***International Journal of Engineering Research and Development***
*e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com*
*Volume 22, Issue 6 (June 2026), PP 12-16*

# Sensitivity Analysis as an Enhancement to Hybrid MCDM Approach for IoT Wireless Protocol Selection

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***Abstract***
*The massive development in the Internet of Things deployments requires efficient methods for selecting optimal wireless protocols in conflicting situations. In this paper, the authors propose a hybrid Multi-Criteria Decision-Making model augmented with sensitivity analysis for selecting optimal IoT protocols. Five wireless protocols: Wi-Fi HaLow, NB-IoT, LoRaWAN, Sigfox, and Zigbee are considered in terms of Power consumption, Data Rate, Latency, Coverage range, and Cost. Robustness of ranking of the wireless protocols was tested by One-at-a-Time (OAT) sensitivity analysis by changing the value of criterion weights by ±10%. Results proved the robustness and reliability of the framework since Wi-Fi HaLow protocol occupied the leading positions in most of the scenarios. However, when the weight of the Power criterion exceeded the 45% mark, NB-IoT proved to be a preferred solution; the latter emphasizes the significance of heat map visualization technique. Specifically, Wi-Fi HaLow represents the optimal solution for latency-sensitive and balanced environments where Power (0.80), Latency (0.75), and Data Rate (0.70) are key criteria, whereas NB-IoT is more suitable for large-scale, coverage-driven environments. Furthermore, LoRaWAN and Sigfox can be recommended as energy-efficient sensing solutions. Meanwhile, Zigbee fits best for automation systems in local networks.*

***Keywords: Sensitivity Analysis, MCDM, IoT Wireless Communication Protocols***

Date of Submission: 24-05-2026 Date of acceptance: 02-06-2026

## I. INTRODUCTION

Today it becomes evident that IoT will lead to a revolution in modern technologies by connecting various devices to provide real-time exchange of information, intelligent and autonomous operation within various spheres such as households, industrial processes, healthcare and so on. The expected explosive growth of IoT installations is estimated at exceeding 75 billion by 2025 compared to 15.4 billion units installed in 2015, according to IHS Technology estimates, (2016). However, selection of optimal wireless communication protocols represents a challenging task due to issues related to limitations in available resources and battery life, variety of protocols and technologies, different latency, data throughput demands, security and privacy problems, interoperability issues between various IoT standards as well as difficulties associated with scalability, (Ahmad et al. 2019).

Thus, utilizing the potentialities of a hybrid Multi-Criteria Decision-making model can help to solve this task. Specifically, the goal is to develop a framework for selecting optimal wireless protocols for IoT applications via developing an assessment matrix in order to calculate the normalized weights of criteria using Analytic Hierarchy Process (AHP) methodology, normalization of the decision matrix by applying ReliefF algorithm and finally ranking of the alternatives via Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS); these methods allow for accurate modeling of different scenarios and enable selection of optimal wireless communication protocols (Cui et al. 2023).

Overall, the utilization of a hybrid MCDM approach can not only improve the network efficiency and performance but also highlight the robustness and reliability of the obtained ranking. Sensitivity analysis as an enhancement of hybrid MCDM models is crucial for testing the robustness of decision frameworks as well as for identification of the most critical parameters in order to achieve reliability. Experiments in such cases can be conducted using a series of variations of criterion weights by means of one-at-a-time (OAT) experiments, multidimensional perturbations, and/or Monte Carlo simulation techniques (Radulescu et. al 2024). Thus, sensitivity analysis serves to identify the stability of the final decision and the most significant criterion weights, and it helps to ensure robustness of the final decision.

## II. MATERIALS AND METHOD

### 2.1 Materials Used

**The materials used in this research are;**

Software and Hardware Requirements
MATLAB 2024a

Microsoft Excel
Research articles
Protocol specification sheets
Computer System, core i7, 16GB RAM.

### 2.2 Method used

The dataset used in this study was collected from industrial specification sheets, previous benchmarking studies (IEEE, 2023; LoRa Alliance, 2024; 3GPP, 2023)., as well as reports on performance of IoT protocols (Cisco, 2019). Realistic numerical values are considered in order to simulate realistic conditions typical for IoT smart city and industrial IoT applications.

