HINTS: A Methodology for IoT Network Technology-and-Configuration Selection

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Summary

Context and problematic

- An IoT network technology allows a wireless connectivity between physical assets (oil trucks, medical devices, industrial machinery) equipped with end-devices and computing servers (edge, cloud, etc.).
- Important growth of the number of IoT network technologies in the market:
  - ➢ How to choose the most adapted one to a given application context?

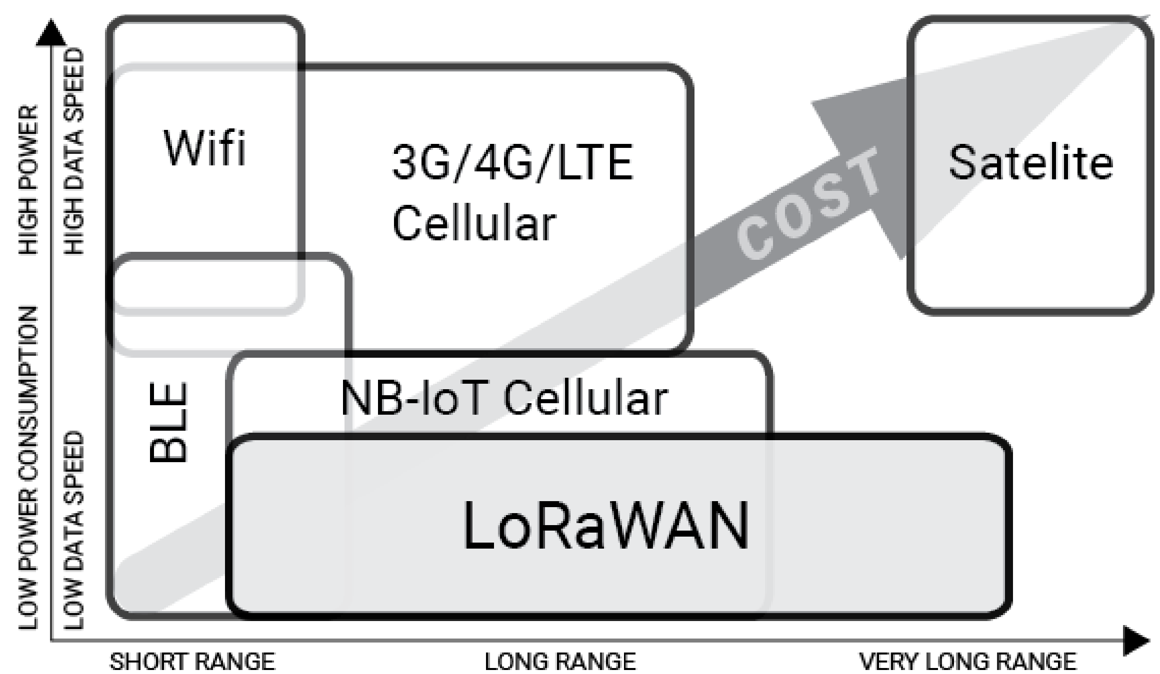


Figure 1: Diversity in IoT Network Technologies (Baranidesign)

➢ **There is the need of a generic approach to select the best network technology and as well as its configuration for a given application context.**

Related Works

- Several papers in the literature (for instance [1], [2] or [3]) are either restricted to the study of a single network technology, or alternately, to only one application. In addition, they do not provide guidelines about the network parameters to take into consideration.

- MADM (Multi Attribute Decision Making) is used for network selection (for example in [4], [5] and [6]) , but without a rigorous evaluation on the score assignment.
  - This may lead to arbitrary results, not depending on the targeted application scenario.

- Overall, an IoT network technology selection method, which operates prior to the network deployment but takes into account both the key aspects of the scenario and of the network with regards to KPIs (Key Performance Indicators), is still missing - despite the existing literature on IoT.

