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Optimum LPWAN Selection for Industrial IoT

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Abstract. Low Power Wide Area Network (LPWAN) an irreplaceable segment of the Industrial Internet of Things (IIoT) - enabling long-range connectivity for low-power distributed devices and machinery. Nonetheless, selection among the numerous LPWAN technologies, including LoRaWAN, NB-IoT, LTE-M, and Sigfox remain difficult depending on industrial scenarios and their potential trade-offs. This study conducts a multi-criteria decision-making framework for the purpose of addressing the selection of an optimal LPWAN for IIoT. It includes four main criteria - power consumption, coverage range, reliability, and cost. Each of the criteria will be applied on three representative IIoT scenarios: smart factory equipment tracking, remote pipe sensing, and smart grid monitoring. Through direct comparison of LPWAN performance against scenario differences, we find that LoRaWAN is ideal for wide coverage, low-cost (e.g., oil pipelines), NB-IoT excels in secure, reliable applications (e.g., smart grids), and LTE-M suits latency-sensitive use cases (e.g., factory fault detection). This research provides a clear, actionable framework for students, engineers, and beginners to match LPWAN technologies to real-world IIoT requirements, supporting successful, efficient industrial connectivity in projects.

Keywords: Industrial IoT (IIoT), LPWAN, LoRaWAN, NB-IoT, Network Selection, Industrial Connectivity

1. Introduction

Industrial Internet of Things (IIoT) is the connectivity of machines, sensors, and systems in industries like manufacturing, energy regulation, and transportation to reduce time consumption, increase efficiency, and cut costs. For example, smart factories implement sensors to track machine temperature;when overheating is detected, an alert is sent to prevent breakdowns.

Conventional networks (e.g., Wi-Fi, 5G, 4G) fail when utilized in IIoT's unique requirements: (1) WiFi has limited coverage of around 100 meters indoor and is unsuitable for remote connections; (2) 5G and 4G have high power consumption, limiting the practicality of long-term sensor connection availiable for years. Low Power Wide Area Networks (LPWAN) are specialized to run low power, large coverage (up to 10 km in remote areas) internet connection and low cost at different bandwidth as those suggested above. Yet, choosing a suitable LPWAN can be demanding. Each consists of its distinct strengths and weaknesses:

LoRaWAN: An open, unlicensed technology that covers large areas (10 km rural, 2 km urban) and has low deployment cost, but transmits data slowly (0.3–50 kbps) [1].

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NB-IoT: A licensed technology that works with existing cellular networks (4G/5G), offering high reliability (99.9% data delivery) and security but higher device and setup costs [2].

LTE-M: A cellular LPWAN with faster data rates (up to 1 Mbps) and low latency (50–100 ms), ideal for time-sensitive tasks, but uses more power than LoRaWAN [3].

Sigfox: An ultra-low-power, unlicensed option that uses minimal battery but can only send small data packets (<1 kbps) and has limited scalability [4].

Incompatible LPWAN can derail from the purpose of an IIoT project. For instance, using Sigfox for a smart factory (that requires frequent, detailed machinery data) would fail to send the tremendous amount of data required.

This study aims to create a simple evidence-based framework for LPWAN selection. It focuses on four easy measure criteria that apply to three common IIoT scenarios, making complex technical decisions accessible to learners and entry-level practitioners.

2. Related work

The selection for an appropriate low-power wide-area network (LPWAN) for IIoT applications have been a subject of extenisve research in recent years. Due to diverse requirements of industrial scenarios (such as intelligent factories, remote infrastructure monitoring) and the inherent trade-offs of LPWAN solutions, it has become a focus of both academic and industrial research. This section synthesizes the existing literature to present the current state of research on LPWAN selection, which is consistent with the core criteria defined in this study (power consumption, coverage, reliability, cost) and the scenarios.

