INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

Advancing Wireless Sensor Networks through Performance Evaluation of M-PDCH Routing Protocol for Enhanced Quality of Service

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Abstract

Objective: The decisive aim of this investigation is to improve the capabilities and limitations of PEGASIS with Double Cluster Head (PDCH), for enhancing the overall Quality of Service (QoS) in Wireless Sensor Networks (WSNs). **Methods:** This research is intended at the application of efficient routing protocol for wireless sensor networks. It works on the principle of the formation of cluster head and clustering. This is accomplished to achieve high QoS for WSN. Improving the efficacy of a WSN protocol is decisive for optimizing communication, resource utilization, and overall effectiveness. An innovative and novel protocol named Mobile-PDCH (M-PDCH) has been devised, developed, and tested. Here several parameters have been carefully investigated for enhancing the performance of a WSN protocol such as energy consumption, delay, and packet loss. A simulation environment has been created to evaluate, compare, and validate the performance and to suggest the desired applications of the proposed protocol. **Findings:** In the hierarchical category, PDCH performs better compared to all the other protocols. But it suffers from high packet drop, which decrease the performance of the protocol. To improve the performance of sensor networks, there is a need for adaptive routing protocol. The examination of simulation outcomes for the recommended protocol, M-PDCH, has been conducted in comparison with PDCH. The findings indicate that the protocol exhibits superior performance. The proposed algorithm improves the packet drop by 29.75%, reduces delay by 23.28%, and lowers energy consumption by 19.18% when compared to PDCH. **Novelty:** A novel adaptive routing protocol termed M-PDCH has been proposed for the enhancement of the WSN life span and durability of the sensor nodes. The simulation results show that the proposed algorithm produces better results compared to PDCH protocol. The various QoS parameter results are compared, verified, and validated with existing protocol

OPEN ACCESS

Received: 29-12-2023
Accepted: 29-01-2024
Published: 20-02-2024

Citation: Vhatkar S, Aalam Z, Atique M (2024) Advancing Wireless Sensor Networks through Performance Evaluation of M-PDCH Routing Protocol for Enhanced Quality of Service. Indian Journal of Science and Technology 17(9): 794-803. https://doi.org/10.17485/IJST/v17i9.3265

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Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

PDCH.

Keywords: WSN; PDCH; Design issues; Metrics; QoS; HRP

1 Introduction

In today's digital world sensors and sensor technology are in demand for "smart" living. Sensors are used in several applications such as smartphones, health monitoring, industrial controls etc., and the demand for this technology is rising. WSN is a type of networking system that allows communication between sensors, so that sensors can work together to monitor and balance various factors. A WSN consists of many sensor nodes, and each node consists of a sensing unit, data processing unit, transceiver, and a power source. Latest research in WSNs give rise to development of many new routing protocols exclusively designed for sensor networks, where energy utilization is an essential consideration. In general, routing techniques are mainly divided into network structure and network operations. They are further classified into three categories data centric, hierarchical and location based (1).

Hierarchical Routing Protocols (HRP) mainly focus on energy utilization, by restricting communication within a cluster and aggregate the data to reduce transmission to the Base Station(BS). To acquire data through communication, diminutive sensing nodes are utilized within WSNs. These compact nodes encompass diverse elements like a Central Processing Unit (CPU), memory, battery, and transceiver, performing tasks such as data processing, storage, energy preservation, and the exchange of signals and/or data among nodes. It is crucial to highlight that these sensing nodes function within specified limitations, including restricted power, processing capabilities, storage capacity, and battery life (2).

Networks showing distinctive features similar to WSNs include cellular systems. These networks share characteristics such as closely located nodes, storage considerations, and constraints on the energy required for computation. The design and implementation of WSNs present numerous challenges, as sensor networks are frequently customized for specific applications with distinct requirements. As underlined in (3), the sensor nodes size varies from dimensions comparable to a large shoebox to minuscule particles of dust. In specific applications like military or surveillance, sensor nodes may be microscopically small. In contemporary scenarios, sensors find application in diverse fields such as health, traffic management, and environmental monitoring.

