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Performance and QoS Assessment in WSN: Comparative Analysis of MBC, ECHERP, and PDCH Routing Methods

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Abstract: - Objective: The objective of this research is to assess the performance and Quality of Service (QoS) provided by PDCH when compared with ECHERP and MBC routing protocols(RPs) within Wireless Sensor Networks (WSNs). Methods: Utilizing the NS2 Simulator, this paper provides an in-depth exploration of three hierarchical RPs viz. Equalized Cluster Head Election RP (ECHERP), Mobility Based Clustering (MBC), and PDCH (PEGASIS with Double Cluster head). A thorough examination of each protocol's performance is conducted, focusing on a range of QoS metrics such as Energy Consumption, Packet Drop Ratio, Throughput, and Delay. Findings: A comparative assessment is conducted between PDCH, ECHERP, and MBC, extracting QoS parameters. The examination and findings reveal that PDCH exhibits superior performance over ECHERP by 26.15%, 20%, 15.71%, and 37.73%. Similarly, PDCH outperforms MBC by 23.19%, 14.29%, 4.87%, and 15.13% across the mentioned parameters. Novelty: In this simulation, the NS2 software is utilized, with a specific emphasis on the suggested parameters. These metrics are crucial for evaluating the overall performance of different RPs in Wireless Sensor Networks (WSNs).

Keywords: WSN, ECHERP, HRP, Mobility, Cluster, Double, QoS

1. Introduction

In a WSN, nodes operate on battery power, which is inherently limited in its capacity to provide energy over a finite duration. Additionally, these nodes possess constrained processing capabilities and limited storage capacity [1]. Typically, WSN nodes are installed in locations where human interference is impractical or where battery replacement is unfeasible. Consequently, maximizing the lifespan of the installed batteries and prolonging the utilization of resources are paramount objectives in WSN design.

To address these imperatives, many RPs have been devised for WSNs, aimed at extending the network's operational longevity [2]. As shown in Figure.1These RPs are categorized into various types based on the network's architecture and the tasks it needs to perform. In this research we are focus into Hierarchical RPs according to their structural attributes and operational functionalities.

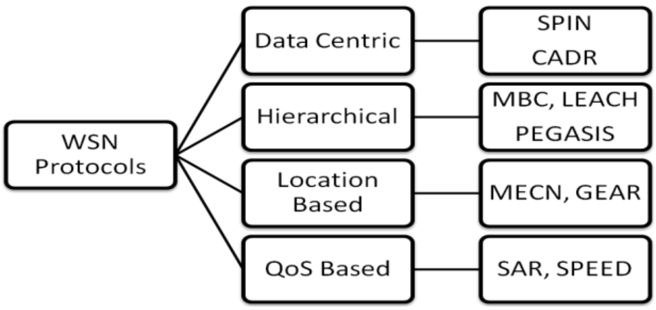

Figure 1: Categories of WSN RPs [3]

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Among the routing protocols listed above, in a hierarchical RP, sensors are initially organized into distinct groups known as clusters. Within each cluster, a sole node is chosen as the leader, known as the Cluster Head (CH), due to its superior energy reserves, whereas the rest of the nodes are labeled as sensing nodes (SN) or member nodes. These SNs within each cluster collect environmental data and relay it to the CH. Subsequently, the CH consolidates the data and forwards it to the Sink node, alternatively referred to as the Base Station(BS), directly or via intermediary CHs.

RPs for WSNs presents unique challenges compared to fixed sensor networks. With no established infrastructure, unreliable wireless links, potential sensor node failures, and stringent energy-saving requirements, RPs must be tailored to address these specific constraints [2]. Figure 2 illustrates different types of Homogeneous Hierarchical RPs (HHRP).

