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Optimizing Packet Processing in IoT-Enabled Wireless Sensor Networks: A Novel Data Mining Approach

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ABSTRACT

This form of automation endows devices with intelligence, enabling them to assimilate data through sensor nodes and formulate informed decisions. Traditionally, data mining has been portrayed as a safeguard against threats or malfunctions in networks. The primary objective here is to minimize redundancy in information packets recognised by nodules, subsequently transmitted to the cluster head for pre-processing. In the realm of IoT, the sensor node network operates in two dimensions: spatial detection and collection of data by nearby nodes, followed by temporal monitoring at specified intervals. Regardless of the scenario, the proposed approach stands out as the optimal choice. It emphasizes the elimination of redundant characteristics in the detected data, employing a packet classification method for filtering and essential packet mining. The suggested novel data mining (NDM) approach in this study not only supports QoS (Quality-of-Service) for diverse requests and amenities but also facilitates capacity paired, traffic flow accounting, and the observing of recognised information. The effectiveness of an NDM-based Wireless Sensor Network (WSN) tailored for IoT is gauged through various metrics. Simulation results unequivocally underscore the superior performance of the suggested strategy compared to alternative methods. Future endeavours aim to implement this framework in dynamic settings, creating an application tailored to real-time problem-solving.

1. INTRODUCTION

The IoT is an arrangement of interrelated computing strategies, sensors, and additional "things" in the actual world. These gadgets necessitate Internet access for data sharing and collection. Therefore, IoT refers to the network of interconnected computing devices that enable seamless data exchange [1]. While the IoT has many uses and applications, its precise definition remains elusive. IoT refers to the network of physical devices that are interconnected and capable of exchanging data and interacting with one another and with humans. These tangible tools are the entities or objects that can be modified in accordance with the task at hand. Data severance in IoT poses challenges such as fragmented data flows, hindering cohesive analysis. Inconsistent data transmission, network disruptions, and security issues can impede the seamless integration of information, impacting the reliability and effectiveness of IoT systems. For the purposes of this study, we will use the definition of the IoT as put forth by the ITU (International Telecommunication Union), which states that IoT is a worldwide organization for the data culture, allowing progressive facilities by interrelating (physical and virtual) things founded on current and developing interoperable data and communication knowledge [2]. The term signifies the fusion of physical objects with digital simulations, enabling universal accessibility. It empowers individuals to access these resources at their convenience, transcending geographical constraints. Physical entities are virtually interconnected for interaction, operation, sensing, and information exchange.

These tangible objects can be accessed, stored, and processed, aligning with the Internet of Things (IoT) vision to make intelligence readily available, portable, and adaptable in daily life. Technologies like radio frequency (RF), Bluetooth, and Wi-Fi facilitate communication among IoT devices, fostering connectivity within networks [3]. In essence, IoT strives to seamlessly integrate the physical and digital realms for enhanced human experiences and operational efficiency.

Sensors are built into IoT devices for the purpose of sensing and collecting data. As a result, the IoT is coupled with a concept known as Wireless Sensor Network (WSN) to carry out the appropriate application-oriented task.

The packet classification method categorizes data, prioritizing essential information, and filters out redundancies, improving efficiency and reducing unnecessary data traffic. Devices with such sensors as cameras, global positioning systems, and accelerometers are becoming increasingly common in cellphones. Once data has been sensed, it must be sent, stored, and processed among the various devices that make up the network. The physical and link layers are responsible for the necessary communication to accomplish this goal [4]. Therefore, the communication can be established via a variety of protocols. As seen in instance C of 1.2, direct communication protocols like WLoWPAN, Bluetooth, or ZigBee allow for data to be exchanged between devices that are in close proximity to one another. Case A in Figure 1 depicts a scenario in which the devices are able to communicate with one another using the gateway protocol in order to establish an Internet connection, such as 6LoWPAN. In scenario B of Figure 1, however, it is clear that a gateway protocol is not required because a direct link can be established among the devices [5]. In addition, IoT gadgets have their own unique qualities that set them apart from the rest of the world's physical gadgets.

Following is a list of these qualities:

1. Connectivity is a cornerstone feature of the IoT. That the things are linked using an appropriate communication mechanism, as indicated above. However, issues like as battery life, power consumption, and processing power, among others, can limit communication. In addition, each of these objects is linked to the Internet and a worldwide communication network designed specifically for its intended use.
2. Support for physical objects: The semantic consistency between real-world objects and their digital counterparts is exceptionally high in an IoT system. As a result, IoT gadgets are distinguished by their consistently connected services to things.