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Step 1: Establishment of Base Case

- Computation of integrated weights vector $w = (w_1, w_2, \dots, w_5)$ using the AHP-ReliefF method.
- The construction of initial decision matrix $X_{ij}$ having dimensions of $m * n$ (where $m = 5$ representing protocols-Wi-Fi Halow, Sigfox, NB-IoT, Zigbee, LoRaWAN and $n = 5$ representing criteria-power consumption, latency, data rate, coverage range, cost effectiveness).
- Application of the TOPSIS methodology based on initial weights calculation and obtaining a baseline closeness coefficient $CC_i^0$and ranking $R^0$.

Step 2: Definition of Perturbation Levels
Selection of perturbation levels. Values of Δ usually considered in this study include $\delta \in \{-10\% - +10\%\}$
Step 3: OAT variation for each criterion. For each criterion $j = 1$ to $n$ (where $n = 5$): For each perturbation level $\delta_k$in the chosen set, perform the following steps:
a. Calculation of the new weight for criterion $j$:

$$w_j' = w_j \times (1 + \delta_k) \tag{1}$$

b. Computation of the new sum of weights:

$$S' = \sum_{k=1}^{n} w_k' \text{ (where only } w_j \text{ changed)} \tag{2}$$

c. Normalization of the weight vector ( so that the new vector sums up to 1):

$$w_k'' = \begin{cases} \frac{w_k}{S'} & \text{if } k \neq j \\ \frac{w_j'}{S'} & \text{if } k = j \end{cases} \tag{3}$$

d. Recalculation of the weighted normalized decision matrix is recomputed using updated $w''$
e. Application of the whole TOPSIS methodology in order to obtain a new set of closeness coefficients $CC_i'$ and new ranking vector $R'$.
f. Recording of:

- New closeness coefficient of the top-ranked alternative
- Complete ranking changes.

Step 4: Aggregation and analysis of results

- Identification of the most sensitive (critical) criteria that cause rank changes with minimum ∣ δ ∣ values.

Step 5: Visualization of findings

- Creation of plots displaying the impact of ranking positions on alternatives.
- Preparation of sensitivity analysis tables and rank stability heatmaps.

## III. RESULTS AND DISCUSSION

In order to analyze robustness of our MCDM model and validate reliability of ranking, a sensitivity analysis for all criteria in the model was performed, changing weights by ±10% each. Rank variations are shown in Table 1.0.

**Table 1.0: Sensitivity Analysis (±10% Weight Variation)**

| Protocol | Power | Data Rate | Latency | Coverage | Cost |
|---|---|---|---|---|---|
| Wi-Fi HaLow | 1 | 1 | 1 | 2 | 1 |
| NB-IoT | 2 | 2 | 2 | 1 | 2 |

| | | | | | |
|---|---|---|---|---|---|
| LoRaWAN | 3 | 3 | 3 | 3 | 3 |
| Sigfox | 4 | 4 | 4 | 4 | 4 |
| Zigbee | 5 | 5 | 5 | 5 | 5 |

As can be seen from Table 1.0 above, the ranking varies from 1 (best) to 5 (worst) depending on the protocol performance with respect to the corresponding criterion (lower value is better). Five candidate protocols for evaluation using our MCDM framework are considered for five main criteria. Wi-Fi HaLow obtained the best overall ranking achieving the first position in four criteria, namely Power consumption, Data rate, Latency and Cost. Meanwhile, NB-IoT ranked second occupying the first position in Coverage criterion and obtaining strong results in the remaining four criteria.

LoRaWAN shows relatively balanced but mediocre results, achieving consistently good but not outstanding results (ranking third) across all criteria. Sigfox and Zigbee show the poorest results ranking fourth and fifth respectively, for all criteria.

Thus, one can draw some conclusions regarding the peculiar features of each protocol: the former shows a strong result in performance-oriented criteria such as Power, Latency, and Data rate and Cost while the latter stands out due to outstanding coverage capability. In order to proceed with sensitivity analysis, the above-obtained values were used in order to find their normalized values for a further use during the AHP-TOPSIS-ReliefF analysis; this helped to develop the foundation of final closeness coefficients for obtaining a ranking for these protocols.

