Smart Meter Data Transmission using LoRaWAN and NB-IoT with Adaptive Network Selection

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Abstract— **Several years of IoT implementation of smart meters need high-quality communication that is both energy-efficient and reliable. LoRaWAN and NB-IoT technologies are LPNWs that are both used in smart metering applications because of their low power consumption and wide coverage. But when only one fixed communication technology is used, it seems that the performance is always suboptimal in the case of dynamic network conditions. The paper suggests a proposal of a smart meter data transmission that combines both LoRaWAN and NB-IoT in the presence of an adaptive network choice mechanism. An algorithm of detecting changes is used to send data only when there is a significant change in meter readings in order to curb redundant transmissions. The adaptive selection algorithm gives an optimal selection of the network dynamically depending on parameters like RSSI, latency, energy usage, and ratio of packet delivery. The suggested system is tested with the help of MATLAB simulation and the findings indicate that the energy efficiency, latency, and reliability are better than in the case of single-network communication strategies. The suggested solution fits the smart metering applications of the IoT which is energy-efficient and flexible.**

Index Terms—**Adaptive Network Selection, Change Detection Algorithm, LoRaWAN, NB-IoT, Smart Meter**

I. INTRODUCTION

The Internet of Things (IoT) has been rapidly expanding, which has made it possible to create smart metering systems that enable one to monitor, gather information, and manage energy in real time. Smart meters are essential in the contemporary smart grid infrastructures as they are able to give precise and updated information regarding energy utilization which is essential in promoting effective decision-making, billing and optimization of resources. Nevertheless, smart metering devices are frequently installed in large scale and not only that, they are often battery powered, making energy efficient communication a highly needed requirement.

The use of Low Power Wide Area Network (LPWAN) technologies has become an appropriate option to smart metering applications because it has a long communication range and low power consumption. LoRaWAN and Narrowband Internet of Things (NB-IoT) are some of the popular technologies in use. LoRaWAN is based on the unlicensed spectrum and provides long-range communication at low energy levels, which makes it appropriate in applications with the low-data rate. However, NB-IoT, in its turn, uses licensed bands on cellular networks, offers a higher level of reliability, enhanced coverage in difficult areas, and reduced latency than other technologies of the type of the LPWAN.

Although they have merits, the current smart metering systems are normally based on one communication technology. Network conditions such as signal strength, latency and the presence of interference are very critical to the performance of such systems. A fixed network selection in dynamic environments can increase the use of energy, latency, or decrease reliability. Also, unnecessary and frequent data transmissions are another reason why there is excess consumption of energy and congestion of the network.

In dealing with these challenges, in this paper, a smart meter data transmission system has been proposed that integrates LoRaWAN and NB-IoT with a dynamic network selection scheme. The change detection strategy is employed to transmit data when major changes were detected in meter readings to ensure a reduction in unnecessary transmissions. Moreover, the suggested system dynamically chooses the most appropriate communication technology according to the real-time network performance specifications, i.e., RSSI, latency, power consumption, and the ratio of packets delivery. The efficiency of the given approach is tested with the help of MATLAB simulation and it is proven that it is more efficient in terms of energy and less specific on the use of latency and communication reliability than more traditional single-network smart metering systems.

II. RELATED WORK

There are a number of studies that have concentrated on Low Power Wide Area Network (LPWAN) technologies to be applied in smart metering and IoT-based energy monitoring system. LoRaWAN based smart metering solutions are extensively researched because of their low power usage and long-range communication, which is applicable in low-data rate application. The limitations of these works however, include increased latency and unreliability in the demanding network conditions.

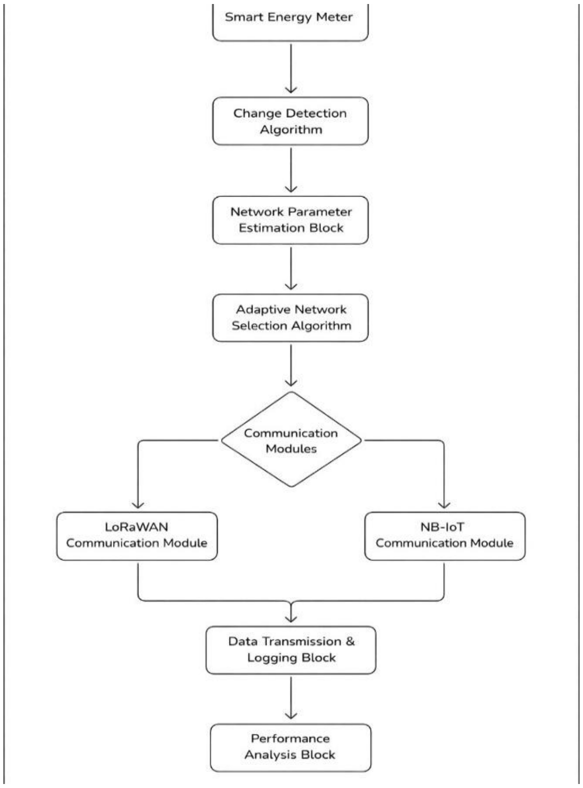
Conversely, the NB-IoT-based smart metering systems have been suggested to enhance coverage and reliability through the use of licensed cellular bands. These have superior Quality of Service (QoS) and reduced latency than LoRaWAN, although tend to be more expensive in terms of energy consumption, which is unwanted with battery-powered smart meters.