Due to energy constraints and limited battery capacity, the providers designed for wired networks are not suitable for WSNs. To mitigate energy consumption and enhance the lifespan of WSNs, numerous protocols have been devised. The intricacies of designing Routing Protocols (RPs) are notably exigent due to a great number of limitations inherent in wireless networks. Key architectural challenges include limitations in node life span, artificial sensor positions, insufficiency of hardware materiel and components, extensive and arbitrary node deployment, asymmetrical network attribute, an unstable condition, intricacy in data agglomeration, and the crucial is scalability. Within WSNs, considerations such as network size, QoS requirements, and path redundancy metrics are pivotal in addressing RP design issues. This is achieved by presenting relevant applications and elucidating the QoS aspects of RPs tailored for WSNs (2) (3).

Scholars, departments, and organizations have ventured exploration to investigate and discourse the inherent challenges in the building the appliances of WSNs. To conquer these challenges, an RP tailored to applications, known as LEACH, has been introduced. To optimize performance, LEACH integrates concepts from media access and cluster-based RP, incorporating application-specific data aggregation. The evaluation metrics encompass system lifetime, dormancy, and application-perceived quality. A comparative study contrasts the simulation results of LEACH with PEGASIS, revealing superior performance by PEGASIS[4].

To further enhance performance, particularly concerning QoS parameters, the necessity arises to conceive and develop a new RP. This study introduces a pioneering routing algorithm named M-PDCH, demonstrating superior results compared to other protocols in the hierarchical protocol category.

1.1 Classification of HRP and Methods

In several aspects, the routing strategies employed in WSNs diverge from those in static sensor networks. Broadly, HRPs can be classified as hybrid, reactive, or proactive. In proactive protocols, sensor nodes remain static and follow a table-driven approach, whereas in reactive protocols, routes are computed on-demand. The paramount requirement for HRP protocols in WSNs is efficient energy conservation. Various HRP algorithms have been devised for WSNs, and the primary HRPs can be grouped into four types, as illustrated in Figure 1. This study specifically concentrates on Homogeneous HRP[4].

The design considerations for HRPs in WSNs are extensively discussed in[5], encompassing diverse spectrum and metrics like agility, energy, liability, and QoS. The analysis provides an extensive summary of diverse HRPs suitable to WSNs. Generally, HRPs are categorized as hybrid, reactive, or proactive, with proactive sensor nodes being stationary and reactive sensor nodes exhibiting dynamic behavior. Wireless HRPs must adhere to stringent energy-saving criteria. Figure 1 portray the foremost HRP types feasible for WSNs can be parted into four classes. This investigation precisely emphases on homogeneous HRP. Hierarchical clustering is a well-explored concept in WSNs, with numerous researchers delving into this subject from various perspectives. The main classifications of homogeneous HRP include LEACH, PEGASIS, and CBR[6].

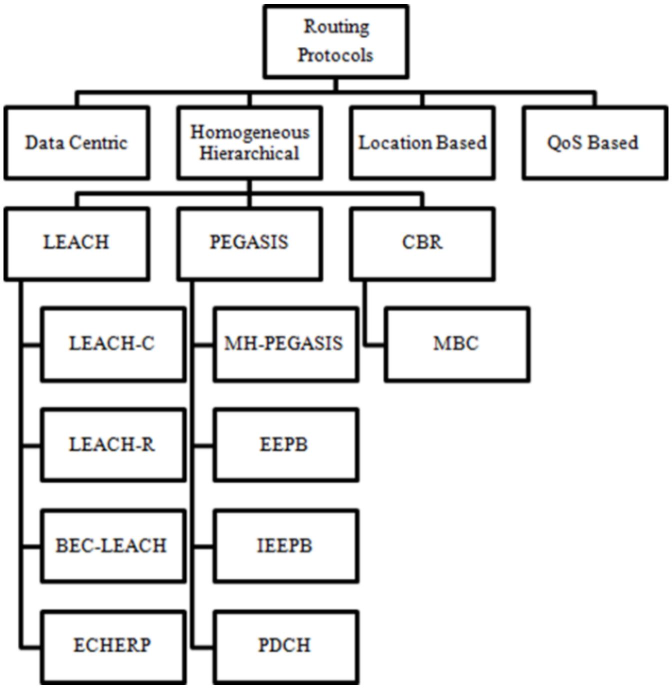

Fig 1. Categories of HRP

1.2 LEACH Based Protocol[7]

The LEACH protocol, initially introduced as a pioneering approach to minimize power consumption, has gained widespread popularity as a power proficient HRP for WSNs. Despite its acclaim, the protocol exhibits certain limitations:

- Cluster heads (CHs) positioned at considerable distances from the sink node face elevated power requirements.
- The protocol lacks a guarantee of an optimal distribution of CHs, as it relies on uniform energy requirements for CH selection.