[1] Y. Lalle et al., “A Comparative Study of LoRaWAN, SigFox, and NB-IoT for Smart Water Grid,” Global Information Infrastructure and Networking Symposium, 2019.
[2] J. Sommers and P. Barford, “Cell vs. wifi: On the performance of metro area mobile connections,” in Proceedings of the 2012 Internet Measurement Conference. Association for Computing Machinery.
[3] M. A. Senouci et al., “TOPSIS- based dynamic approach for mobile network interface selection,” Computer Networks, 2016.
[4] F. Bari and V. Leung, "Multi-Attribute Network Selection by Iterative TOPSIS for Heterogeneous Wireless Access," 2007 4th IEEE Consumer Communications and Networking Conference, 2007, pp. 808-812, doi: 10.1109/CCNC.2007.164.
[5] A. Bazrafkan and M. R. Pakravan, "An MADM network selection approach for next generation heterogeneous networks," 2017 Iranian Conference on Electrical Engineering (ICEE), 2017, pp. 1884-1890, doi: 10.1109/IranianCEE.2017.7985361.
[6] Wael Ayoub, Abed Samhat, Mohamad Mroue, Hussein Joumaa, Fabienne Nouvel, et al.. Technology Selection For IoT-Based Smart Transportation Systems. International Workshop on Vehicular Adhoc Networks for Smart Cities (IWVSC'2019), Nov 2019, Paris, France.

HINTS Overview

- We propose HINTS, a rigorous approach for selecting the network technology by taking into account its usage context.
- It considers the network configuration and topology.
- It consists of five major stages:
  1. Modeling
  2. Generating
  3. Evaluating
  4. Ranking
  5. Scaling

HINTS - Modeling

- The application scenario, the KPIs and the network technologies are formalized in this stage.

Modeling	
Application Scenario	Number of end-devices
	Scenario range
	Traffic direction
	Message size
	Inter-messages period
	Radio environment (urban, suburban, rural, indoor)
Key Performance Indicators	Message delivery
	Battery lifetime
	Message latency
	Cost
Network Technologies	Network technology + Configuration parameters

Table 1: Modeling stage parameters

HINTS - Generating

- We pass through two steps:

1. Pruning
   - The network technologies that are inappropriate to a given application scenario are phased out.

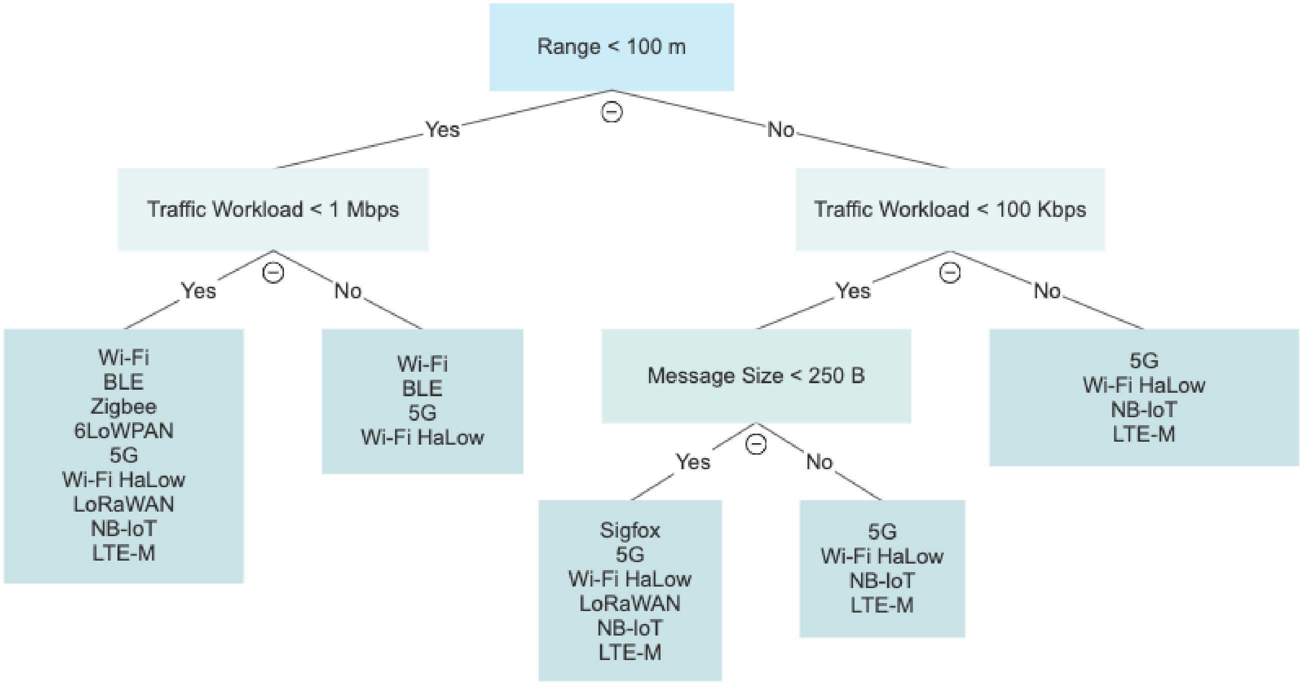


Figure 2: Pruning decision tree

2. Configuring
   - Assigning values to network technologies parameters.

HINTS - Evaluating

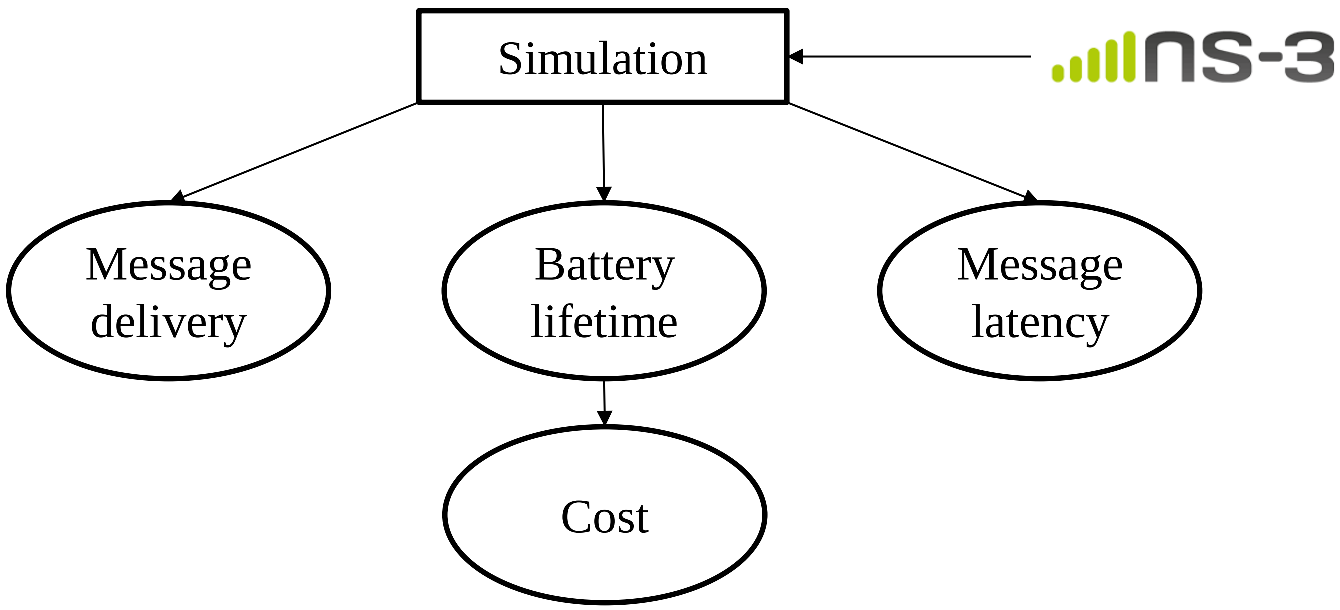


Figure 3: KPIs issued from simulation

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

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

Table 2: Cost parameters

- The number of gateways is varied for each alternative:

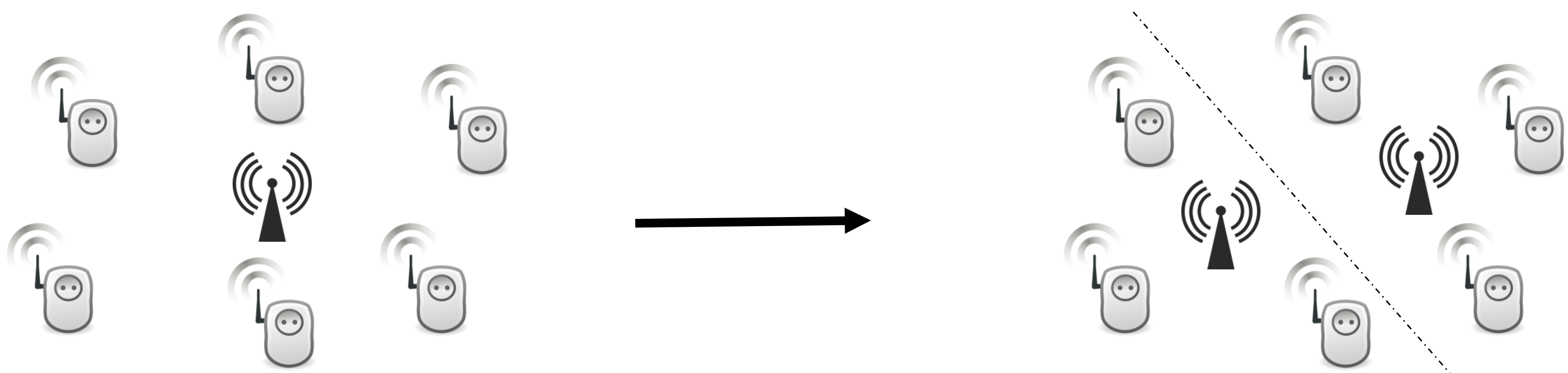


Figure 4: Gateway modeling

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

HINTS - Ranking

- This stage aims at ranking the evaluated alternatives, using an MADM (Multi-Attribute Decision Making) method (like TOPSIS).
- TOPSIS calculates the distance from each alternative to the best and worst possible solution, and attributes a score depending on that.

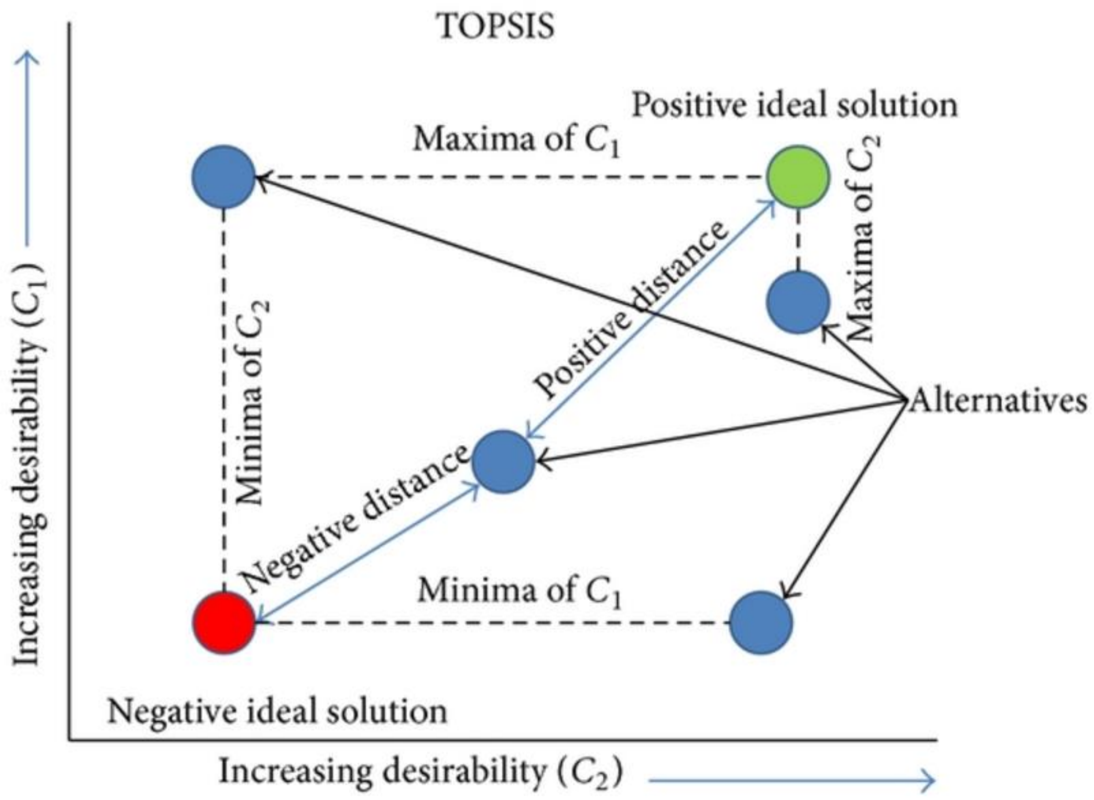


Figure 5: TOPSIS (Basset et al., 2019)

HINTS - Ranking

- A filter that caps the KPIs according to their targeted values is applied:
  - For the message delivery and the battery lifetime:

$$f(x, C) = \begin{cases} x & \text{if x > C} \\ 0 & \text{otherwise} \end{cases}$$

  - and for the message latency:

$$f(x, C) = \begin{cases} C & \text{if x < C} \\ x & \text{otherwise} \end{cases}$$

where x is the KPI value, and C the targeted value.

HINTS - Scaling

- Provide insights about the scalability of the best alternative selected by the Ranking stage of HINTS for the considered application scenario.

- IoT networks may be expected to evolve with time, in terms of network density or network traffic.

