

# Outline

1. Introduction

2. State of the art

# Why I started a PhD ?

3 main reasons

- ➡ Research methodology lecture.
- ➡ Bac+5 in networking ? not really !
- ➡ Being paid to study and to develop yourself !

# IoT devices

IoT devices are useless without a good communication capability

Connected devices (billions)



	2016	2022	CAGR
Wide-area IoT	0.4	2.1	30%
Short-range IoT	5.2	16	20%
PC/laptop/tablet	1.6	1.7	0%
Mobile phones	7.3	8.6	3%
Fixed phones	1.4	1.3	0%
	16 billion	29 billion	10%



Figure 1. IoT devices [1].

# IoT applications requirements

Each application has its own communication requirements

Challenges/Applications	Grids	EHealth	Transport	Cities	Building
Resources constraints	✗	✓	✗	-	✗
Mobility	✗	-	✓	✓	✗
<b>Heterogeneity</b>	-	-	-	✓	✗
Scalability	✓	-	✓	✓	-
QoS constraints	-	-	✓	✓	✓
Data management	-	✗	✓	✓	-
Lack of Standardization	-	-	-	-	✓
Amount of attacks	✗	✗	✓	✓	✓
Safety	-	✓	✓	-	✓

Table 1. Main IoT challenges [2] [3]



Figure 2. IoT Applications.

# IoT platforms

IoT platforms is a chain of communication process

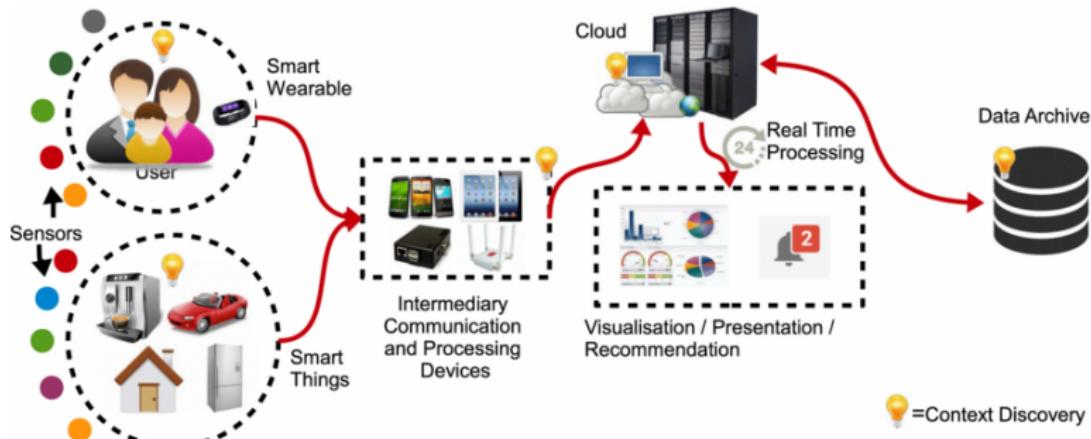


Figure 3. IoT platform.



Figure 4. IoT challenges.

# IoT applications requirements

## Context

Use Case	Packet rate [pkt/day]	Min success rate [Ps,min]	Payload Size [Byte]
Wearables	10	90	
Smoke Detectors	2	90	
Smart Grid	10	90	10-20
White Goods	3	90	
Waste Management	24	90	
VIP/Pet Tracking	48	90	
Smart Bicycle	192	90	
Animal Tracking	100	90	
Environmental Monitoring	5	90	
Asset Tracking	100	90	50
Smart Parking	60	90	
Alarms/Actuators	5	90	
Home Automation	5	90	
Machinery Control	100	90	
Water/Gas Metering	8	90	
Environmental Data Collection	24	90	
Medical Assisted Living	8	90	
Micro-generation	2	90	
Safety Monitoring	2	90	100-200
Propane Tank Monitoring	2	90	
Stationary Monitoring	4	90	
Urban Lighting	5	90	
Vending Machines Payment	100	90	
Vending Machines General	1	90	1K

Table 2. Application requirements for the use cases of interest [4] [3].

# IoT wireless communication

Wireless communication performance need to be evaluated to match applications requirements

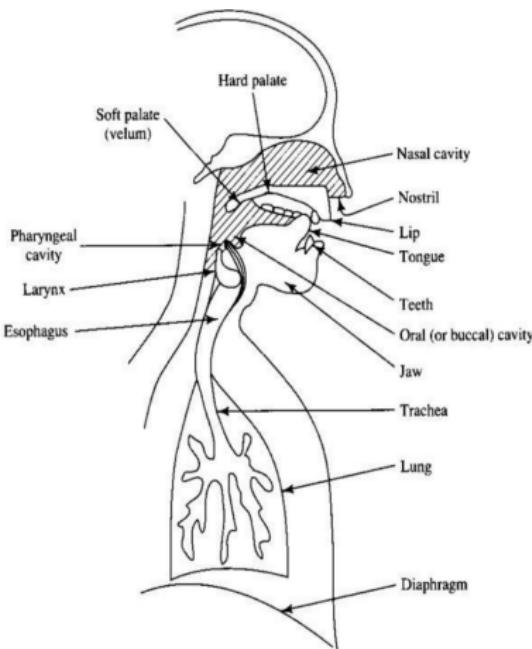


Figure 5. Human voice.