- Dynamic clustering introduces overhead in the form of CH changes, advertisements, and a subsequent decrease in energy efficiency.

In response to these challenges, several subsequent protocols have been proposed. The LEACH-C algorithm adopts a central control approach integrated with the clustering algorithm. LEACH-R represents an enhancement of the original LEACH protocol. The BEC–LEACH protocol addresses the unspecified and uneven distribution of CHs seen in LEACH (4).

Among these, the ECHERP protocol stands out by employing a model-based approach for CH selection. What sets this protocol apart is its more efficient mechanism for designating a node as a CH. This optimization aims to extend the network's lifespan by keeping the present and future residual energy of nodes, together with the projected round count as CHs (8).

In the ECHERP algorithm, each node broadcasts its position and energy level to adjacent nodes while maintaining a neighbor information table. Once the BS receives information from every node, it initiates the CH selection process. This process utilizes the Gaussian Elimination algorithm to determine CHs. The BS strategically chooses nodes for direct communication with higher CH levels and others with lower CH levels. Every node subsequently transmits data to its respective CH, and the CHs integrate the specifics, routing it to higher-level CHs as needed. This sophisticated approach aims to mitigate the shortcomings of previous protocols and enhance the overall efficiency and longevity of WSNs (8).

1.3 CBR Based Protocols

CBR, categorized as a homogeneous HRP, employs the TDMA scheduling technique and a round-free CH protocol referred to as CBR. This protocol efficiently transmits data to CHs. CBR assimilate most likely connection time to construct a reliable route, subject to the durability of every linkage between a CH and non-CH node (9).

1.4 PEGASIS Based Protocols

PEGASIS (10) extends the LEACH RP model by having each node communicate solely with its neighboring node and seizing opportunities to relay information to the BS. The protocol surpasses 'LEACH' across various network sizes and topologies, reducing the overhead associated with active cluster formation in LEACH. Additionally, PEGASIS minimizes the data broadcast workload by efficiently organizing a chain for data gathering, ensuring a more evenly distributed power capacity throughout the network (11) (12).

2 Methodology

Existing work simulation results compare the EEPB protocol with the IEEPB protocol and show that the IEEPB protocol has enhanced performance than the EEPB protocol in terms of number of packets loss, delay, energy consumption, and throughput.

The research work in (13) provides a complete exploration of the IEEPB protocol's methodology. In contrast to the EEPB protocol, IEEPB employs a different approach for constructing the chain by assigning weight coefficients to nodes, taking into account factors such as residual energy and inter-node distances. This innovative technique mitigates the issues associated with LL formation in PEGASIS, as well as those observed in the EEPB protocol. A detailed comparative analysis between the IEEPB and EEPB protocols is conducted, resulting in an enhancement of Quality of Service (QoS). The findings indicate that IEEPB surpasses EEPB by 37.5%, 28.57%, 50%, and 22.22% concerning Packet Delivery Ratio, Energy Consumption, Delay, and Throughput, respectively. Consequently, it is established that IEEPB exhibits superior end-to-end performance compared to the EEPB protocol. Furthermore, it is suggested that future research could involve comparing the IEEPB protocol with other PEGASIS-based protocols, with a focus on analyzing QoS parameters.

