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NFRM - A Node Failure Recovery Mechanism for Mobile Wireless Sensor Networks

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Abstract- Wireless Sensor Networks (WSNs) have revolutionized communication networks and are utilized in various applications such as environmental monitoring, military surveillance, and healthcare. Despite their widespread use in data transmission, the mobility of sensor nodes between clusters often results in high energy consumption and data loss, driving researchers to explore different routing protocols. However, the previous routing protocols were unable to reduce energy consumption and data loss. Many issues in data transmission with the sensor nodes and nature of resource constrained. To address the limitations of WSN, in previous research paper D Swapna et al, used a Cross Layer Technique for Cluster Routing Protocol(CLT-CRP) for Mobile Wireless Sensor Network(MWSN). Even though the CLT-CRP contributed significantly to the field of MWSN by providing an innovative solution to address the limitations data transmission and energy consumption, but resolution for node failure is still alive. To overcome the CLT-CRP problem in MWSN, in this research work proposed Node Failure Recovery Mechanism(NFRM). The NFRM provide alternate way for data transmission and avoid loss of data and reduce delay. The mechanism also resolution for recovery of node failure. The detection of node failure mechanism is made using NS2. The performance is verified the comparison of LEACH and CRPD using NS2 simulation. The simulation results indicate that NFRM achieves improved performance in terms of delay, PDR, energy, throughput, Overhead and Communication Cost.

Keywords *- Node Failure Detection, Recovery Mechanism, Cross Layer Technique, Mobile Wireless Sensor Network, Trust Signal.*

1. INTRODUCTION

The rapid progression of wireless communication technologies and the miniaturization of electronic devices have led to the creation of low-power, cost-effective sensor nodes. These nodes are capable of processing and communicating wirelessly, making them ideal for deployment in various applications. By forming wireless networks, these sensor nodes can perform sensing, processing, and communication tasks, enabling applications in disaster management, military surveillance, home security, emergency response, vehicular, environmental, health, industrial, and habitat monitoring[1].

In wireless sensor networks (WSNs), detecting and identifying failures is critical due to deployments in distributed and harsh environments like military zones and underwater locations. Sensor nodes are vulnerable to various failures from environmental factors, battery depletion, and aging, which can disrupt network operations. Additionally, challenging deployment conditions can cause nodes to inaccurately detect failures, leading to unnecessary resource usage in recovery attempts. Efficient failure detection mechanisms are vital to mitigate resource consumption and maintain service quality in WSNs. Implementing effective strategies to detect failures and take timely actions is essential for preserving overall network performance [2]. Wireless sensor networks (WSNs) consist of autonomous sensor nodes (SNs) deployed to monitor parameters like temperature, pressure, and humidity across various applications such as military surveillance and environmental monitoring. A key challenge lies in the limited energy capacity of SNs, often equipped with non-rechargeable batteries for unattended and hostile environments. Efficient energy conservation is crucial for prolonging the network's lifespan and ensuring sustained operation [3]. Clustering is a prominent strategy for conserving energy in WSNs, where sensor nodes (SNs) are grouped into clusters with a designated Cluster Head (CH) responsible for data aggregation and transmission to the sink[4]. However, serving as a CH is demanding and can quickly deplete energy reserves. SNs, including CHs, are susceptible to various failures such as energy depletion, hardware/software malfunctions, and adverse conditions[5]. Failures, especially of CHs, significantly impact network performance by potentially causing network partitioning and disrupting data transmission to the sink. Therefore, developing fault-tolerant mechanisms, particularly for CHs, is crucial to ensure network reliability and resilience in WSNs[6].

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II. LITERATURE REVIEW

The significance of fault tolerance in various highlights diverse applications of Wireless Sensor Networks (WSNs) such as wildlife monitoring and battlefield surveillance, despite challenges stemming from sensor node limitations and failures due to resource constraints. Yasmine Djebaili et al [7] propose an innovative scheme integrating a link quality estimation algorithm and congestion detection mechanism to address these issues. Their approach routes traffic through high-quality links in non-congested areas during faults, achieving fault tolerance with minimal cost compared to the HEEP protocol. HEEP optimizes energy efficiency by organizing nodes in a hierarchical chain structure within clusters, limiting direct communication with Cluster Heads (CH) to neighboring nodes. This arrangement in HEEP optimizes energy use and bandwidth by aggregating data along a chain structure within clusters. Each node forwards its data to the nearest neighbor, with the last node aggregating and sending it to the Cluster Head (CH), which then transmits to the Base Station (BS). HEEP enhances energy efficiency through CH rotation and a Transmission Plan (TDMA schedule) that assigns specific transmission times to nodes, thereby extending CH lifespan. In contrast, our proposed protocol integrates fault tolerance across network, MAC, and physical layers, addressing node and CH failures. Unlike HEEP, which lacks these mechanisms and operates solely at the network layer, our protocol enhances overall network reliability and performance[8].

