Multi-Criteria Selection and Configuration of IoT Network Technologies

Public PhD Defense

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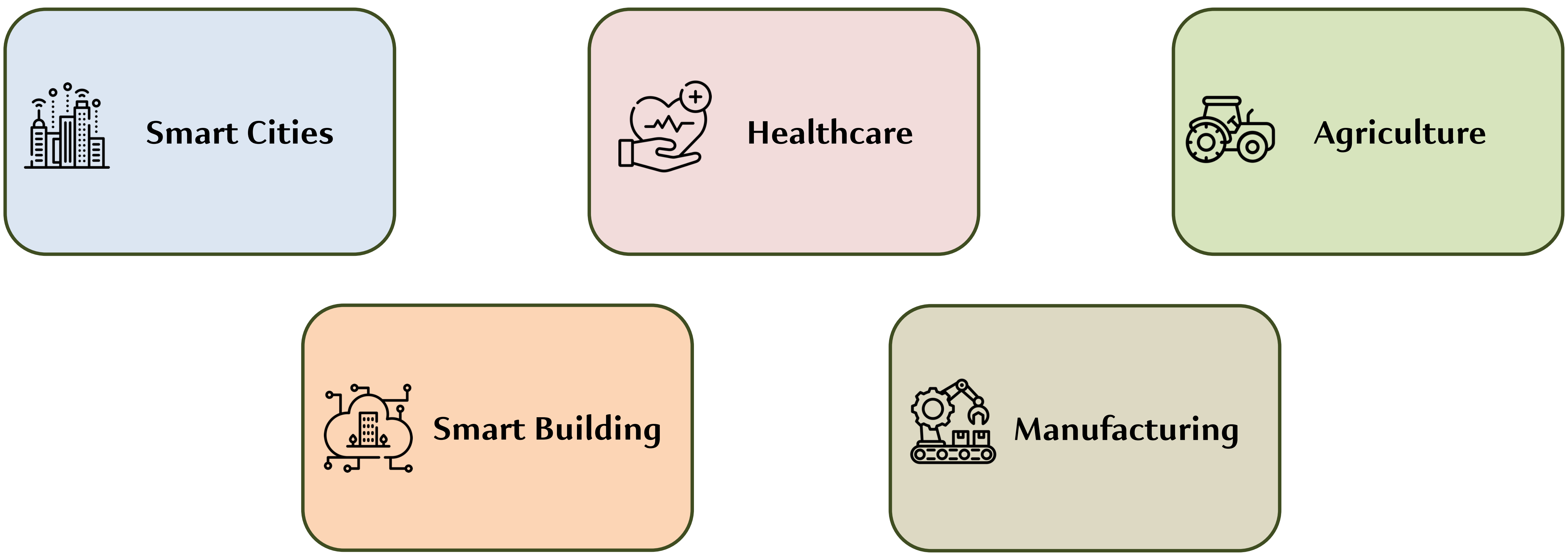
IoT Ecosystem

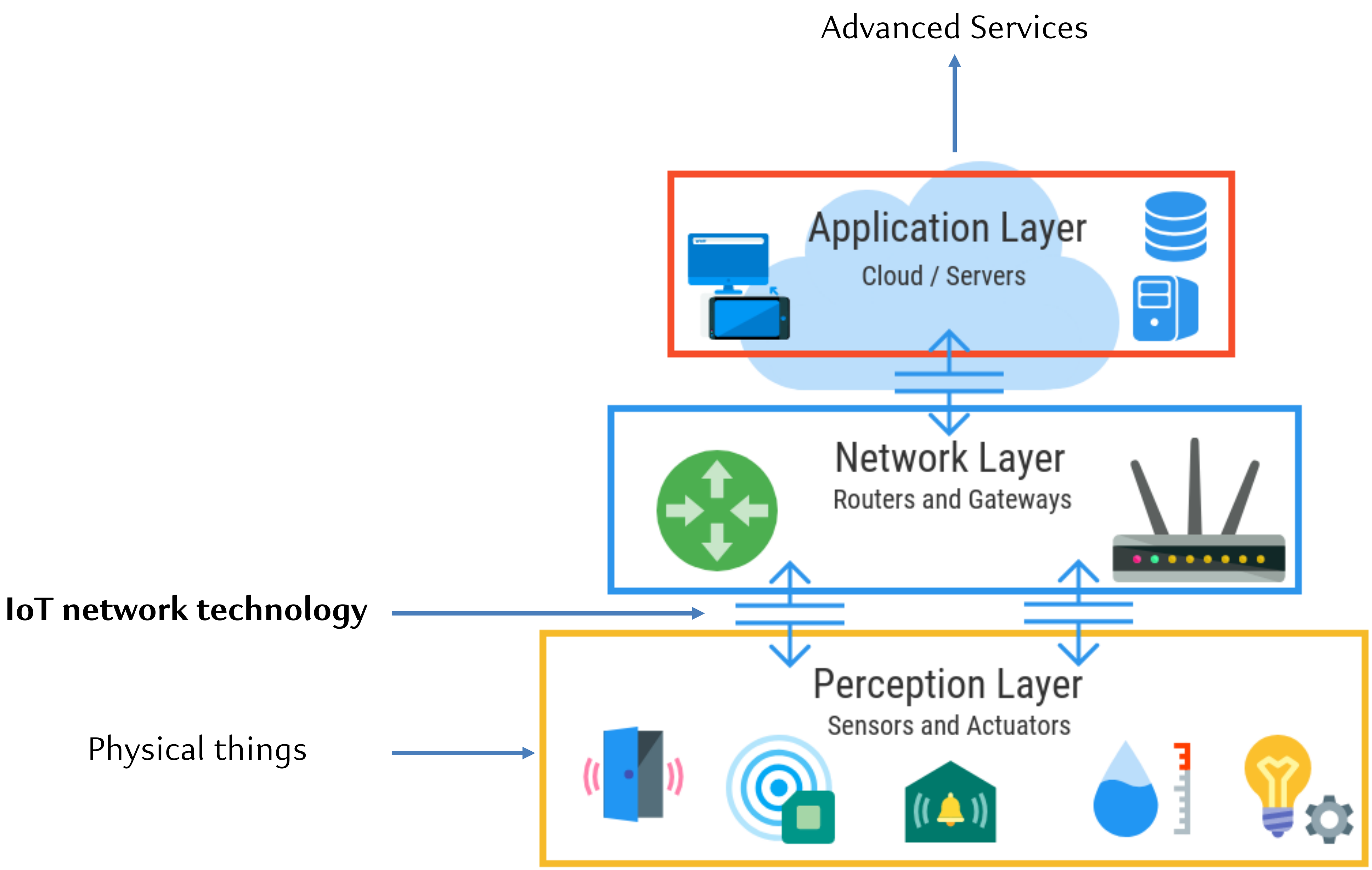
- « Internet of Things is a global infrastructure enabling advanced services by interconnecting (physical and virtual) things based on network technologies » [1]
- Main impacted sectors:



[1] Biggs, Philippa, et al. "Harnessing the Internet of Things for global development." ITU (2016).

IoT Solution Architecture

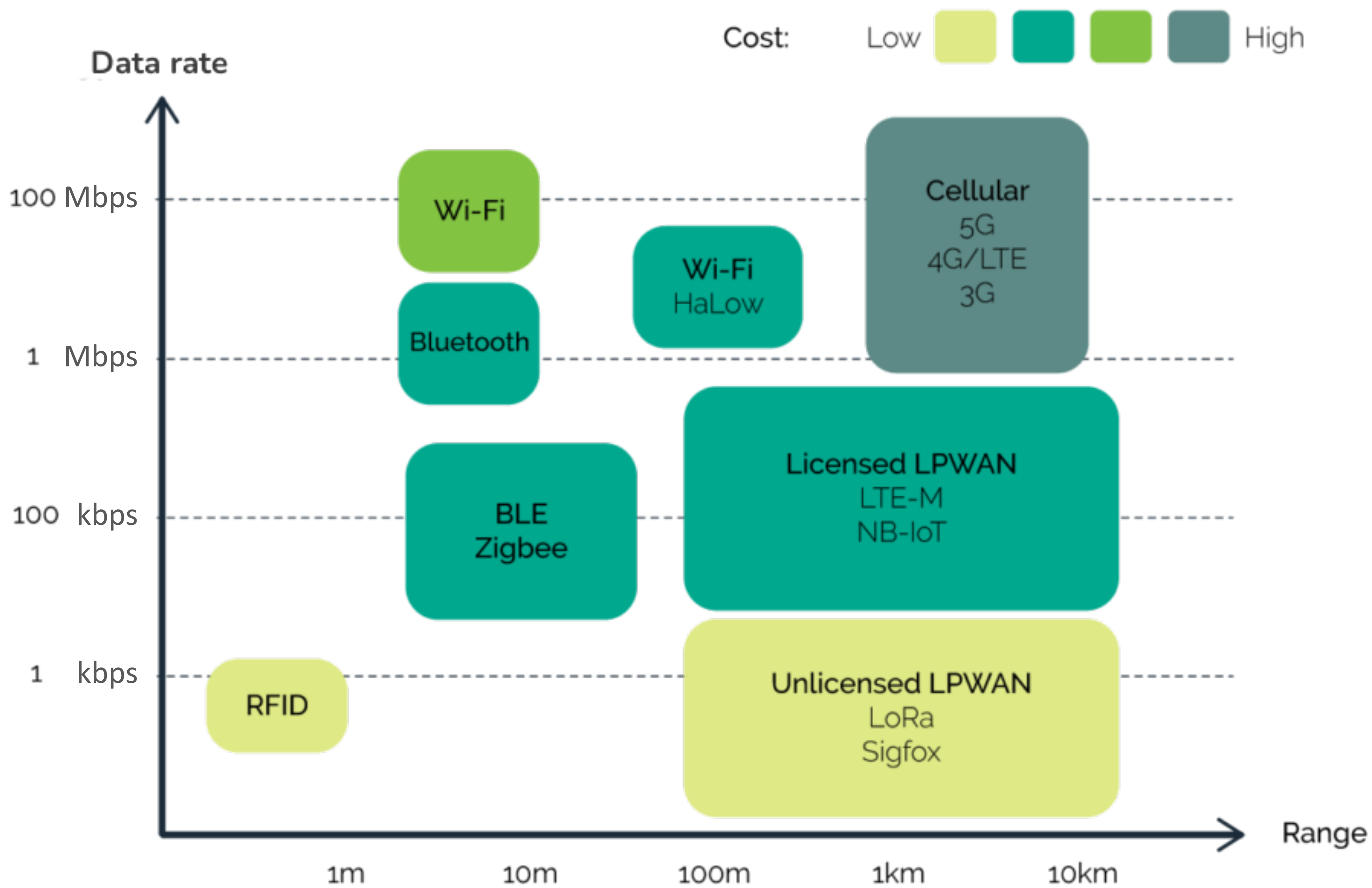
- Typical IoT solution architecture [2]:



[2] Abu Al-Haija, Qasem, et al. "An Efficient Deep Learning-based Detection and Classification System for Cyber-attacks in IoT Communication Networks." Electronics (2020)..

IoT Network Technologies

- Multiple available network technologies*:

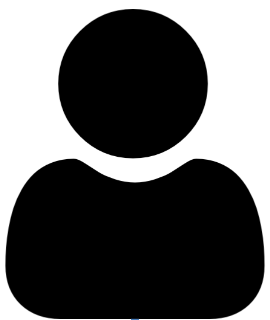


❖ **It is challenging to select the right network technology and configuration for an IoT solution**

(*) https://embeddedams.nl

Illustrative Example: Smart Building

IoT Architect



End-user Objectives:

- **Real-time monitoring (energy consumption, occupancy, temperature, etc.)**
- Optimize energy consumption
- Enhance occupants comfort

?

Decisions to be made for designing the IoT solution:

- Which IoT sensors to collect relevant data?
- How will user privacy be safeguarded?
- How much traffic will be needed?
- What are the IoT solution's requirements (latency, reliability, etc.)?
- **What network technology (communication protocol) should be used? How should it be configured?**
- ...

Outline

- Introduction
- **Contribution 1:** IoT Network Technologies Evaluation
- **Contribution 2:** IoT Network Technologies Selection & Configuration
- **Contribution 3**: Addressing the Limits of Simulation
- **Contribution 4:** IoT Network Technologies No-Code Simulation
- **Conclusion**

Contribution 1

IoT Network Technologies Evaluation

Problem Statement

Objective: Analyze the performance of a network technology for an IoT application

- IoT application = Adaptation of an IoT solution in a given context

- **Different aspects to consider:**

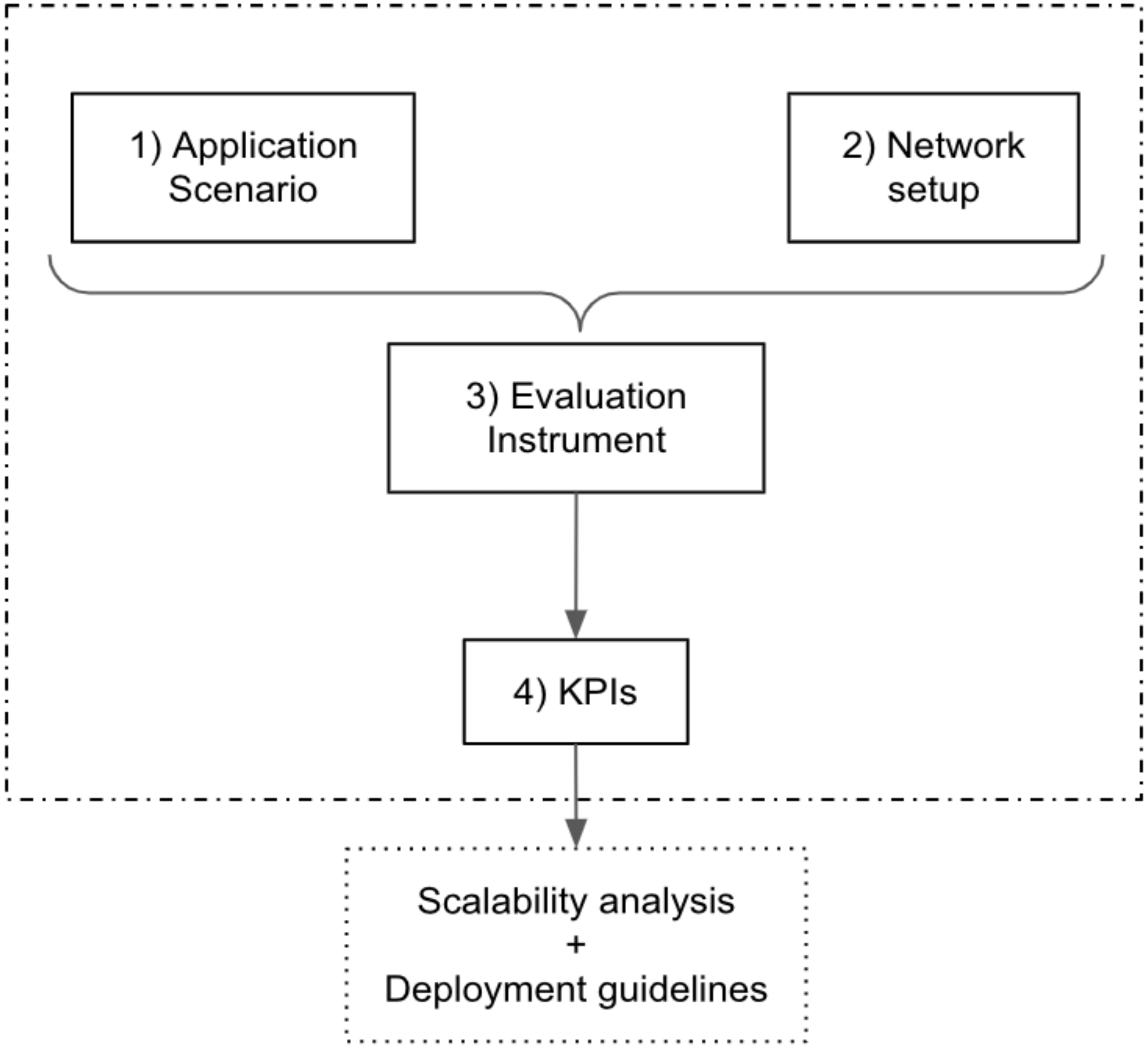
1. IoT applications can be defined by several parameters
2. Network technologies can be configured in different ways
3. Network technologies can be evaluated using several approaches
4. The performance of a network technology can be measured using different metrics

❖ Most works in the SOTA [3-6] neglect important parameters in the evaluation (application model, network configuration, KPIs, etc.)

