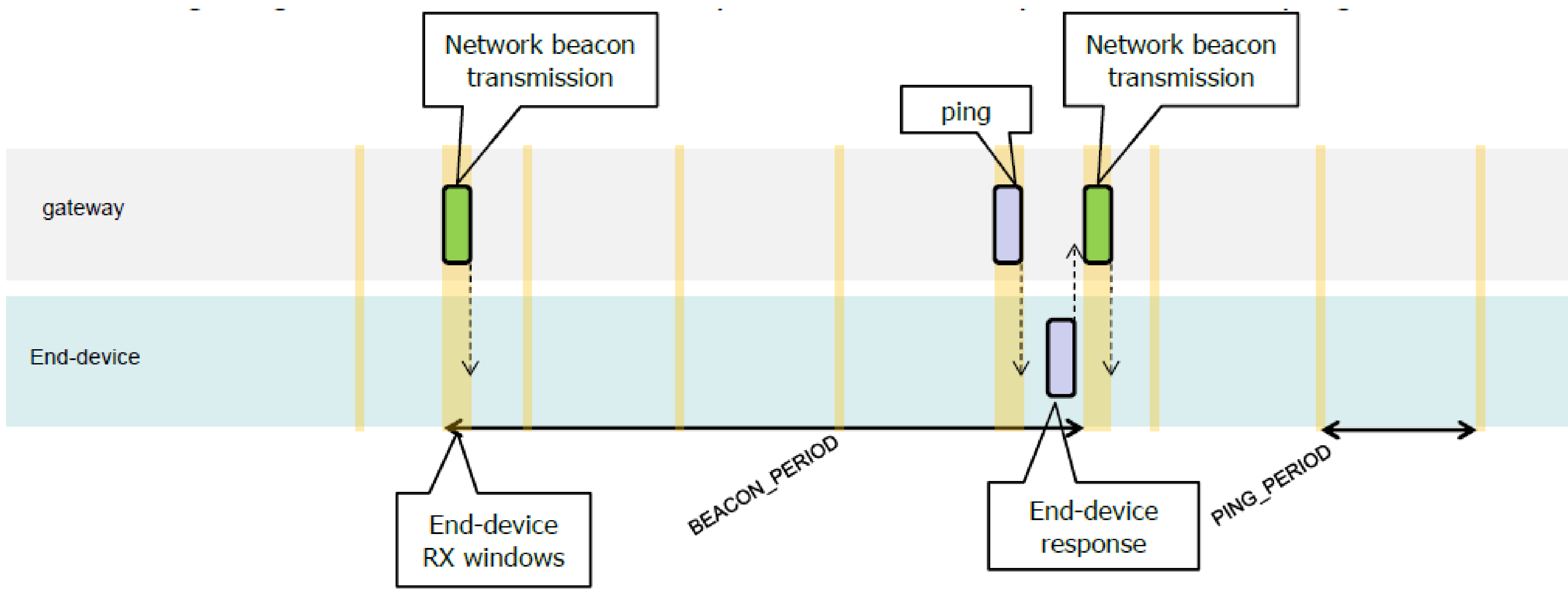


Mode A



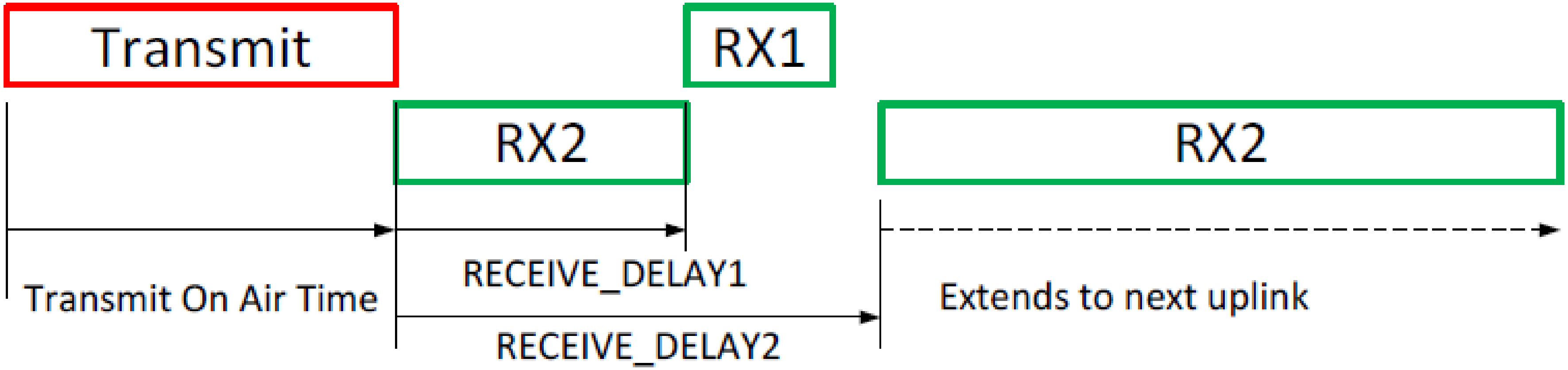
Pure Aloha access scheme

Mode B



Network beacon transmission
ping
Network beacon transmission
gateway
End-device
End-device RX windows
BEACON_PERIOD
End-device response
PING_PERIOD

Mode C


Transmit
RX1
RX2
RX2
Transmit On Air Time
RECEIVE_DELAY1
RECEIVE_DELAY2
Extends to next uplink