The results of the sensitivity analysis confirmed robustness and reliability of the framework since it did not influence the ranking of criteria significantly excepting the case when a weight for criterion of Coverage exceeded the mark of 45%; the latter confirms importance of the use of heatmap visualization technique.

Highlighting Figure 1.0 below,

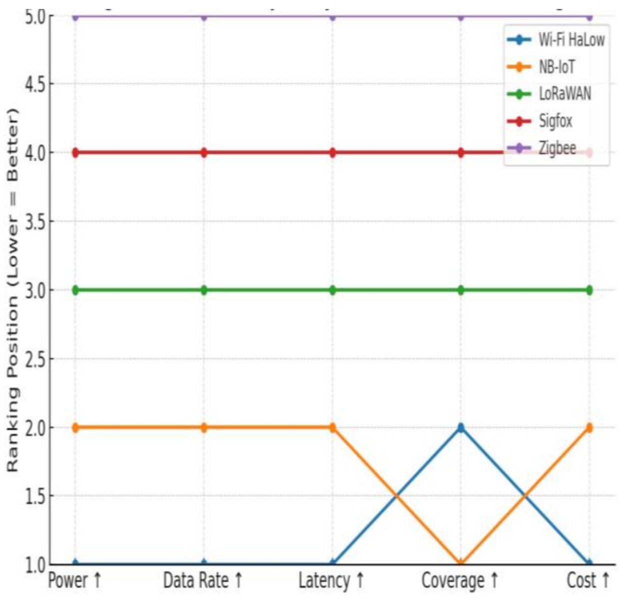

**Figure 1.0: Sensitivity Analysis (line chart showing Ranking Stability).**

The figure represents the plot of the relative ranking positions for the set of selected IoT Wireless Communication Protocols depending on five performance metrics. Comparisons are made based on the ranking position for five Wireless Communication Protocols viz: Wi-Fi HaLow, NB-IoT, LoRaWAN, Sigfox, and Zigbee along five important metrics: power consumption, data rate, latency, coverage, and cost.

Wi-Fi HaLow indicated by the blue color shows the strongest overall ranking achieving the first ranking for three criteria, namely Power Consumption (1.0), Data Rate (1.0) and Cost (1.0). It also achieved a competitive ranking position of 2.0 in coverage and excellent position of 1.0 in terms of latency.

In turn, NB-IoT indicated in orange exhibits mid-level results with stable performance in criteria such as Power, Data Rate, and Latency. Meanwhile, the protocol shows the best results in Coverage (1.0 ranking). In the aspect of Cost, NB-IoT achieves a slight degradation in ranking obtaining value 2.0.

LoRaWAN, represented by the green line, obtains quite constant mediocre ranking positions with values of 3.0 across all considered performance criteria, reflecting balanced results in evaluation of this protocol. The red line, representing Sigfox, shows poor overall performance having a steady ranking position of 4.0; it indicates the limitation of this protocol. Finally, the purple line, indicating Zigbee, shows the weakest result in ranking across all performance criteria (values approaching to 5.0).

Therefore, the results of the sensitivity analysis depicted both on the line chart and in Table 1.0 confirm that Wi-Fi HaLow protocol is the best for applications that require low power, high data rates and low latency, while NB-IoT protocol becomes a serious competitor in the coverage criterion.

The heatmap given below (Figure 2.0) is a representation of normalized results in the form of a matrix.