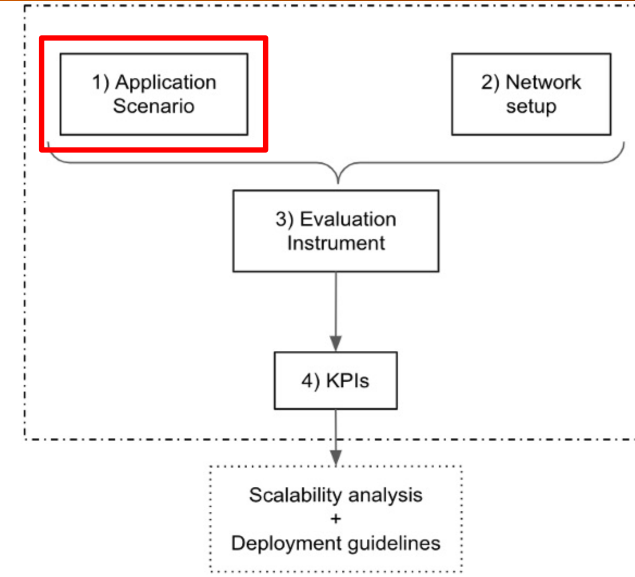
➢ **Can we propose a holistic approach to analyze the match between a network technology and an IoT application?**

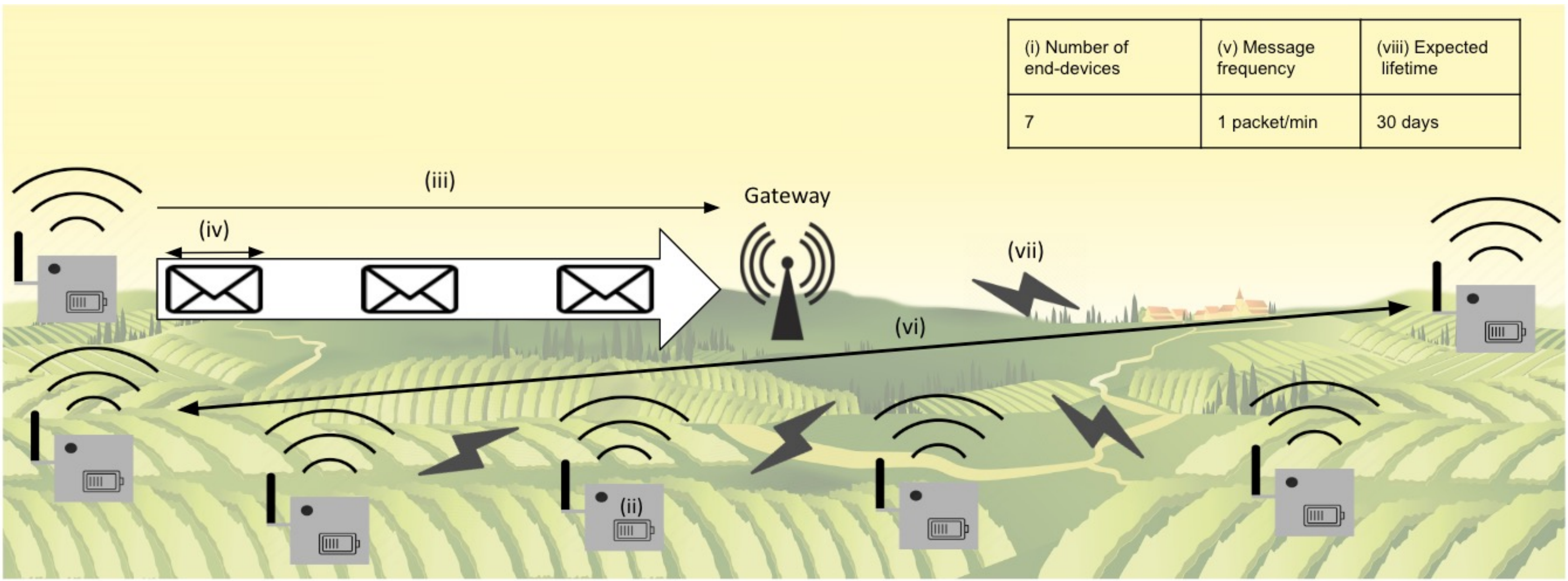
[3] Ayoub, Wael, et al. "Technology Selection for IoT-based Smart Transportation Systems." Vehicular Ad-hoc Networks for Smart Cities. Springer Singapore, 2020.
[4] Senouci, Mohamed Abdelkrim, et al. "TOPSIS-based Dynamic Approach for Mobile Network Interface Selection." Computer Networks (2016).
[5] Lalle, Yandja, et al. "A Comparative Study of LoRaWAN, Sigfox, and NB-IoT for Smart Water Grid." Global Information Infrastructure and Networking Symposium (GIIS). IEEE, 2019.
[6] Sommers, Joel, and Paul Barford. "Cell vs. WiFi: On the Performance of Metro Area Mobile Connections." Internet Measurement Conference. 2012.

Proposed Solution



Application Modeling





End-devices:

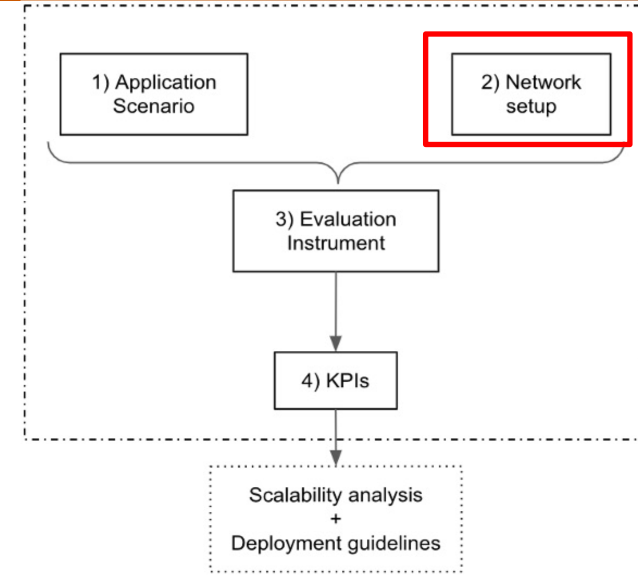
- (i) (Min/max) Number of end-devices
- (ii) Battery capacity

Workload:

- (iii) Traffic direction
- (iv) Message size
- (v) (Min/max) Message frequency

Environment:

- (vi) Deployment scope
- (vii) Deployment environment
- (viii) Expected lifetime



Network Setups Abstraction

- Considerd network technologies, with their respective setup:

Wi-Fi (802.11ac)

- Channel width (20/40/80 MHz)
- Frequency band (2.4/5 GHz)

- Nb. of spatial streams
- Guard interval
- Frame aggregation
- Modulation and Coding Scheme (MCS)

5G mmWave

- Channel width (1 GHz)
- Frequency band (24 GHz)

- 5G NR Numerology
- Hybrid Automatic Repeat Request (HARQ)
- RLC-Acknowledge Mode

802.15.4

- Channel width (5 MHz)
- Frequency band (2.4 GHz)

- Frame retries
- CSMA backoffs
- Maximum backoff exponent
- Minimum backoff exponent

LoRaWAN

- Channel width (125/250 KHz)
- Frequency band (868 MHz)

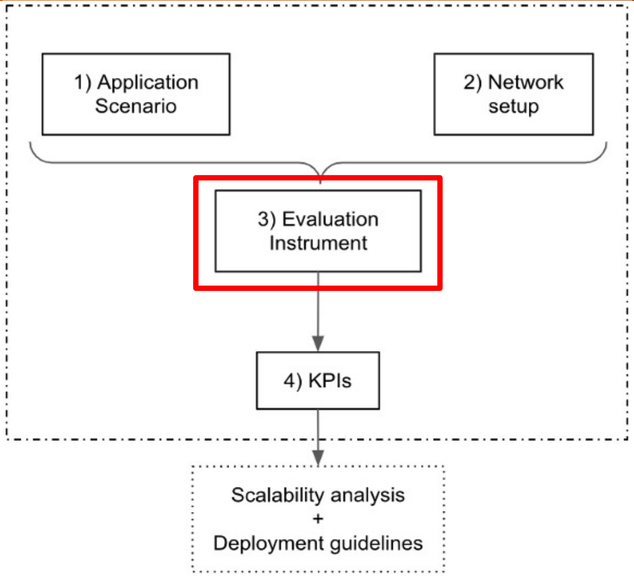
- Spreading Factor (SF)
- Coding rate
- Cyclic redundancy check (CRC)
- Confirmed traffic

Wi-Fi (802.11ah) Wi-Fi HaLow

- Channel width (1/2 MHz)
- Frequency band (868 MHz)

- Guard interval
- Beacon interval
- Nb. RAW groups
- MCS

Evaluation Approaches



Experimentation

Pros:
- High Accuracy
- Real Data

Cons:
- Low Scalability
- High Cost
- Time-consuming

Analytical Models

Pros:
- High Scalability
- Low Cost
- Low Computing Time

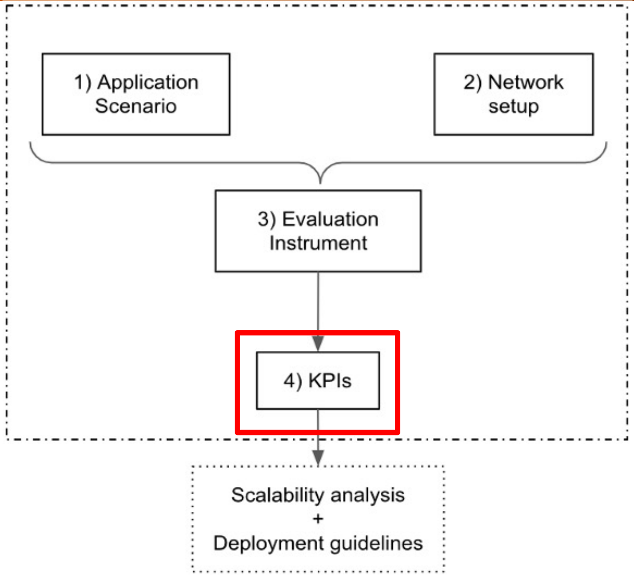
Cons:
- Low Accuracy
- Low Flexibility

Simulation

Pros:
- High Scalability
- High Flexibility
- Relative Accuracy
- Low Cost

Cons:
- High Computing Time
- Relative Accuracy

Key Performance Indicators



- **End-to-end Reliability**: The ratio of the packets successfully received over all the sent ones
- **Message Latency**: Time taken by a packet from source to destination
- **Energy Consumption**: How much energy is consumed by a device. We can derive from it:
  - **Battery Lifetime:** End-devices battery lifetime (depends on battery capacity)
- **Cost:** Deploying and maintaining the network for the lifetime of the deployment

Example of Application

- Considered application (smart metering) and network technology:

Application modeling	Parameters	Values
End-devices	• Minimal number • Maximal number • Battery capacity (Amperes.hour)	1 15,000 2.4
Workload	• Traffic direction • Message size (bytes) • Minimal frequency (packets/second) • Maximal frequency (packets/second)	Upstream 23 0.001 0.003
Environment	• Type • Scope (meters) • Expected lifetime (days)	Suburban 3000 N/A

LoRaWAN

- Channel width = 125 KHz
- SF dynamically adjusted by the LoRa manager
- Coding rate = 1
- No cyclic redundancy check
- Unconfirmed traffic