Other research has investigated power-efficient data transmission methods such as periodic reporting pruning, event-based or change-detection mechanisms, to be able to reduce avoidable data transmissions. Though they are energy effective, these approaches are normally platformed on one communication technology and fail to adjust with dynamism of network conditions.

Based on the literature available, it can be noted that the majority of the smart metering solutions are based on a predetermined communication structure and do not provide adaptive decision-making due to real-time performance indicators, including RSSI, latency, power usage, and packet delivery ratio. To deal with these shortcomings, this article offers a dynamic smart meter communication system which incorporates LoRaWAN and NB-IoT with a rule-based network selection algorithm and change-detection system to maximize energy efficiency, reduce latency and improve communications reliability.

III. PROPOSED METHOD

A. Overall Software Architecture



The general software layout of the proposed system will be to test energy-efficient communication of smart meters with the help of a MATLAB based simulation environment. The architecture is designed in a modular format which allows data acquisition, processing, decision-making and performance evaluation without the physical implementation using a hardware platform.

First, the data of smart meters is to be imported into the MATLAB environment using the publicly available dataset of Bareilly smart meters that was received on Kaggle. This is a set of actual data on the use of energy which is recorded over time and is the input to the simulation model. The process of preprocessing including filtering of particular meter IDs and the extraction of energy consumption parameters are undertaken to prepare data to be analyzed.

The digitalized data is then forwarded to the change detection module, which calculates the difference in the amount of energy consumed in successive measurements. Significant changes in consumption are identified with the help of a predetermined threshold value. The transmission of data is only initiated when the change that has been identified is above the threshold, thus minimizing the inconvenient events of data transmission and enhancing general energy efficiency.

After a transmission event is started, the adaptive network selection module is selected to run. The simulated parameters of network performance measured in this module are the RSSI, latency, transmission energy, and ratio of the delivery of packets to the sent packets (PDR) of both LoRaWAN and NB-IoT communication technologies. According to a rule-based decision logic, an appropriate network is chosen dynamically on a case-by-case transmission.

Upon network selection the relevant communication metrics are logged and the data sent across the network is relayed to a simulated central data storage and analysis module that is represented in MATLAB. This module accumulates the results on per-event basis and calculates the average performance of LoRaWAN, NB-IoT and the adaptive approach. Lastly, the modules of visualization and result analysis produce comparative graphs and tables to measure the efficiency of the offered adaptive communication framework.

Its software architecture is modular in nature thus ensuring it is clear, reproducible and flexible and has the ability to evaluate adaptive smart metering communication strategies under varying network scenarios using real world datasets.

B. Smart Meter Data Acquisition

The first step of the proposed adaptive framework of communication is the smart meter data acquisition. In this study, actual real-world energy consumptions observations have been applied in order to model the smart meters behavior in an accurate manner without the involvement of the physical hardware implementation. The dataset to be used in the given research is the Bareilly smart meter dataset that is available on the Kaggle platform and is comprised of time-stamped energy consumption data available on residential smart meters.

The data is loaded to the MATLAB working environment and it is arranged in a structured format to be analyzed. Particular meter identifiers are chosen, which mimics the individual smart meter running. The cumulative energy consumption in kilowatt-hours (kWh) is the main parameter taken into account in the process of data acquisition since the chosen parameter is the basic input in the process of monitoring and billing usage in smart grids.

The data take the form of smart meters that are sampled in regular intervals. The sampled data is sent to other processing modules to be evaluated rather than sending all the acquired readings. This will make it possible to model realistically the periodic generation of smart meter data, and make the suggested system optimize the transmission efficiency using change-based and adaptive communication methods.

The proposed system will have reproducibility, realism, and good assessment of energy-efficient communication mechanisms of different network conditions by employing a real-world dataset and acquisition process with MATLAB.