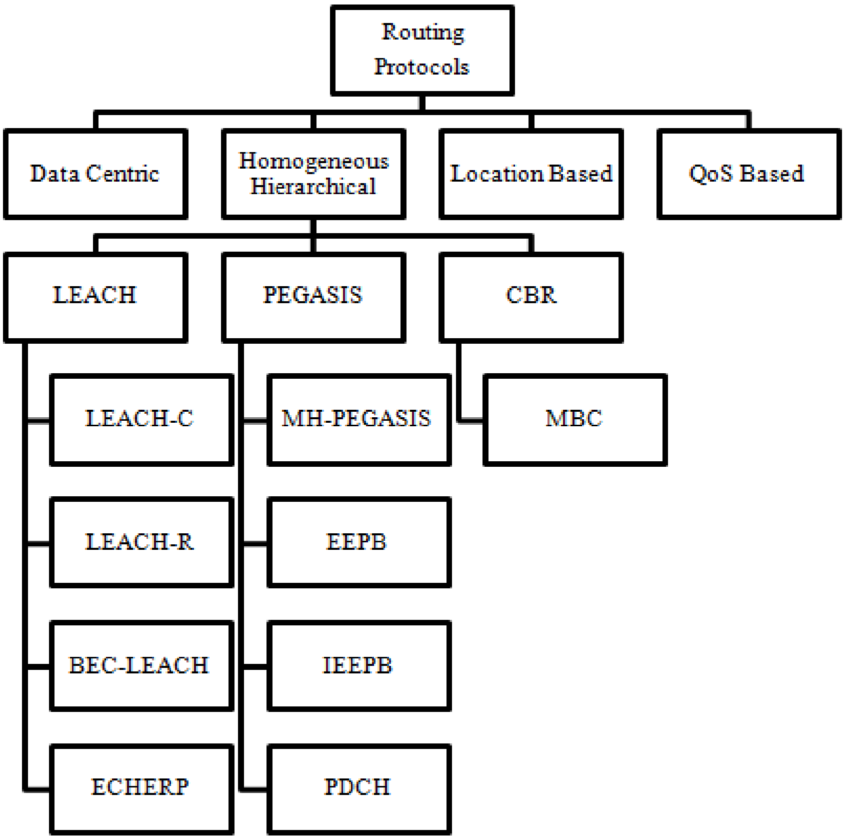


Figure 2. Various HHRPs

In WSNs, network formation can occur either deterministically or non-deterministically. Over the years, a primary focus in WSNs has been on developing protocols that prioritize energy efficiency. In addition to energy efficiency, considerations such as network lifetime, effective data collection, data transfer rate, mobility, and scalability have emerged as significant factors in ensuring the reliability of protocols. This paper explores specific RPs, MDC, ECHERP and PDCH, focusing on QoS parameters. ECHERP is based on the LEACH protocol, while PDCH utilizes the PEGASIS method. Each protocol employs distinct techniques for CH selection.

The WSNs [4] comprise numerous distributed and specialized sensors designed to monitor various environmental parameters such as pressure, temperature, pollution, humidity, and sound levels. These nodes operate with limited communication capacity and computational resources. Maximizing transmission distance, enhancing route efficiency, balancing load distribution, ensuring network longevity, and minimizing energy consumption have become central focal points within the domain of RPs for WSNs. RPs in WSNs are commonly classified into various groups, which include Hierarchical RPs (HRPs) [4], QoS-based RPs, Location-based RPs, and Flat-based RPs. HRPs are especially valued for their outstanding energy efficiency. This hierarchical routing strategy effectively reduces energy consumption within individual clusters through data aggregation and fusion, thereby decreasing the number of messages transmitted to the BS.

1.1 PEGASIS with double CH (PDCH):

The distribution of workload across nodes is essential for enhancing network durability. Unlike the conventional PEGASIS protocol, which relies on a single CH communicating with the BS, the proposed approach employs two CHs in a hierarchical structure within a single chain. This configuration minimizes the need for lengthy chaining, thus enhancing efficiency.

The PDCH protocol outperforms PEGASIS by sidestepping the need for dynamic cluster formation, reducing inter-node distances, minimizing message exchanges between nodes, and consolidating data transmission to the BS into a single round. By distributing energy load evenly among nodes, both network lifetime and quality are bolstered.