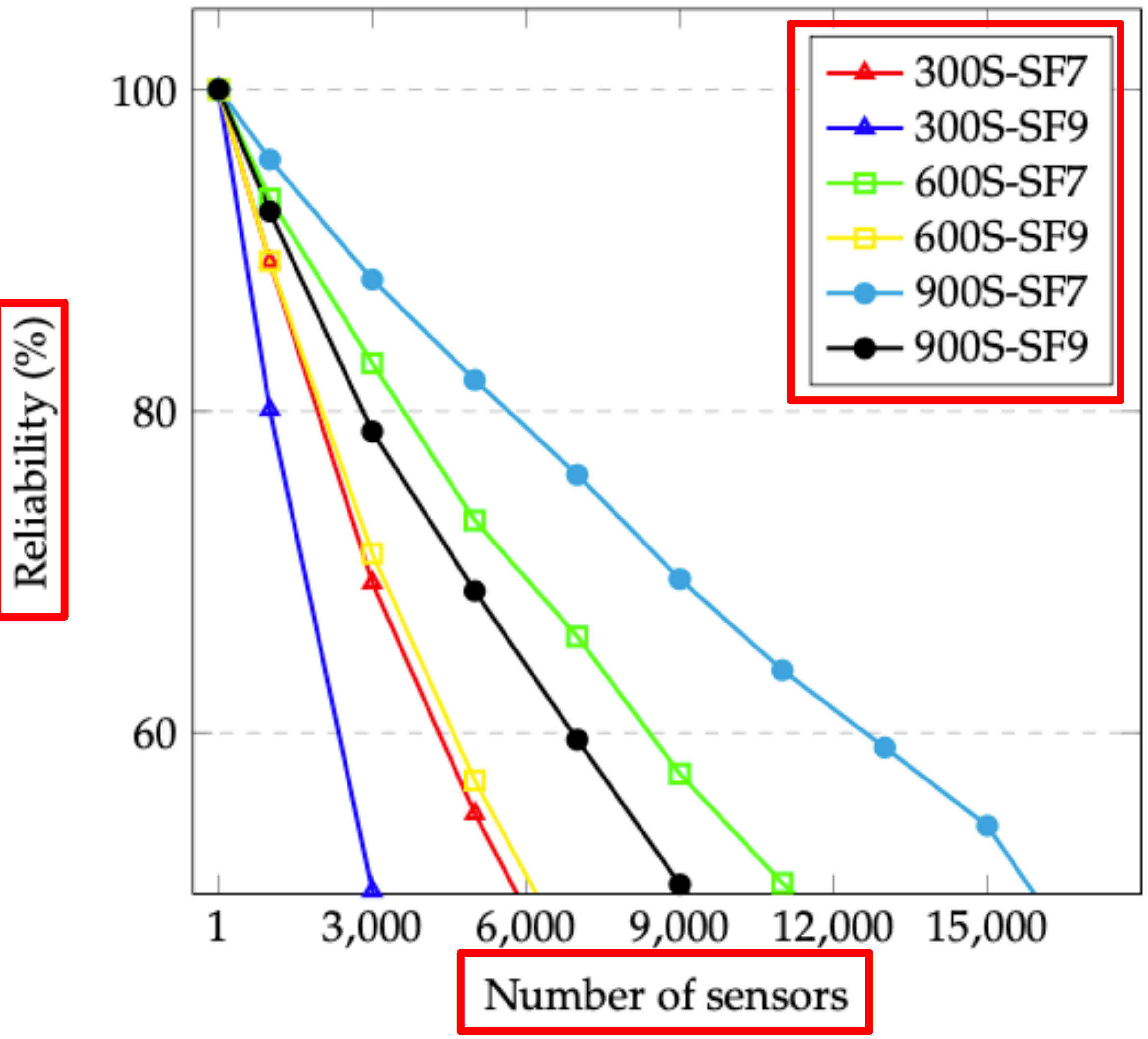
- Evaluation Tool: Simulation using ns-3 [7]

ns-3

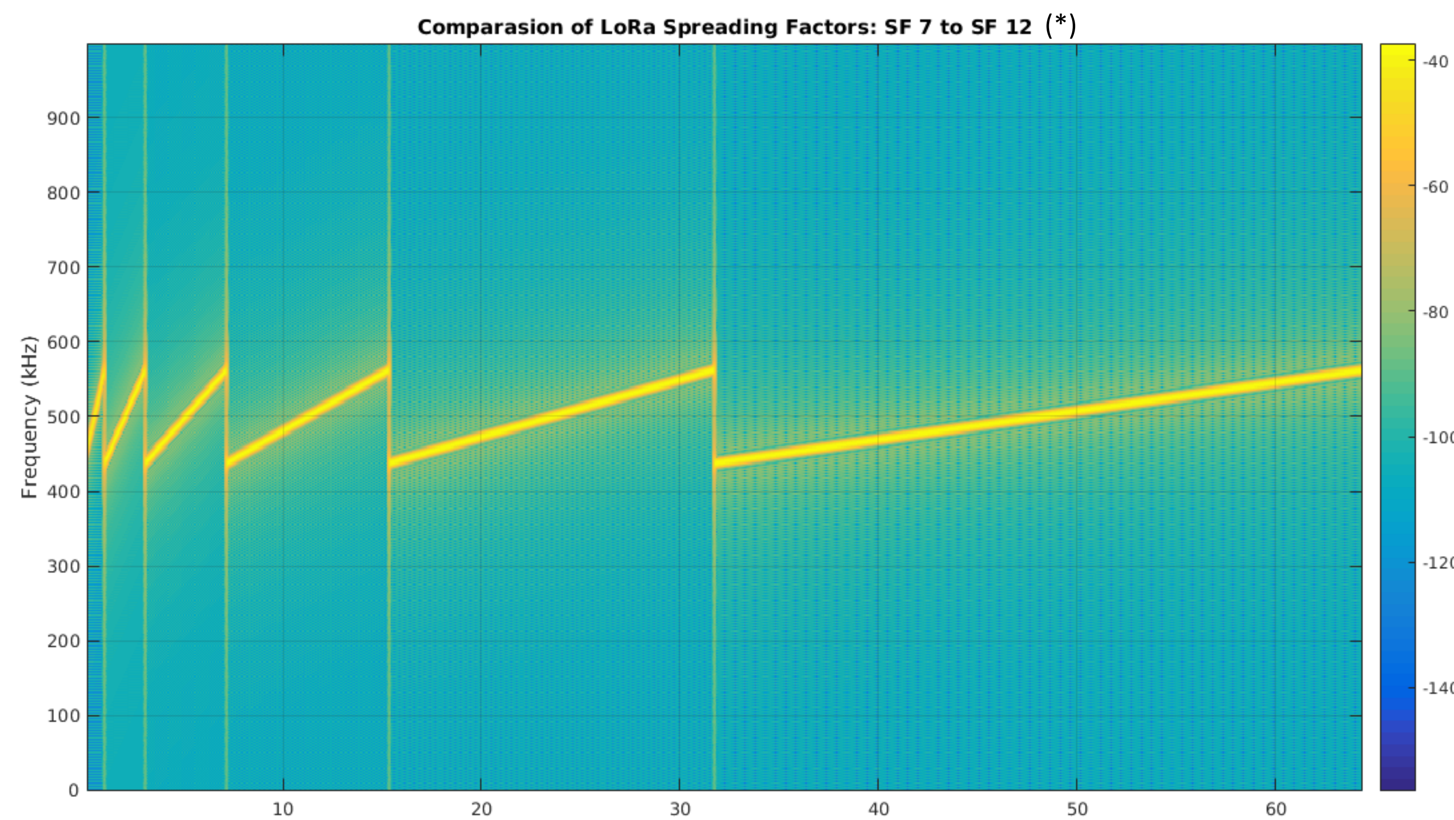
[7] Henderson, Thomas R., et al. "Network Simulations with the ns-3 Simulator." SIGCOMM Demonstration 14.14 (2008): 527.

Results

(a) Reliability



	Energy consumption (mJ)		Battery lifetime (Years)	
Period (s) \ SF	7	9	7	9
300	250	442	13	7
600	134	229	25	14
900	94	158	36	21



- **Spreading Factor (SF):** Determines the chirp rate (speed at which the signal frequency changes). Can take values from 7 to 12. Higher SF ➔ Lower data rate.

(*) https://support.machineq.com/s/article/What-is-the-Spreading-Factor-SF

Summary

- **Contribution:**
  - ✓ Generic evaluation framework including:
    - High-level application modeling
    - Network technologies setup abstraction
    - Based on simulation
    - IoT-relevant KPIs

- **Limitations:**
  - ❖ Simple topologies with one gateway
  - ❖ No automatic network technologies selection and configuration

Contribution 2

IoT Network Technologies Selection and Configuration

Problem Statement

Objective: Automatic network technology selection and configuration

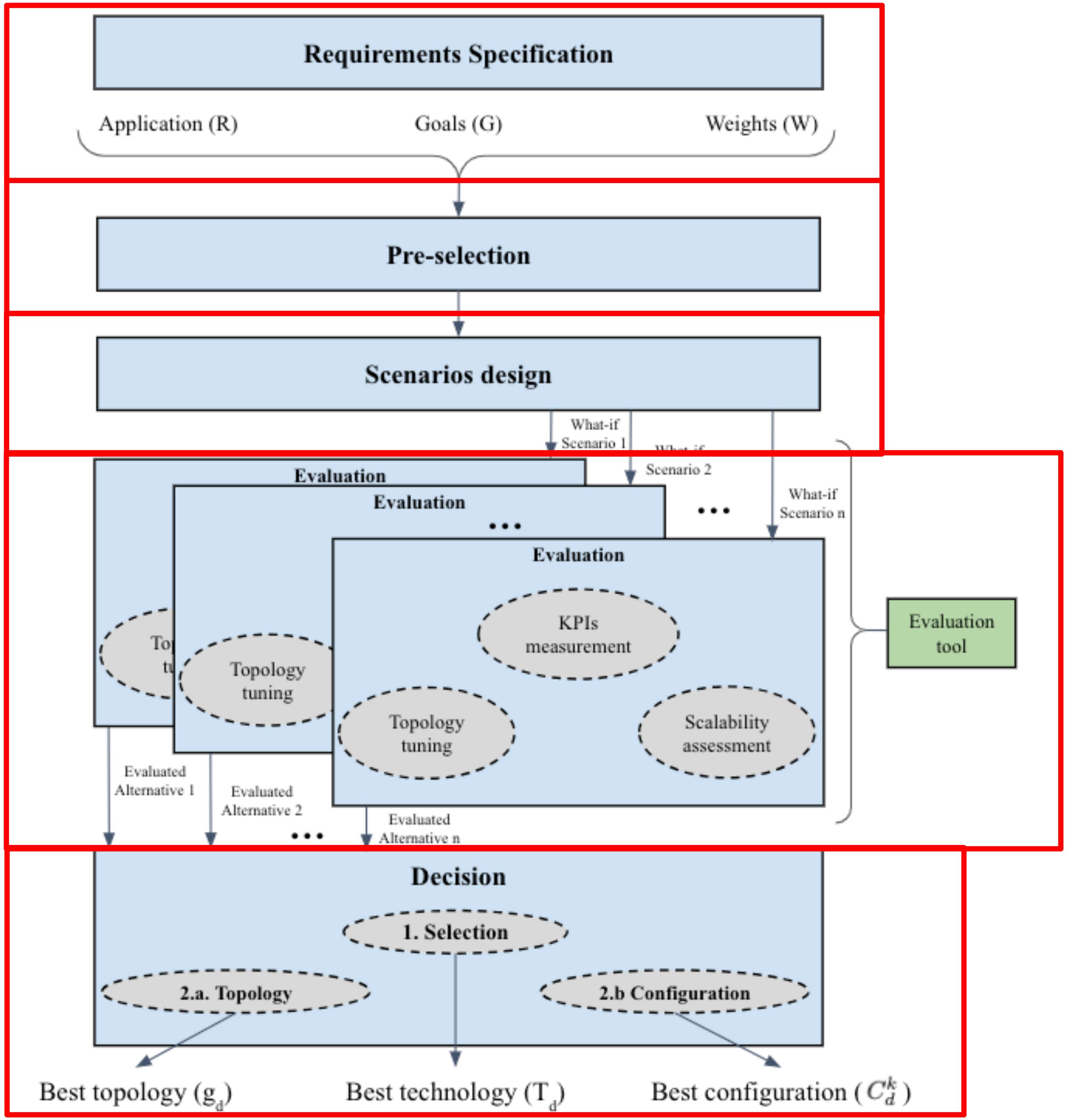
- The comparison must be made on different alternatives according to several criteria (QoS, energy consumption, etc.)
  - ➢ **Multi-Attribute Decision Making (MADM) methods [8]**

- MADM is used for network selection (for example in [9], [3] and [10]), but without a rigorous KPIs evaluation

➢ **Can we define a method for the automatic selection of the network technology and its configuration?**

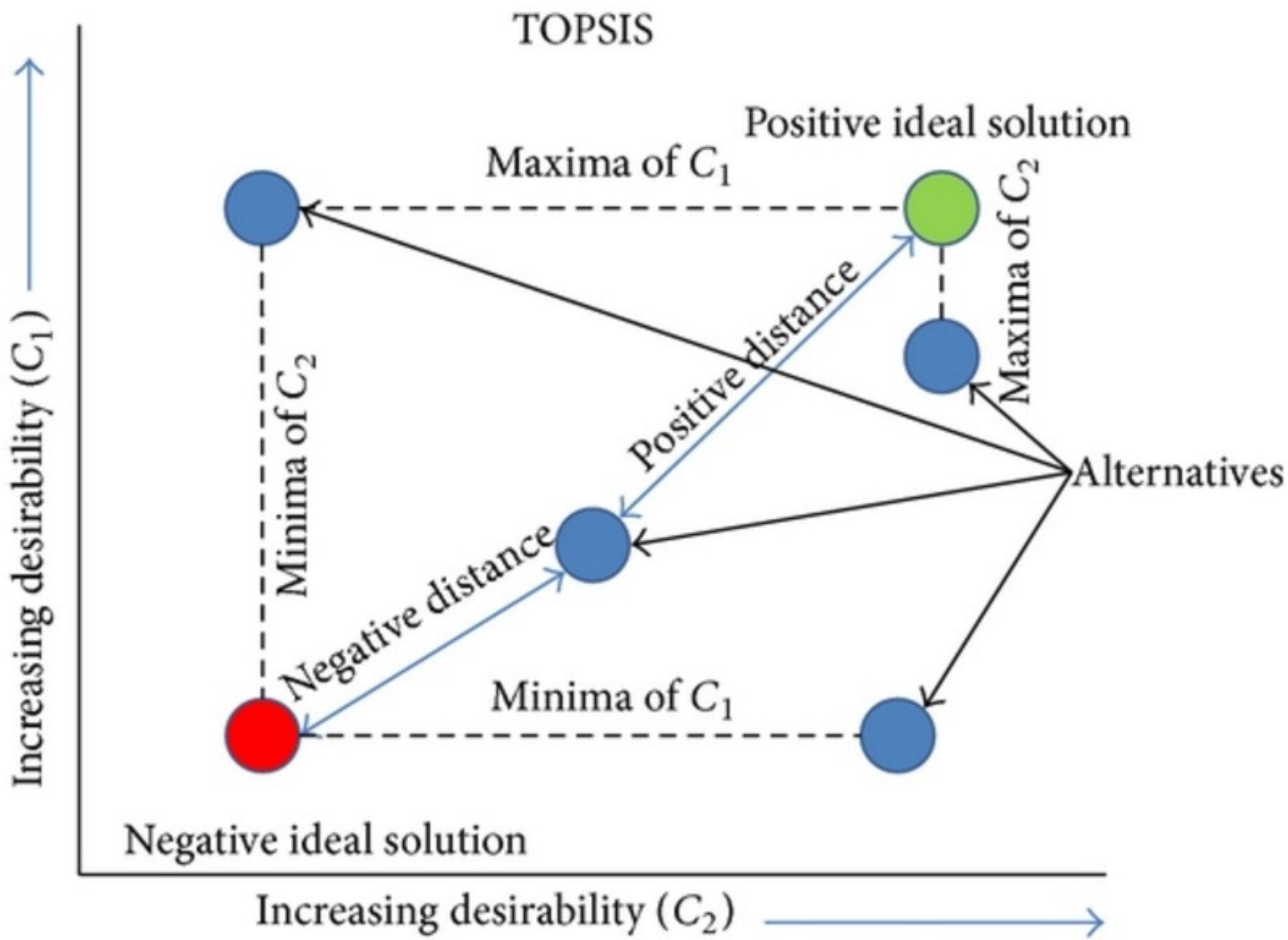
[8] Yoon, K. Paul, and Ching-Lai Hwang. "Multiple Attribute Decision Making: An Introduction". Sage publications, 1995.
[9] F. Bari and V. Leung, "Multi-Attribute Network Selection by Iterative TOPSIS for Heterogeneous Wireless Access," IEEE CCNC, 2007.
[3] Ayoub, Wael, et al. "Technology Selection for IoT-based Smart Transportation Systems." Vehicular Ad-hoc Networks for Smart Cities. Springer Singapore, 2020.
[10] Bazrafkan, Armin, and Mohammad R. Pakravan. "An MADM network selection approach for next generation heterogeneous networks." IEEE ICEE, 2017.