C. Change Detection Mechanism

One of the aspects of the recommended communication infrastructure of the smart meter is the change detection mechanism, which will help to minimize unnecessary data transmission and enhance energy efficiency. In the traditional smart meter systems, the meter readings are sent at regular intervals regardless of the variation in energy consumption, thereby creating higher communication overhead and energy usage.

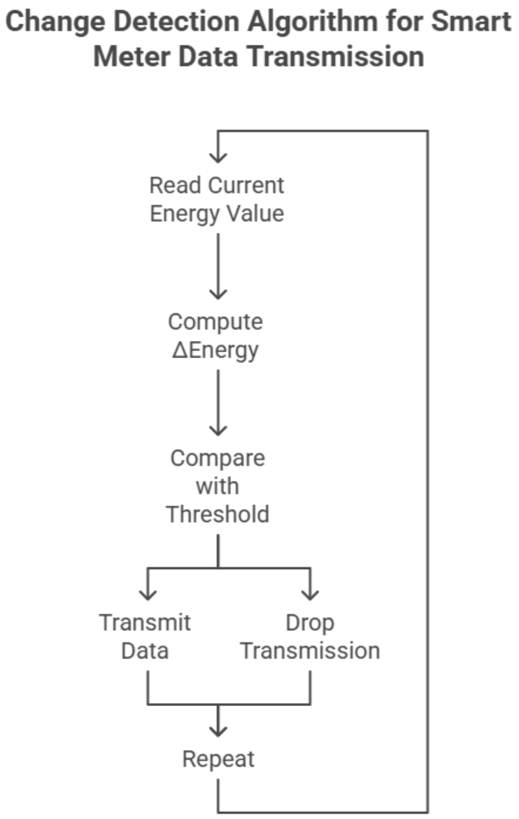


Fig 3.1 Change Detection Algorithm

Under the proposed method, the readings of the smart meters obtained through the dataset are used to determine any notable changes in the energy consumption between sequential time periods of sampling. It is the change detection that is carried out by computing the difference in the cumulative values of energy consumption. This difference is drawn against a preset threshold value to ascertain whether transmission event is to be raised or not.

When the calculated change in energy consumption is above the threshold then the reading is deemed to be important and the data is sent to be transmitted. On the other hand, when the change is less than the threshold, the transmission will not go through, and thus unnecessary communication will be prevented. Such a selective transmission technique is useful in minimizing the number of packets being sent across the network resulting to lesser energy usage and network congestions are minimized.

The threshold value is set depending on the preferred compromise between accuracy of the data and efficiency in communication. The proposed system incorporates this change detection mechanism with adaptive network selection to guarantee that only useful information is relayed via the most appropriate communication technology and hence overall system performance in the areas of energy efficiency, latency, and reliability is improved.

D. Adaptive Communication Network Selection.

The adaptive network selection algorithm is the most significant part of the suggested communication model of smart meters. It is mainly aimed at dynamically choosing the most appropriate technology between LoRaWAN and NB-IoT to use in each transmission event, depending on the current network performance statistics. Such adaptive decision making process ensures that the energy efficiency, latency, and communication reliability are improved as opposed to fixed network selection methods.

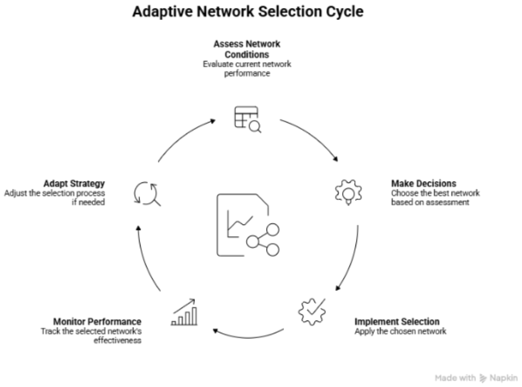


Fig 3.2 .Adaptive Network Selection Cycle

The network condition is evaluated using the following assessments:

D.1 Network Condition Assessment.

When there is a change that is triggered by the change detection mechanism, the system tests the performance of available communication networks. The proposed MATLAB-based simulation defines the network performance through the main parameters such as Received Signal Strength Indicator (RSSI), transmission latency, energy consumption and packet delivery ratio (PDR). These parameters are simulated to show real-life working situations of LoRaWAN and NB-IoT networks.

A signal quality and coverage availability of every network is measured by use of RSSI. Latency is defined as the delay in the transmission of the data, which is suffered, and the energy consumption is approximated by the transmission power and communication time. The ratio of the packet delivery is used to show how reliable the data transmission is in different network conditions. Combined, these parameters give a thorough analysis of network-suitability.