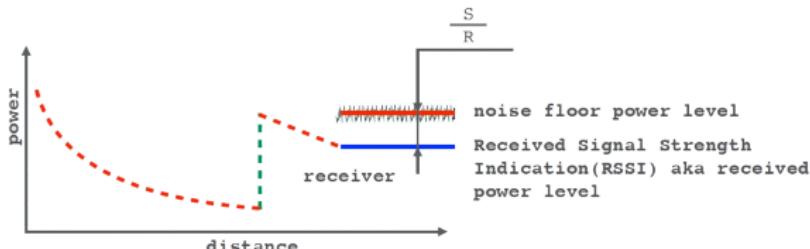


Figure 6. SNR & RSSI.



Figure 7. Time on air.

# Problem statement

## Introduction<sup>2</sup> ?

- ➡ Parameters
  - Bandwidth (*BW*)
  - Spreading Factor (*SF*)
  - Coding Rate (*CR*)
  - Transmission Power (*Tx*)
- ➡ Metrics
  - Receiver Sensitivity (*RS*)
  - Signal Noise Rate (*SNR*)
  - Data Rate (*DR*)
  - Air Time (*AT*)
  - Payload length (*PktL*)

Setting	Values	Rewards	Costs
<i>BW</i>	7.8 → 500kHz	<i>DR</i>	<i>RS, Range</i>
<i>SF</i>	$2^6 \rightarrow 2^{12}$	<i>RS, Range</i>	<i>DR, SNR, PktL, Tx</i>
<i>CR</i>	4/5 → 4/8	Resilience	<i>PktL, Tx, AT</i>
<i>P<sub>tx</sub></i>	-4 → 20dBm	<i>SNR</i>	<i>Tx</i>

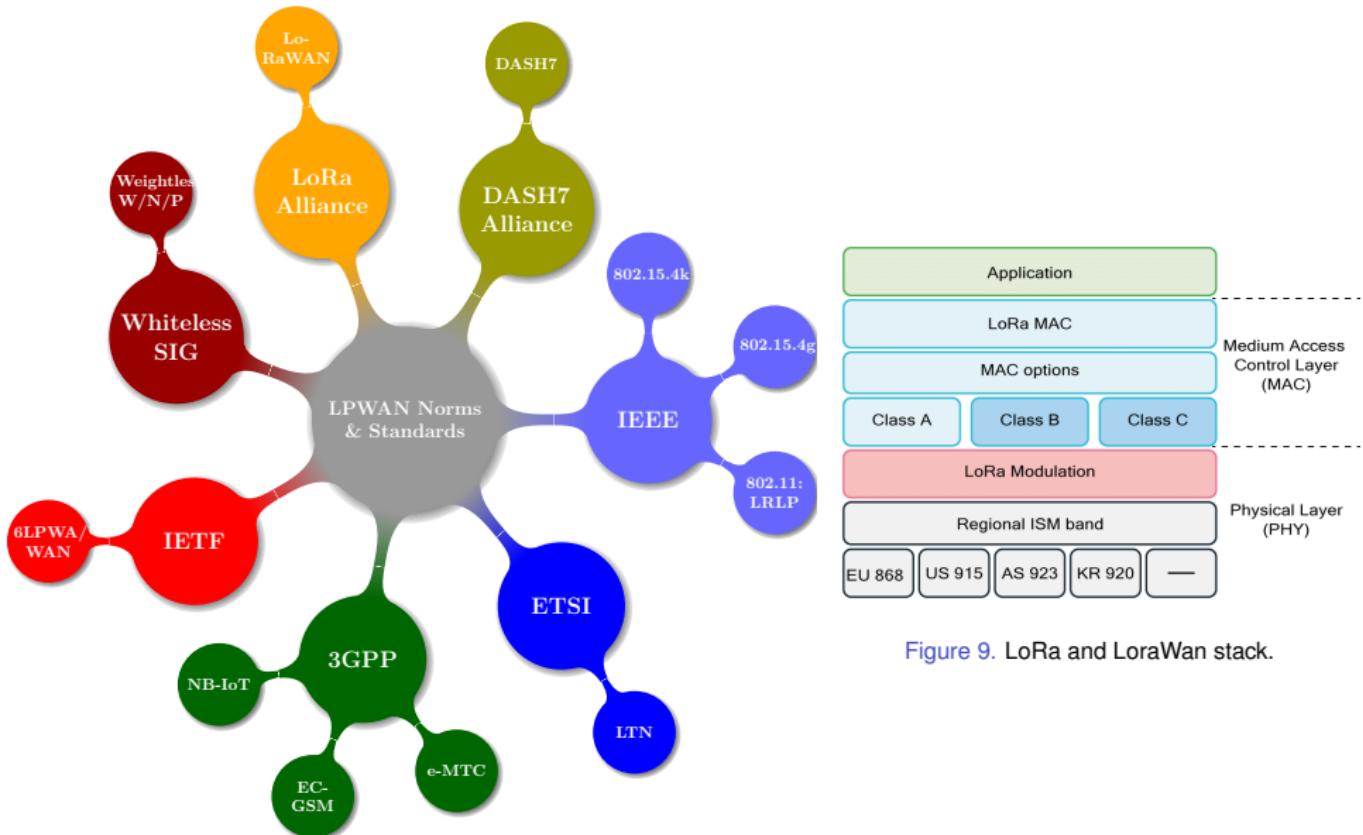
Table 3. <sup>1</sup>

<sup>1</sup>M. Cattani, C. Boano, and K. Römer, " An Experimental Evaluation of the Reliability of Lora Long-Range Low-Power Wireless Communication ", *Journal of Sensor and Actuator Networks*, vol. 6, no. 2, p. 7, 2017, 00042.