Proposed Solution - HINTS



MADM Method - TOPSIS

- Technique for Order of Preference by Similarity (TOPSIS) [11]



[11] Chauhan, Aditya, and Rahul Vaish. "A Comparative Study on Decision Making Methods with Interval Data." Journal of Computational Engineering (2014).

Example of Application 1: Selection

- Considered application (smart building):

Application modeling	Parameters	Values
End-devices	• Minimal number	50
	• Maximal number	100
	• Battery capacity (Amperes.hour)	2.4
Workload	• Traffic direction	Upstream
	• Message size (bytes)	100
	• Minimal frequency (packets/second)	1
	• Maximal frequency (packets/second)	1
Environment	• Type	Indoor
	• Scope (meters)	50
	• Expected lifetime (days)	730

- Considered network technologies:

Wi-Fi HaLow

802.15.4

- Channel width = 80 MHz
- One spatial stream
- Long guard interval
- No frame aggregation

- Channel width = 2 MHz
- Long guard interval
- Beacon interval = 51200 ms
- One RAW group

- Channel width = 5 MHz
- Frame retries = 4
- CSMA backoffs = 5
- Maximum backoff exponent = 4
- Minimum backoff exponent = 3

Results 1: Selection

Network technology		Minimal deployment (50 end-devices)				Maximal deployment (100 end-devices) *Scalability factor: 1*				
Technology	Nb. of GW	**Reliability**	**Battery Lifetime**	**Message Latency**	**Cost**	**Reliability**	**Battery Lifetime**	**Message Latency**	**Cost**	**Score**
		Weight: 1 Unit: % Goal: >90	*Weight: 1 Unit: d Goal: >80*	*Weight: 1 Unit: ms Goal: <100*	*Weight: Unit: $*	*Weight: 1 Unit: % Goal: >90*	*Weight: 1 Unit: d Goal: >80*	*Weight: 1 Unit: ms Goal: <100*	*Weight: 1 Unit: $*	
Wi-Fi	1	42.0	61.72	0.05	3850	30.0	49.1	0.05	9100	0.02
Wi-Fi	2	80.0	66.28	0.05	3700	86.0	61.24	0.05	7700	0.07
Wi-Fi	3	87.5	66.45	0.05	3800	96.97	85.86	0.05	5800	0.32
Wi-Fi	4	100.0	89.09	0.05	3150	100.0	88.38	0.05	5900	0.46
Wi-Fi	5	100.0	89.27	0.05	3150	100.0	88.71	0.05	5900	0.46
HaLow	1	100.0	362.16	48.41	2250	100.0	277.78	57.28	3500	0.87
HaLow	**2**	**100.0**	**421.69**	**48.9**	**3000**	**100.0**	**331.8**	**58.72**	**4500**	**0.93**
802.15.4	1	54.31	91.76	29.62	3700	44.63	71.44	12.61	9700	0.12
802.15.4	2	94.46	125.07	12.38	3400	88.29	85.75	21.67	7400	0.36
802.15.4	3	98.09	142.95	16.47	3350	94.10	112.28	7.46	7100	0.49

Example of Application 2: Configuration

- HINTS can also be used for configuring a network technology
- Considered application (smart metering) and network technology:

Application modeling	Parameters	Values
End-devices	• Minimal number	200
	• Maximal number	300
	• Battery capacity (Amperes.hour)	2.4
Workload	• Traffic direction	Upstream
	• Message size (bytes)	30
	• Minimal frequency (packets/second)	0.005
	• Maximal frequency (packets/second)	0.005
Environment	• Type	Rural
	• Scope (meters)	1500
	• Expected lifetime (days)	3650

LoRaWAN

- SF = ?
- Coding rate = ?
- Confirmed traffic ?

Results 2: Configuration

Configuration			Minimal deployment (50 end-devices)				Maximal deployment (100 end-devices) *Scalability factor: 1*				
SF	Coding Rate	Traffic Type	**Reliability** *Weight: 1 Unit: % Goal: >90*	**Battery Lifetime** *Weight: 1 Unit: d Goal: >730*	**Message Latency** *Weight: 1 Unit: ms Goal: <1000*	**Cost** *Weight: 1 Unit: $*	**Reliability** *Weight: 1 Unit: % Goal: >90*	**Battery Lifetime** *Weight: 1 Unit: d Goal: >730*	**Message Latency** *Weight: 1 Unit: ms Goal: <1000*	**Cost** *Weight: 1 Unit: $*	**Score**
7	**1**	**0**	**95.78**	**2560.7**	**82.17**	**12000**	**95.73**	**2560.7**	**82.17**	**17500**	**0.98**
7	1	1	99.44	331.37	82.17	112000	99.19	332.6	82.176	167500	0.51
7	4	0	93.65	1819.54	82.17	22000	93.74	1819.54	82.176	17500	0.81
7	4	1	98.65	232.95	82.17	152000	97.83	234.18	82.176	227500	0.5
12	1	1	43.47	126.44	197.4	282000	31.97	114.1	197.4	467500	0.0
12	1	0	43.31	126.44	197.4	282000	31.78	112.7	197.4	482500	0.38
12	4	1	33.29	126.77	197.4	282000	22.33	232.95	197.4	422500	0.38
12	4	1	33.11	126.77	197.4	282000	22.13	232.95	197.4	422500	0.38

Summary

- **Contribution:**
  - ✓ Automatic selection methodology considering:
    - Multi-criteria comparison
    - Topology
    - Configuration

- **Limitations:**
  - ❖ Accessibility of the solution
  - ❖ Computing time for a more rigorous configuration decision (>7 hours for the previous application LoRa)
  - ❖ Simulation accuracy

Contribution 3

Addressing the Limits of Simulation

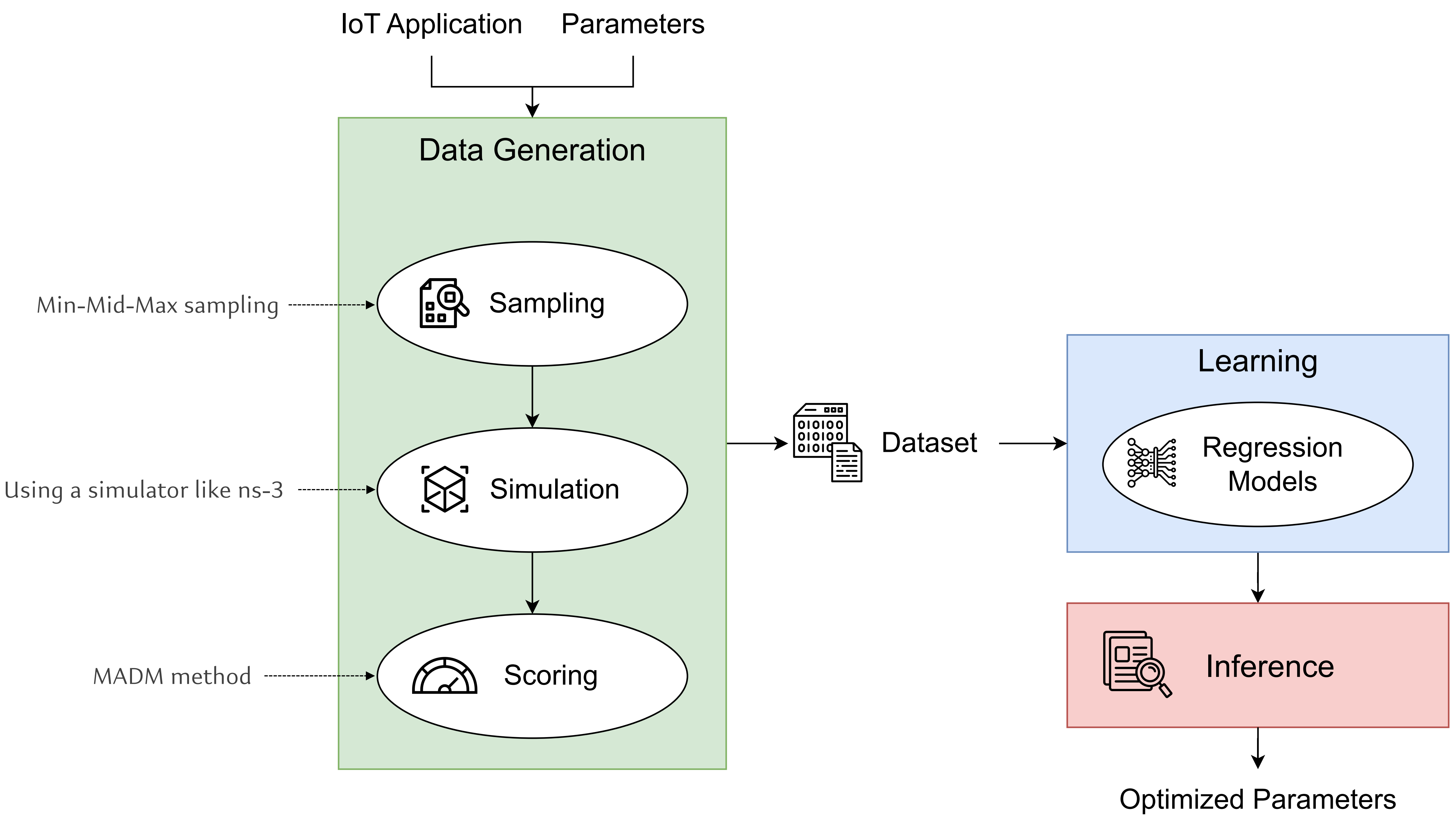
Problem Statement

Objective: Reducing the number of simulations for the configuration decision

- A single network technology can be configured differently with an impact on its performance
- Using HINTS can help. However, the range of possible configurations is considerable
  - **Important number of simulations:** For n different parameters, where each one can take m different values, a comprehensive simulation would lead to $\mathbf{m^n}$ simulations

➢ **Can we use surrogate modeling and machine learning to reduce the number of simulations?**

Proposed Solution - COSIMIA



Application

- Considered application (smart metering) and network technology:

Application modeling	Parameters	Values
End-devices	• Minimal number • Maximal number • Battery capacity (Amperes.hour)	50 50 2.4
Workload	• Traffic direction • Message size (bytes) • Minimal frequency (packets/second) • Maximal frequency (packets/second)	Upstream 100 1 1
Environment	• Type • Scope (meters) • Expected lifetime (days)	Suburban 200 N/A

802.15.4

- Frame retries = ?
- CSMA backoffs = ?
- Maximum backoff exponent = ?
- Minimum backoff exponent = ?

Example of Application

- **Proximity:** Ratio of the score of the best solution on the optimal one (through the comprehensive simulation)

Model	Solution	KPIs				Data generation		Proximity
		Reliability (%)	Energy consumption (Watts)	Latency (ms)	Cost ($)	Time (minutes)	Number of simulations	
Comprehensive simulation	[3,4,3,4,0]	92	0.03	5.56	300	1367	23040	N/A
Gradient boosting	[3,5,3,5,3]	99.37	0.032	5.58	300	26	405	0.99
Extra trees	[3,6,0,0,4]	93.75	0.031	3.91	300			0.99
Random forest	[3,8,7,5,3]	100	0.033	31.16	300			0.98
KNN	[3,8,7,5,6]	100	0.033	31.16	300			0.98
SVR	[5,7,7,5,6]	100	0.03	30.15	500			0.94
Linear regression	[10,8,7,5,7]	100	0.02	26.02	1000			0.79

- **Results format:** [NGW,MaxBE,MinBE,CB,FR]

Summary

- **Contribution:**
  - ✓ Method for accelerating configuration decision process:
    - Important computing time reduction
    - Generic method

- **Limitations:**
  - ❖ No theoretical guarantee (heuristic)
  - ❖ Simulation accuracy

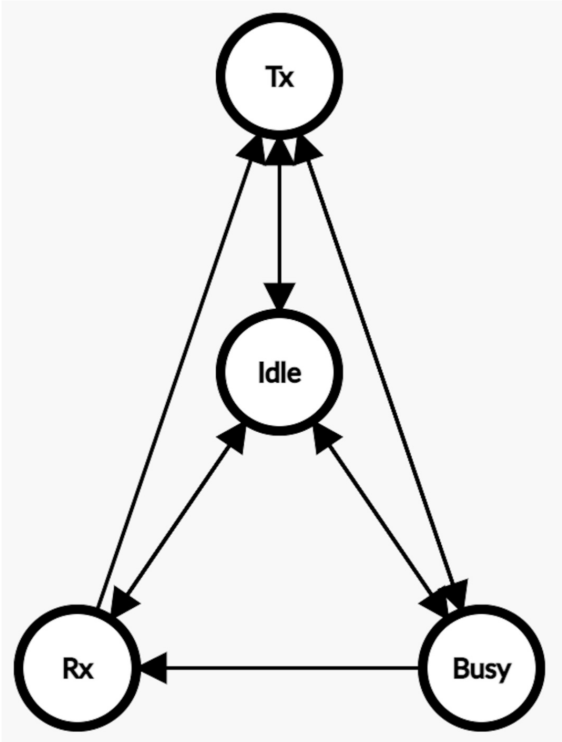
Problem Statement

Objective: Enhancing the simulation credibility

- We focus here on the energy consumption calculation

- Simulators use state machines to calculate energy consumption.
  - The nodes can be in different physical states (Tx, Rx, etc.)
  - Each state is associated to a current consumption value
  - Energy is calculated with:

$$E = \sum_{i \in S} (\alpha_i \,.\, t_i) \,.\, V$$



where:

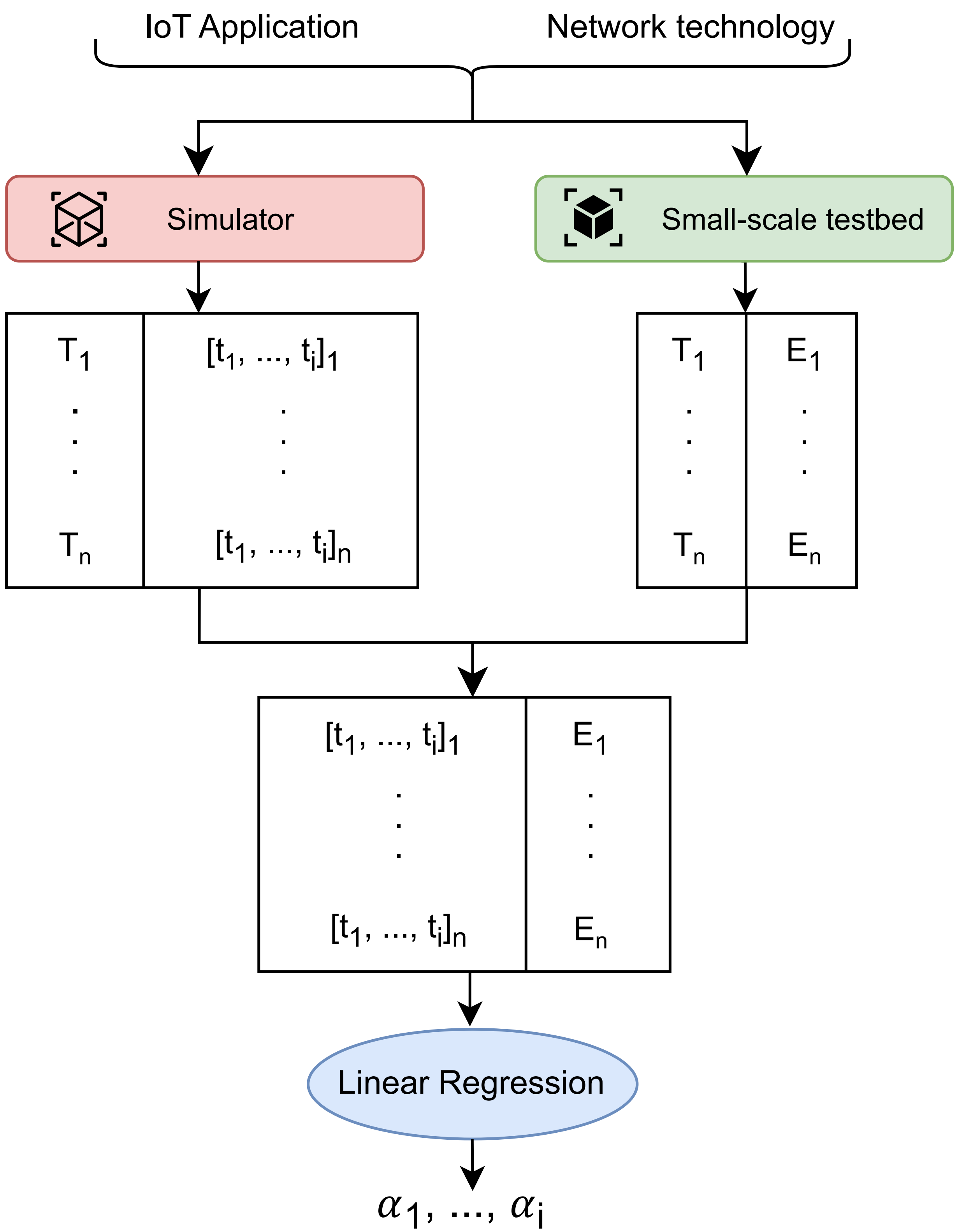
- E in the energy in Joules,
- S is the set of possible states of the physical NIC,
- α_i is the current consumption value of state i in Amperes,
- t_i is the time passed in state i in Seconds,
- V is the voltage in Volts, which is considered constant

- The α_i values depend on the used radio chip
- May lead to errors if the simulator transitions are not accurate

➢ **Can we calibrate energy consumption models in simulators using real data?**

Proposed Solution

- **Assumption:** Small testbed with access to energy consumption measurements



Example of Application

- We consider the following application (smart metering) with 802.15.4:

Application modeling	Parameters	Case Study
End-devices	• Minimal number • Maximal number • Battery capacity (Amperes.hour)	40 60 2.4
Workload	• Traffic direction • Message size (bytes) • Minimal frequency (packets/second) • Maximal frequency (packets/second)	Upstream 100 1 2
Environment	• Type • Scope (meters) • Expected lifetime (days)	Suburban 200 N/A

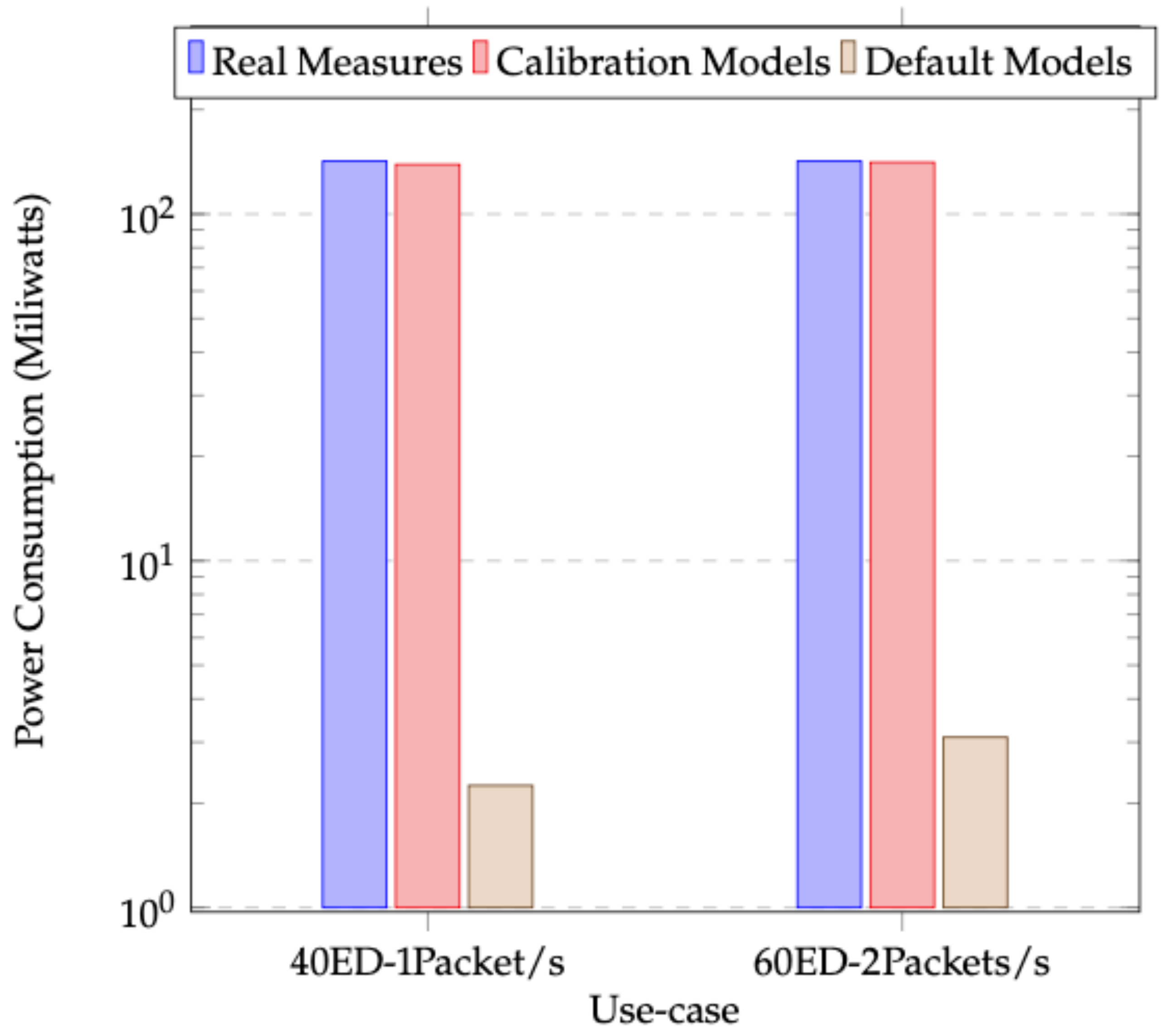
- We use the FIT IoT-Lab [12] as an experimental platform for our testbed
  - Open-source experimentation platform
  - M3 boards equipped with radio chips supporting IEEE 802.15.4 norm
  - Radio sniffer for RSSI and energy measurement tools
  - Firmwares implemented using the RIOT [13] Operating System

FIT IOT-LAB

[12] Adjih, Cedric, et al. "FIT IoT-LAB: A Large scale Open Experimental IoT Testbed." 2015 IEEE 2nd World Forum on Internet of Things (WF-IoT). IEEE, 2015.
[13] Baccelli, Emmanuel, et al. "RIOT OS: Towards an OS for the Internet of Things." 2013 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS). IEEE, 2013.

Results

- We show the impact on the calibration for both the initial and scaled deployment:



Summary

- **Contribution:**
  - ✓ Method for calibrating energy consumption models in simulation:
    - Data from real measures
    - Validation using a real testbed

- **Limitations:**
  - ❖ Costly infrastructure
  - ❖ Considers only energy consumption

Contribution 4

IoT Network Technologies No-Code Simulation

Problem Statement

Objective: Allowing non-network experts to use simulation

- IoT architect needs:
  - Assess the suitability of a network technology for a specific application
  - Optimize the network configuration to align with evolving deployment requirements

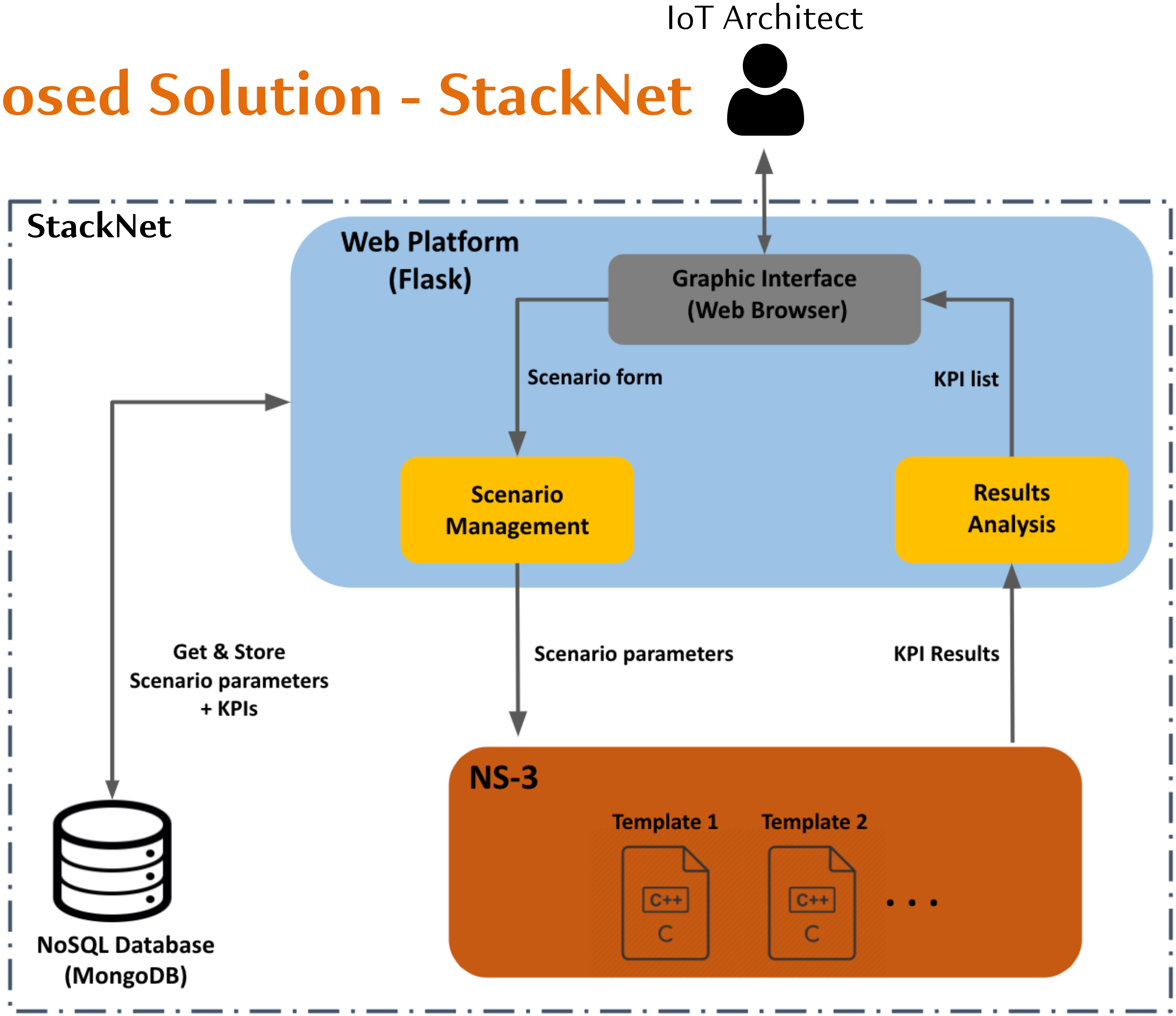
❖ Complexity of the simulation workflow for non-network experts

➢ **Can we abstract the simulation complexity?**

✓ Describe the application and the network technology

✓ Compare a set of simulation scenarios

Proposed Solution - StackNet



Example of Application

- Considered application (smart building):