Communication between IoT devices can be established and maintained via a wide variety of protocols. It manages the difficult task of interconnecting gadgets from various networks. The use of a suitable gateway protocol in Case B in Figure 1 exemplifies the heterogeneity of an IoT system. In the same way, two devices using different Internet protocol versions can nevertheless talk to one another and share data.

Addressing data redundancy in IoT is crucial for optimizing system performance and efficiency. Redundant data increases network traffic, consumes unnecessary bandwidth, and strains resources. By implementing effective measures, such as packet classification, to identify and filter out redundant information, IoT systems can operate more smoothly. This not only enhances the overall performance but also conserves energy, extends device lifespan, and ensures a more responsive and reliable IoT ecosystem, essential for its widespread adoption and effectiveness.

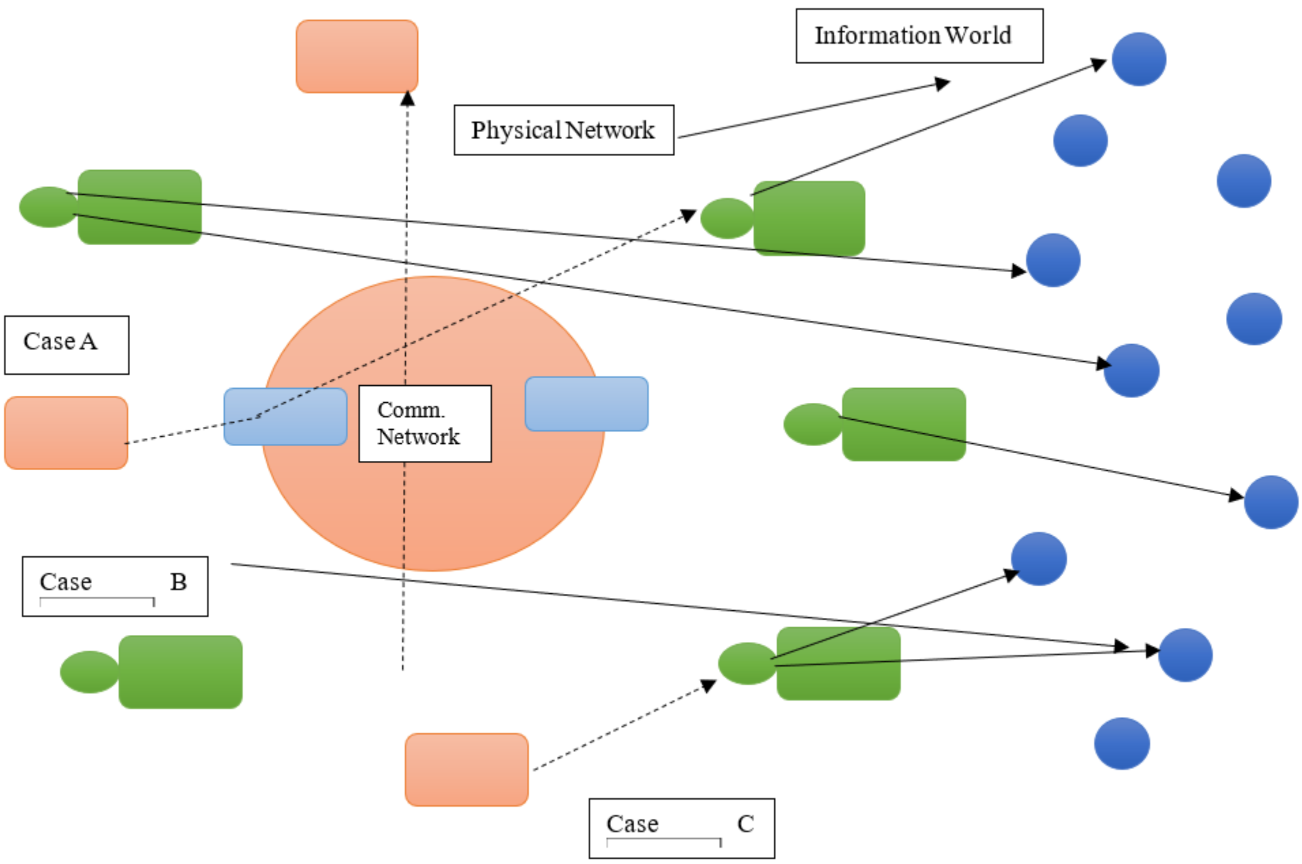

Figure 1. A communication situation in IoT organization

2. LITERATURE REVIEW

For example, the IoT system considered identification, Wired/Wireless Sensor Networks, location management, networked communication, and distributed intelligence as enabling technologies for the development of smart devices [6]. Thus, the author argues, a wide range of disciplines, including electronics, telecommunications, education, industry, ecology, and IT, must be covered in order to make a contribution to the IoT. Sensors and actuators need to collaborate in a seamless, effective fashion in order to create a Common Operational Picture (COP). Ubiquitous computing is cutting-edge technology that enables this function. Indicator outcomes can be comprehended, inferred, and measured, and the relevant data can be disseminated [7]. It's also important for IoT gadgets to be compatible with a wide range of networks and systems. The IoT provides value-added services in its objects to facilitate efficient management and administration, thereby realizing the smart city goal. The IoT allows for the deployment of cutting-edge technology when applied to mission-critical services and streaming applications [8]. Edge or fog computing can be used in extremely time-sensitive scenarios. The IoT system benefits from fog computing's location awareness, mobility, low latency, and scalability capabilities [9].

The robust industrial system provides additional context for understanding the usefulness, value, and potential uses beyond the context of the smart city. RFID, WSN, and wireless mobile all work together to make it possible to create and roll out a wide range of industrial IoT applications [10]. In layman's terms, the phrase IoT can be used as an umbrella to cover the many facets of bridging the virtual world of the Internet with the real world through the usage of communication protocols. Embedded sensors and actuators in smart, distributed devices are allowing for a technological sea change in the realm of automation [11]. The IoT is sometimes referred to as the "Future Internet" because the current Internet technology is evolving into IoT as a result of connecting devices and people. The goal of the IoT is to make people's lives easier and more convenient. The implementation of all-pervasive computing and related identifying technologies allows this to take place. Smart sensors are installed in physical devices that are connected with the other devices via a communication protocol, all part of the incredible development of applications. Intelligent decision making support will be available through future studies [12]. In order for the devices to function without interfering with one another, horizontal integration is required. IoT gadgets require the revolutionary new cloud and fog computing to achieve this. The reason for this is that the complexity and overlap of a real-world IoT device's integrated sensors, actuators, communication, and power etc. makes it a fertile field for study [13].