<sup>2</sup>dimartino\_internet\_2018.

# IoT wireless communication

Exp: LPWAN in a new technology that satisfy IoT applications requirements



# Problematic

One size fits all problem: 1) Many configurations, 2) Diversity of service requirements

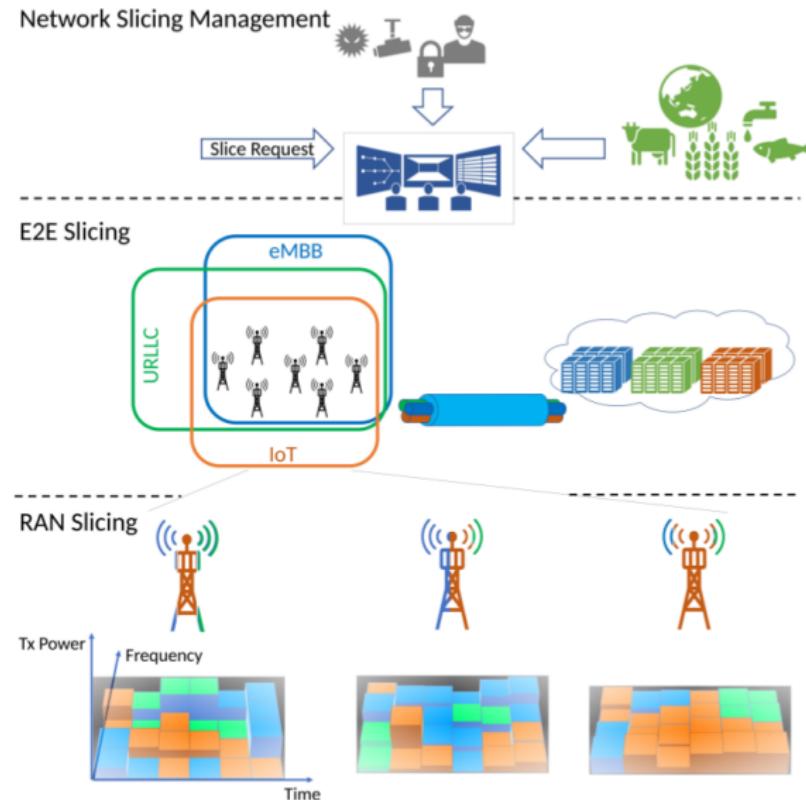


Figure 10. Key barriers in adopting IoT in the industry [6].

# Problematic

One size fits all problem: 1) Many configurations, 2) Diversity of service requirements

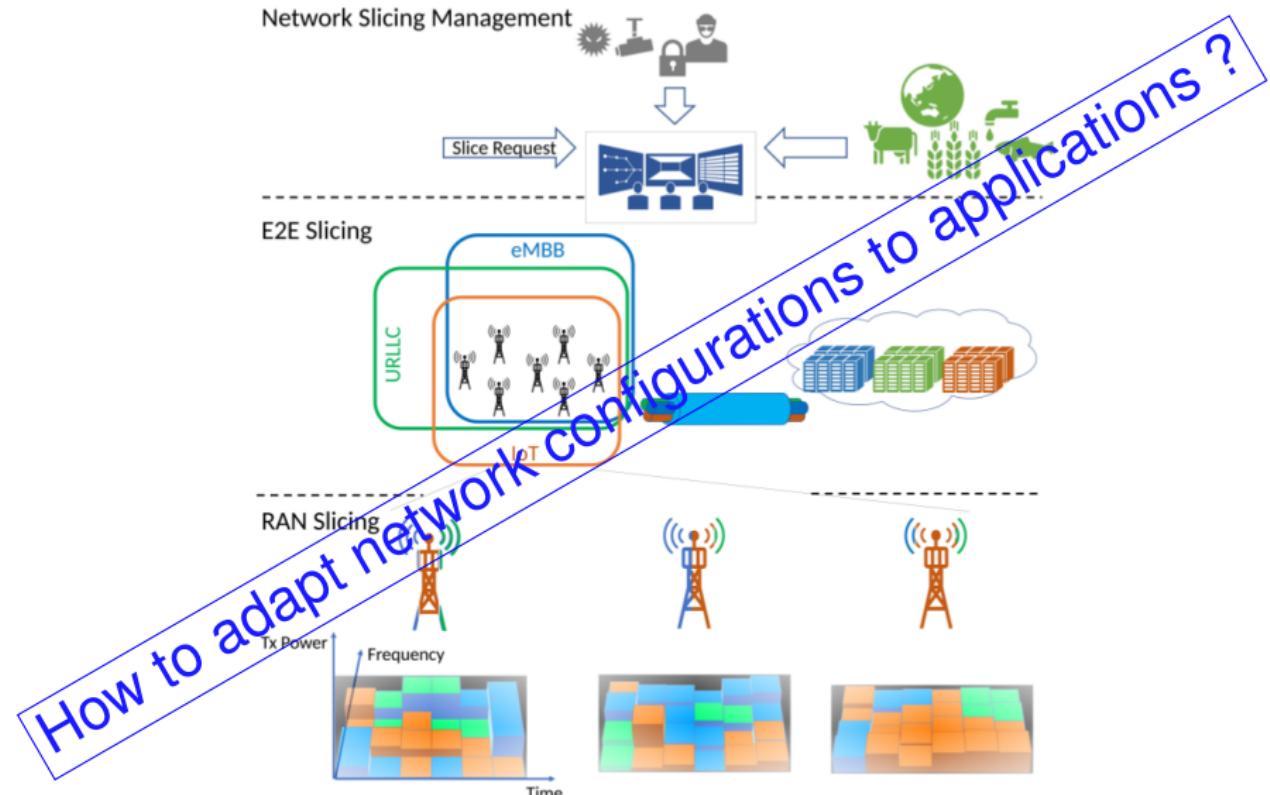


Figure 10. Key barriers in adopting IoT in the industry [6].