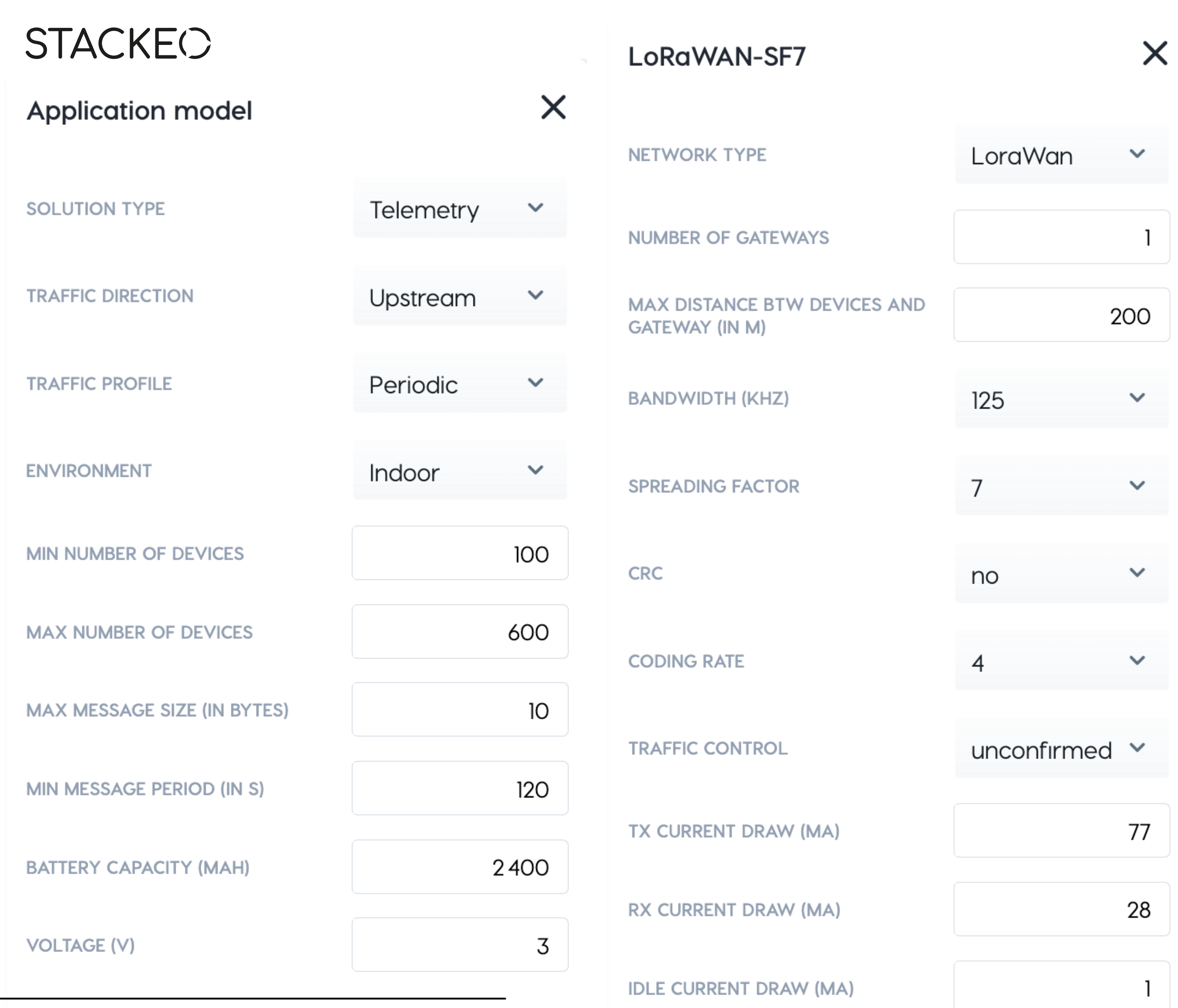
Application modeling	Parameters	Case Study
End-devices	• Minimal number • Maximal number • Battery capacity (Amperes.hour)	100 600 2.4
Workload	• Traffic direction • Message size (bytes) • Minimal frequency (packets/second) • Maximal frequency (packets/second)	Upstream {100, 110} 0.016 0.032
Environment	• Type • Scope (meters) • Expected lifetime (days)	Indoor 200 N/A

- Considered network technologies:

Wi-Fi　　802.15.4　　Wi-Fi HaLow　　LoRaWAN

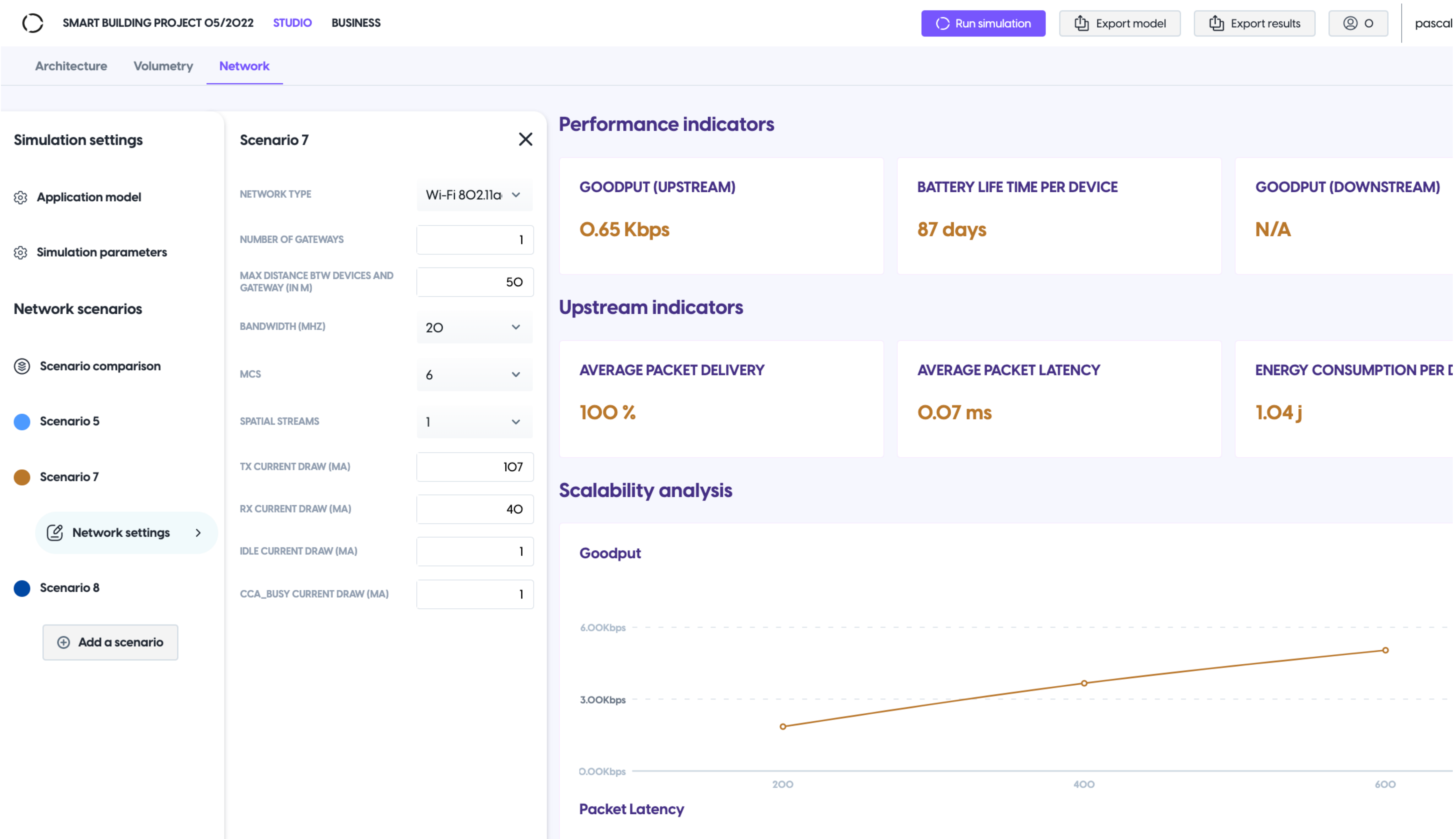
Example of Application

- StackNet is integrated in the STACKEO* platform



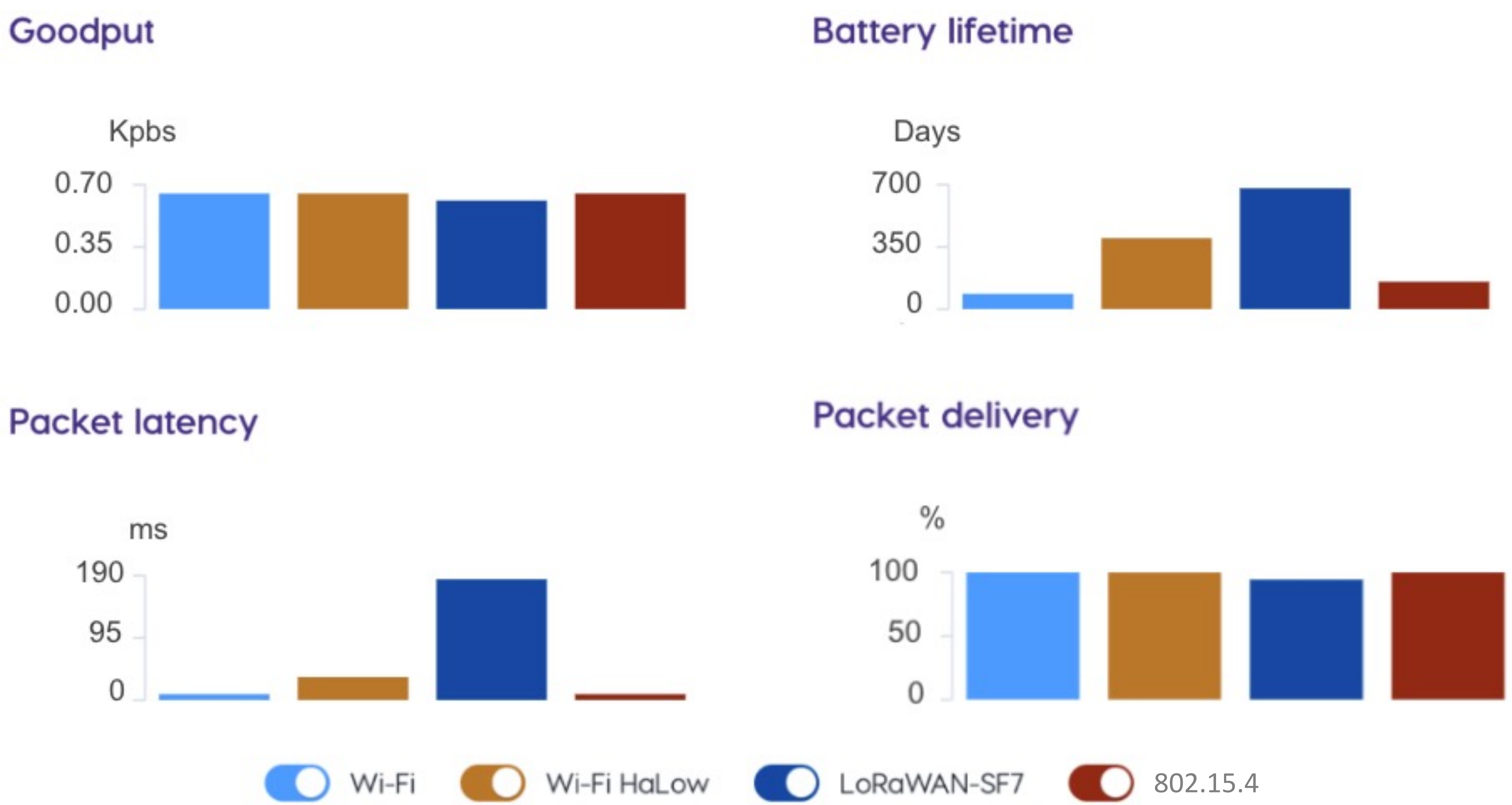
(*) https://stackeo.io

Example of Application



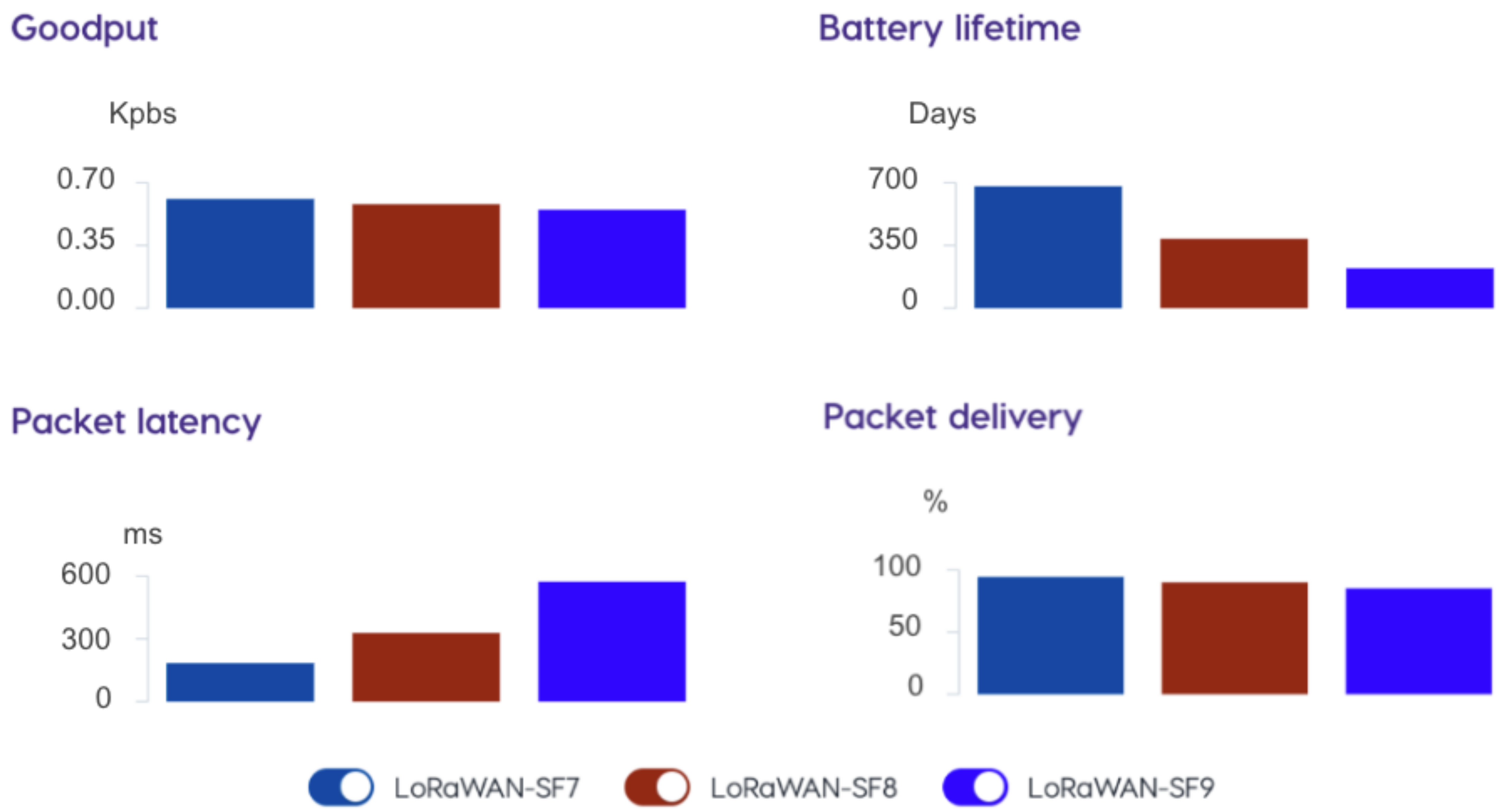
Results

- Network technologies comparison:



Results

- LoRa configuration decision:



Summary

- **Contribution:**
  - ✓ No-code platform that:
    - Captures the major needs of IoT architects and hides the complexity of simulation
    - Allows to make decisions about the design and the configuration of an IoT solution in an interactive way

- **Limitations:**
  - ❖ Considers random end-devices placement
  - ❖ Based on simulation only

Conclusion & Perspectives

Conclusion

- **Contributions:**
  - Simulation-based framework for evaluating IoT network technologies for a given application
  - Multi-criteria method for automatically selecting and configuring an IoT network technology
  - ML-based method for accelerating the configuration decision process
  - ML-based method for calibrating energy consumption models of simulation
  - No-code platform to abstract the simulation complexity

- **Limitations:**
  - Availability of other network technologies (NB-IoT, LTE-M, BLE, etc.)
  - Availability of other network simulators

Perspectives

- **HINTS as a general network evaluation and comparison framework:**
  - Include applications with mobility
  - Include mesh topologies (routing, load-balancing, etc.)
  - Include other KPIs (security, environmental impact, etc.)
  - Use Pareto-front exploration methods [14] instead of MADM methods

- **Addressing the limits of simulation as IoT network evaluation tool:**
  - Combining experimentation with simulation
  - Explore the calibration of other parameters such as RSSI ([15])
  - Consider a "smarter" space exploration method for COSIMIA (*e.g.*, using Bayesian Optimization)
  - Extend simulation and experimentation combination to Network Digital Twin
    - ➢ **Ongoing work, submitted to FGCS [16]**

- **No-code platform:**
  - Integrate other simulators and testbeds
  - Consider different nodes placement models
  - ➢ **Ongoing work with a team from University at Buffalo, USA**

[14] Paria, Biswajit, et al. "A Flexible Framework for Multi-objective Bayesian Optimization using Random Scalarizations." Uncertainty in Artificial Intelligence. PMLR, 2020.
[15] S. Si-Mohammed, et al. "Smart Integration of Network Simulation in Network Digital Twin for Optimizing IoT Networks". Submitted to FGCS, Elsevier. 2023.
[16] Almeida, Eduardo Nuno, et al. "Position-Based Machine Learning Propagation Loss Model Enabling Fast Digital Twins of Wireless Networks in ns-3." arXiv preprint (2023).

Thank you for your attention

- **International Journals and Conferences:**
  - **S. Si-Mohammed**, T. Begin, I. Guérin Lassous, P. Vicat-Blanc. "HINTS: A Methodology for IoT Network Technology and Configuration Decision". *Internet of Things Journal,* Elsevier, 2023.
  - **S. Si-Mohammed**, T. Begin, I. Guérin Lassous, P. Vicat-Blanc. "Introducing ADIperf, a Framework for Application-driven IoT Network Performance Evaluation". *IEEE ICCCN*, July 2022.
  - **S. Si-Mohammed**, M. Janumporn, T. Begin, I. Guérin Lassous, P. Vicat-Blanc. "SIFRAN: Evaluating IoT with a Framework based on ns-3". *ACM LANC*, October 2022.
  - **S. Si-Mohammed**, Z. Fraoui, T. Begin, I. Guérin Lassous, P. Vicat-Blanc. "StackNet: Network Simulation as a Service". *IEEE ICC*, May 2023.

  Submitted
  - **S. Si-Mohammed**, A. Bardou, T. Begin, I. Guérin Lassous and P. Vicat-Blanc. "Smart Integration of Network Simulation in Network Digital Twin for Optimizing IoT Networks". *Future Generation Computer Systems*, Elsevier. 2023.

- **National Conferences**
  - **S. Si-Mohammed**, T. Begin, I. Guérin Lassous, P. Vicat-Blanc. "COSIMIA : Combiner Simulation et Apprentissage Automatique pour Optimiser la Configuration des Réseaux IoT". *CoRes*, May 2023.

Appendix

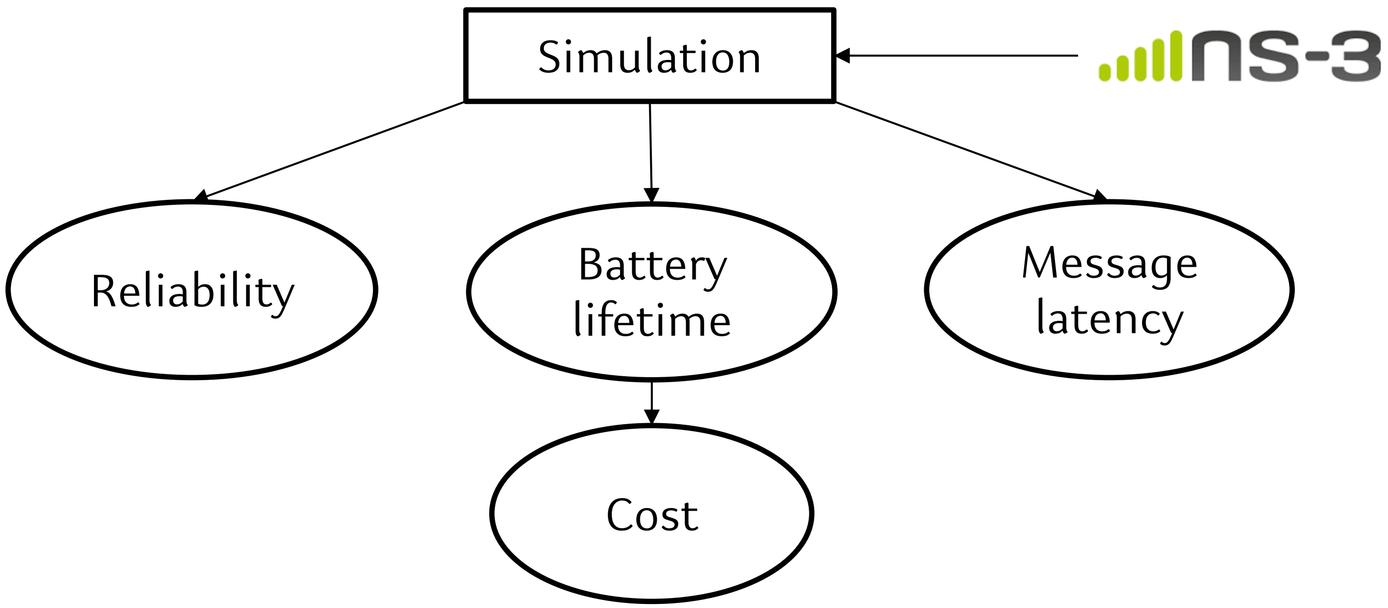
Environment Propagation Models

- Radio environments and their propagation models [17]:

Environment Type	Propagation Model
Indoor	HybridBuildings
Outdoor Rural	OkumuraHata
Outdoor Urban	COSTHata
Outdoor Suburban	LogDistance

[17] Stoffers, Mirko, et al. "Comparing the ns-3 Propagation Models." IEEE International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems, 2012.

Cost Calculation

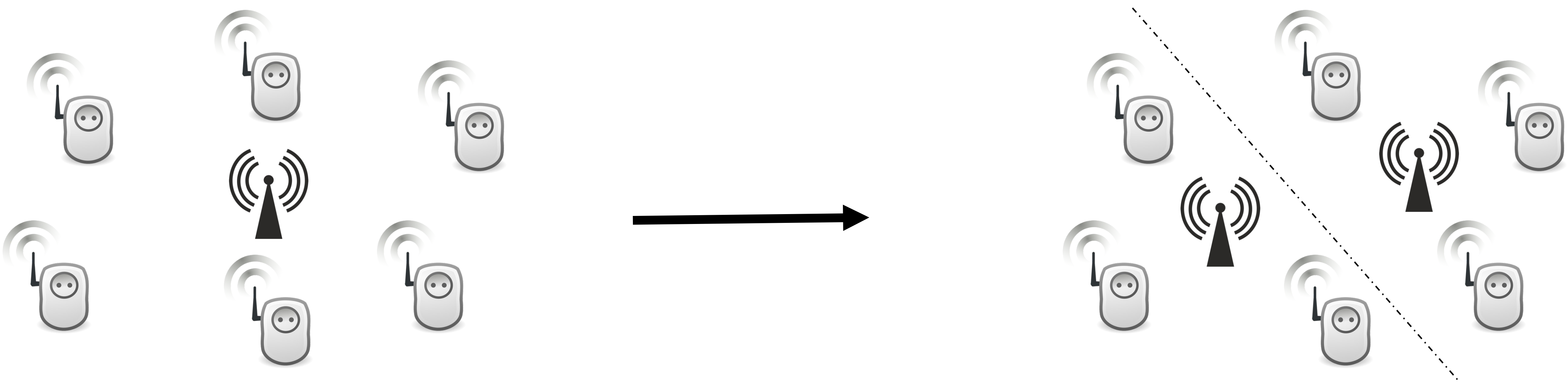


$$Cost = p_{GW} * n_{GW} + p_{ED} * n_{ED} + (pe/bl) * p_{bc} * n_{ED}$$

p_{GW}	Price of a gateway
n_{GW}	Number of gateways
p_{ED}	Price of an end-device
n_{ED}	Number of end-devices
pe	Expected scenario lifetime
bl	Estimated battery lifetime
p_{bc}	Price of a battery replacement

Topologies Modeling

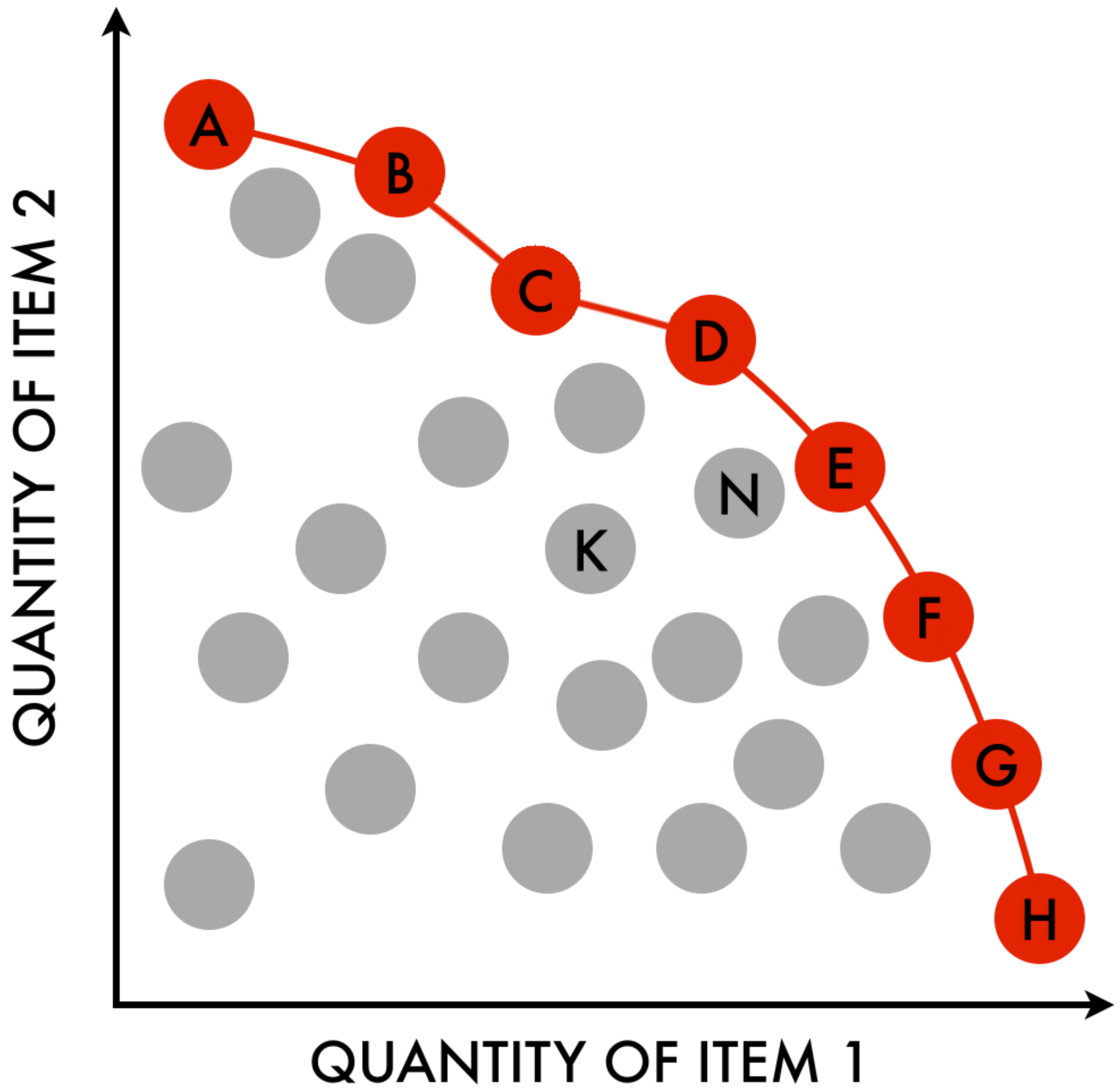
- The number of gateways is varied for each alternative:



- This number is varied until the targeted values are satisfied, or the performance improvement does not exceed 5%.