WSNs are increasingly deployed across diverse applications, necessitating robust failure detection and recovery mechanisms due to sensor node constraints and challenging environments. This paper introduces a cluster-based failure detection and recovery mechanism designed for large-scale distributed WSNs structured on a grid framework. It also analyzes existing research on failure detection mechanisms, comparing performance metrics like communication cost, detection accuracy, network connectivity, and complexity. Using the OPNET simulation tool, the proposed scheme's communication cost and scalability are evaluated in a grid-based WSN scenario with a significant number of sensor nodes [9].

In cluster-based Wireless Sensor Networks (WSNs), Cluster Heads (CHs) are crucial for data aggregation and transmission to sink nodes. CH failures can lead to network partitions and degraded performance, highlighting the need for robust fault tolerance mechanisms. Existing solutions often suffer from drawbacks like increased energy consumption or reliance on additional resources. To address these issues, this paper proposes a Centralized Fault Tolerant Mechanism (CFTM) capable of efficiently managing both permanent and transient CH failures, ensuring network continuity. Simulation-based comparisons with LEACH and IHR protocols show that our mechanism excels in energy and time efficiency, enhancing data reception at the sink [10].

III. PROPOSED METHODOLOGY

A. Problem Statement

The WSNs have transformed communication networks, serving diverse applications like environmental monitoring and healthcare, driven by technological innovations enhancing data transmission. In Mobile WSNs (MWSN), the CLT-CRP enhances efficiency and energy use, yet struggles with node failure resolution. Addressing this, a Node Failure Recovery Mechanism (NFRM) in Multi-hop WSNs provides alternative paths to prevent data loss and reduce delays, offering robust node failure recovery solutions..

B. Proposed NFRM

1. Route Establish Phase

In WSN, a route discovery phase incorporating node distance utilizes proximity-based routing to efficiently establish routes between source and destination nodes. Initially, the source node broadcasts a route request (RREQ) packet containing its own identifier and the destination node's identifier. Upon receiving the RREQ, intermediate nodes assess their proximity to the destination based on predefined metrics such as signal strength, hop count, or geographic distance. Nodes with closer proximity to the destination prioritize forwarding the RREQ, thereby reducing latency and energy consumption. As the RREQ propagates through the network, nodes update their routing tables with information about neighboring nodes and their corresponding distances. Once the RREQ reaches the destination or a node with a route to the destination, a route reply (RREP) is generated and sent back to the source node, establishing the optimal path based on node distances. In this phase proposed optimizes route selection by favoring paths with shorter distances, enhancing network efficiency and reliability in MWSN deployments.

2. Data Transmission Phase

In WSN, data transmission from a source node to a destination node involves the efficient relay of information through a multi-hop communication scheme. Initially, the source node collects data from its sensors and encapsulates it into packets for transmission. Using routing information obtained through route discovery mechanisms, the source node determines the most suitable path to the destination node, often considering factors such as node proximity, energy levels, and network congestion. The source node initiates data transmission by sending packets along the established route, intermediate nodes along the route facilitate packet forwarding, utilizing techniques like store-and-forward to relay data to subsequent nodes until it reaches the destination. The proposed mechanism maintain status of transmission process, node failure detection, node recovery, and data integrity verification are employed to ensure reliable delivery in the resource-constrained and dynamic WSN environment.

3. Node Failure Detection

In the NFRM for a WSN, multiple scenarios are employed to detect node failures and initiate appropriate recovery actions. Firstly, through Neighbor Monitoring, sensor nodes continuously assess the connectivity and communication status of their neighboring nodes. If a node fails to receive any messages from its neighbors for a specified duration, it is presumed that the neighbor has failed. Secondly, Energy Monitoring plays a vital role, as nodes constantly track their energy levels and relay this information to the base station or neighboring nodes. A node's energy level dropping below a certain threshold or ceasing to report its energy status could signify failure. Lastly, Mobility Detection is crucial, particularly in mobile WSNs where nodes may relocate due to environmental factors or deliberate actions. By monitoring node mobility patterns, the system can detect abnormal behaviors or unexpected node movements, signaling potential node failures. These mechanisms collectively enable proactive detection of node failures, facilitating timely recovery actions such as rerouting data, energy-aware routing, or dynamic adjustment of routing strategies to maintain network efficiency and reliability. The complete node failure detection flow given in Fig 1.