# Problematic

Where is the problem ?

- ➡ Some network configuration are static and not adaptive to the application
  - Decision and optimisation problem..
  - Various network access
  - Various configuration of each network access
  - Lack of selection tools
- ➡ Users have to select the network and the application
  - How to select the **best** network.
  - How to select the network required by the application.

# End-to-end Network slicing

Exp: 4G/5G, Content provider (GAFA) want to be directly connected to users devices

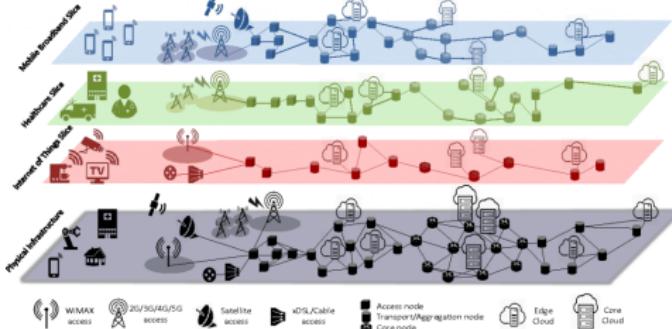


Figure 11. Network slicing [6].

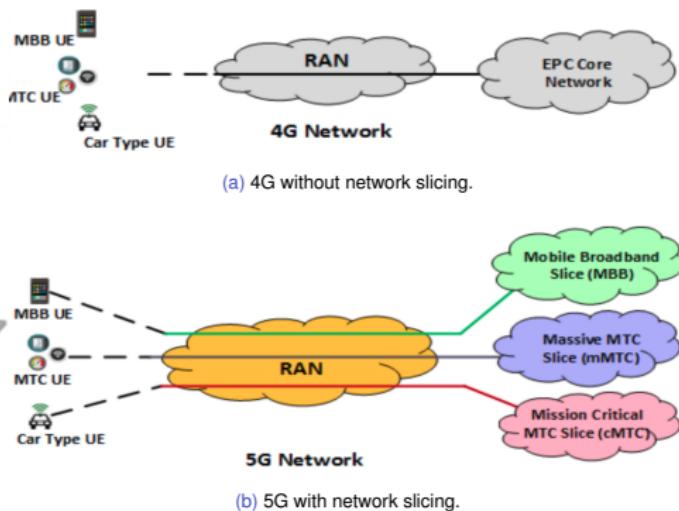


Figure 12. Network slicing concept sama\_servicebased\_2016.

# Conclusion

In the future, network administration function will disappear and will be replaced by a slice orchestrator

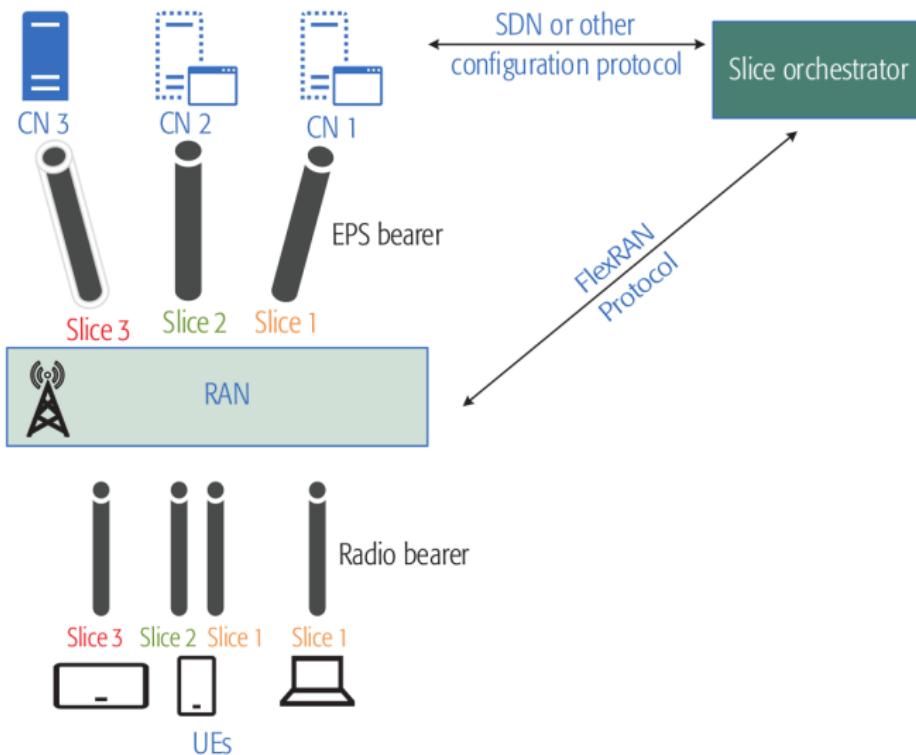


Figure 13. Slice orchestrator [7].