DENSITY-BASED THROUGHPUT IN ALOHA NETWORKS

Notation (1)

τ time on air of a packet [seconds]

λ average generation rate [packets/second]

$p = 1 - e^{-\tau\lambda}$ probability to start transmitting a packet in less than τ seconds

$1 - (1-p)^m$ probability that a packet is transmitted in less than τm seconds

Notation (2)

m = 1

Pure Aloha

m = 2

Slotted Aloha

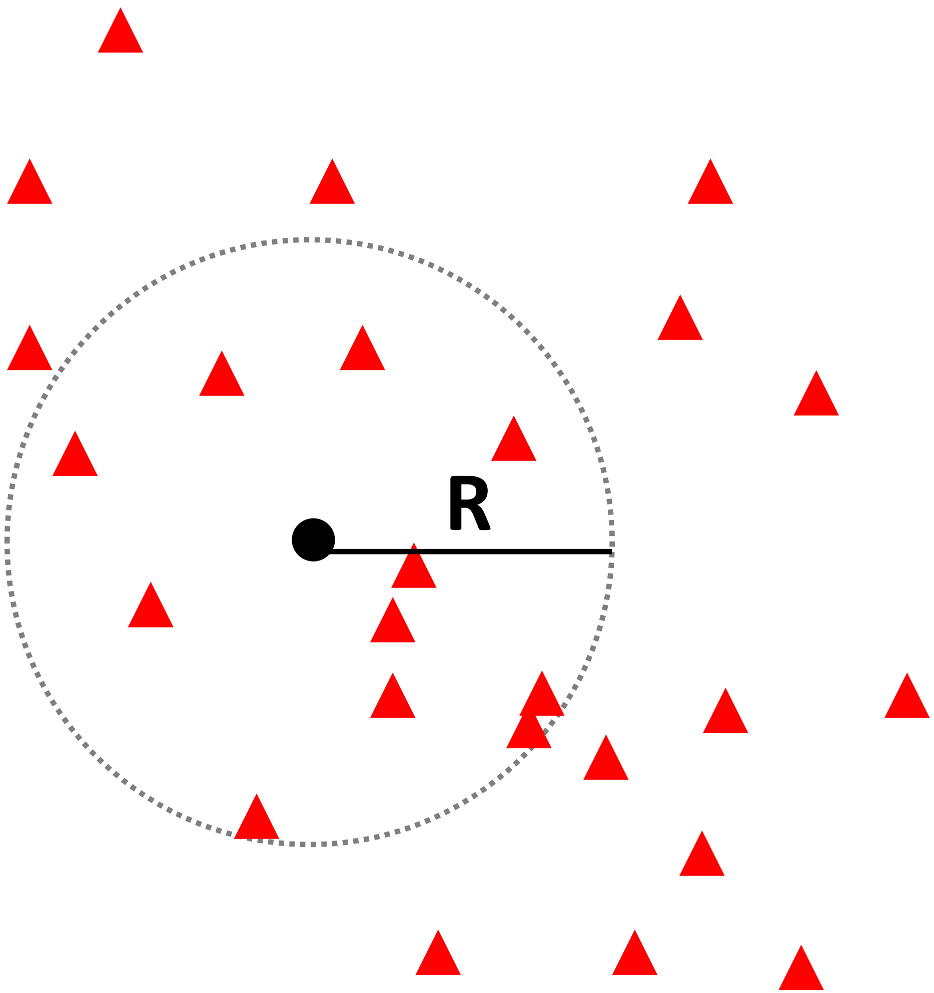
Notation (3)