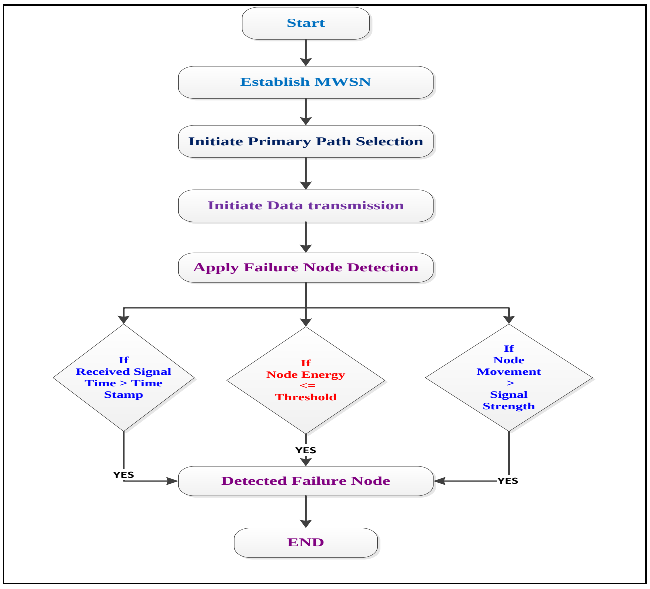


Fig 1 Node Failure Detection Model

4. Failure Node Recovery

In the NFRM for a WSN, to recovery failure node we adapting trust factor from source to destination. The trust signal sends through the failure node.

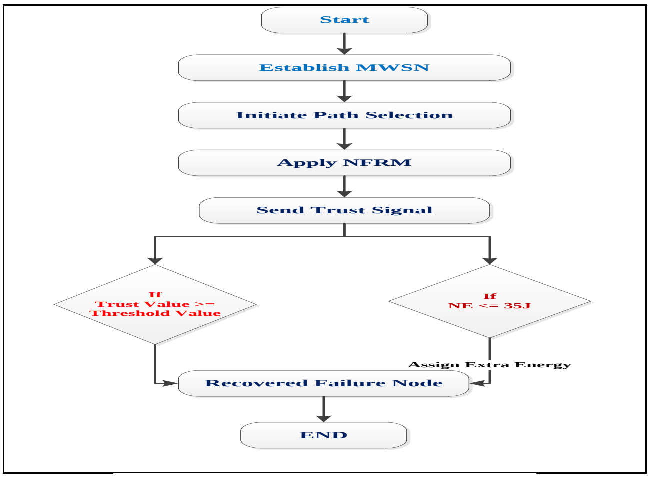


Fig 2 Architecture of NFR Mechanism

The calculation of trust factor is greater than threshold value , the failure node consider as recovered. Later the failure node consider for path between the source and destination. Fig 2 represents the node failure recovery mechanism.

```
Algorithm Name - NFRM Algorithm
Input - Source Node SN, Destination Node DN, Neighbor Node NN, Intermediate Node IN, Node Distance ND
Output - Performance Metrics
Start
Initiate Route Discovery
SN sends RREQ packet
Calculate ND
ND = $\sqrt{(X2 - X1)2 + (Y1 - Y1)2}$
If(ND1 <= ND2) {
Add to Primary Path
} else {
Add to Alternate Path
}
Primary Path = SN + IN1 + IN2 + IN3 + ------- + DN
Initiate Data Transmission
SN Sends Data to DN
Apply Node Failure Detection
SN Sends Signal
If( IN Signal Receive Time > Timestamp ){
IN is Failure Node
} else
If( Node Energy <=Threshold ) {
IN is Failure Node
} else
If(Node Movement Distance > Signal Strength) {
IN is Failure Node
}
```

```
Apply Failure Recover
SN sends trust signal
If(FN trust signal >= Threshold) {
    FN is recover
}
If(NE <=35){
    Assign Energy(NE)
}
FN is recover
End
```

IV. RESULT ANALYSIS

A. Simulation Environment

In the NS2 environment for implementing a NFRM in Wireless Sensor Networks (WSN), the focus lies on simulating a realistic network environment conducive to testing and evaluating the effectiveness of the recovery mechanism. NS2, a discrete event simulator, provides a platform for modeling WSN scenarios, incorporating parameters such as node mobility, energy consumption, and communication protocols. Within this environment, the Node Failure Recovery Mechanism can be designed and validated through simulation experiments. These experiments can involve triggering node failures under various conditions and observing the response of the recovery mechanism in restoring network connectivity and functionality. Additionally, NS2 enables the customization of network topologies, routing algorithms, and failure scenarios, allowing for comprehensive performance analysis and optimization of the recovery mechanism.