# Conclusion

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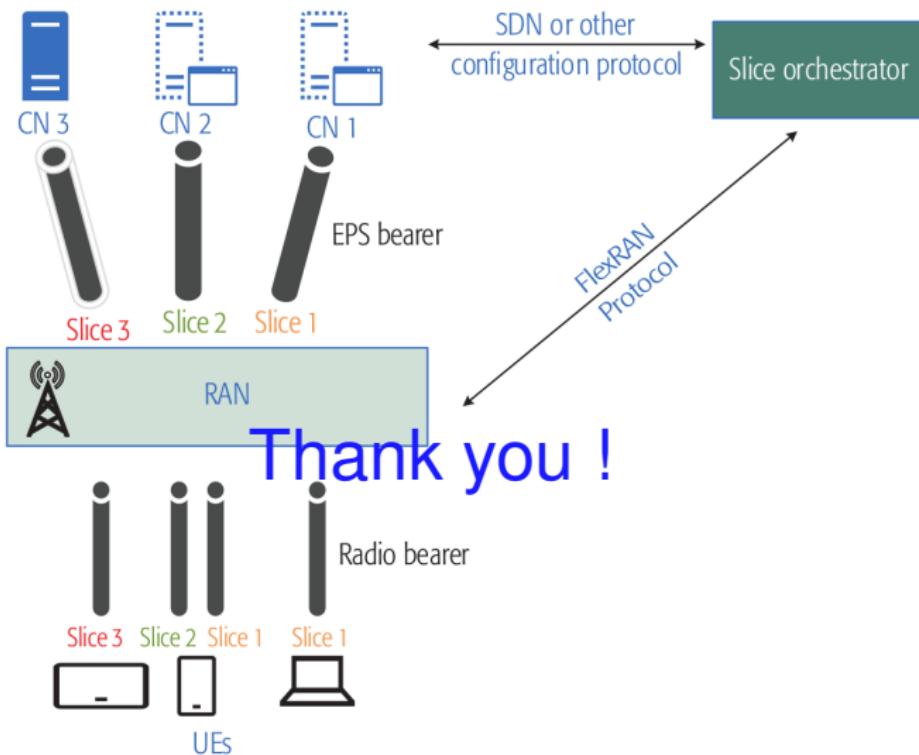


Figure 13. Slice orchestrator [7].

# Contribution

## Contributions

- **3 Applications**

- Voice, Images and Text transmission.

- **3 Environment conditions**

- Rural/Urban
  - Static/Mobile
  - Temperature

- **6 Scenarios**

- Application protocol (MQTT, COAP, XMPP)
  - Network protocol (Star, Mesh)
  - MAC protocol (LoraWan, Sigfox, ...)

- **6 algorithms**

- ..
  - ..
  - ..

- **Inputs:**

- QoS metrics:
    - ★ User metrics: Cost
    - ★ Network metrics: Receiver sensitivity, SNR, DR, Air time, Payload length.

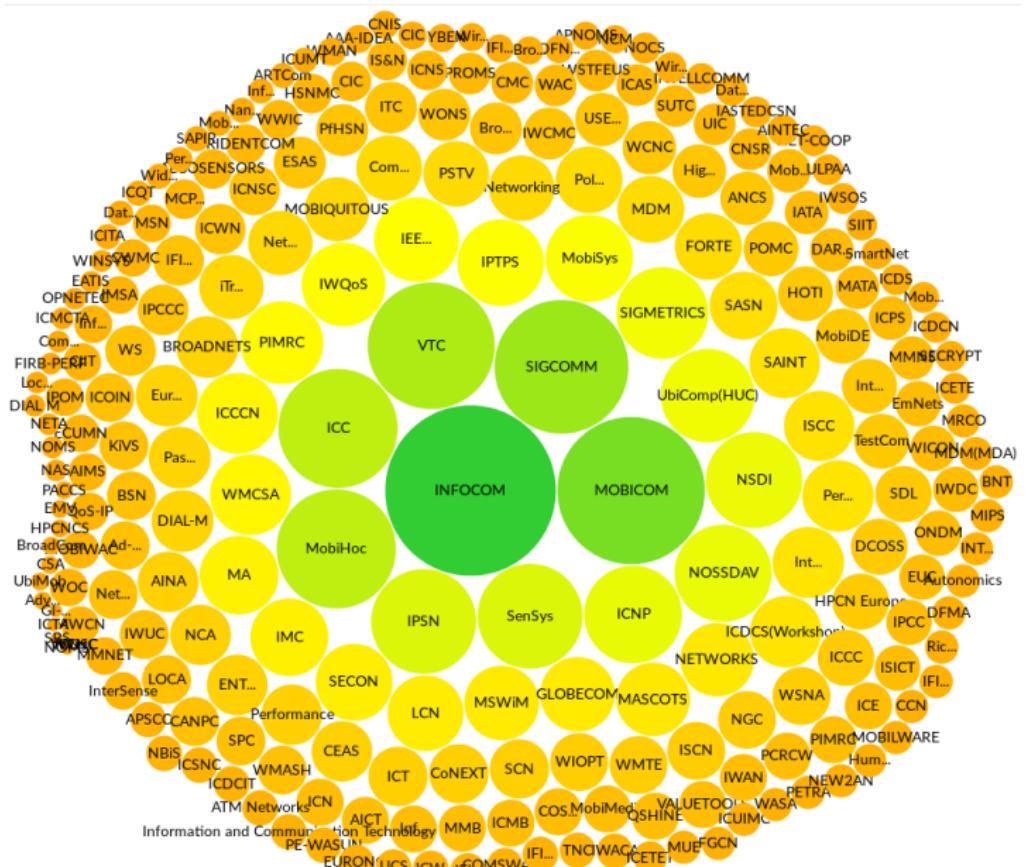
- MAC configuration (SF, CR, BW, Tx)