Among the examined protocols, PEGASIS demonstrates superior performance compared to LEACH. However, PEGASIS exhibits certain limitations. Its use of a greedy algorithm for data chain formation results in prolonged chains, leading to increased energy consumption and premature node depletion. Additionally, data transmission in PEGASIS introduces time delays, and the method for selecting cluster heads lacks suitability for load balancing. To address these drawbacks, the EEPB protocol introduces a distance threshold, prioritizing short distances to allow for the existence of branch chains. A novel enhancement, the PDCH algorithm, is then introduced based on double cluster heads. PDCH surpasses both PEGASIS and EEPB by eliminating the overhead associated with dynamic cluster formation, minimizing inter-node distances, reducing the number of transmissions and receptions among nodes, and achieving a single transmission to the base station per round. Extensive efforts have been dedicated to comparing the Quality of Service (QoS) parameters of EEPB and PDCH. Further analysis and comparison of parameters such as delay, throughput, energy consumption, and packet drop ratio are recommended. Additionally, there is room for improvements in these parameters to enhance the overall end-to-end performance of the PDCH protocol (14).

The study of PDCH protocol as a solution to address the shortcomings of the EEPB protocol. The innovative PDCH protocol incorporates a new distance-based cluster selection method and employs a double cluster head approach within each cluster to achieve a balanced network load, thereby enhancing overall network performance. A comparative analysis between PDCH and EEPB protocols is conducted, leading to improvements in Quality of Service (QoS). Simulation results reveal that PDCH surpasses EEPB by 57.77%, 41.42%, 50%, 69.12%, 16.66%, and 17.50% in terms of delay, energy consumption, dead nodes, network overhead, throughput, and packet loss ratio, respectively. Consequently, it is established that PDCH exhibits superior end-to-end performance compared to the EEPB protocol. Future research endeavors may involve comparing the PDCH protocol with other PEGASIS-based protocols, accompanied by a detailed analysis of QoS parameters(15).

Drawing insights from the above observations, there is a need for an adaptive RP. This recognition has inspired the design of an adaptive RP known as M-PDCH, which is developed as an extension of PDCH by giving the mobility to nodes to choose random energy for each node(16). M-PDCH operates through four distinct phases and are detailed in Figure 2.

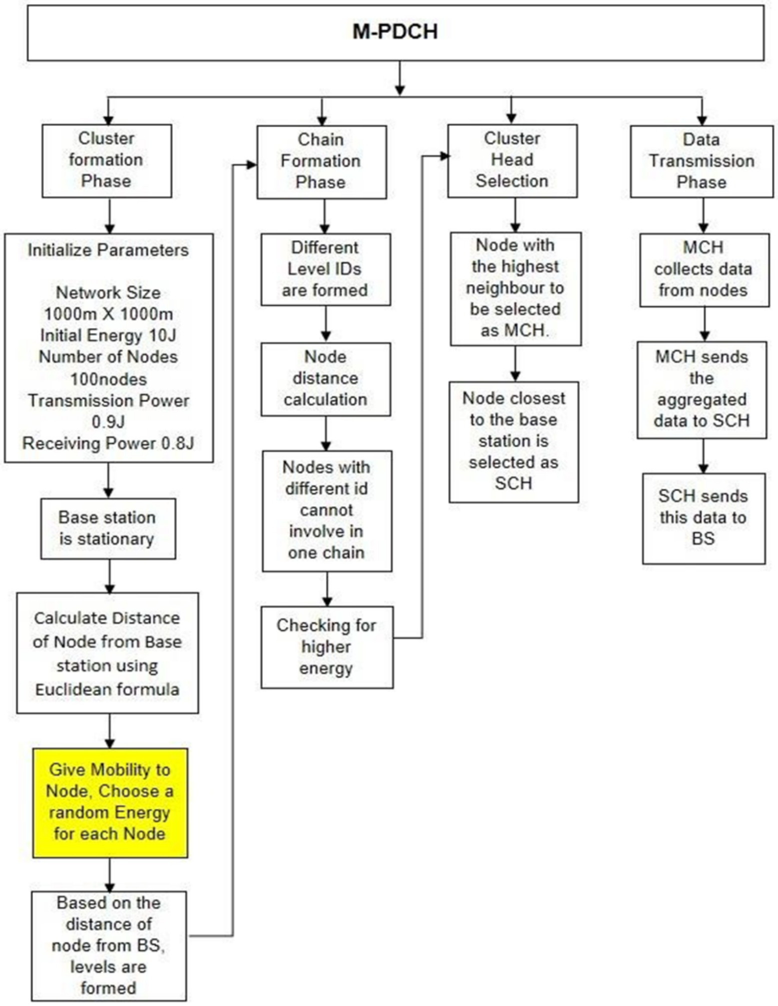

Fig 2. Flow chart of M-PDCH

1. **Network Setup**
   (a) The network area spans 1000 × 1000m.
   (b) Consideration of 500 densely deployed nodes.
   (c) Initialization of all network parameters.
   (d) Determination of the number of nodes, power, and location.
   (e) Node configuration.