n number of available channels

$$q = (1-p)^m + [1-(1-p)^m] \cdot \left(1 - \frac{1}{n}\right) =$$
$$= 1 - \frac{1-(1-p)^m}{n}.$$

probability that an end-device is not interfering with an ongoing transmission on a given channel

Notation (4)



Homogeneous Poisson Point Process

i	number of end devices in the tx range

$$\Pr(0\ \mathrm{tx}|i) = q^i,$$

$$\Pr(1\ \mathrm{tx}|i) = i\frac{p}{n}q^{i-1}$$

Notation (5)

μ average number of end-devices spread on a unit area R^2

μ A average number of end-devices in the area AR^2

$$\Pr(i) = e^{-\mu A}\frac{(\mu A)^i}{i!}$$

probability that i end devices are present on AR^2

No one transmitting

$$Q(\mathcal{A}) = \sum_{i=0}^{\infty} \Pr(0 \text{ tx}|i) \Pr(i) = e^{-(1-q)\mu\mathcal{A}}$$

Throughput

$$S(A) = n \sum_{i=1}^{\infty} \Pr(1 \text{ tx}|i) \Pr(i) =$$

$$= p\mu A \cdot e^{-(1-q)\mu A} =$$

$$= p\mu A \cdot Q(A).$$

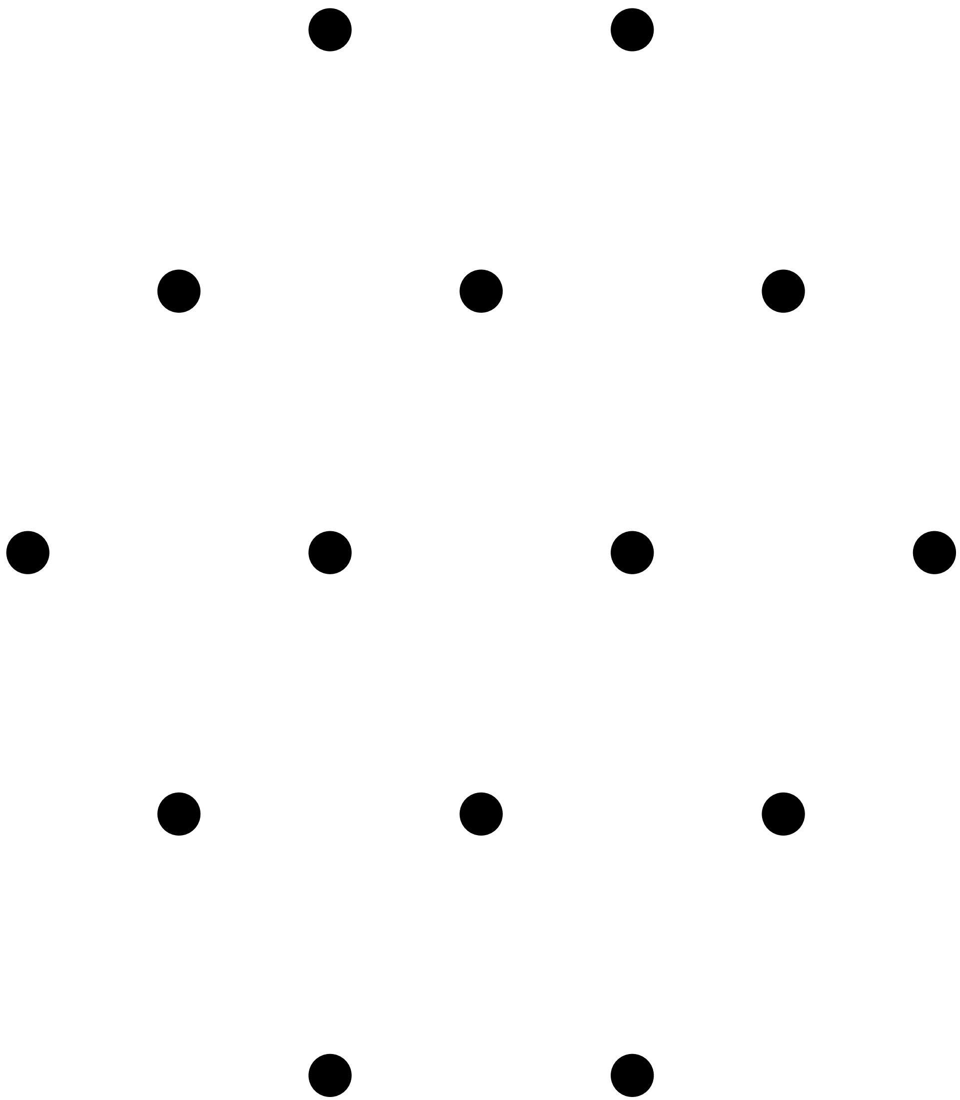
Recall what is q

$$q = (1-p)^m + [1-(1-p)^m] \cdot \left(1 - \frac{1}{n}\right) =$$

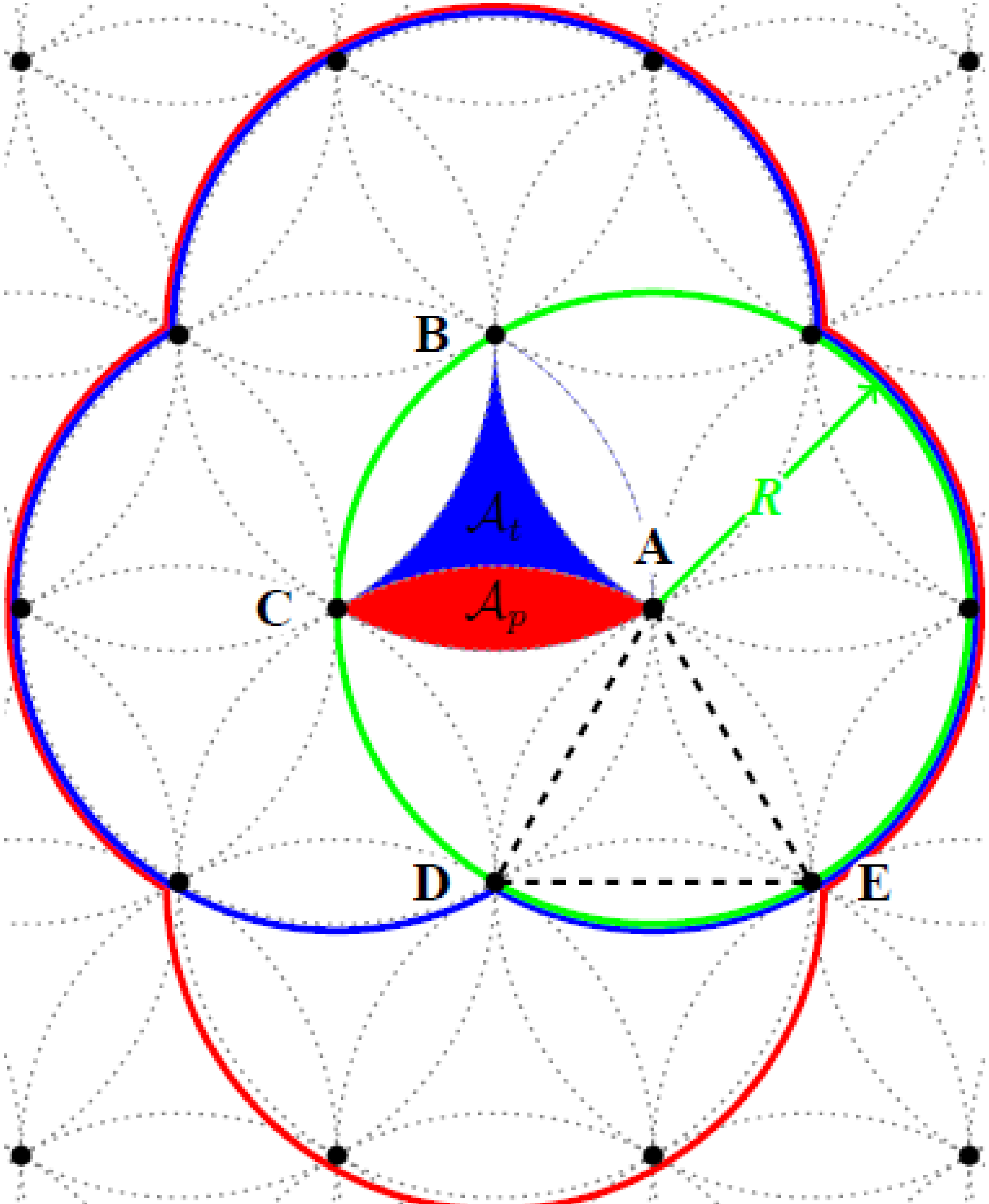
$$= 1 - \frac{1-(1-p)^m}{n}.$$

THROUGHPUT IN LORAWAN NETWORKS

Gateways displacement