- **Outputs:**

- $(SF_i, CR_j, BW_k, Tx_l)$

## Contribution

## Contributions



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6. Matching Theory
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$$Q_{n,m} = \begin{pmatrix} & Metric_1 & Metric_2 & \dots & Metric_m \\ Configuration_1 & q_{11} & q_{12} & \dots & q_{1m} \\ Configuration_2 & q_{21} & q_{22} & \dots & q_{2m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ Configuration_n & q_{n1} & q_{n2} & \dots & q_{nm} \end{pmatrix}$$

$$ETC_{ij} = \begin{pmatrix} & Metric_1 & Metric_2 & \dots & Metric_m \\ Metric_1 & ETC_{11} & ETC_{12} & \dots & ETC_{1m} \\ Metric_2 & ETC_{21} & ETC_{22} & \dots & ETC_{2m} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ Metric_n & ETC_{n1} & ETC_{n2} & \dots & ETC_{nm} \end{pmatrix}$$

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# Multi-Armed-Bandit Algorithm

## Related work

- ➡ Arms:  $K = 1, \dots, K$
- ➡ Decision:  $T = 1, \dots, T$
- ➡ Reward:  $X_t^k$  with  $\mu_t^k = E [X_t^k]$ 
  - ➡ Best reward:  $X_t^*$  with  $\mu_t^* = \max \mu_t^k, k \in K$

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# Genetic Algorithm

Related work [alkhawlani\\_access\\_2008a](#)

- ➡ **N** transceiver configurations:  $(x_1, \dots, x_n)$
- ➡ **I** QoS metrics  $(m_1, \dots, m_i)$ . ex: the operators, the applications, and the network conditions.
- ➡ **I** weights  $(w_1, \dots, w_i)$  are sent to the MCDM in the second component.
- ➡ GA component assigns a suitable weight  $(w_1, w_2, \dots, w_i)$

# Genetic Algorithm

Related work

## Evaluation function

Define the number of parameters

{SF, Tx, CR, BW}

Define the target QoS

{RSSI, SNR, delay, PDR, RTD}

Define evaluation function

Score(SF, Tx, CR, BW) -> {RSSI, SNR, delay, PDR, RTD}

## Parameters

Define a population of individuals (solutions)

6720

Define probabilities of crossing and mutating

0.5, 0.2

Define the number of generations

60

## Generations

Select individuals randomly

$\{SF_i, Tx_i, CR_i, BW_i\}^{random}$

Clone, crossover and mutate this individuals

$\{SF_{i+1}, Tx_{i+1}, CR_{i+1}, BW_{i+1}\}^{random}$

Evaluate the offspring with an invalid Fitness

Score( $SF_{i+1}, Tx_{i+1}, CR_{i+1}, BW_{i+1}$ )

## (Crossover, Mutation)

Remove some bad solutions

Duplicate some good solutions

Make small changes to some of them

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# Q Learning

## Related work

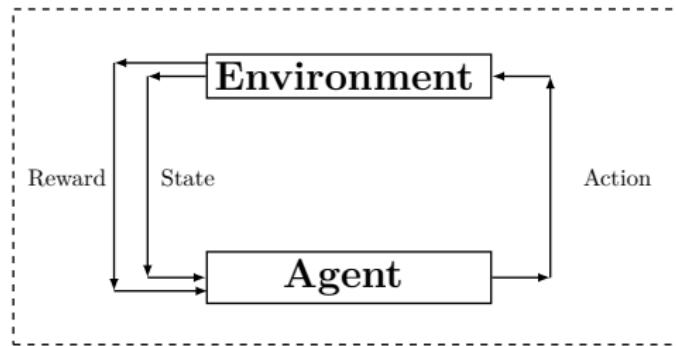


Figure 15. qlearning.

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# Marcov chain

## Related work

$$V(s, \pi) = \mathbb{E}_s^\pi \left( \inf_{k=0}^{\infty} \gamma^k \cdot r(s_k, a_k) \right), s \in \mathbb{S} \quad (1)$$

$$r(s_k, a_k) = G_k \cdot PRR(a_k) \quad (2)$$

$$\pi^* = \arg \max_{\pi} V(s, \pi) \quad (3)$$

$$PRR = (1 - BER)^L \quad (4)$$

$$BER = 10^{\alpha e^{\beta SNR}} \quad (5)$$

# Marcov chain

## Related work

Learning iterative steps:

- ➡ **Choose** action  $a_k(t) \sim \pi_k(t)$
- ➡ **Observe** game outcome

- ➡  $a_{-k}(t)$
- ➡  $u_k(a_k(t), a_{-k}(t))$

- ➡ **Improve**  $\pi_k(t+1)$

Thus, we can expect that  $\forall k \in K$

$$\pi_{k(t)} \xrightarrow{t \rightarrow \infty} \pi_k^* \quad (6)$$

$$u_k(\pi_k(t), \pi_{-k}(t)) \xrightarrow{t \rightarrow \infty} u_k(\pi_k^*, \pi_{-k}^*) \quad (7)$$

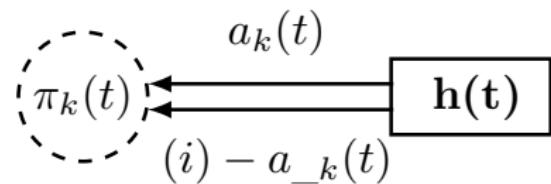


Figure 16. .