    (f) Definition of the maximum number of nodes in one cluster.

2. **Cluster Formation**
    (a) Identification of the maximum X and Y values for the clusters.
    (b) Node creation with assigned values.
    (c) Execution of the cluster formation phase and establishment of the base station.
    (d) Utilization of the Euclidean distance formula for cluster creation.
    (e) Formation of distinct clusters with concurrent updating of cluster numbers.
    (f) Introduction of mobility to nodes, with random energy assignment for each node.
3. **Chain Construction within a CH**
    (a) Formation of levels within a cluster.
    (b) CH selection phase.
    (c) Creation of CH based on residual energy.
    (d) Evaluation of the highest and second-highest energy nodes.
    (e) Choose MCH node having the highest power.
    (f) Choose SCH having second-highest power.
4. **Data Transmission Phase**
    (a) MCH gathers local data in the cluster.
    (b) Aggregation of the collected data.
    (c) SCH receives the aggregated data from the MCH.
    (d) SCH to BS transmission.
    (e) Chaining up all the SCHs.

3 Results and Discussion

It is important to set the simulation environment before performing actual simulation. Hence, the Network Simulator–2.35 is being used on an Ubuntu 14.04.4 on laptop with an Intel i5 CPU and 8 GB RAM. Performance evaluation is based on QoS parameters, including delay, energy consumption, packet drop, among others. Prior to simulation, it is crucial to configure the network environment. The simulation environment is established by defining network parameters, as outlined in Table 1.

Table 1. Network initialization and configuration

Parameters	Value
Size of Network	1000 x 1000 m^2
No. of Nodes	500 Nodes
Initial energy of Nodes	10j
Sensing Power	0.0175j
Tx power	0.9j
Rx power	0.8j
Idle power	0.0j
Energy renewal time	0.5

These initialization parameters collectively provide insights into the characteristics and capabilities of the WSN. The initial energy levels, along with the energy consumption rates during sensing, transmission, and reception, are vital considerations for assessing the network's overall performance and sustainability over time. The number of nodes and network size further contribute to understanding the scale and coverage of the deployed wireless sensor network.

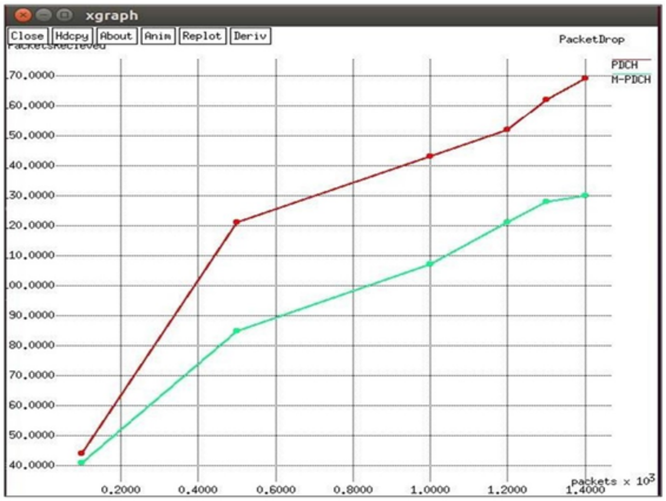

Fig 3. PDR for PDCH and M-PDCH

3.1 Packet Drop Ratio (PDR)

The Figure 3 displays PDR percentages for different numbers of packets, distinguishing between two types of protocols: PDCH and M-PDCH. The proposed protocol M-PDCH consistently outperforms PDCH. This improvement is evident in the decreasing PDR values for M-PDCH compared to PDCH. While M-PDCH performs better, the performance gap between PDCH and M-PDCH increases as the number of packets increases. This suggests that the modifications in M-PDCH have a more significant impact at lower packet counts. M-PDCH starts to approach PDCH in performance as the packet count increases. Therefore, there might be an optimal range of packet counts where the benefits of M-PDCH are most pronounced.