Pareto Front

- Points in red in the following figure (*) are not Pareto-dominated



(*) https://en.wikipedia.org/wiki/Pareto_front

Dataset Format

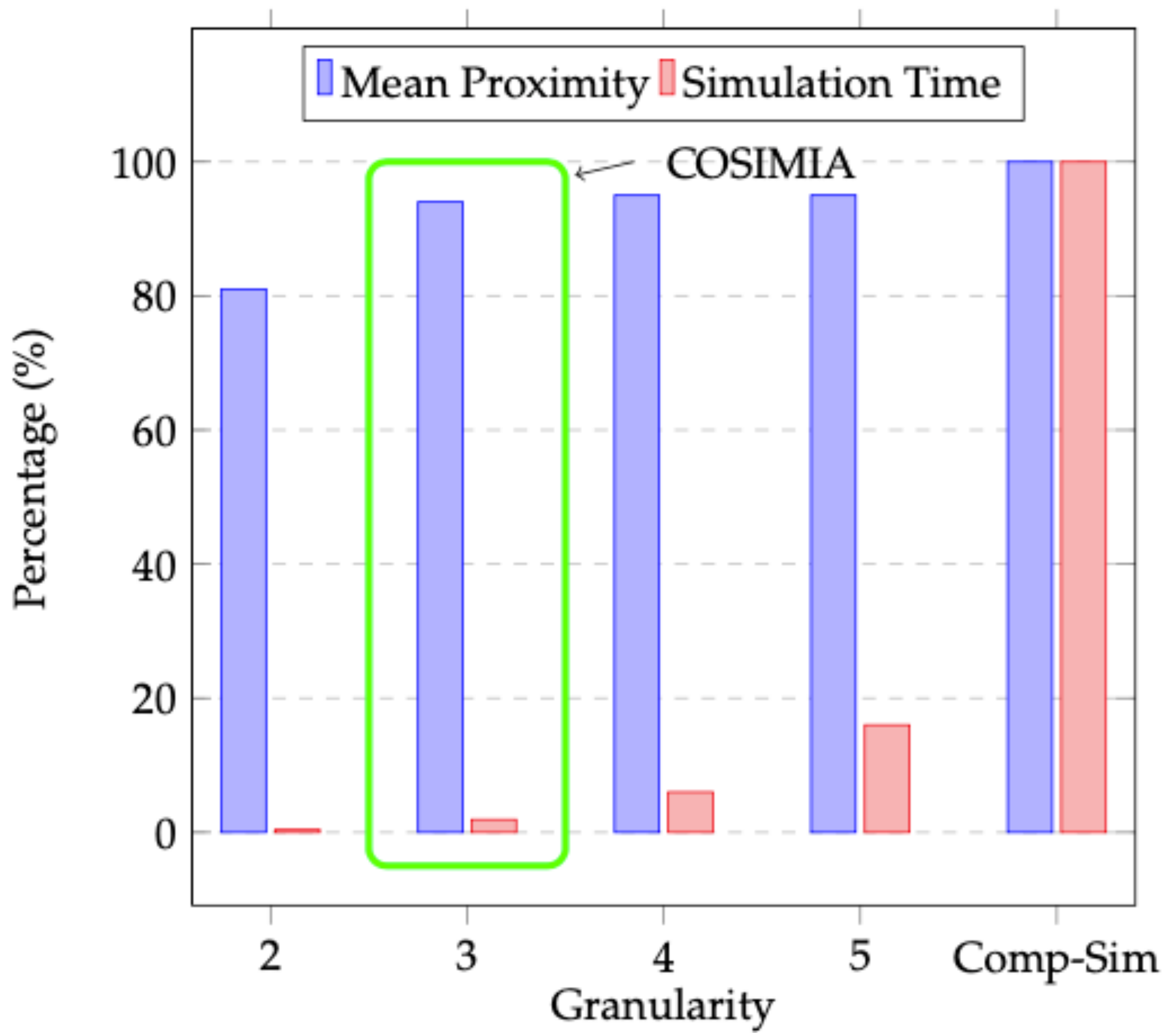
Input

Output

nGW	sf	traffic_type_	coding_rate	crc	success_rate	energy	latency	price	score
3	8	1	2	1	91,25	0,00223759	238,08	3000	0,69705853
3	9	0	2	1	85,2	0,00050719	427,008	3000	0,67935014
3	9	1	2	1	97,47	0,00231686	427,008	3000	0,68267309
3	10	0	2	1	89,38	0,00089007	755,712	3000	0,79743684
3	10	1	2	1	100	0,00239554	755,712	3000	0,65457617
3	11	0	2	1	94,38	0,00199821	1708,03	3000	0,58826983
3	11	1	2	1	93,55	0,00219818	1708,03	3000	0,57321259
3	12	0	2	1	88,39	0,00247255	3022,85	3000	0,41632534
3	12	1	2	1	88,39	0,00247255	3022,85	3000	0,41632534
4	7	0	2	0	83,58	0,00015571	125,184	4000	0,69048149
4	7	1	2	0	95,83	0,00121376	125,184	4000	0,79111444
4	8	0	2	0	84,17	0,00027286	225,792	4000	0,8493187
4	8	1	2	0	100	0,00209729	225,792	4000	0,70091466
4	9	0	2	0	91,67	0,0004786	402,432	4000	0,83734485
4	9	1	2	0	100	0,00190094	402,432	4000	0,71031007

Sampling Granularity Impact

- **Granularity:** Number of parameters taken for the sampling



Calibration Need

- Wi-Fi with a specific transmission workload
- When sending frame, the transitions are:
  - Idle -> Tx (Send frame)
  - Tx -> Idle (Finished sending)
  - Idle -> CCA_Busy (Detects signal in the medium for the ACK)
  - CCA_Busy -> RX (Receives ACK)
  - RX -> Idle (Goes back to Idle state)

State	Value
Tx	107
Rx	40
CCA_Busy	1

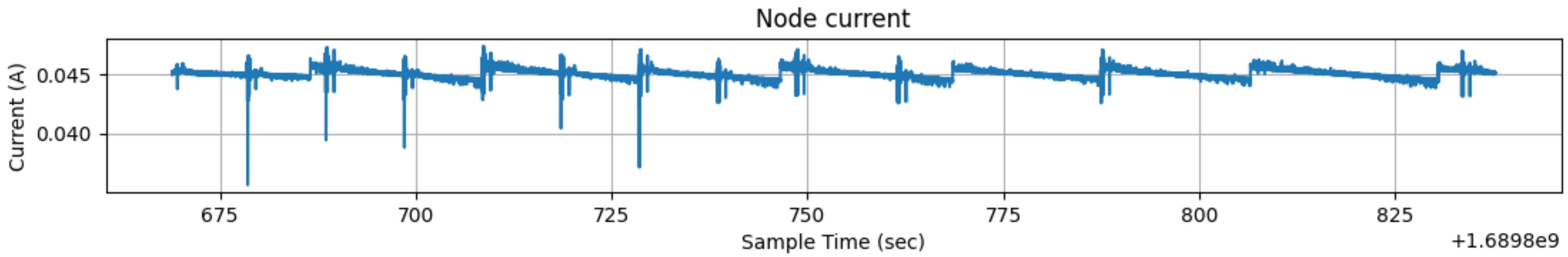
- Let's suppose the following transitions (in ms) for each packet sent:

State	Experimentation	Simulation
Tx	15	10
Rx	5	7
CCA_Busy	3	5
Energy (J) for 100 transmissions	0.518	0.387

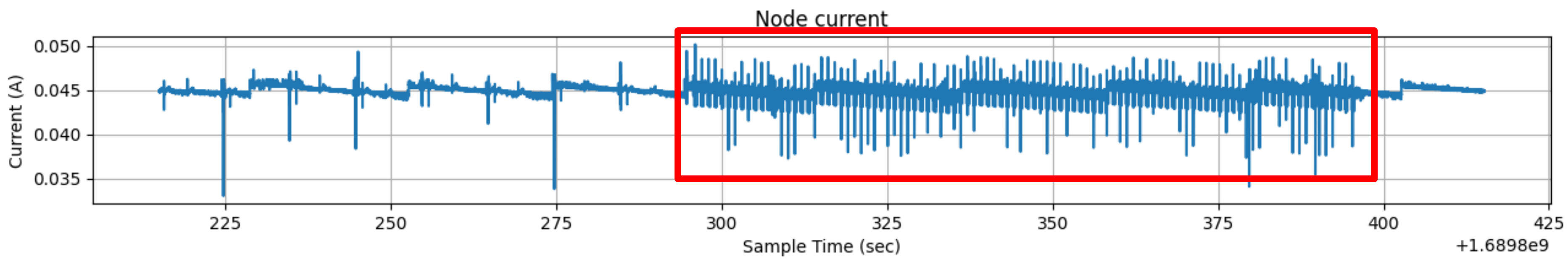
❖ Important difference in the transitions ➔ Important error

Energy Consumption in IoT-Lab

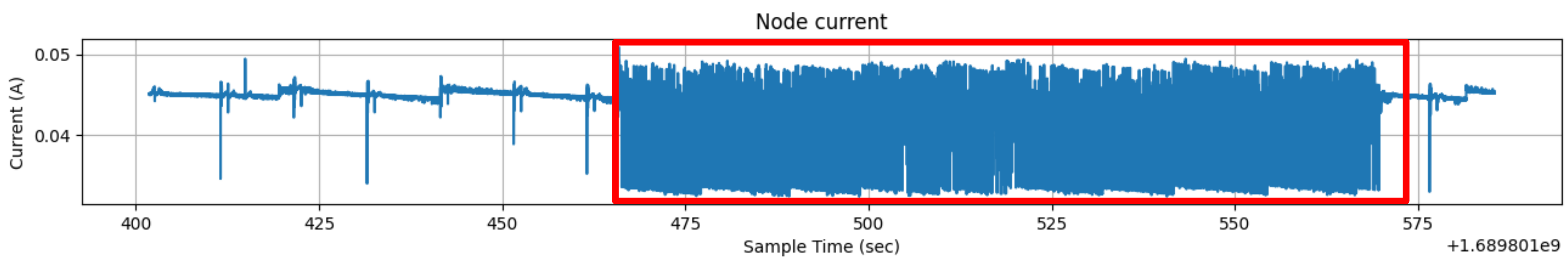
- Without transmission:



- 1 packet/s

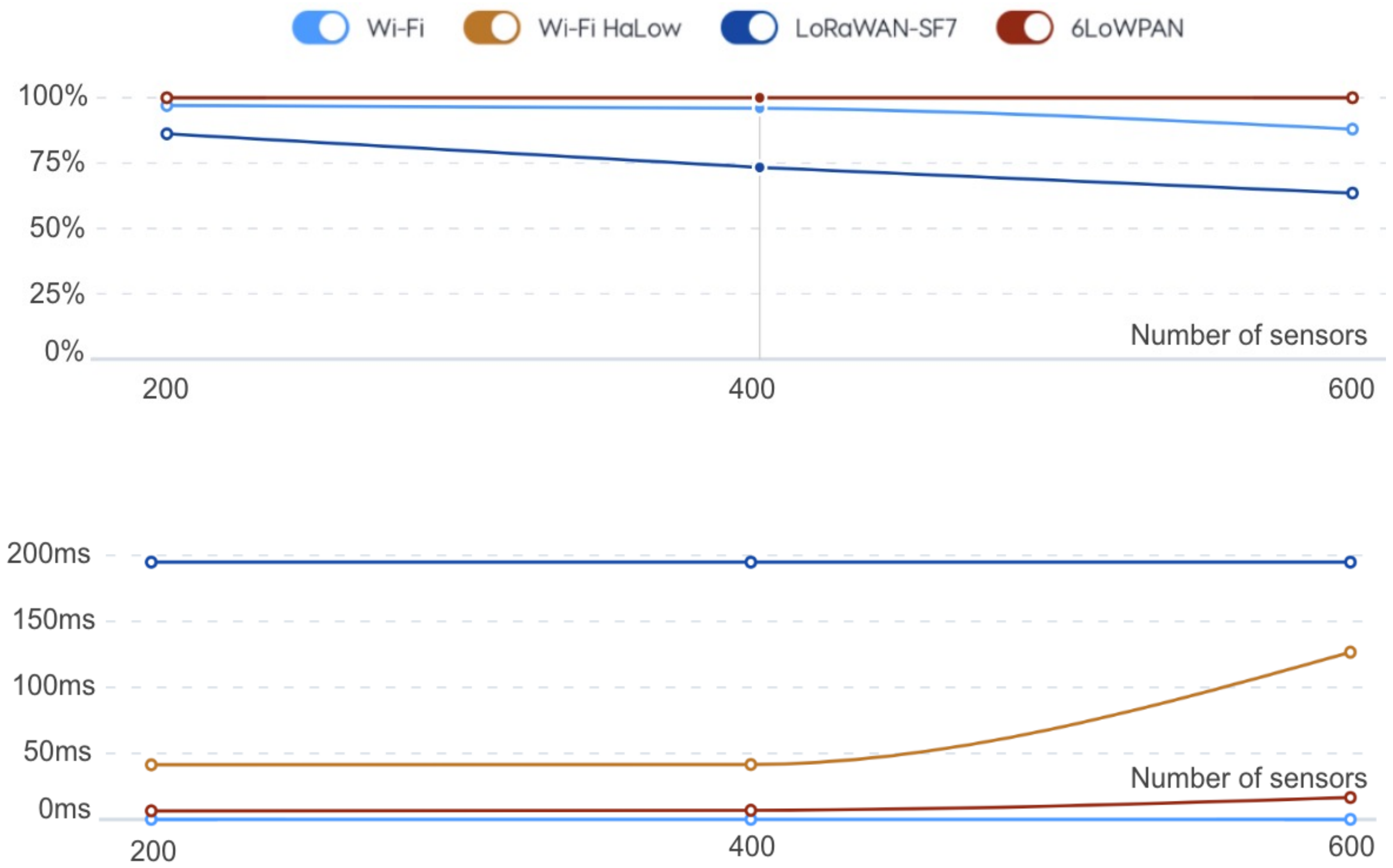


- 10 packet/s



Scalability Analysis

- How will the network technologies behave when scaling the density (from 200 to 600 sensors) and the traffic workload (110 bytes-packets and a period of 90 seconds) ?



Integration to WT-Tool

- WT-Tool (*) is a graphical tool for simulating wireless topologies

Collect.
Create.
Share.

WT-Tool

WT-Tool - A Powerful Tool to Integrate Real Geographic Data in Wireless Research

Wireless Topology Tool (WT-Tool) is an application designed to foster the use of real (or realistic) geographic data in the wireless networking research community. The tool can be used to conduct more realistic, geography - based simulations. One of the main objectives is to increase the reproducibility of results. Using this platform, you can load, create, and export realistic network topologies through our map-based interface.

(*) https://wttool.eng.buffalo.edu/