By giving commonplace items, the intelligence to detect and respond to changes in their surroundings, the IoT makes people's lives easier. The IoT employs near-field communication, embedded sensors and actuators, and real-time location to endow inanimate objects with intelligence [14]. These things serve as the foundation of the IoT, allowing for the introduction of cutting-edge ICT services and their associated software. Interactivity, abstraction, and a sense of time in the present were all necessary components. In addition to these characteristics, security and privacy concerns must be taken into account to foil the adversary's attempts to break through the system's defences [15-17]. The IoT system must adhere to strict protocols for access control, authentication, and authorisation in this regard. The privacy of the customers and the limitations of the mechanisms utilized by the IoT system should be incorporated into these procedures [16-19].

Current approaches in IoT data management face challenges like increased redundancy and inefficient resource utilization. The proposed NDM method tackles these limitations by employing packet classification, enabling precise identification and filtering of redundant data. This selective processing optimizes resource usage, enhances network efficiency, and improves overall system performance [20]. By addressing these issues, the NDM method offers a more streamlined and effective approach to managing data in IoT environments, overcoming the shortcomings of existing methods. Table 1 summarizes the review findings of many research work.

Table 1. The existing work comparisons and findings

S. No.	Citations	Research Work	Findings
1	[21]	Compressed data analysis of patterns, sub-patterns, and streams has been proposed using a CT-based approach. In order to identify malfunctioning network nodes, this project employs a data mining strategy to extract the necessary temporal patterns.	It has been reported that processed duplicated data can be used to acquire insights using a CT founded arrangement in WSN. To train the nodes of a WSN to submit their data on time, CT-based patterns can be used to provide a solution that is similar to a lesson.
2	[22]	For the purpose of forming the network of sensors, the K-MDR clustering technique has been devised. Sensing and collecting massive amounts of data that are continuously generated presents additional challenges for the sensor network. The information must then be sent to the sink, where it can be used to inform further decisions. Sensory data clustering is the meat and potatoes of data mining.	In addition, the number of cluster nodes can be decreased without a noticeable drop in coverage thanks to the COM algorithm. Limitations in transmission bandwidth, electricity, and storage space are just a few examples of the many obstacles that the COM algorithm must overcome.
3	[23]	A technique based on CT has been developed for analysing compressed data streams, patterns, and sub-patterns. In this effort, an information's drawing out strategy has been implemented to excerpt the sequential designs necessary for identifying malfunctioning network nodes. It was claimed that analysing redundant data can be used to get insights.	To Eurostar the nodules of a WSN to submit their information on time, CT-based patterns can be used to provide a solution that is similar to a lesson.