- We compute the KPIs of the best given network alternative while varying the number of devices and the inter-messages period.

HINTS Overview

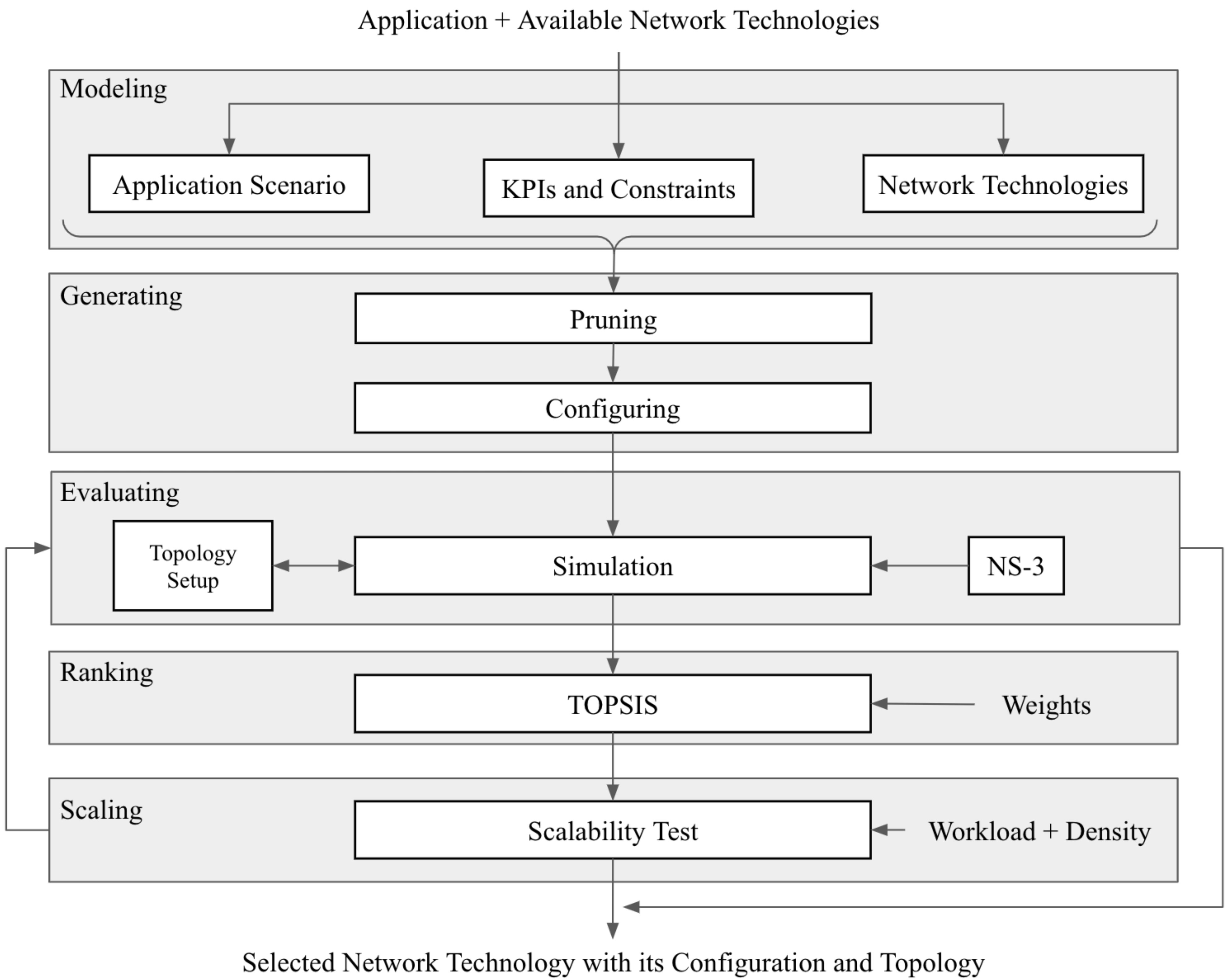
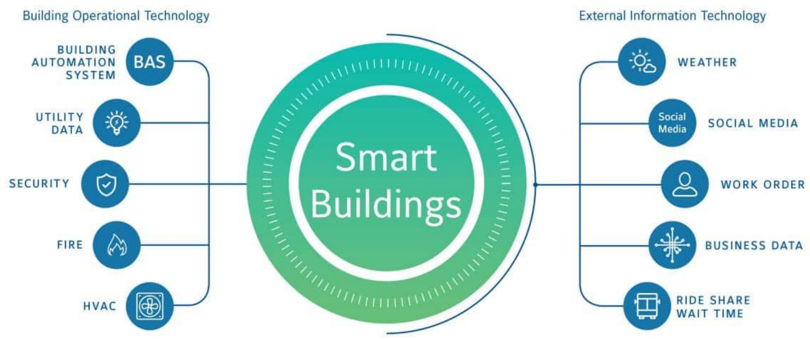