2.1. Comparative performance studies of LPWAN technologies

A fundamental research focuses on quantitatively evaluating the performance of mainstream LPWANs—LoRaWAN, NB-IoT, LTE-M, and Sigfox—across key IIoT metrics. 3GPP's (2022) technical specification directly illustrated the reliability benchmarks of NB-IoT, documenting its 98–99.9% data delivery rate in licensed cellular networks, the essential advantage for security-sensitive scenarios like smart grids [1]. This information aligns with Ericsson's (2023) analysis of LTE-M, which emphasizes the technology's low latency (50–100 ms) and high reliability (97–99%), positioning it as a preferred choice for time-sensitive industrial tasks such as equipment fault detection [2].

For unlicensed LPWANs, Sigfox's (2022) technical guide provides detailed data on its ultra-low power consumption (7–10 years of battery life) and long rural coverage (10–12 km), but it also highlights the limitations of lower than 1 kbps data rates and 88–90% reliability, which restrict its use in critical applications [3]. To complement these research reports targeting specific suppliers, IoT Analytics' (2023) market report offers cross-technology cost comparisons, noting that LoRaWAN sensors ($15-25 per unit) balance the affordability with its performance, making them suitable for large-scale deployments like remote pipelines—where cost and coverage are considered as its priority [4].

Recent independent research expands on these findings. Wang et al. (2021) conducted field tests in rural industrial zones (e.g., oil fields) and approved LoRaWAN's superior coverage stability: its 8-10 km rural range outperformed NB-IoT's 5–7 km urban-focused coverage, while, on the other hand, its 5–7 year battery life met the low-maintenance needs of remote sensing [5]. Similarly, Zhang et al. (2023) compared LPWANs in smart factory environments, confirming LTE-M's latency advantage—iIts 50 ms response time is 30% faster than the LoRaWAN solution, enabling faster

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fault alerts to be sent out, meeting the priority requirement for low latency in factory equipment tracking [6].

2.2. LPWAN selection methodologies and frameworks

Researchers have proposed various decision-making tools to streamline LPWAN selection, though most focus on complex multi-criteria models. For example, Liu et al. developed a fuzzy analytic hierarchy process (AHP) framework that contains 12 criteria (including power, coverage, and cost) to rank LPWANs [7]. While comprehensive as is, this model requires advanced data analysis skills, making it less accessible for beginners or entry-level engineers a — gap this study addresses by simplifying criteria to four core metrics.

Other frameworks place more emphasis on practicality. Chen et al. created a scenario-matching matrix for IIoT, mapping the advantages of LPWAN to the priorities of different scenarios (e.g., “low power” + “wide coverage” = LoRaWAN). Their matrix, however, lacked quantitative performance data (e.g., specific battery life or coverage ranges), which was supplemented by referring to scores from industry specifications and on-site tests [8]. These existing methodologies all highlight the need for a balance between rigor and accessibility — a key objective of the framework proposed here aim to achieve.

2.3. Research gaps and opportunities

Despite the progress made, three critical shortcomings remain. First, most studies focus on single scenarios (e.g., only factories or only pipelines) rather than cross-scenario comparisons, limiting a holistic LPWAN evaluation. Second, few frameworks prioritize simplicity: existing models either are too complex (e.g., 12-criteria AHP) or too vague (e.g., no quantitative scores). Third, ultra-low-cost LPWANs like Sigfox are often not given sufficient attention. People often abandon them without conducting in-depth research on their specific application scenarios (e.g., non-critical environmental sensing), leaving gaps in cost-sensitive project guidance.

This study addresses these gaps by: (1) comparing LPWANs across three distinct scenarios, (2) simplifying criteria to four measurable metrics with clear scores, and (3) explicitly defining where niche technologies like Sigfox may be applicable. Future research could build upon this foundation and incorporate emerging LPWAN technologies (e.g., LPWAN 5G) or adding criteria like environmental resilience (e.g., temperature resistance for mining scenarios).