Figure 3 assists as a comprehensive illustration of the PDRs observed in two protocols within a network comprising 100 nodes. The plotted data unveils a notable distinction: at the peak of packet transmissions, PDCH encounters a significant drop of approximately 70,000 packets, whereas M-PDCH exhibits a more reasonable drop, totaling only 30,000 packets. This difference emphasizes the superior packet delivery performance of M-PDCH in comparison to PDCH. The observed contrast in drop rates is vital for evaluating the reliability and efficacy of each protocol under maximum load conditions. The discrepancy in dropped packets highlights M-PDCH's ability to mitigate potential packet loss, showcasing its superior resilience compared to PDCH.

To compute this difference, the percentage change in PDR is computed, revealing that M-PDCH validates a 23.08% lower PDR compared to PDCH. This specifies a considerable improvement in the packet delivery performance of M-PDCH, solidifying its dominance in sustaining a higher rate of effective packet delivery. The data highlights the flexibility and efficiency of M-PDCH in scenarios with exhaustive packet transmissions, thereby justifying its preference in applications prioritizing robust and consistent packet delivery.

3.2 Delay

The research study's emphasis on delay is critical for applications where timely communication is paramount, such as in real-time data acquisition or monitoring scenarios. The comparative nature of the analysis aids scientists and practitioners in making informed decisions regarding protocol selection based on specific application requirements.

Figure 4 highlights the relationship between the number of packets and the associated delay in PDCH and M-PDCH. The delay is measured in milliseconds, and the number of packets is characterized in increments of 1000. The delay is practically nonexistent when the packet count is 0, signifying negligible processing time in the absence of incoming packets. As the number of packets increases, a noticeable pattern emerges in the delay time.

In the PDCH, as the packet count increases from 100 to 1400, the delay constantly rises. This increase is demonstration of the increasing workload, and the corresponding processing time reflects the system's response to the increasing number of packets. On the other hand, M-PDCH demonstrates comparable trends in delay, with increasing values corresponding to higher packet quantities. However, significant peculiarities are observed in the delay times between the two approaches. Especially, M-PDCH consistently proves lower delay times compared to the traditional PDCH across all observed packet quantities.

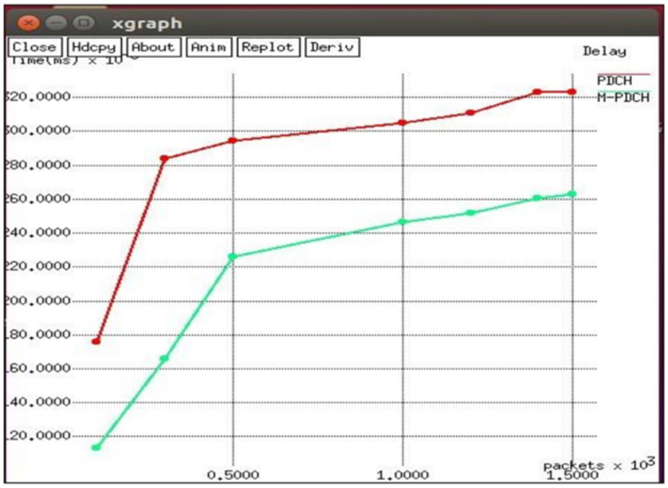

Fig 4. Delay for PDCH and M-PDCH

The findings reveal that, at the highest number of packet transmissions, PDCH encounters a processing delay of 0.322 ms, whereas M-PDCH demonstrates a reduced delay of 0.26 ms. The operational efficiency of M-PDCH is further illustrating its superior speed and lower delay in handling packet transmissions when compared to PDCH. The mobility aspect in M-PDCH likely introduces more dynamic and efficient packet handling, leading to reduced processing times. This could be advantageous in scenarios where timely communication and data processing are critical.

3.3 Energy Consumption (EC)

The advancement of WSN has paved the way for the deployment of compact sensor nodes, catering to critical military monitoring and medical applications. One of the significant challenges lies in the reliance on battery-powered sensor nodes, given the impracticality of frequent battery changes or recharging. Considering this inherent constraint, a thorough examination of the EC parameter becomes imperative.