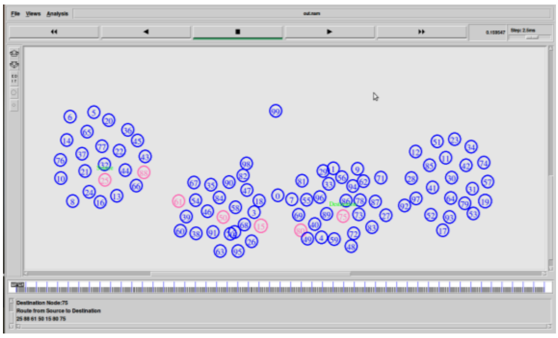
Table 1 given the environment for network simulation for the empirical study.

S NO	Network Parameter	Network Value
1	Type of Channel	WirelessChannel
2	Radio-Propagation	Propagation/TwoRayGround
3	Network Interface	WirelessPhy
4	Interface Queue Type	DropTail
5	Model of Antenna	OmniAntenna
6	Length of Queue	50
7	Routing Protocol	AODV
8	Number of Nodes	100
9	Data Rate	2MB
10	Basic Rate	1MB
11	Total Simulation Time	50

This table 1 outlines the key parameters necessary to configure the network simulation environment using NS2. It specifies details such as the type of wireless channel, radio propagation model, network interface, queue management algorithm, antenna model, length of the queue, routing protocol, number of nodes in the network, data rate, basic rate, and the total simulation time. These parameters collectively define the characteristics and behavior of the simulated WSN, providing a standardized setup for conducting experiments and evaluating the performance of the Node Failure Recovery Mechanism.

The NFR mechanism practical results showed below figures such as path selection, failure node detection and failure node recovery.

Primary Path Selection in MWSN



```
Destination Node:75
Route from Source to Destination
25 88 61 50 15 80 75
```

Fig 3 Primary Path Selection in MWSN

In the MWSN with 100 nodes, the path selection from source node 25 to destination node 75 using a Node Failure Recovery Mechanism (NFRM) involves an adaptive approach to ensure robust communication despite potential node failures. Initially, neighboring nodes (including nodes 88, 61, 50, 15, 80, and 75) are evaluated based on connectivity metrics such as signal strength and hop count to establish an efficient primary path. The path selection nodes showed in fig 3.

Failure Node Detection in MWSN

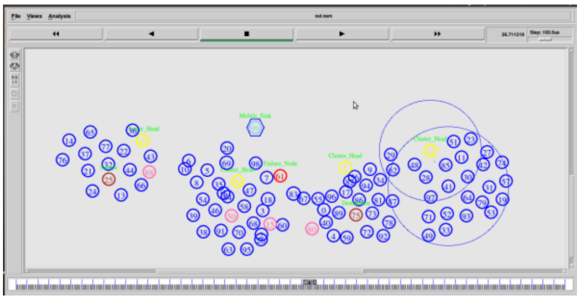


Fig 4 Node Failure Detection in MWSN

In the above scenario where node 61 is detected as a failure node during the route from source node 25 to destination node 75 in the MWSN, the Node Failure Recovery Mechanism (NFRM) will automatically trigger a response to adapt the routing and ensure continued communication. The failure node showed in fig 4.

Node Failure Recovery in MWSN

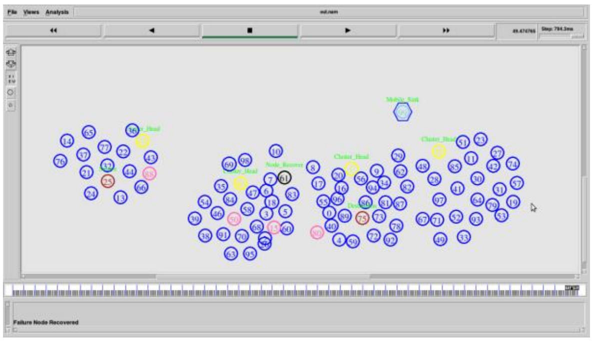


Fig 5 Failure Node Recovery in MWSN

In a MWSN, the recovery of a failure node like node 61 using a Node Failure Recovery Mechanism (NFRM).

B. Analysis of Performance Metrics

1. Packet Delivery Ratio

Packet Delivery Ratio (PDR) is a metric used to evaluate the effectiveness of data transmission in a network. It represents the ratio of successfully delivered packets to the total number of packets transmitted. Mathematically, the formula for Packet Delivery Ratio is expressed as:

$$\text{Packet Delivery Ratio} = \frac{\text{Number of Successfully Deliverd Packets}}{\text{Total Number of Packets Delivered}} \text{ x } 100\%$$

2 .Delay

In Wireless Sensor Networks (WSNs), transmission delay refers to the time taken for a packet to be transmitted from the source node's to the destination node's.