In PDCH, the primary CH manages data collection from cluster nodes and their aggregation. Subsequently, this aggregated data is relayed to the secondary CH via chain transmission. The secondary CH then compiles the information received from the primary CH and forwards it to the BS. For a visual representation, refer to Figure 3 illustrating the operational workflow of the PDCH protocol.

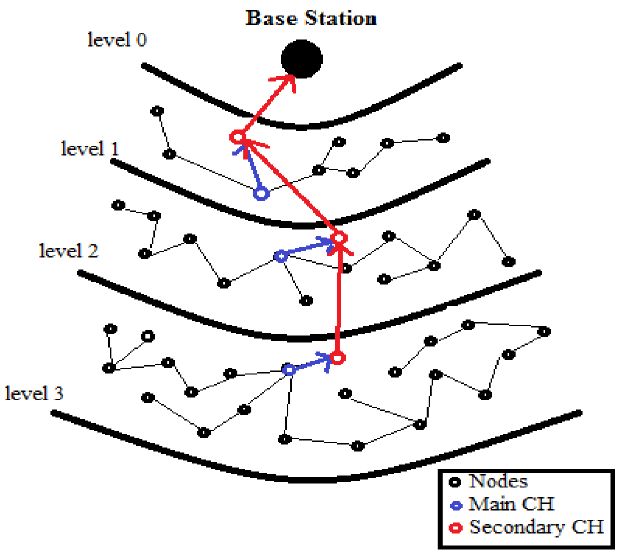


Figure 3 PDCH Layer Diagram [6]

1.1.1 Algorithm: Double Cluster [9,10]

Step 1: The network initialization process begins with the 'rand' command, which involves positioning the BS at the specified location.

Step 2: Using the Euclidean distance formula, calculate the distances between the BS and all other nodes within the network.

- *di* denotes the distance of the i-th node from the BS
- (*xbs*, *ybs*) indicate the coordinates of the BSB,
- (*xi*,*yi*) represent the coordinates of the i-th node.
- Next, arrange the nodes into levels according to their proximity to the BS, assigning a distinct identifier to each level. Nodes located within 100 meters form the first cluster (level id=1), those falling between 100 to 150 meters comprise the second cluster (level id=2), nodes between 150 to 200 meters constitute the third cluster (level id=3), and those within 200 to 250 meters form the fourth cluster (level id=4).

Step 3: Once clusters are formed, designate a CH for each cluster. The selection of the CH is based on the residual energy of the nodes. Initially, in cases where all nodes have equal energy, a random node is chosen as the CH during the initial transmission round. The CH is determined as the node with the highest residual energy.

Step 4: With the CH selected, establish a chain utilizing nodes within the cluster. Nodes sharing the same level identifier are eligible to participate in the formation of the chain.

Step 5: Following the establishment of chains within each cluster, initiate data transmission within the cluster utilizing the first-order radio model.

Step 6: Subsequently, transmit the data stored in the cluster nodes to the designated CH. These CHs, referred to as primary heads, consolidate into a distinct cluster. From this cluster, the primary head nearest to the BS is designated as the secondary CH. Establish another chain among these nodes to relay data to the secondary head, which then forwards the data to the BS.

This concludes a single round of transmission. Continue with Steps 3 to 6 for multiple rounds, monitoring for dead nodes after each iteration. Nodes with residual energy equal to or less than zero are eliminated from their respective clusters. Record the count of dead nodes in each round, storing the values in an array. Additionally, calculate the sum of residual energies of all active nodes in each round, saving these values in another array. Generate a plot illustrating the number of active nodes and the residual energy of the network for each round.

1.2 The Equalized CH Election RP (ECHERP)

The framework is established on the fundamental principles of the LEACH protocol, an acronym for "Low Energy Adaptive Clustering Hierarchy." LEACH is widely recognized and employed in wireless sensor networks to facilitate effective data transmission while conserving energy resources.