4	[24]	A K-MDR grouping procedure for forming the network of sensor nodules is proposed. Sensing and collecting massive amounts of data that are continuously generated presents additional challenges for the sensor network. The information must then be sent to the washbasin, where it can be used to inform subsequent decisions. The clustering of sensory data is the data mining's essential task. In addition, the number of cluster nodes can be decreased without a noticeable drop in coverage thanks to the COM algorithm.	Limitations in transmission bandwidth, electricity, and storage space are just a few examples of the many obstacles that the COM algorithm must overcome.
5	[25]	For the determination of pulling out episodic actions and spilling them, a novel outline termed customised WSN has been presented that works in tandem with trampled torrents of evidence. We have tested the suggested framework with both simulated data from a smart home simulator and real data from a self-organizing WSN.	It can analyse heterogeneous sensor patterns from a wide range of applications and services. Author claims the framework is self-adaptive, energy-efficient, less redundant, and scalable based on simulation findings.

3. THE CONTRIBUTION OF THE RESEARCH WORK

The following is a summary of the main contributions of this study:

• New data-packet-selection methods (NDM) are introduced to boost efficiency and dependability before packets are forwarded. By analysing the data, the proposed NDM approach can decide whether or not to get rid of unnecessary or redundant packets.

• This work takes into account two parameters for the NDM strategy's operational module. To begin, NDM relies on the leaf nodes' ability to collect data on spatial modes. Second, the suggested approach makes use of leaf and intermediate sensor nodes to coordinate with the temporally gathered data. Selecting relevant and filtered data in this way allows for enhanced enactment of the IoT concerned with WSN.

The effectiveness of the projected NDM approach is analysed and compared to other mining methods. Multiple randomised systems and real Internet topologies have been recycled in the simulation.

4. THE PROJECTED WORK

Redundancy reduction in information packages recognized by the nodules and sent to the cluster head for pre-processing is the primary focus of this study. In IoT, the network of sensor nodes serves a dual purpose: At first, its neighbouring nodes do geographical sensing and data collection. Second, the data is temporally detected and monitored on the specified interval. The recommended approach is superior in both cases. Certain characteristics and aspects of the detected data are needed to eradicate redundancy. The suggested solution uses a packet classification method to filter the packets and perform the necessary packet mining. The nodes' ability to correctly accept or reject data packets depends on a cataloguing arrangement that records the package's contents. The proposed NDM technique relies on a collection of rules, known as classifiers, to arrive at a sound conclusion. Characteristics and properties of detected information that remain in the package header arrangement are used to define the classifier rules, as shown in Figure 2.

As can be seen in Figure 2, the suggested NDM technique employs a data packet format similar to that shown. In the operational element of the decision-making procedure, we use a hardware grounded classifier called TCAM (Ternary Content Addressable Memories).

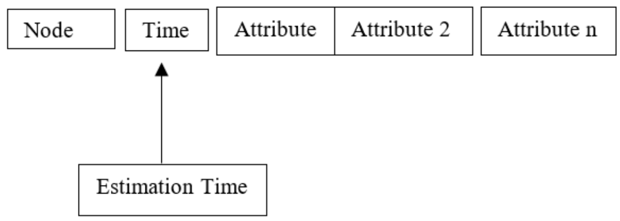

Figure 2. IoT system flow diagram

Individually aperture entrance on the chip in the default TCAM configuration stores instructions for the classification decision creating progression. As soon as a node detects a packet of data, its TCAM hardware goes to work, comparing the predicted and computed values of the packet's properties simultaneously. The classification rules are applied to the results of the comparison.

Ubiquitous computing aligns with the proposed NDM approach by extending seamless connectivity to diverse devices. In the context of data severance, NDM ensures efficient data flow and processing across ubiquitous devices. This synergy enables ubiquitous computing to transcend data severance challenges, fostering continuous, reliable interaction and information sharing among interconnected devices in various environments, thereby enhancing the overall effectiveness and connectivity of the IoT ecosystem.