Delay = Packet Received Time - Packet Sent Time

3. Throughput

In Wireless Sensor Networks (WSNs), throughput refers to the rate at which data is successfully delivered from source nodes to destination nodes over the network. It is a measure of the network's efficiency in transmitting data and is typically expressed in bits per second (bps) or packets per second (pps). The formula to calculate throughput in WSNs is:

$$\text{Throughput} = \frac{\text{Total Delivered Data Packets}}{\text{Total Time Taken}}$$

4. Energy Consumption

It denotes the aggregate energy consumption of sensor nodes within the network during data transmission, as expressed by Equation (4).

$$\text{Energy} = \sum_{i=1}^{n} \text{NEi}$$

C. Comparative Analysis

1. Throughput Performance Analysis

Table 2 Throughput Analysis Between NFRM and Previous Protocols

Simulation Time(s)	Throughput(Bytes)			
	LEACH	CRPD	CLT-CRP	NFRM
0	0	0	0	0
5	0	8512	29792	42560
10	4256	8512	25536	42560
15	4256	8512	29792	42560
20	4256	8512	25536	42560
25	4256	8512	29792	42560
30	4256	8512	25536	42560
35	4256	8512	29792	42560
40	4256	8512	25536	42560
45	4256	8512	29792	42560
50	4256	8512	25536	42560

Table 2 compares throughput performance of LEACH, CRPD, CLT-CRP, and NFRM in mobile WSNs over 50 seconds. At 0 seconds, all protocols show zero throughput. By 5 seconds, LEACH has no throughput, CRPD achieves 8512 bytes, CLT-CRP reaches 29792 bytes, and NFRM achieves 42560 bytes.

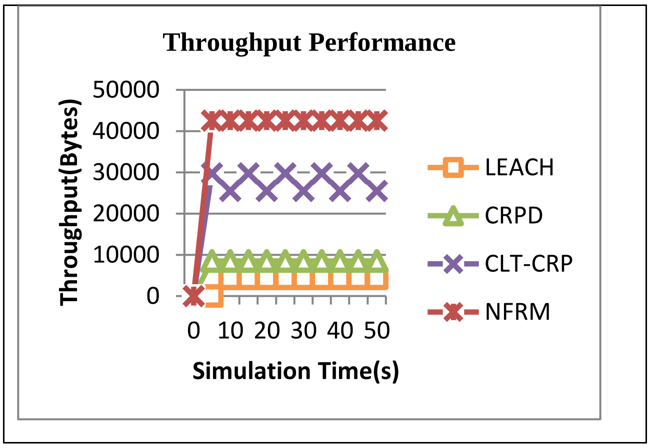


Fig 6 Throughput performance

Throughout the simulation, LEACH maintains 4256 KBPS from 10 seconds onward. CRPD consistently achieves 8512 bytes, while CLT-CRP and NFRM fluctuate between 25536 bytes and 29792 bytes, and maintain 42560 bytes, respectively, from 10 to 50 seconds. NFRM consistently performs best in throughput, followed by CLT-CRP and CRPD, while LEACH lags significantly behind, showing limitations in high-throughput scenarios in mobile WSNs.

In Figure 6, throughput performance analysis over time for LEACH, CRPD, CLT-CRP, and NFRM in a mobile Wireless Sensor Network (WSN) shows distinct trends. Initially, at 0 seconds, all protocols exhibit zero throughput. By 5 seconds, CRPD, CLT-CRP, and NFRM achieve significant throughputs of 8512 bytes, 29792 bytes, and 42560 bytes respectively, while LEACH remains at zero. At 10 seconds, LEACH starts maintaining a consistent throughput of 4256 bytes throughout the simulation. CRPD maintains a steady throughput of 8512 bytes without variation. CLT-CRP alternates between 25536 bytes and 29792 bytes every 5 seconds, indicating fluctuating performance. Conversely, NFRM consistently achieves the highest and stable throughput of 42560 bytes from 5 seconds onwards. This graphical analysis highlights NFRM as the most efficient protocol in maintaining high throughput in mobile WSNs, followed by CLT-CRP and CRPD, with LEACH showing the least efficient performance.