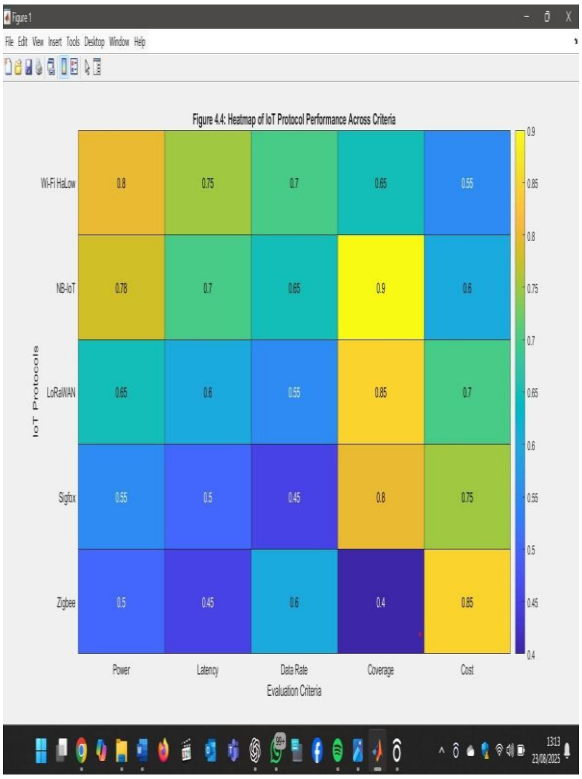

**Figure 2.0 Performance Validation using Heatmap**

Warm colors (from yellow to light yellow) demonstrate high normalized scores, while cooler colors (from light blue to dark blue) correspond to low scores. The range of normalized scores is 0.4 to 0.9, showing a moderate to significant variation of results across all protocols and criteria.

**Table 2.0 Heat Map Interpretation**

| Protocol | Power | Late-ncy | Data Rate | Coverage | Cost |
|---|---|---|---|---|---|
| Wi-Fi HaLow | 0.80 | 0.75 | 0.70 | 0.65 | 0.55 |
| NB-IoT | 0.78 | 0.70 | 0.65 | 0.90 | 0.60 |
| LoRaWAN | 0.65 | 0.60 | 0.55 | 0.85 | 0.70 |
| Sigfox | 0.55 | 0.50 | 0.45 | 0.80 | 0.75 |
| Zigbee | 0.50 | 0.45 | 0.60 | 0.40 | 0.85 |

Higher values are better for each criterion. All values are normalized between 0 and 1.

As it is seen from the table 2.0 above, a list of normalized results for five candidate communication protocols in five key criteria was obtained. Wi-Fi Halow shows the strongest results for the Power (0.80), Latency (0.75) and Data Rate (0.70) criteria, meaning that the protocol is characterized by high efficiency in the terms of energy resources and response time. It has lower scores for the remaining two criteria (0.65 and 0.55 for Coverage and Cost respectively).

Meanwhile, NB-IoT obtains the best results for the Coverage criterion (0.90) and competitive results for the remaining criteria, especially for Power. In turn, LoRaWAN obtains fairly even and competitive results for Coverage and Cost, but rather low scores for the remaining criteria. The latter applies to Sigfox protocol, as well, however, it has the highest Cost score (0.85). Zigbee obtains the best Cost score and the lowest Coverage (0.40), as well as scores of Powers (0.50) and Latency (0.45).

All above-obtained values will serve as the basis for further AHP-TOPSIS analysis for finding normalized weights and closeness coefficients of the protocols in accordance with the criteria; they help to identify the trade-offs and justify using this model to determine the ranking.

## IV. Conclusion

This research demonstrates the use of a robust and reliable decision-making model that allows evaluating and selecting optimal IoT wireless protocols despite significant perturbations of the criteria weights: this has been done using the hybrid multi-criteria decision making methodology in order to select optimal wireless protocols for IoT applications; Analytic Hierarchy Process, Technique for Order Preference by Similarity to Ideal Solution and ReliefF methods are used in this hybrid framework.

Heat map visualization proved that Wi-Fi HaLows' is the best protocol for power, latency, and data rate criteria, while NB-IoT is best for coverage; in such way, this sensitivity analysis confirms accuracy of the model.

The study makes the following substantive contributions to knowledge and practice in IoT communication:

i. Development of Hybrid AHP–TOPSIS Framework for Selecting IoT Protocols

While AHP and TOPSIS have separately been utilized in different decision-making scenarios in engineering and manufacturing industries, this study makes a unique contribution of proposing a hybrid decision-making pipeline. The combination of machine learning algorithms (ReliefF) with MCDM methodologies (AHP-TOPSIS) in this study ensures objective assessment of competing technologies.

ii. Empirical Contribution

This study provides comparative ranking of leading IoT wireless protocols based on their current performance specifications. The empirical findings provide clear decision rules for selecting wireless protocols. Wi-Fi HaLow is recommended as the optimal protocol in balanced scenarios, NB-IoT in coverage-based deployments and Zigbee in cost limited IoT scenarios.

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