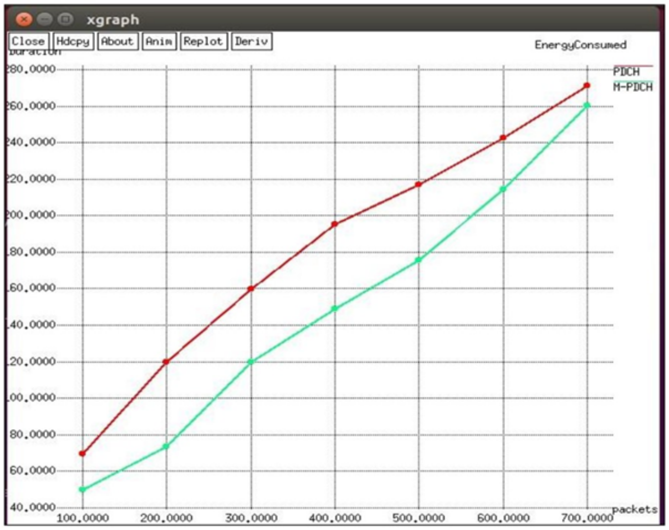

Fig 5. Energy Consumption (EC) for PDCH and M-PDCH

In evaluating EC, the study compares conventional PDCH and M-PDCH protocols concerning the energy consumed during the maximum number of packet transmissions, revealing notable differences. Specifically, the EC for PDCH is measured at 500K packets is 216.99 J, while M-PDCH exhibits a lower energy consumption of 175.37 J. To provide a comprehensive view, a graphical representation of EC concerning varying packet numbers is presented in Figure 5. The graph accentuates the superior performance of the proposed M-PDCH protocol in comparison to the conventional PDCH protocol. The discernible trend suggests that as the number of packets increases, M-PDCH consistently outperforms PDCH in energy efficiency.

In essence, these findings underscore the significance of energy conservation in sensor networks, where the longevity of battery-powered nodes is crucial. The observed improvements in energy consumption with M-PDCH emphasize its potential as a more energy-efficient protocol compared to PDCH, making it a promising choice for enhancing the sustainability and operational effectiveness of wireless sensor networks.

Table 2. Comprehensive analysis and performance enhancement

Protocols Vs QoS Parameters	Delay	Energy Consumption	Packet Drop
PDCH	0.29458	216.997	121
M-PDCH (proposed)	0.22599	175.373	85
Performance enhancement in percentage for 500×10^3 Packets	**23.28%**	**19.18%**	**29.75%**

Table 2 presents a detailed analysis and contrast between the PDCH and the proposed protocol, highlighting significant performance improvements. The results indicate that the proposed method is innovative, offering energy savings and enhanced packet transfer by mitigating packet drop, distinguishing itself from other key protocols like (9-15).

4 Conclusion

In the obtained simulation results, it is evident that M-PDCH showcases a prominent improvement over PDCH in several key performance metrics. Firstly, the data for 500×10^3 packets indicates that M-PDCH experiences a remarkable 29.75% reduction in packet drops when compared to PDCH. This decline in packet drops implies a more robust and reliable data transmission process, contributing to enhanced data integrity within the network. Furthermore, the delay performance plot of M-PDCH illustrates a significant advantage, being 23.28% faster than PDCH. This improved speed in data transmission is crucial for applications that demand low latency, ensuring a more responsive and efficient communication network.

Additionally, the simulation results highlight another noteworthy aspect: M-PDCH consumes 19.18% less energy compared to PDCH. The reduced energy consumption is a crucial factor in the context of wireless sensor networks, where energy efficiency directly impacts the network's overall sustainability and operational lifetime. The findings underscore the potential of M-PDCH to contribute to EC within the network infrastructure.

Collectively, these results establish a compelling case for the superiority of M-PDCH over PDCH, particularly in terms of EC, reduced packet drops, and improved data transmission speed. The implementation of M-PDCH holds promise for enhancing the overall lifetime and efficiency of wireless sensor networks, making it a noteworthy protocol for consideration in network design and implementation.

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