3. Key criteria and IIoT scenarios

The selection of an appropriate LPWAN can be simplified into four core categories, which serve as the critical factors to consider when creating IIoT projects with real-world applications:

First, power consumption is measured by the average battery life of a sensor, typically expressed in years. This criterion is particularly critical for devices deployed in long distance connection in hard-to-reach areas (e.g. pipeline sensors), where frequent recharging is impractical.

Second, coverage range refers to the maximum distance over which data can be transmitted, measured in kilometers. Crucial for remote sites or areas (e.g., farmland, rural pipelines).

Third, reliability is defined as the percentage of data successfully delivered to its destination. High reliability is fundamental in applications where data loss could have significant consequences, such as smart grids, which requires accurate energy usage data.

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Finally, deployment cost includes both the per-unit cost of each sensor (in US dollars) and setup fees. Key for projects containing hundreds or thousands of devices (e.g., factory sensors).

To demonstrate the practical application of these criteria, this study considers three representative IIoT scenarios—each prioritizing in different criteria, reflecting the real-world industrial requirements.

3.1. Scenario 1: smart factory equipment tracking

Factories use sensors to monitor motors and conveyors for signs of wear. The ultimate goal aims to detect early faults to avoid production halt.

Priority Criteria: reliability (data lossage could miss faulty detection) and low latency (fast alert means quick fixes)

Less Critical: coverage (factories are indoor, small-scale) and power (sensors can be recharged constantly or in shorter intervals).

3.2. Scenario 2: remote oil pipeline sensing

Pipelines stretch for kilometers across rural areas. Sensors are integrated to detect leakage and pressure drops to prevent occasional spills.

Priority Criteria: low power (sensors are in remote areas, no easy recharging methods underground) and wide coverage (pipelines span miles).

Less Critical: cost (spill fixes cost more than low cost sensors) and latency (leaks don’t require instant alerts).

3.3. Scenario 3: residential smart grid metering

Smart meters track household electricity usage and transmit data to utility companies. The goal lands on securing bills.

Priority Criteria: reliability (data loss will lead to incorrect bills) and security (licensed networks prevent data hacks).

Less Critical: power (meters are plugged into electricity directly rather than with batteries) and coverage (residential areas are dense, easy to cover).

4. Comparing LPWAN technologies in different scenarios

This is a collection of the performance data for four mainstream LPWANs (LPWAN, NB-IoT, LTE-M, Sigfox) from industry reports and specifications from [1-4]. To quantify their suitability for IIoT scenarios, each technology is scored on the four core criteria (power consumption, coverage range, reliability, deployment cost) using a 1-5 scale (1=worst performance, 5=best performance). Scores are weighted according to the priority of criteria in specific scenarios (e.g., reliability carries higher weight in smart grid metering), with the final score reflecting overall adaptability (see Table 1).

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Table 1. Key metrics (power, coverage, reliability, cost) of LPWAN technologies for IIoT applications

LPWAN Type	Power Consumption (Years)	Coverage Range (km)	Reliability (%)	Deployment Cost ($/Sensor)	Score (1-5)
LoRaWAN	5-7	8-10 (rural)	92-95	$15-25	4
Nb-IoT	3-5	5-7 (urban)	98-99.9	$25-35	4.5
LTE-M	2-4	4-6 (urban)	97-99	$30-40	3.5
Sigfox	7-10	10-12(rural)	88-90	$10-20	3

4.1. Explanation of scoring basis and weight allocation

Table 2. Metric-score mapping

Criterion	Score=5	Score=4	Score=3	Score=2
Power Consumption	≥7years (Sigfox)	5-6years (LoRaWAN)	3-4years (NB-IoT)	2-3years (LTE-M)
Coverage (Rural/Urban)	≥10 km / ≥6 km	8-9 km / 5-6 km	5-7 km / 3-4 km	3-4 km / 2-3 km
Reliability	≥99% (NB-IoT)	97-98% (LTE-M)	92-96% (LoRaWAN)	88-91% (Sigfox)
Deployment Cost	≤$15 (Sigfox)	$16-25 (LoRaWAN)	$26-35 (NB-IoT)	$36-45 (LTE-M)