Figure 6: HINTS Overview

Application



(Johnson Controls)

(AndroidFun)

Wi Fi

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

6LoWPAN

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

Wi-Fi HaLow

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

LoRaWAN

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

Application – Smart Building

- **Modeling:**

Modeling		Value
Application Scenario	Number of end-devices	50
	Scenario range	50 m
	Traffic direction	Upstream
	Message size	100 bytes
	Inter-messages period	1 s
	Radio environment	Indoor
Key Performance Indicators	Message delivery	> 90 %
	Battery lifetime	> 100 days
	Message latency	< 100 ms
	Cost	/
Network Technologies	Network technology + Configuration parameters	/

Table 3: Smart building modeling

- **Generating:**
  - LoRaWAN is eliminated due to the high data rate.
  - We use the previously provided configuration for Wi-Fi, Wi-Fi HaLow and 6LoWPAN.

Application – Smart Building

- **Evaluating & Ranking:**

Network technology	Nb. of GWs	Message Delivery (%) [>90]	Battery Lifetime (Days) [>100]	Message Latency (ms) [<100]	Cost ($)	Score
Wi-Fi	1	98.0	76.85	**0.07**	3100	0.343
Wi-Fi	2	**100.0**	86.07	**0.07**	2950	0.351
Wi-Fi	3	**100.0**	86.49	**0.07**	3050	0.349
Wi-Fi	4	**100.0**	86.67	**0.07**	3150	0.347
Wi-Fi HaLow	1	**100.0**	351.15	49.29	**2250**	**0.932**
Wi-Fi HaLow	2	**100.0**	**381.40**	49.23	3250	0.88
6LoWPAN	1	83.51	92.21	8.17	3950	0.201
6LoWPAN	2	96.94	123.98	6.32	3400	0.465
6LoWPAN	3	98.23	141.97	6.32	3350	0.496