A. Operation of LEACH Protocol:

The LEACH protocol, employs a randomized method for cluster formation. Within each cluster, a single node is chosen using a threshold mechanism to act as the CH. This CH is liable for gathering data from the SNs within its cluster and then transmitting the aggregated data to the BS through intermediary nodes. The energy distribution strategy of the LEACH protocol aims to evenly distribute the energy workload among all deployed nodes across the sensing field. Its operation consists of 2 phases: the setup and data transmission phase.

B. Network Setup of Equalized CH Election RP:

During the setup of the ECHERP network, a predefined "N" nodes placed arbitrarily within the given network zone, assuming all nodes remain stationary. Each sensor node is initialized with an equal amount of energy "X" and possesses uniform communication and processing capabilities. The nodes operate without prior knowledge of their specific locations within the network.

C. Explanation of Equalized CH Election RP:

This follows a similar cluster formation process to its predecessor, LEACH, by selecting a CH within each cluster for data aggregation from SNs. However, it diverges in its approach is data transmission to BS. ECHERP employs multi-hop communication from the CH to the BS, alleviating the energy-intensive task of the CH covering long distances to relay data to the BS. Additionally, the protocol integrates a “Gaussian Elimination Algorithm(GAA)” for CH election and determines the frequency of CH designation. This approach effectively reduces energy consumption within the network.

1.3 Mobility-Based Clustering (MBC) [12]

In MBC nodes in a Mobile WSN are equipped with the ability to move beyond their initial cluster boundaries, potentially entering the coverage area of another cluster. In such scenarios, once a node seeks to join a new cluster, it initiates a request accordingly. MBC operates with a blend of static and mobile sensor nodes, which actively collect data within their vicinity and relay it towards the BS.

Within the Mobile WSN framework known as MBC, the designation of CHs is determined by considering both the remaining energy and mobility aspects. Non-CH nodes are tasked with transferring data to the CH before depleting their transmission power. This necessitates adherence to a Time Division Multiple Access (TDMA) schedule for efficient data transmission.

2. Methodology [13]

2.1 PEGASIS with Double CH Execution

Following are the steps involved in Execution of PEGASIS with Double CH protocol involves the following phases:

A. Cluster Creation: Nodes are initially distributed randomly to establish a network, with a fixed BS deployed at a designated location. Using the Euclidean distance formula, the span between nodes and BS is projected. Based on these distances, organization of nodes into distinct layers, with communication occurring only within the same layer. Nodes within each layer establish connections with neighboring nodes, forming chains.

B. Selection of CH: Within each layer, two nodes are chosen to serve as Main CH (MCH) and Secondary CH (SCH). The MCH is carefully chosen from the main chain based on long lasting energy, while node connected to the branch of the chosen MCH becomes the SCH.

C. Phase of Data Transmission: In PDCH, the MCH collects data from other nodes in the same chain and advanced to the SCH. The SCH then gathers information from the MCH and transmits it to the BS. By distributing the task of CH among two CHs, PDCH enhances energy efficiency, balances node loads, and prolongs network lifetime.

2.2 Equalized CH Election RP Execution

Following steps are involving in execution of the ECHERP:

A. Network Organization: The network parameters are initially defined. A Network Coverage Area of 1000m × 1000m is used, with 100 SNs randomly deployed. A fixed BS is positioned at a distance from the field. Each SN is assigned equal energy and processing capabilities and conducts sensing operations within the environment at regular intervals. While the protocol supports immobile nodes, it also accommodates node movability. All sensors share the same physical characteristics at network formation.

B. Arrangement Stage: During this Stage, each node advertises a “Hello” message to neighbouring nodes, conveying its location and power. Simultaneously, each node maintains an information table containing power & places of adjacent nodes. This table is updated with own node information and forwarded to the next neighbour until information regarding all nodes reaches the BS. The BS utilizes the GAA to select CHs and determine the duration. Following the selection of CH, the BS disseminates the unique IDs of the chosen nodes and their corresponding cluster members, thereby facilitating the formation of clusters.