Weight Formula & Scenario Allocation:

Final Score = (Power×W1) + (Coverage×W2) + (Reliability×W3) + (Cost×W4) (W1-W4 sum into 1):

Smart Grid: Reliability (W3 = 0.4) > others (each 0.2, power non-critical for grid meters)

Remote Pipeline: Power (W1 = 0.4) > Coverage (0.3) > Reliability (0.2) > Cost (0.1)

Smart Factory: Cost (W4 = 0.5, many sensors) > Reliability (0.3) > others (each 0.1, easy recharging/coverage)

4.2. LPWAN technology selection for typical IIoT scenarios

4.2.1. Scenario 1: smart factory equipment tracking

Requirements: High reliability, low latency.

Best Match: LTE-M --> LTE-M has a faster data transmission (low latency) than LoRaWAN/Sigfox, so alerts can reach factory manager faster. Its reliability lays on 97-99% second to NB-IoT, which is enough in factory. Although LTE-M use more power, factories are capable of recharging the sensors easily without problem.

4.2.2. Scenario 2: remote oil pipeline sensing

Requirements: Low power, wide coverage.

Best Match: LoRaWAN --> LoRaWAN covers a range of 8-10km, perfect for long distance rural pipelines. Its battery life (5-7years) means that it doesn't need frequent recharges. Sigfox has a longer battery life but lower reliability (88-90%) - the low data loss could cause leakage to expand, so LoRaWAN is a safer option.

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4.2.3. Senario 3: residential smart grid metering

Requirements: High reliability, security.

Best Match: NB-IoT --> NB-IoT uses licensed cellular networks (4G/5G), which is more secure than unlicensed LoRaWAN/Sigfox - critical for protecting electricity data. Its reliability is of the highest (98-99.9%) to ensure no data leakage, so utility companies are able to get accurate billing info. Meters are plugged in, so NB-IoT's shorter battery life doesn't exist.

5. Conclusion

This study illustrates the priority of each LPWAN selection for IIoT is scenario-dependent, with no universal "best" option — the ultimate choice depends on project needs. To analyze results through key findings:

Choose LoRaWAN for remote, low-power scenarios (e.g., cross-county oil pipelines, rural crop farms). Its unlicensed spectrum avoids cellular subscription costs, while 8-10 km rural coverage and 5-7 year battery life to solve two critical pain points: connecting devices across sparse terrain and minimizing maintenance in hard-to-access areas (e.g., underground pipelines). Select NB-IoT in secure, reliable use cases (e.g., residential smart grids, municipal water meters). Through leveraging licensed 4G/5G infrastructure, the transmission success rate can reach 98-99.9% — essential for avoiding billing errors from lost usage data — and built-in encryption protects against hacks, a must for sensitive utility information. Select LTE-M for fast-response scenarios (e.g., smart factory fault detection, industrial park gas leak alerts). It has 50-100 ms latency that ensures alerts to reach teams quickly enough to pause faulty machinery or evacuate areas, reducing unplanned downtime by up to 30% compared to slower LPWANs. Avoid Sigfox for critical applications (e.g., hospital equipment monitoring, power plant sensors) due to 88-90% reliability (risking missed alerts); instead, it excels in low-cost, non-critical projects (e.g., DIY classroom temperature trackers) due to $10-20 handmade sensors and ultra-low power use.

For beginners, this framework simplifies the decision-making process: first, list the two most important non-negotiable conditions among the options that you are considering (for a farm, these would be "remote coverage" + "low maintenance cost"). Then, compare them with the ratings in Table 1. (e.g., the rating of LoRaWAN in terms of power is 5/5, while the rating of Sigfox in terms of reliability is 3/5). This step-by-step approach avoids common mistakes - such as using Sigfox for smart grids or LoRaWAN for factories. Future work can add new scenarios (e.g.,smart mining, where "dust resistance" should be considered) or standards (e.g., scalability to accommodate the growing sensor network), making the framework more adaptable.

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