D.2 Rule-Based Decision Logic

According to the calculated network performance parameters, the decision logic adopted uses the rule based system in order to choose the best communication network. First, the signal strength is taken into account as a guarantee of good connection. When the RSSI of a particular network decreases below a certain threshold, the other network will be chosen. Latency limits are considered when the signals in both networks are within an acceptable range in order to champion timely delivery of data.

When the signal strength and latency conditions are both acceptable, energy consumption is taken as the criterion to prefer to use the energy-efficient communication. The ratio of the packets being delivered is implicit in nature so as to deliver reliable information. This top-down decision-making method allows the system to dynamically compromise energy efficiency, latency and reliability as per real time network requirements.

Choosing LoRaWAN or NB-IoT for each transmission of the network enables the proposed adaptive network selection algorithm to overcome the restrictions of single-network smart metering systems and improve the overall communication performance significantly, which is the main contribution of the proposed study.

E. Performance Metrics

In order to measure the successfulness of the adaptive smart meter communication framework offered, some key performance metrics are taken into account. The metrics are chosen to examine the quality of the communication, energy consumption, and stability of the LoRaWAN, NB-IoT, and the suggested adaptive network selection strategy. The metrics applied in one communication strategy are also used in the other communication strategies in order to make a fair comparison.

1) Received Signal Strength Indicator (RSSI)

The signal quality and coverage performance of the communication network is measured by using RSSI. It shows the power of the signal being received by the receiver and is very important in determining the reliability of the network. The larger the value of RSSI, the higher the quality of signal and the more credible transmission of data. RSSI is a significant input parameter in the adaptive network selection in the proposed system.

2) Latency

Latency is a delay in transmission between the smart meter and the effective receipt by the data analysis part. Timely monitoring and effective response in smart grid applications requires low latency. The adaptive framework proposed will help to reduce transmission delay by dynamically choosing the network that meets the latency requirement provided the conditions.

3) Energy Consumption

The use of energy in transmitting data is known as the energy consumption. Considering that smart meters are generally battery operated gadgets, the minimization of transmission energy is one of the main goals. Transmission energy is estimated in this work depending on transmission power and communication duration. The mechanism of detecting changes and adaptive selection of the network is achieved together to reduce the total amount of energy used.

4) Packet Delivery Ratio (PDR)

The ratio of the number of packets received and the number of packets sent is referred to as Packet Delivery Ratio (PDR). This is applied to assess the trustworthiness of the communication network. A greater PDR means that there is more reliable transmission of data. PDR is taken into account in the proposed system to make sure that the improvements in efficiency of energy usage do not impact on the reliability of communication.

The given performance measures allow assessing the adaptive communication framework proposed to the research on the energy efficiency, latency reduction, signal quality, and reliability and comparing its performance with traditional single-network smart metering solutions.

IV. SIMULATION SETUP

The simulation of the proposed system is done with real-world smart meter data of the Bareilly dataset on Kaggle under MATLAB. The data is composed of time-stamped cumulative energy consumption data in kilowatt-hours (kWh). A predetermined threshold is used to determine relevant changes in energy consumption and minimize unnecessary transmissions of change detection.

To simulate the realistic operation of the network, LoRaWAN and NB-IoT communication networks are characterized through the representative values of the RSSI, latency, transmission power, and packet delivery ratio (PDR). Estimation of consumption in transmission energy is done considering power in transmissions and time of communication. The adaptive network selection algorithm is a dynamical algorithm that determines the most appropriate network to be used in a given transmission event using the parameters of network performance assessed. RSSI, latency, energy consumption, and PDR are used to conduct performance analysis.

V. RESULTS AND DISCUSSIONS

A. Dropped Packet Analysis and Transmitted Packet Analysis

Consecutive readings are compared to the threshold value values using the change detection algorithm which compares the variation in energy (ΔE) to the threshold values. In case ΔE is lower than the threshold, the packet is dropped and in case it is higher the packet is transmitted.

As can be seen in the bar graphs, the more the threshold the more the amount of dropped packets and less the amount of transmitted packets. This proves that redundant transmissions are shunned, a factor that results in a lot of saved energy and minimized.