The information gathered by sensor nodes can be broken down into two categories: raw and intermediate. The spatial leaf nodes are the source of the raw data. However, during the transmission phase between sensor nodes, the raw data is referred to as intermediate data (temporal). So, the classifier of sensor node TCAM hardware chips used a pair of decision criteria. Raw data is subject to the first rule R1, whereas intermediate data forwarded by neighbouring nodes is subject to the second rule R2, which is used to determine whether or not redundancy should be removed. Using classifier rules, the proposed NDM technique in this study discards redundant data packets observed by sensor nodes.

Beforehand promoting incoming data from sensor nodes, the suggested NDM technique is employed to remove duplicate packets. Afterwards equating the predicted and premeditated feature standards of the packages, the NDM classifier employs a dual-type classification scheme. There are two types of groups that can be classified: those that match and those that don't. If k attribute fields (A1, A2, ...Ak) have matching values, then the packet or collection of packets that satisfy rule R_i will have those values. IoT-focused WSN services and applications can place different demands on these characteristics. Attributes include things like time, sensed data, precision, etc., when tracking things like a person's core temperature. In accumulation, the Pre of the instructions will be similar, while it will remain within an application- or user-defined range, so that redundancy in the data may be accurately estimated. However, the non-matching set does indeed consist of packets that have no matching attribute fields, as suggested by the name. Due to the similarity in the values of the matching characteristics, the severance plaid for the matching set returns a high score, causing the Dse value to be discarded. The data packet is sent to the cluster-head for further processing or aggregation if it is classified as belonging to a non-matching set.

Cosine similarity function was utilised by NDM to determine the similarity score. One can define the connection between the classifier id's matching set $M(R_i)$ and its non-matching set $NM(R_i)$ as follows:

$$NM(R_i) = \sum_{j=1}^{i-1} NM(R_j) - M(R_j) \tag{1}$$

Furthermore, the classifier's rules should adhere to the four constraints below.

If $P_iM(R_j)$ is the number of matching packets, then $P_iNM(R_j)$ must contain the same number of packets. This parity ensures that the two sets have similar workloads.

$$P_iNM(R_i) = P_iM(R_i) \tag{2}$$

Mining information packages from the non-toning set is then accomplished to estimate the judgement once the similarity score has been calculated. Non-matching data packets in storage are evaluated based on their attributes as part of the mining process.

$$NM(R_i) = \sum_{j=1}^{i-1} NM(R_j) - M(R_i) \tag{3}$$

Data packages detected by the sensor nodules of an IoT concerned with WSN should not be duplicated, hence the sets should not contain any such duplicates. Overwhelming communication overhead is the result of severance in both the corresponding and non-corresponding sets.

$$NM(R_i) \cap NM(R_j) \cap M(R_i) = \emptyset \tag{4}$$

A generic probability estimate framework, Prob, is established to further cut down on information severance amongst the packets observed by the sensor nodules. To optimise the compromise between data packet characteristics, a heuristic solution approach is proposed.

$$Pre =< R_1\, prob\left(\frac{C_1}{R_1}\right) \dots\dots\dots\dots prob\left(\frac{C_N}{R_1}\right) > \cdots \dots\dots < R_N\, prob\left(\frac{C_1}{R_N}\right) \dots\dots prob\left(\frac{C_N}{R_N}\right) > \tag{5}$$

It is crucial to train the mining method with data sets in order to appropriately estimate the redundancy. Therefore, working together with the training set T= x1... xN is initiated by the above calculated class probability. In this case, *k* (A1...Ak) properties are associated with each instance *x*. The probability is determined by thinking about the characteristics present in the dataset used for training. It can be assessed as over the rules *R* for the first class *M* that matches:

$$Prob\left(\frac{R}{x}\right) = \prod_{i=1}^{N} M_{xAi}\, f(Ai) \tag{6}$$

$$Prob\ M\left(\frac{R}{x}\right) = M_{xA1}(acc, rej) X M_{xA2}(acc, rej) \tag{7}$$

$$Prob(NM)\left(\frac{R}{x}\right) = NM_{xA1}(acc, rej) X NM_{xA2}(acc, rej) \tag{8}$$

5. RESULT AND DISCUSSION

Previous, our proposed NDM scheme was compared with ICP, CT and NSM strategies and their performance was also discussed here. In the same scenario, the sensor nodes are the ones that contribute to the creation of the erroneous data. Consequently, we used CT scheme to tackle this issue. Effects such as the ability to provide alive sensor nodes, end to end delay, the span of network lifetime, energy efficiency average delay, through put, packet redundancy check are used to evaluate performance. For IoT focused WSN real-world internet topologies are randomly selected. It is assumed that there is no form of network related noise, congestion, or even malignant traffic on it.