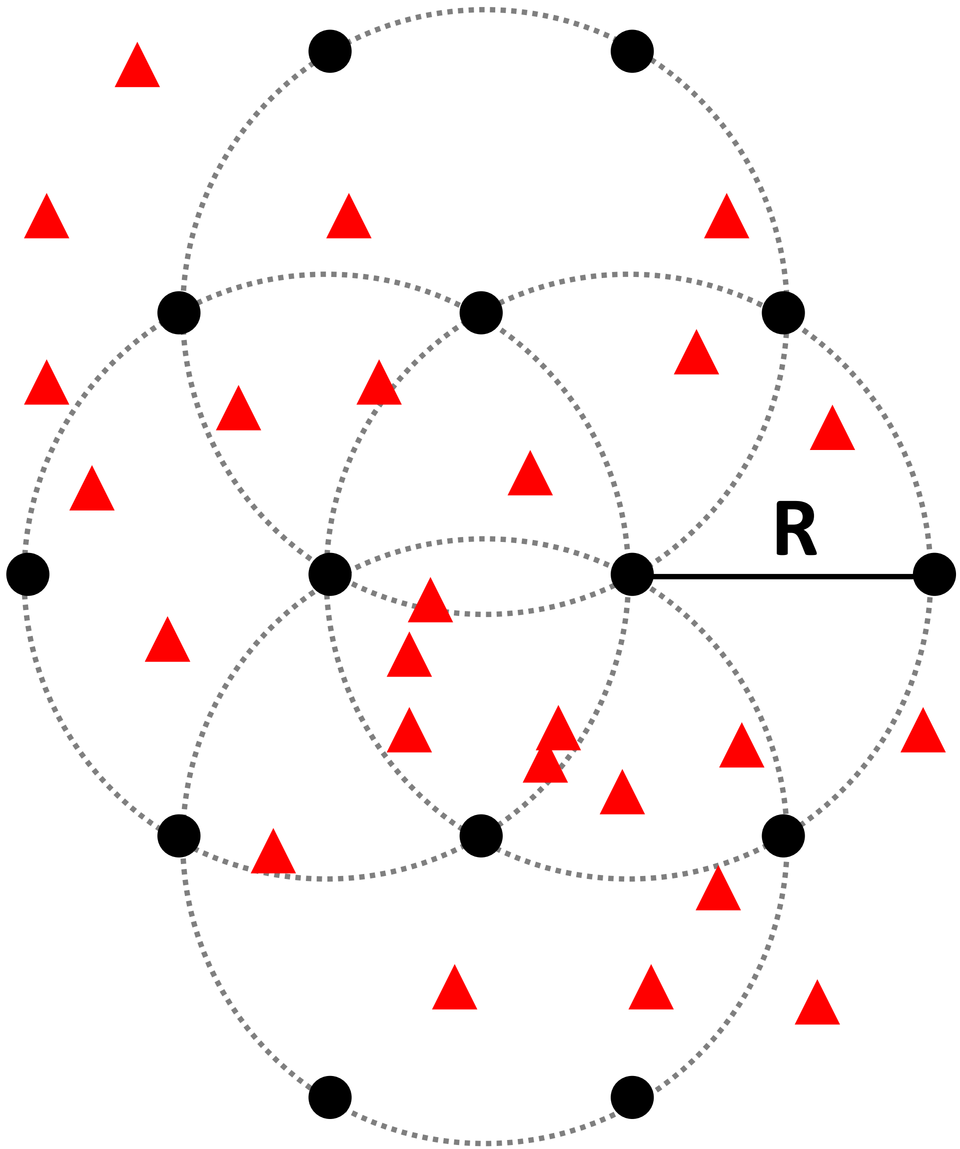


Honeycomb geometry



Any point On the Surface Covered By at least 3 gateways

End devices displacement



Homogeneous Poisson Point Process

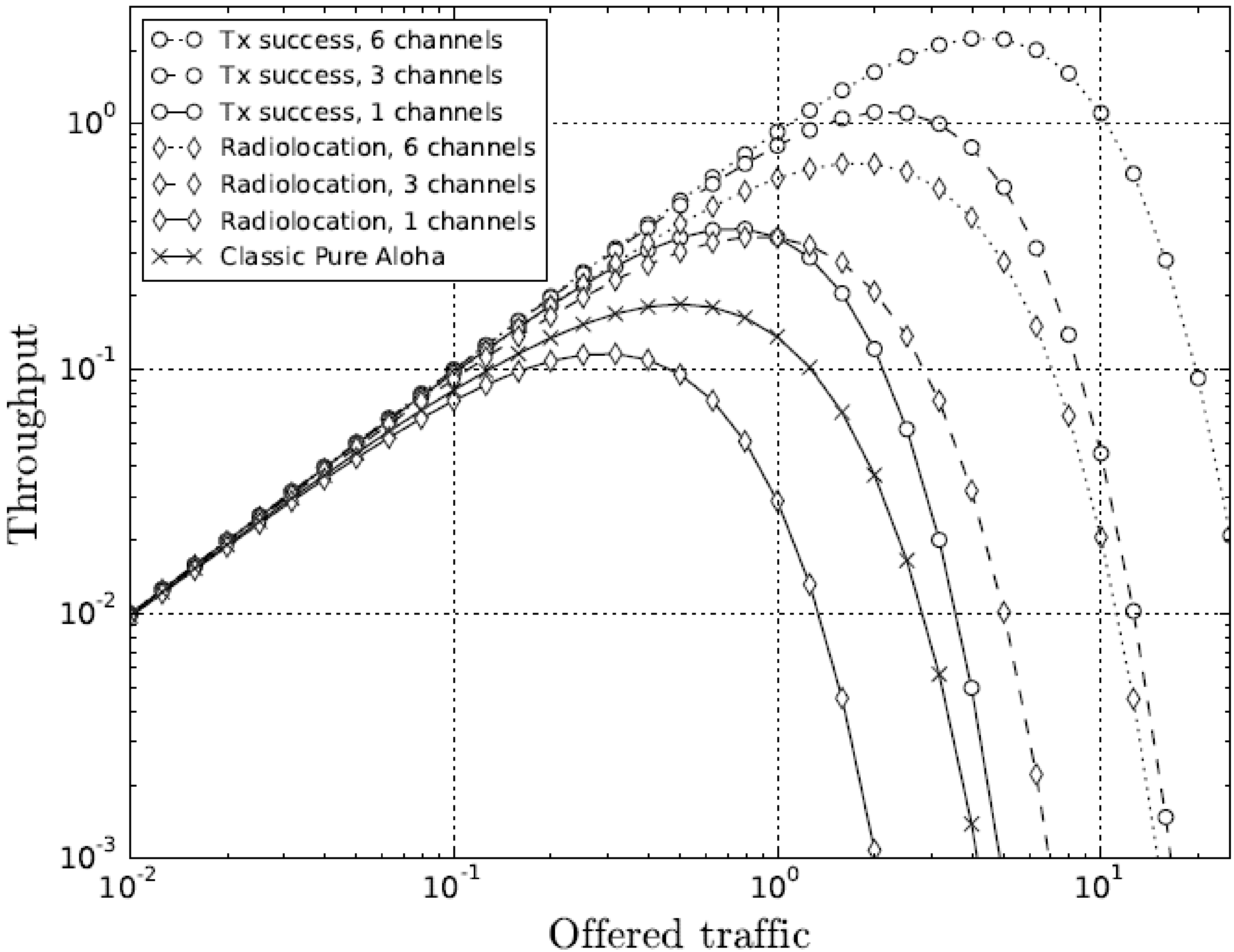
Througput formula

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

Pure Aloha for mode A of LoRaWAN (m = 1)

Radiolocation throughput (at least 3 gateways receiving a packet)