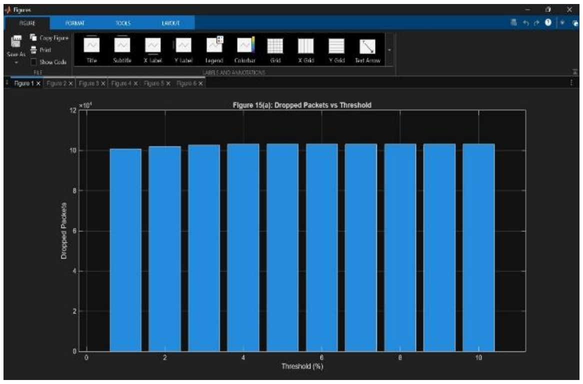


Fig 5.1 Dropped Packets vs Threshold

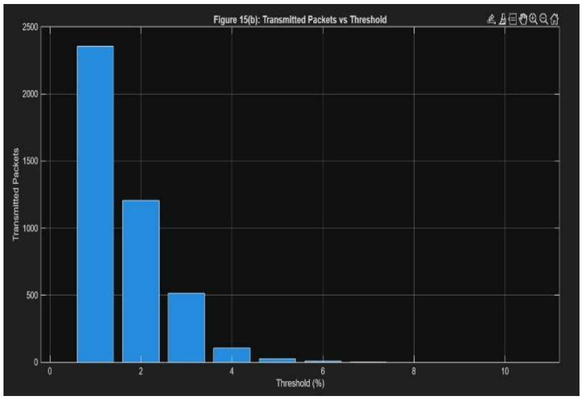


Fig 5.2 Transmitted Packets vs Threshold

B. Energy Comparison

Calculation of energy usage is done on the basis of the transmission power and communication time. LoRaWAN is low-energy in nature compared to NB-IoT as it is a low-energy system, but NB-IoT is relatively more energy-intensive and provides a better quality of service and reliability. The suggested adaptive system dynamically chooses the communication network that meets the RSSI and latency requirements with the least amount of energy used. The change detection, also, minimizes redundant transmissions, which additionally leads to the overall efficiency of energy. Consequently, the adaptive approach performs well in terms of energy performance, as opposed to conventional single network smart metering systems.

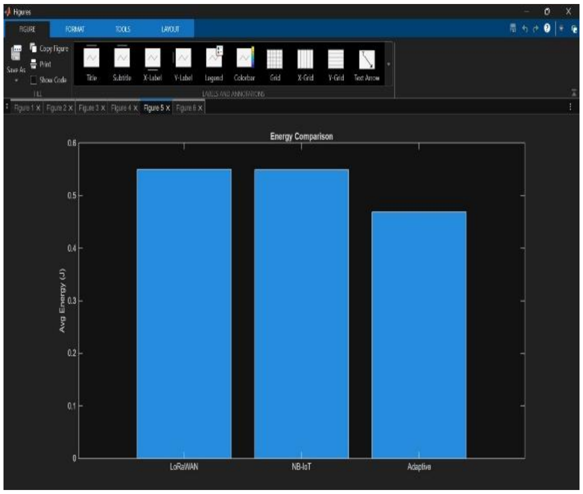


Fig 5.3 Energy Comparison

C. Comparison of Packet Delivery Ratio (PDR)

The estimation of PDR is based on values of RSSI. The NB-IoT demonstrates greater PDR in well-covered locations, whereas LoRaWAN presents reasonable PDR with the long distances. As the adaptive system is always selecting the network with a high-link quality, it will reach the highest average PDR.

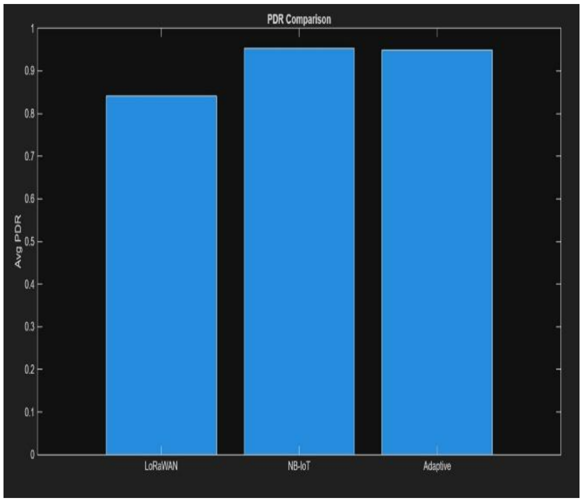
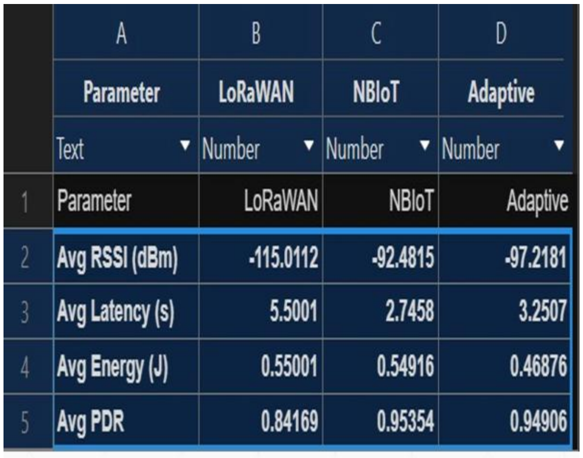