2. PDR Performance Analysis

Table 3 PDR Analysis Between NFRM and Previous Protocols

Simulation Time(s)	**PDR(%)**			
	LEACH	**CRPD**	**CLT-CRP**	**NFRM**
0	0	0	0	0
5	0	0	0	2
10	2	4	2	22
15	5	8	4	50
20	7	12	17	75
25	10	16	32	100
30	12	21	48	125
35	15	25	64	150
40	17	29	79	175
45	20	33	91	200
50	22	37	105	222

The table 3 of Packet Delivery Ratio (PDR) performance over simulation time for the four protocols—LEACH, CRPD, CLT-CRP, and NFRM—highlights the progressive improvement in packet delivery efficiency in a mobile Wireless Sensor Network (WSN). At the initial simulation time of 0 seconds, all protocols start with a PDR of 0%. By 5 seconds, NFRM begins to show a slight PDR of 2%, while LEACH, CRPD, and CLT-CRP remain at 0%. As the simulation progresses to 10 seconds, LEACH and CLT-CRP exhibit a modest PDR of 2%, CRPD increases to 4%, and NFRM significantly rises to 22%. This trend continues, with each protocol showing an upward trajectory in PDR values. By 25 seconds, LEACH, CRPD, and CLT-CRP reach PDR values of 10%, 16%, and 32% respectively, whereas NFRM leads significantly with 100%. At the 50-second mark, LEACH, CRPD, and CLT-CRP achieve PDRs of 22%, 37%, and 105% respectively, while NFRM peaks at 222%. These results demonstrate that NFRM consistently achieves the highest PDR, indicating superior packet delivery performance over time, followed by CLT-CRP, CRPD, and LEACH in decreasing order of effectiveness.

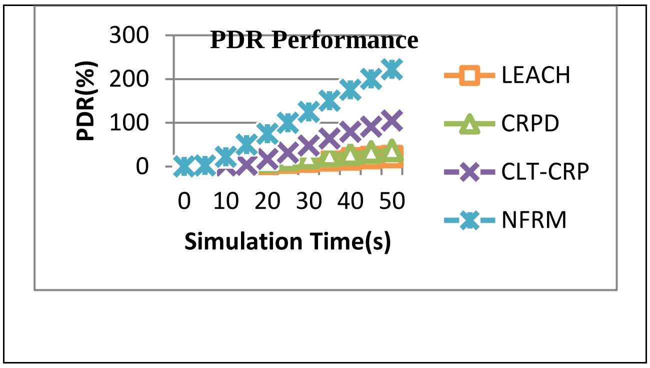


Fig 7 PDR Comparative Analysis

The fig 7 representation of of Packet Delivery Ratio (PDR) performance over simulation time for the protocols LEACH, CRPD, CLT-CRP, and NFRM in a mobile Wireless Sensor Network (WSN) shows distinct trends of improvement. Initially, at 0 seconds, all protocols have a PDR of 0%. By 5 seconds, only NFRM shows a minimal PDR of 2%, while the others remain at 0%. At 10 seconds, NFRM significantly outperforms the other protocols with a PDR of 22%, whereas LEACH and CLT-CRP both have a PDR of 2%, and CRPD reaches 4%. As time progresses, NFRM continues to lead, reaching a PDR of 50% at 15 seconds and 100% at 25 seconds, eventually peaking at 222% by 50 seconds. In contrast, LEACH, CRPD, and CLT-CRP show a steady but slower increase: by 25 seconds, their PDRs are 10%, 16%, and 32% respectively, and by 50 seconds, they reach 22%, 37%, and 105% respectively. This graphical trend indicates that NFRM consistently achieves the highest and most rapid improvement in PDR, demonstrating superior packet delivery performance, followed by CLT-CRP, CRPD, and LEACH in that order.

3. Energy Performance Analysis

Table 4 Energy Analysis Between NFRM and Previous Protocols

Simulation	**RESIDUAL ENERGY(J)**

Time(s)	LEACH	CRPD	CLT-CRP	NFRM
0	100	100	100	100
5	95	95	96	99
10	90	90	98	96
15	85	88	95	95
20	75	85	95	95
25	72	82	96	97
30	71	81	96	95
35	65	77	97	98
40	65	75	97	95
45	65	74	95	98
50	62	72	97	97

Table 4 compares energy performance across four protocols (LEACH, CRPD, CLT-CRP, and NFRM) in a mobile WSN over simulation time. Initially, all protocols start with 100J of energy. At 5 seconds, energy levels drop slightly: LEACH and CRPD to 95J, CLT-CRP to 96J, and NFRM to 99J. By 10 seconds, energy continues to decrease: LEACH and CRPD to 90J, CLT-CRP to 98J, and NFRM to 96J.