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



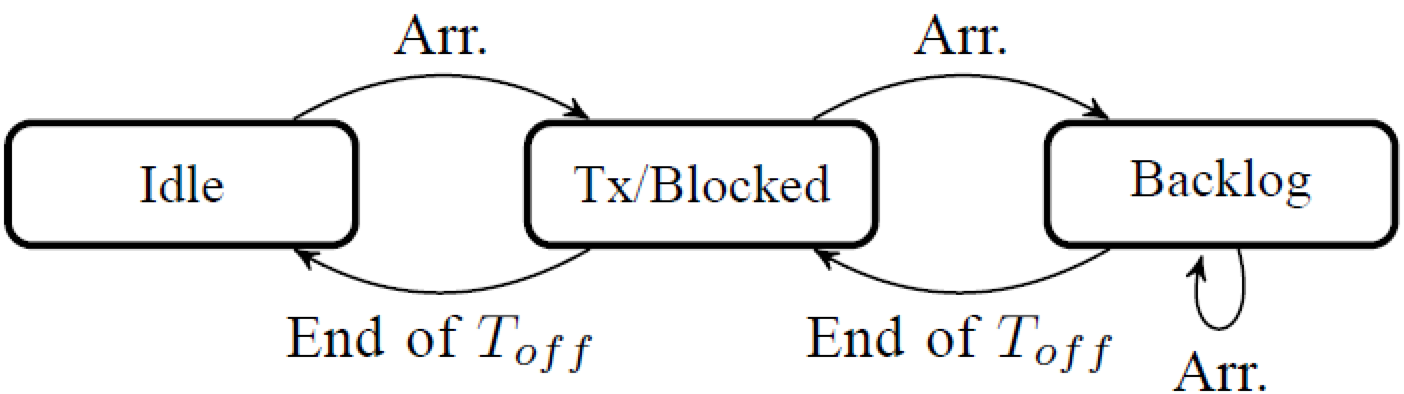
Tx success, 6 channels
Tx success, 3 channels
Tx success, 1 channels
Radiolocation, 6 channels
Radiolocation, 3 channels
Radiolocation, 1 channels
Classic Pure Aloha
10^0
10^{-1}
10^{-2}
10^{-3}
Throughput
10^{-2}
10^{-1}
10^0
10^1
Offered traffic