Fig 5.4 Packet Delivery Ratio

D. Comparative Analysis

A quantitative comparison is carried out for:

- Average RSSI
- Average Latency
- Average Energy Consumption
- Average PDR

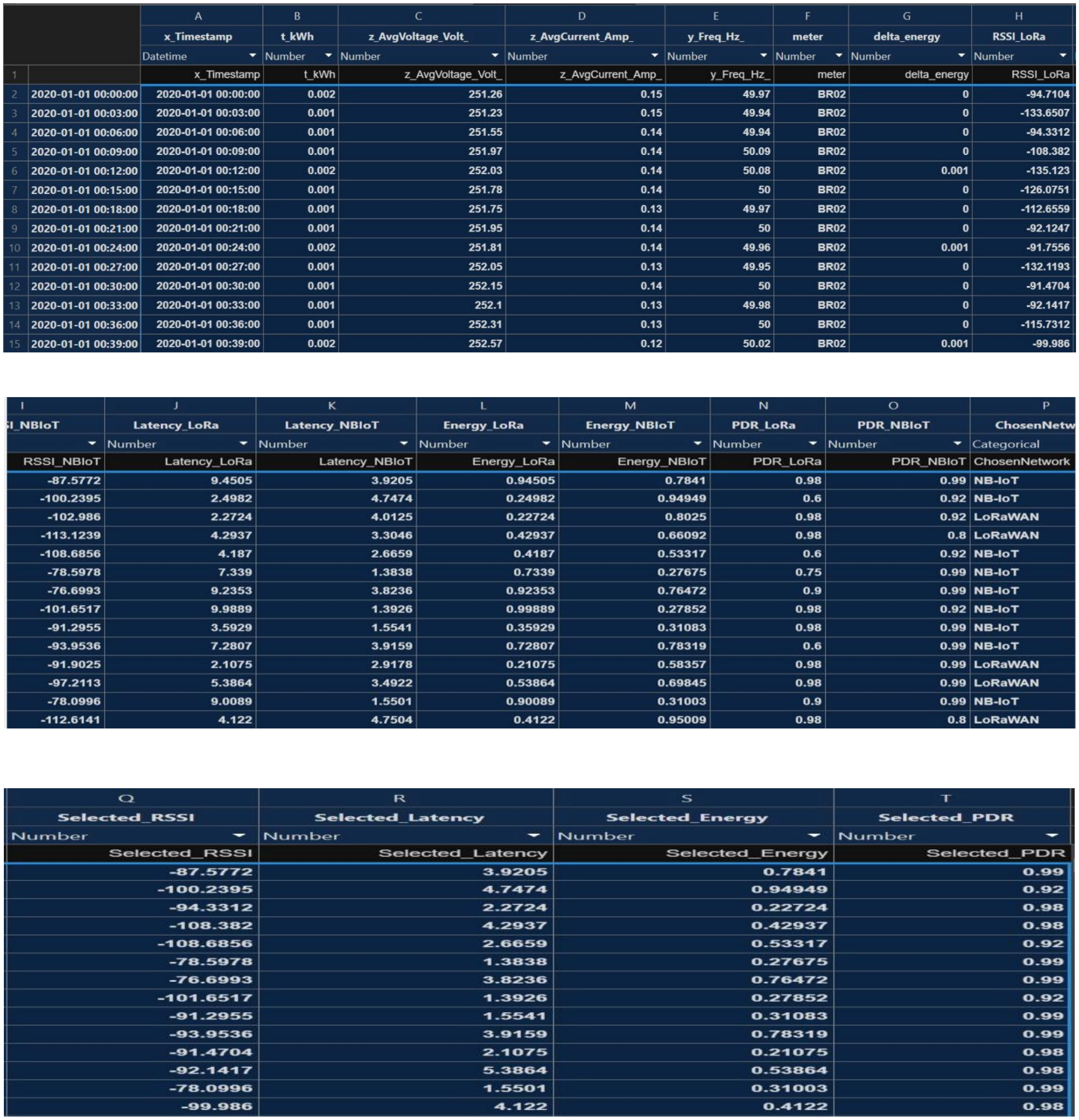


	A	B	C	D
	Parameter	LoRaWAN	NBIoT	Adaptive
	Text ▾	Number ▾	Number ▾	Number ▾
1	Parameter	LoRaWAN	NBIoT	Adaptive
2	Avg RSSI (dBm)	-115.0112	-92.4815	-97.2181
3	Avg Latency (s)	5.5001	2.7458	3.2507
4	Avg Energy (J)	0.55001	0.54916	0.46876
5	Avg PDR	0.84169	0.95354	0.94906