Table 4: Smart Building Results

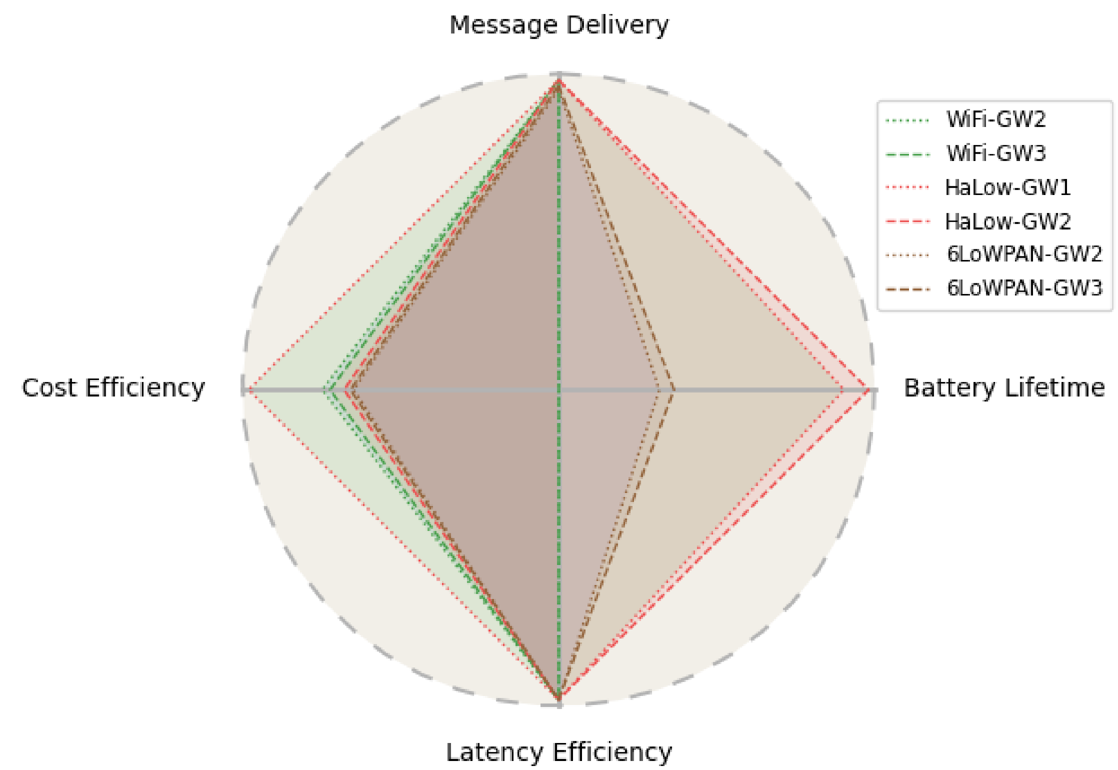


Figure 7: Smart Building Radio Chart

Application – Precision Agriculture

- **Modeling:**

	Parameter	Value
Application Scenario	Number of end-devices	200
	Scenario range	1500 m
	Traffic direction	Upstream
	Message size	20 bytes
	Inter-messages period	180 s
	Radio environment	Outdoor rural
Key Performance Indicators	Message delivery	> 90 %
	Battery lifetime	> 365 days
	Message latency	< 1000 ms
	Cost	/
Network Technologies	Network technology + Configuration parameters	/

Table 5: Precision Agriculture modeling

- **Generating:**
  - Wi-Fi & 6LoWPAN are eliminated due to the long scenario range.
  - We use the previously provided configuration for Wi-Fi HaLow and LoRaWAN.

Application – Precision Agriculture

- **Evaluating & Ranking:**

Network technology	Nb. of GWs	Message Delivery (%) [>90]	Battery Lifetime (Days) [>365]	Message Latency (ms) [<1000]	Cost ($)	Score
Wi-Fi HaLow	1	**100.0**	470.16	51.73	74000	0.028
Wi-Fi HaLow	2	**100.0**	471.13	**42.16**	75000	0.025
LoRaWAN	1	95.78	2327.91	82.17	**12000**	0.974
LoRaWAN	2	99.63	**2327.93**	82.17	13000	**0.988**