SIMULATION RESULTS

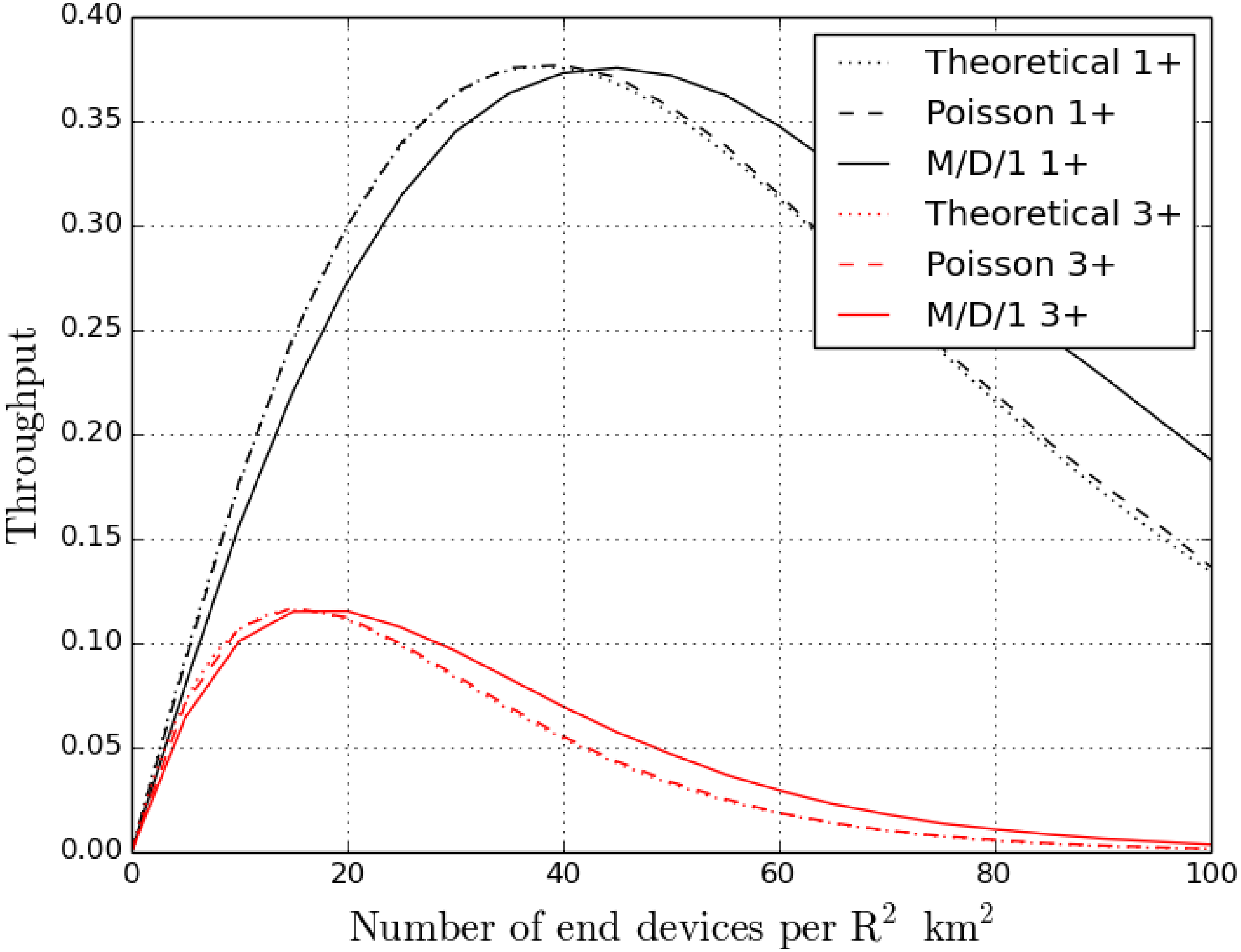
Settings

- Developed **Python simulator**
- Simulated deployment **10x10.3 R^2**
- Duration **1 hour**
- **1 channel** (but simulated also with 3 and 6)
- **1 pkt/min** on average (but simulated also with 1/10 pkt/min and 1/100 pkt/min)

Duty-cycle limitation



A significant plot



QUESTIONS?