Fig 5.5 Comparative results between LoRaWAN ,NB-IoT & Adaptive

E. Adaptive Network Selection using Bareilly Data

Adaptive network selection approach is tested on the basis of real-life smart meter data of Bareilly dataset. The change detection is used to create transmission events when there are considerable changes in energy consumption. In both of the transmissions, the systems of LoRaWAN and NB-IoT are compared in terms of RSSI, latency, energy requirements, and the percentage of packets delivered. The algorithm dynamically chooses LoRaWAN in good conditions to use minimum energy, and in case of some necessity to use NB-IoT to achieve higher reliability or less latency. The findings indicate that adaptive approach enhances the general efficiency of the energy consumption and ensures a stable communication as compared to that of fixed single-network operation.



		A	B	C	D	E	F	G	H
		x_Timestamp	t_kWh	z_AvgVoltage_Volt_	z_AvgCurrent_Amp_	y_Freq_Hz_	meter	delta_energy	RSSI_LoRa
		Datetime	Number	Number	Number	Number	Number	Number	Number
1		x_Timestamp	t_kWh	z_AvgVoltage_Volt_	z_AvgCurrent_Amp_	y_Freq_Hz_	meter	delta_energy	RSSI_LoRa
2	2020-01-01 00:00:00	2020-01-01 00:00:00	0.002	251.26	0.15	49.97	BR02	0	-94.7104
3	2020-01-01 00:03:00	2020-01-01 00:03:00	0.001	251.23	0.15	49.94	BR02	0	-133.6507
4	2020-01-01 00:06:00	2020-01-01 00:06:00	0.001	251.55	0.14	49.94	BR02	0	-94.3312
5	2020-01-01 00:09:00	2020-01-01 00:09:00	0.001	251.97	0.14	50.09	BR02	0	-108.382
6	2020-01-01 00:12:00	2020-01-01 00:12:00	0.002	252.03	0.14	50.08	BR02	0.001	-135.123
7	2020-01-01 00:15:00	2020-01-01 00:15:00	0.001	251.78	0.14	50	BR02	0	-126.0751
8	2020-01-01 00:18:00	2020-01-01 00:18:00	0.001	251.75	0.13	49.97	BR02	0	-112.6559
9	2020-01-01 00:21:00	2020-01-01 00:21:00	0.001	251.95	0.14	50	BR02	0	-92.1247
10	2020-01-01 00:24:00	2020-01-01 00:24:00	0.002	251.81	0.14	49.96	BR02	0.001	-91.7556
11	2020-01-01 00:27:00	2020-01-01 00:27:00	0.001	252.05	0.13	49.95	BR02	0	-132.1193
12	2020-01-01 00:30:00	2020-01-01 00:30:00	0.001	252.15	0.14	50	BR02	0	-91.4704
13	2020-01-01 00:33:00	2020-01-01 00:33:00	0.001	252.1	0.13	49.98	BR02	0	-92.1417
14	2020-01-01 00:36:00	2020-01-01 00:36:00	0.001	252.31	0.13	50	BR02	0	-115.7312
15	2020-01-01 00:39:00	2020-01-01 00:39:00	0.002	252.57	0.12	50.02	BR02	0.001	-99.986