5.1 Active sensor node count

Using the number of functional sensor nodes, the performance of the proposed NDM scheme is evaluated. To evaluate the performance, the number of operational sensors after having run the simulation is communicated.

5.2 End to end delay

The proposed NDM system is analyzed against prior data mining configurations by referencing the performance metric called end-to-end delay.

$$\text{End to end Delay} = \text{Time for (Data transmission} + \text{Data processing} + \text{Data delivery)} \tag{9}$$

5.3 Network energy

How effectively the suggested NDM data mining scheme reduce the power as compared to another scheme. From the Figures 3-7, it may be observed that the NDM system has superior performance compared to the other schemes.

5.4 Throughput

For each of the data mining methods described above, as well as each of the proposed methods, we show the typical throughput in kilobits per second. With the help of the data mining method the average throughput of the network can be increased significantly.

$$\text{Throughput} = \frac{\text{Forwaded data}}{\text{Transmission time}} \quad (10)$$

5.5 Packet redundancy check

Incidentally the simulation environment is employed to illustrate the performance measure called packet redundancy check (PRC). The table exhibits the features of redundancy which abbreviated as Rd. The percentages are obtained by scaling the PRC values of various schemes to a range of zero to one hundred percent. Also, for the purpose of clarity all the PRC values for all the schemes are presented as shown below.

From Tables 2-6, we have compared different parameters as Active sensor nodes, End to end delay, Network Energy, Throughput and PRC for various node counts 100, 200, 300, 400 and 500 shown in Figures 3-7 respectively. Moreover, compared the performance of proposed algorithm with existing algorithms as NSM, W-leach, K-MDR and ICT.

Table 2. The projected system's enactment based on efficiency at 100 nodes

S. No.	Algorithms	Sensor Nodes Active	End to End Delay (ms)	Network Energy	Throughput	PRC
1	NSM	58	38	45.49	45.23	86
2	W-Leach	64	32	54.28	54.47	72
3	K-MDR	75	27	46.13	62.73	52
4	ICT	84	21	58.24	79.15	79
5	NDM	102	14	79.28	97.96	89

Table 3. The projected system's enactment based on efficiency at 200 nodes

S. No.	Algorithms	Sensor Nodes Active	End to End Delay (ms)	Network Energy	Throughput	PRC
1	NSM	150	36	50.29	31.37	71
2	W-Leach	176	31	42.34	78.29	63
3	K-MDR	163	28	46.48	56.34	43
4	ICT	154	22	62.34	39.19	74
5	NDM	193	18	79.56	94.27	83

Table 4. The projected system's enactment based on efficiency at 300 nodes

S. No.	Algorithms	Sensor Nodes Active	End to End Delay (ms)	Network Energy	Throughput	PRC
1	NSM	246	40	52.73	46.49	41
2	W-Leach	259	23	64.24	22.27	53
3	K-MDR	264	28	50.67	31.57	21
4	ICT	271	36	65.61	60.34	44
5	NDM	288	19	82.32	68.91	84

Table 5. The projected system's enactment based on efficiency at 400 nodes

S. No.	Algorithms	Sensor Nodes Active	End to End Delay (ms)	Network Energy	Throughput	PRC
1	NSM	352	40	68.18	24.48	20
2	W-Leach	358	38	64.24	38.24	32
3	K-MDR	362	34	61.37	42.37	09
4	ICT	375	36	58.27	64.39	18
5	NDM	384	17	91.19	82.57	72

Table 6. The projected system's enactment based on efficiency at 500 nodes

S. No.	Algorithms	Sensor Nodes Active	End to End Delay (ms)	Network Energy	Throughput	PRC
1	NSM	450	48	64.87	18.45	24
2	W-Leach	466	36	65.23	63.12	28
3	K-MDR	475	25	63.47	48.42	12
4	ICT	483	21	60.94	25.58	08
5	NDM	492	20	97.96	78.35	42

In the simulation, 500 nodes are used, and the suggested NDM system surpasses the competition by reaching the maximum number of healthy sensors. When comparing NDM to other approaches, we see that 492 out of 500 nodes in the resulting graph are still functional. The other scheme's sensor nodes all used data mining on the incoming packet, which is why it failed.

When the total number of nodes is 100, the proposed data mining approach achieves very low end-to-end delay as shown in Figure 3. The NDM tactic keeps the delay to a minimum around nodes in the 1-300 range. With 500 simulated nodes, the NSM approach achieves an end-to-end delay of 48 milliseconds as shown in Figure 7.