Where:

- ➡  $\pi^* = (\pi_1^*, \dots, \pi_k^*)$  is the NE strategy profile

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# Fuzzy Logic

Related work

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# Notations

Related work

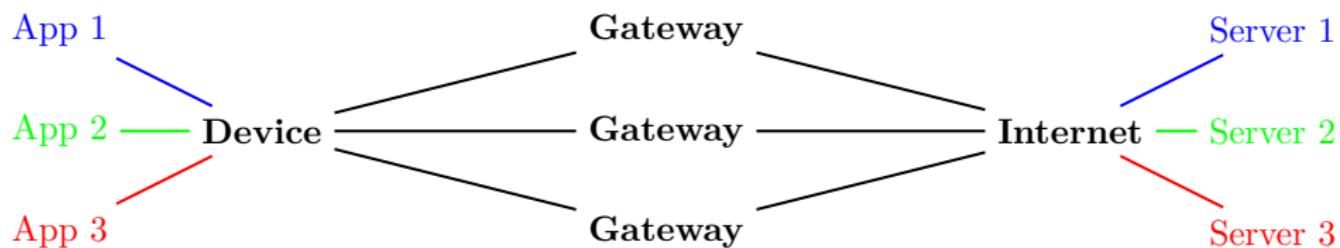


Figure 17. Network selection problem.

# Notations

## Related work

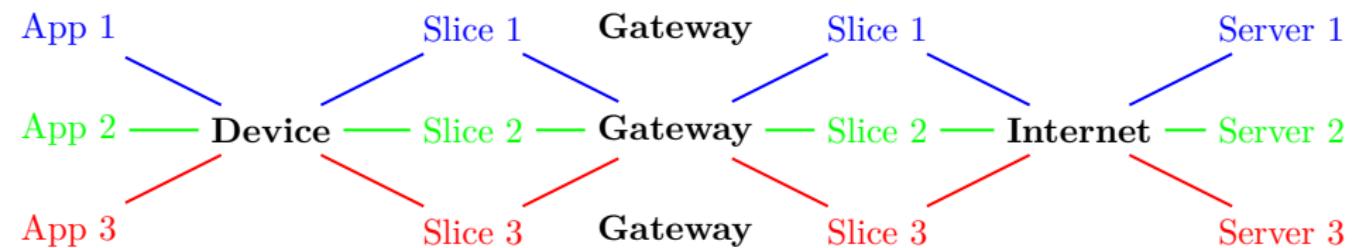


Figure 18. Slice orchestration problem.

# Notations

## Related work

### Set of devices, slices, gateways and flows

$G$  set of LoRa Gateways

$S$  set of Slices

$D_s$  cluster of devices associated to slice s

### Parameters

$F_c$  packets with SF = c

$BW_{s,g}$  bandwidth assigned for slice s over GW g

$P_g^{Tx}$  transmission power of GW g

### Constants

$i_{d,s}$  association index of device d to slice s

$i_{d,g}$  association index of device d to GW g

$w_d$  urgency factor for device d

$w_s$  priority of slice s

$w_r$  weight of reliability

$w_{ld}$  weight of load

### Metrics

$DR_{d,s,g}$  data rate achieved by a device d

$SINR_{i,j}$  SINR with SF=i and SF=j

$G_{d,g}^{tx}$  power gain between a GW g and a device d

$S_{d,s,g}^{rx}$  Receiver sensitivity

$RTD_d$  instant packet delay for device d

$PLR_d$  packet loss rate of device d

$U_{d,s,g}$  utility for device d in slice s on GW g

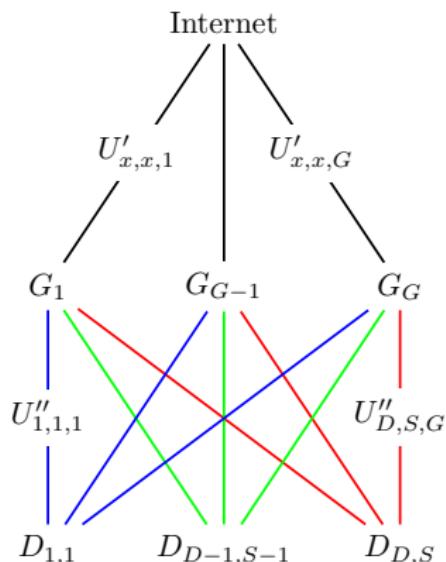


Figure 19. Slicing.