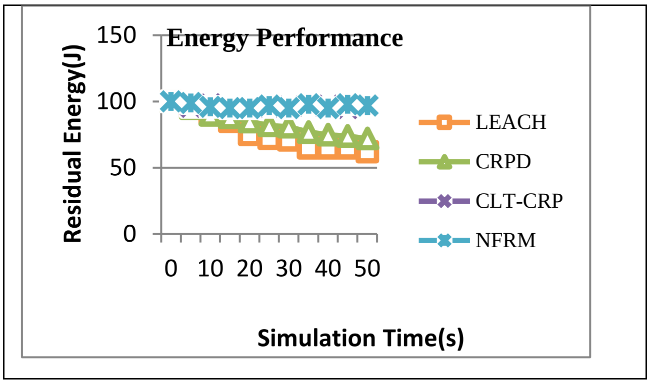


Fig 8 Energy Consumption

This trend persists with varying rates of energy consumption: at 25 seconds, LEACH drops to 72J, CRPD to 82J, CLT-CRP to 96J, and NFRM to 97J. By 50 seconds, LEACH has the lowest energy at 62J, followed by CRPD at 72J, CLT-CRP at 97J, and NFRM at 97J. The results highlight LEACH and CRPD's higher energy consumption compared to CLT-CRP and NFRM, with NFRM demonstrating efficient energy usage and sustainability in mobile WSNs.

Figure 8 illustrates the residual energy analysis over time for LEACH, CRPD, CLT-CRP, and NFRM in a mobile Wireless Sensor Network (WSN), showing varying rates of energy consumption. Initially, at 0 seconds, all protocols start with 100J of residual energy. By 5 seconds, LEACH and CRPD decrease to 95J, CLT-CRP to 96J, and NFRM to 99J. Progressing to 10 seconds, LEACH and CRPD further decrease to 90J, while CLT-CRP maintains 98J and NFRM decreases to 96J. This trend continues, with LEACH and CRPD depleting more rapidly: by 25 seconds, LEACH is at 72J and CRPD at 82J, while CLT-CRP and NFRM remain more efficient at 96J and 97J respectively. At the end of the simulation at 50 seconds, LEACH has the lowest residual energy at 62J, followed by CRPD at 72J, whereas CLT-CRP and NFRM maintain higher levels at 97J each. These findings underscore that CLT-CRP and NFRM are more energy-efficient protocols, ensuring longer sustainability in mobile WSNs compared to LEACH and CRPD.

3.5. 4. Delay Performance Analysis

Table 5 Delay Analysis Between NFRM and Previous Protocols

Simulation Time(s)	DELAY (ms)			
	LEACH	CRPD	CLT-CRP	NFRM
0	0	0	0	0
5	0.61	0.57	0.37	0.21
10	0.38	0.33	0.23	0.11
15	0.33	0.27	0.17	0.02
20	0.26	0.15	0.11	0.02
25	0.24	0.14	0.07	0.02
30	0.23	0.14	0.06	0.02
35	0.23	0.13	0.05	0.02
40	0.22	0.13	0.05	0.02
45	0.22	0.13	0.04	0.02
50	0.22	0.13	0.04	0.02

The table 5 presents the delay performance analysis of various protocols, including LEACH, CRPD, CLT-CRP, and NFRM, in a mobile Wireless Sensor Network (WSN) over simulation time intervals. At the start (time 0), all protocols exhibit no delay. As the simulation progresses, there is a discernible variation in delay values. Initially, LEACH and CRPD demonstrate slightly higher delays compared to CLT-CRP and NFRM, but as time progresses, all protocols show a reduction in delay. By the end of the simulation at time 50, all protocols converge to similar low delay values, with LEACH and CRPD maintaining marginally higher delays compared to CLT-CRP and NFRM.

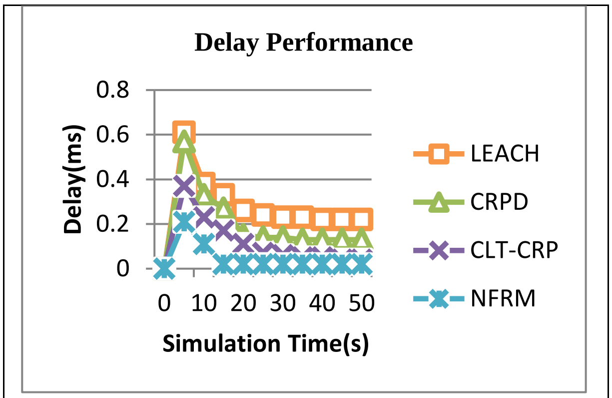


Fig 9 Graphical Analysis of Delay Performance

The fig 9 analysis illustrates the delay performance of LEACH, CRPD, CLT-CRP, and NFRM protocols over simulation time intervals in a mobile Wireless Sensor Network (WSN). Initially, at time 0, all protocols exhibit no delay, forming a horizontal line at the origin. As simulation time progresses, there is a discernible trend where the delay decreases for all protocols. LEACH and CRPD start with slightly higher delay values compared to CLT-CRP and NFRM, but as time advances, all protocols show a consistent reduction in delay. Towards the end of the simulation at time 50, all protocols converge to similar low delay values, forming almost parallel lines, suggesting stable and efficient performance across the board. This graphical representation underscores the dynamic behavior of delay in mobile WSNs and highlights the relative performance of different protocols over time.