Table 6: Precision Agriculture Results

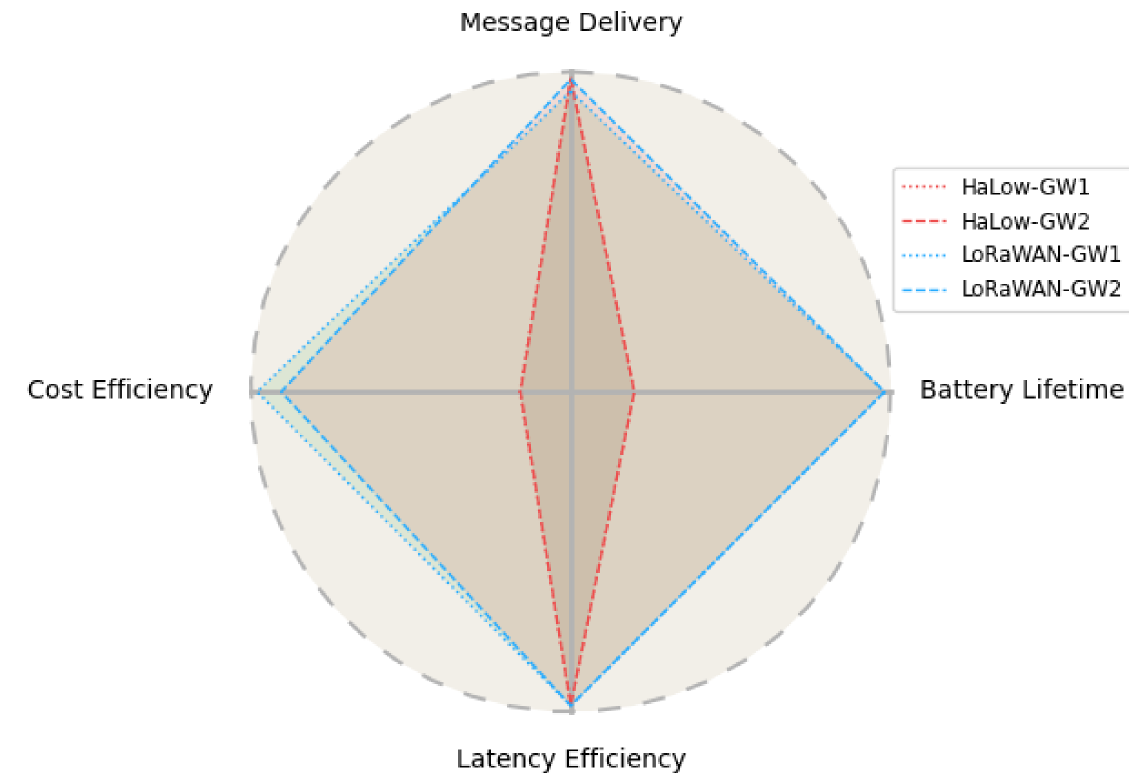
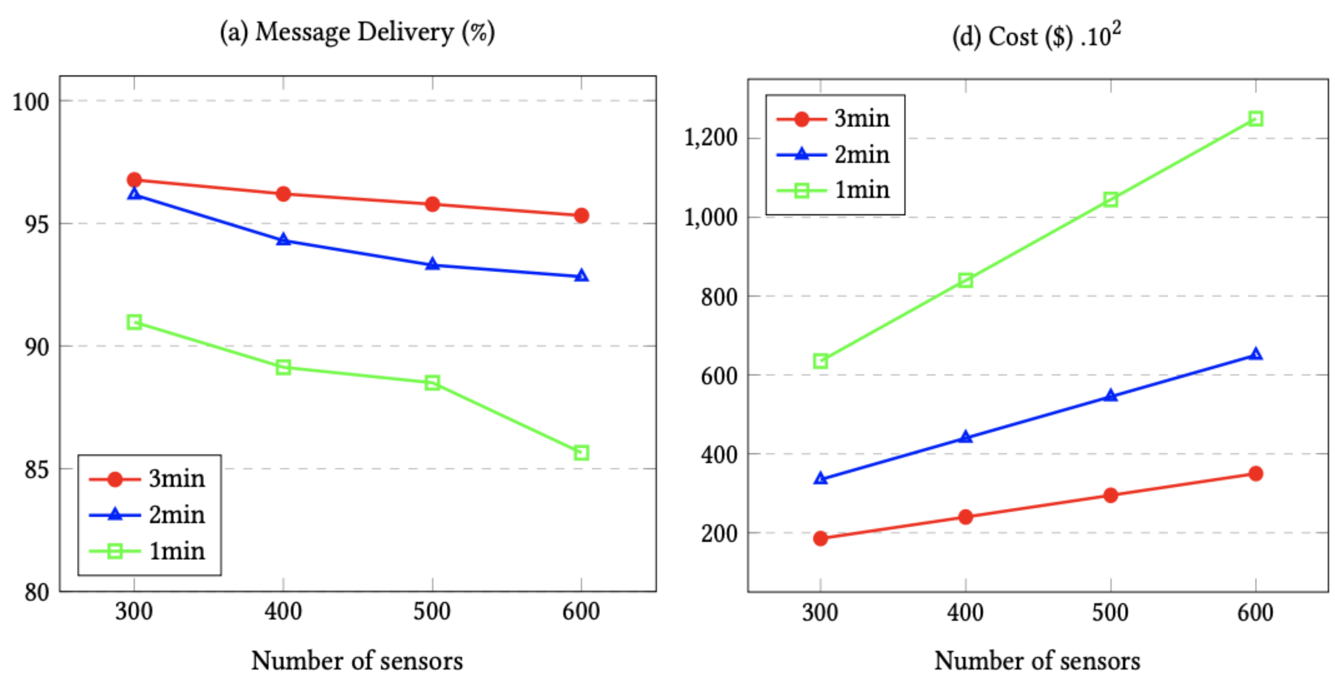


Figure 8: Precision Agriculture Radio Chart

- **Scaling:**



Message period (min)	Battery lifetime (days)
3	2327
2	1580
1	800

Figure 9: Precision Agriculture Scaling

Conclusion

- We have presented HINTS, which relies on five stages: (i) Modeling, (ii) Generating, (iii) Evaluating, (iv) Ranking and (v) Scaling.

- HINTS allows:
  - Comparison based on network KPIs and cost between network technologies considering the usage context.
  - Tuning and determining network parameters to set and the number of gateways to set.
  - Highlighting the solution behavior when scaling the network density and traffic.

- The source code available at https://github.com/SamirSim/Selection-Methodology-IoT.

Future works

- Integrate 5G and NB-IoT with the proposed methods.
- Include the mobility into the studied application scenarios, so that HINTS may handle connected vehicle applications or drone-based use cases.
- Validate and enrich the simulation results with real experiments (for instance on on testbeds such as FIT-IoT lab or SLICES).

Thank you for your attention!

Any question?