When the maximum number of sensor nodes (500) was used in the simulation, the network energy was calculated to be 97.96 joules. In contrast, the NSM system only managed 64.87 joules. The reason for this is that a data mining controller is built into each sensor node. As a result, the network's energy consumption is reduced compared to the NDM proposal.

When there are 100 sensor nodes, as shown in the Figure 3, the NDM achieves an average throughput of 95.26 kbps. In contrast, with only 500 sensor nodes, throughput increases to 78.35 kbps. The suggested NDM technique is more efficient since it takes into account all relevant factors before settling on a decision on where to send data packets. As can be seen in the diagram, the PRC for the proposed plan is quite high, at 92%.

Therefore, the best possible compromise needs to be found. When compared to previous methods suggested in this area, it is clear that the NDM data mining strategy provides superior results. Throughput, PRC, energy savings, and the number of active sensor nodes are all maximised with low latency thanks to the NDM scheme.

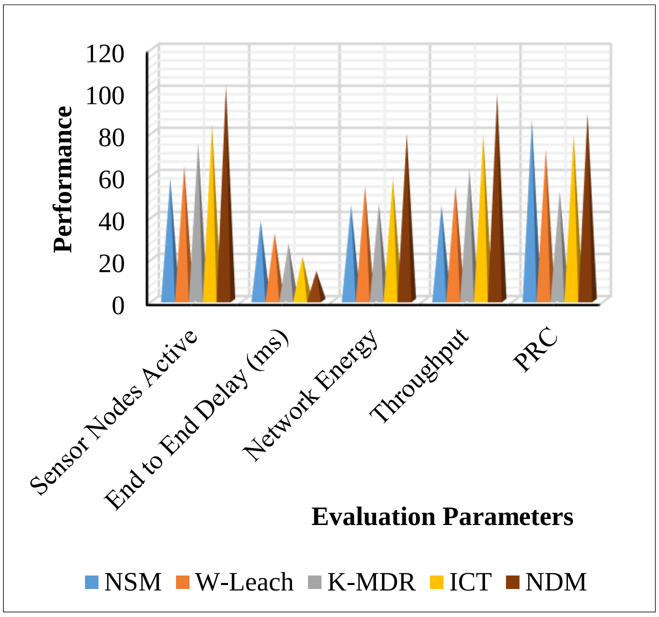

Figure 3. The projected system's enactment based on efficiency at 100 nodes

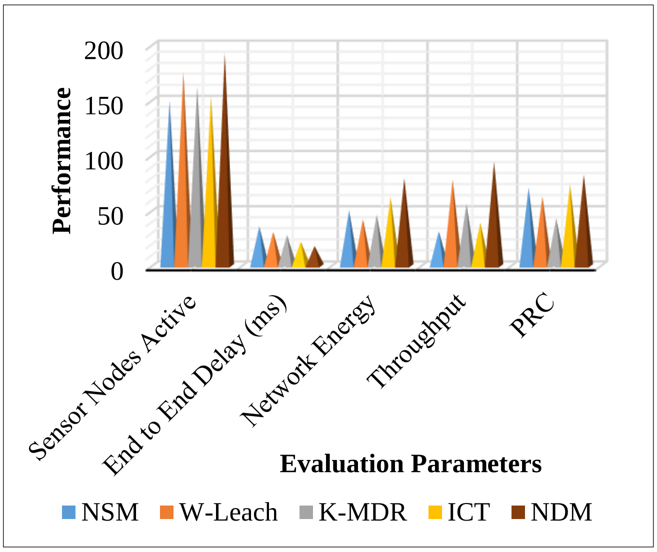

Figure 4. The projected system's enactment based on efficiency at 200 nodes

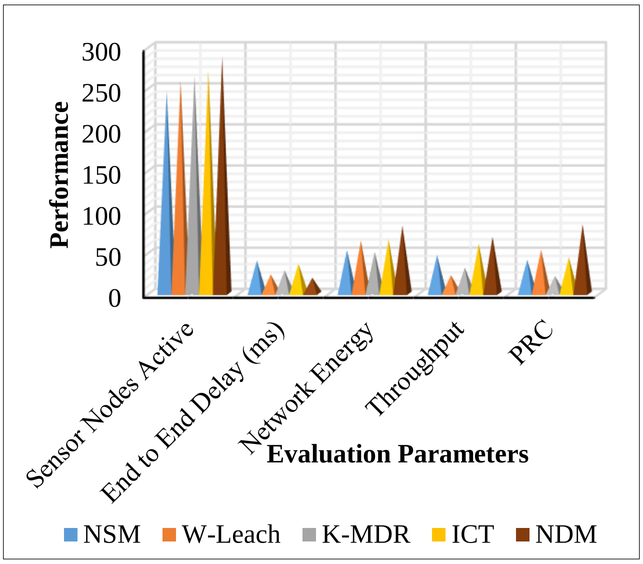

Figure 5. The projected system's enactment based on efficiency at 300 nodes

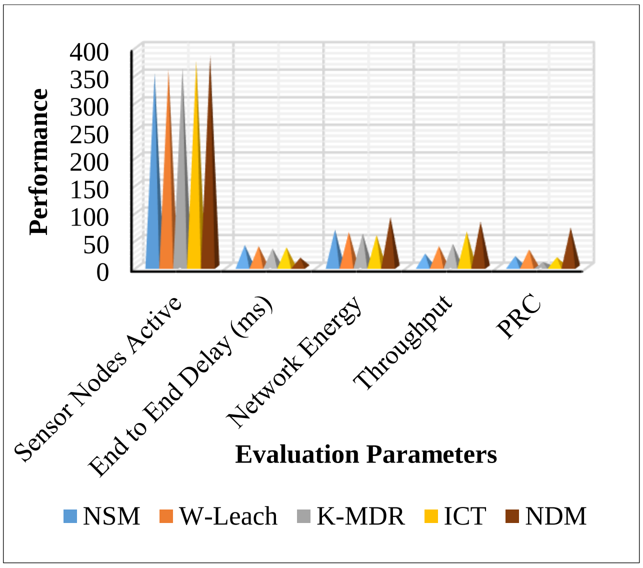

Figure 6. The projected system's enactment based on efficiency at 400 nodes

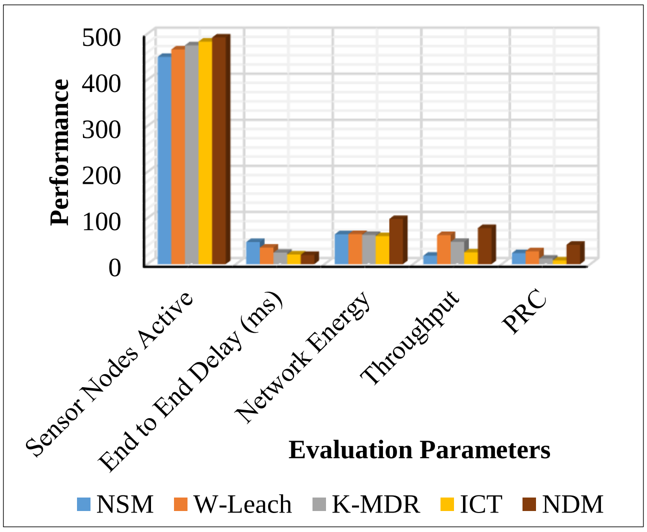

Figure 7. The projected system's enactment based on efficiency at 500 nodes