# Utility function

## Related work

- ➡  $\mathbf{G} = \{1, \dots, G\}$ : Set of gateways
- ➡  $\mathbf{S} = \{1, \dots, S\}$ : Set of slices
- ➡  $\mathbf{D} = \{1, \dots, D\}$ : Set of devices
- ➡  $\mathbf{D}_s = \{1, \dots, D_s\} \in \mathbf{D}$  : Cluster of devices in slice s
- ➡  $\mathbf{F}_{d,s,g} = \{1, \dots, D_s\}$  : Virtual flow for device d in slice s through GW g
  
- ➡  $i_{d,s} \in \{0,1\}$  Association index of device d to slice s
- ➡  $i_{d,g} \in \{0,1\}$  Association index of device d to GW g
  
- ➡  $w_d \in [0,1]$  Urgency factor for device d
- ➡  $w_s \in [0,1]$  Priority of slice s
- ➡  $wr \in [0,1]$  Weight of the impact of reliability (SINR)
- ➡  $wld \in [0,1]$  Weight of the impact of load (congestion)

# Utility Function

## Related work

$$\sigma_r = SINR_{d,s,g} / SINR_{max}$$

$$U_{HCC} = \delta_r (\sigma_r w_r + \sigma_{Id} w_{Id}) \quad \text{with} \quad \delta_r \in \{0, 1\}$$

$$U_{MCC} = \sigma_r w_r + \sigma_{Id} w_{Id}$$

$$U_{LCC} = \sigma_{Id} w_{Id}$$

$$U_{d,s,g} = U'_{d,s,g} + U''_{d,s,g}$$

$$E_{d,s,g} = \frac{P_i^{tx} + P_j^{rx}}{V + epa} \cdot d_{tx/rx}$$

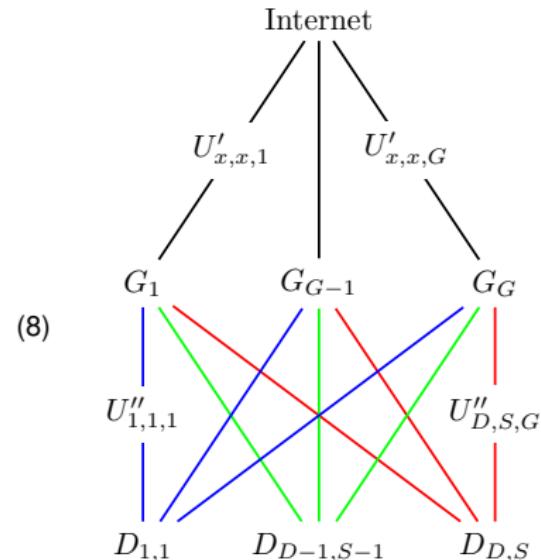


Figure 20. Slicing.

# BIRCH: Clustering

balanced iterative reducing and clustering using hierarchies

T: max number of device per cluster,

B: max number of children per cluster.

$t_0$ : number of clusters = number of devices;

$t_i$ : get D2 the set of closest devices to cluster D1

    → if  $D1+D2 < T \rightarrow$  merge

    → else if  $D2 < B \rightarrow$  create sub-cluster D2 of D1

$$CF : (D_s, LS, SS) = \left( D_s, \sum_{d=1}^{D_s} w_d, \sum_{d=1}^{D_s} w_d^2 \right) \quad (9)$$

# Constraints/Hypothesis

## Related work

$$\max \sum_{d \in D} \sum_{s \in S} i_{d,s} \cdot U_{d,g,s} \quad , g \in G \quad (10)$$

$$C1 : \sum_{s \in S} i_{d,s} = 1, \forall d \in D$$

$$C2 : \sum_{d \in D} i_{d,g} \cdot P_{d,s,g}^{tx} \leq P_g^{tx \ max}, \forall g \in G, \forall s \in S$$

$$C3 : \sum_{d=1}^N i_{d,s} \cdot i_{d,g} \cdot DR_{d,s,g} \leq BW_{s,g}, \forall s \in S, \forall g \in G$$

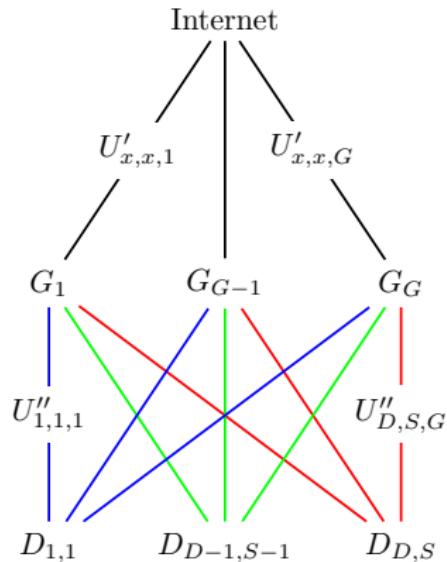


Figure 21. Slicing.

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# Game theory

## Related work

- **Players:**  $K = \{1, \dots, K\}$
- **Strategies:**  $S = S_1 \times \dots \times S_K$ 
  - ⇒  $S_k$  is the strategy set of the  $k^{\text{th}}$  player.
- **Rewards:**  $u_k : S \rightarrow R_+$  and is denoted by  $r_k(s_k, s_{-k})$ 
  - ⇒  $s_{-k} = (s_1, \dots, s_{k-1}, s_{k+1}, \dots, s_K) \in S_1 \times \dots \times S_{k-1} \times S_{k+1} \times \dots \times S_K$

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## Discussion

- ➡ a
- ➡ b

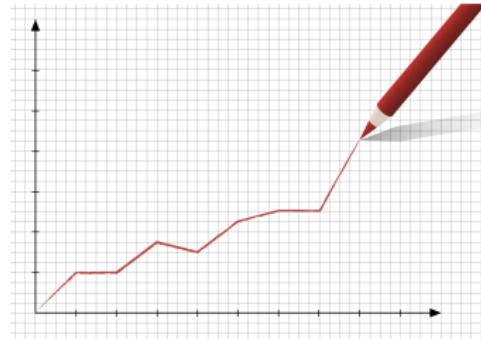


Figure 22. .

# References

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