I	J	K	L	M	N	O	P
I_NBIoT	Latency_LoRa	Latency_NBIoT	Energy_LoRa	Energy_NBIoT	PDR_LoRa	PDR_NBIoT	ChosenNetw
	Number	Number	Number	Number	Number	Number	Categorical
RSSI_NBIoT	Latency_LoRa	Latency_NBIoT	Energy_LoRa	Energy_NBIoT	PDR_LoRa	PDR_NBIoT	ChosenNetwork
-87.5772	9.4505	3.9205	0.94505	0.7841	0.98	0.99	NB-IoT
-100.2395	2.4982	4.7474	0.24982	0.94949	0.6	0.92	NB-IoT
-102.986	2.2724	4.0125	0.22724	0.8025	0.98	0.92	LoRaWAN
-113.1239	4.2937	3.3046	0.42937	0.66092	0.98	0.8	LoRaWAN
-108.6856	4.187	2.6659	0.4187	0.53317	0.6	0.92	NB-IoT
-78.5978	7.339	1.3838	0.7339	0.27675	0.75	0.99	NB-IoT
-76.6993	9.2353	3.8236	0.92353	0.76472	0.9	0.99	NB-IoT
-101.6517	9.9889	1.3926	0.99889	0.27852	0.98	0.92	NB-IoT
-91.2955	3.5929	1.5541	0.35929	0.31083	0.98	0.99	NB-IoT
-93.9536	7.2807	3.9159	0.72807	0.78319	0.6	0.99	NB-IoT
-91.9025	2.1075	2.9178	0.21075	0.58357	0.98	0.99	LoRaWAN
-97.2113	5.3864	3.4922	0.53864	0.69845	0.98	0.99	LoRaWAN
-78.0996	9.0089	1.5501	0.90089	0.31003	0.9	0.99	NB-IoT
-112.6141	4.122	4.7504	0.4122	0.95009	0.98	0.8	LoRaWAN

Q	R	S	T
Selected_RSSI	Selected_Latency	Selected_Energy	Selected_PDR
Number	Number	Number	Number
Selected_RSSI	Selected_Latency	Selected_Energy	Selected_PDR
-87.5772	3.9205	0.7841	0.99
-100.2395	4.7474	0.94949	0.92
-94.3312	2.2724	0.22724	0.98
-108.382	4.2937	0.42937	0.98
-108.6856	2.6659	0.53317	0.92
-78.5978	1.3838	0.27675	0.99
-76.6993	3.8236	0.76472	0.99
-101.6517	1.3926	0.27852	0.92
-91.2955	1.5541	0.31083	0.99
-93.9536	3.9159	0.78319	0.99
-91.4704	2.1075	0.21075	0.98
-92.1417	5.3864	0.53864	0.98
-78.0996	1.5501	0.31003	0.99
-99.986	4.122	0.4122	0.98

Fig 5.6 Adaptive Network Selection

F. Discussion of Results

The outcomes of the simulation prove that the recommended adaptive smart meter communication scheme is effective in enhancing energy efficiency and at the same time reliable data transmission. The change detection system helps minimize unnecessary transmissions to a great extent, and this fact directly leads to decreased energy use. The adaptive network selection also improves performance as the network dynamically selects the best communication technology at real-time network conditions.

The adaptive system provides an improved tradeoff between energy consumption, latency, and reliability in the delivery of packets compared to single-network methods that are fixed. LoRaWAN is chosen in the case of energy-limited situations, whereas NB-IoT is applied in the event the better signal quality or reduction of latency are demanded. Applicability of the proposed approach to large scale smart metering systems is confirmed using real world smart meter data of the Bareilly dataset.

VI. CONCLUSION AND FUTURE SCOPE

A. Conclusion

A smart meter transmission system based on the LoRaWAN and NB-IoT and adaptive network choice is offered as energy-efficient. Actual Bareilly data readings are utilized and a change detection algorithm is applied to minimise transmissions only when there is prominent change in energy levels. The selection of the network is made dynamically by a rule-based system between LoRaWAN and NB-IoT depending on RSSI, latency and energy. According to simulations, the adaptive system is better in comparison to single-network setups, with reduced latency, reduced energy consumption, and increased packet delivery. Its capabilities are confirmed by the results, which implies that it would be suitable to smart metering, have a long battery life, and effective delivery and operation in a flexible network.

B. Future Scope

There are a few ways through which the proposed work can be extended in the future. One potential extension would be to work with the proposed system by incorporating real hardware devices to test the simulation findings under real-time operating conditions, including smart meters, LoRa communication modules, and NB-IoT modems. It would aid in examining real world issues of hardware limitations and real world network behavior.

The other possible extension is to include intelligent and predictive network selection methods that are based on machine learning. These approaches may allow the system to experience what has happened before in terms of network performance and consumption patterns to enhance the accuracy and flexibility in decision making across the dynamic network conditions.

It is also possible to improve the suggested framework by implementing other technologies of IoT communication like LTE-M and 5G New Radio (NR). This would enable the system to work in heterogeneous communication settings and enhance even more on the scalability, coverage and performance.

Moreover, the future work can be aimed at adopting the encryption and security measures on smart meter data transmission to provide data confidentiality, data integrity, and data security against cyber threats. Last but not least, the proposed system can be deployed and tested at large scale in actual smart grid settings to test whether it is scalable, robust and has long-term performance.

VII. ACKNOWLEDGMENT

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