The suggested technique uses data mining on network parameters to identify a suitable packet for forwarding, which is necessary due to the mobility of IoT-oriented WSN. With a higher redundancy rate, the packet has a better chance of reaching its destination. The NDM approach thrives on the integration of diverse IoT technologies. By leveraging packet classification and optimized data processing, NDM seamlessly incorporates technologies like radio frequency (RF), Bluetooth, and Wi-Fi. This integration enhances communication, streamlines information flow, and ensures efficient data management, contributing to the overall effectiveness of the IoT system.

6. CONCLUSION AND FUTURE SCOPE

Research on IoT-oriented WSN is now experiencing a boom since there are so many possible uses and services in such a wide variety of fields. In particular, sensor nodes collect a great deal of data, some of which is duplicated from other sources. The performance of the network is adversely affected in a number of ways as a result of this redundancy. In order to solve this issue, the NDM system was developed. This system makes use of data mining in order to identify which packets from among those perceived by the network are the most important ones to forward on to the following node. When evaluating the effectiveness of an NDM-based WSN created for the IoT, several parameters are taken into consideration. The results of the simulation revealed that the suggested strategy performed significantly better than other methods that were considered. The proposed framework serves as a foundation for developing a future application addressing real-time issues. It lays the groundwork for solving dynamic problems, offering a practical solution through its adaptable design and responsiveness to real-time challenges.

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