5. Overhead Performance Analysis

In fig 10 the graphical analysis of overhead performance for various protocols in mobile Wireless Sensor Networks (WSN), the data demonstrates a clear hierarchy in efficiency. The LEACH protocol exhibits the highest overhead at 50,896 packets, indicating it may be less efficient compared to the others. Following LEACH, CRPD shows a reduced overhead of 46,512 packets. Further improvements are seen with CLT-CRP, which has an overhead of 42,319 packets. The most efficient protocol in terms of overhead is NFRM, with the lowest value of 35,263 packets.

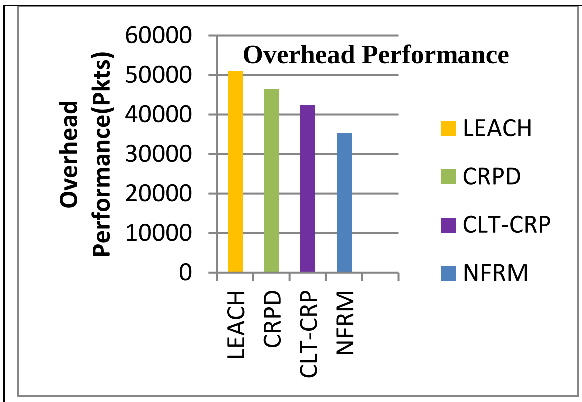


Fig 10 Graphical Analysis of Overhead Performance

This descending trend in overhead values highlights the varying efficiencies of these protocols, with NFRM emerging as the most optimized for reducing overhead in mobile WSN environments.

6. Communication Cost Performance Analysis

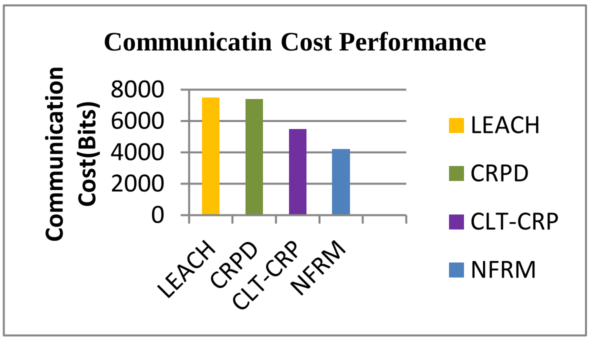


Fig 11 Graphical Analysis of Communication Cost Performance

In the fig 11 graphical analysis of communication cost performance for various protocols in mobile Wireless Sensor Networks (WSN), a clear differentiation in efficiency is observed. The LEACH protocol incurs the highest communication cost at 7,503 bits, suggesting it is the least efficient among the compared protocols. Slightly more efficient, the CRPD protocol has a communication cost of 7,405 bits. The CLT-CRP protocol shows a significant improvement, with a reduced communication cost of 5,489 bits. The NFRM protocol emerges as the most efficient, boasting the lowest communication cost of 4,213 bits. This descending trend in communication costs underscores the varying degrees of efficiency, with NFRM leading in cost-effectiveness for communication in mobile WSN.

V. CONCLUSION

In conclusion, this research work aimed to address the limitations of Wireless Sensor Networks (WSN), particularly in the context of Mobile Wireless Sensor Networks (MWSN). Building upon previous research by D Swapna et al., who introduced the Cross Layer Technique for Cluster Routing Protocol (CLT-CRP) for MWSN, which significantly contributed to enhancing data transmission efficiency and reducing energy consumption, this study identified a persistent challenge: node failure resolution. To overcome this limitation, the proposed Node Failure Recovery Mechanism (NFRM) was developed. NFRM offers an alternative approach to data transmission, aiming to prevent data loss and reduce delays while providing a resolution for node failure incidents. The mechanism's effectiveness was evaluated through NS2 simulations, comparing its performance with existing protocols such as CRPD and LEACH. The simulation results demonstrated that NFRM outperforms these protocols in terms of delay, Packet Delivery Ratio (PDR), energy consumption, and throughput. This research underscores the importance of continuous innovation and adaptation to address evolving challenges in WSNs, and NFRM presents a promising solution to enhance the reliability and efficiency of data transmission in MWSNs while mitigating the impact of node failures.

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