C. Data Transmission Stage: Upon the establishment of clusters and the selection of CHs through voting, nodes commence sensing operations and send the collected data to their respective CHs. These CHs then consolidate the received data from the sensor nodes to reduce transmission overhead. Subordinate CHs forward the aggregated data to higher-level CHs, progressing until it reaches the BS. This process ensures efficient and organized data transmission across the network.

2.3 MBC Protocol Algorithm [14,15]

Among the hierarchical RPs renowned for clustering, MBC stands out as an extended technique derived from the CBR protocol. The protocol unfolds through the following implementation phases:

A. Network Organization: The network spans a 1000m × 1000m area with densely deployed scenarios featuring 100 nodes. All sensors in the network exhibit homogeneity in their physical characteristics, energy capacity, and transmission range upon initial deployment. Every SN equipped with knowledge of its own location and velocity, while the BS remains stationary. Furthermore, all sensors within the network maintain synchronization in time.

B. Arrangement Stage [16]: In this stage, the process of selecting CHs takes place. The selection criteria involve identifying the node with the highest power and the one with the lowest relative mobility, both of which are designated as CHs. Each SN evaluates available information and chooses the most suitable CH to join. Once selected, a sensor node sends a registration message to inform the chosen CH of its intention to join. Upon receiving the registration message, the CH establishes a TDMA schedule, assigning a specific timeslot for the node's transmission.

After the CH selection, the CH broadcasts an advertisement message containing its location to neighboring SNs. Non-CH SNs, upon receiving these advertisements, make decisions about joining the cluster based on the information.

C. Steady Stage: All nodes transition into the Steady Stage concurrently, maintaining synchronization in time. Non-CH nodes utilize their assigned timeslots for transmitting data to the CH. Upon receiving a data packet, the CH sends an acknowledgment (ACK) message to the non-CH sensor node, confirming the successful transmission. Additionally, upon receipt of a cluster join request message, the CH sends a CH message to formalize the joining process.

3. Results and Discussion

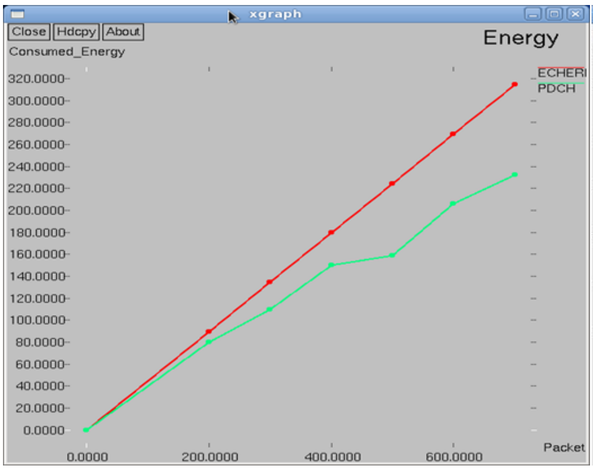
I this research, three protocols within the network simulator tool NS-2 have been simulated. Subsequently, thorough performance evaluations of the RPs PDCH & ECHERP, as well as PDCH & MBC conducted. The aim was to ascertain which protocol stands out as a superior energy-efficient solution. The comparison of the protocols primarily focused on evaluating QoS parameters as mentioned and others. Table 1 illustrates the basic parameters employed for implementing and comparing all the mentioned protocols.

Table 1. Basic Network Setup

Network Parameters	**Parameter Value**
N/w Coverage Area	1000 × 1000 m2
Number of Sensor Nodes	100
Sensing Range of Each Node	250 meter
Data Transmission Rate	512 kbps
Initial Energy Level of Nodes	100 J
Transmission Power Configuration	0.9 J
Receiving Power	0.8 J
Sensing Power	0.0175 J

The simulation is conducted in NS2 Software, with a focus on analyzing mentioned QoS parameters. These metrics serve as crucial indicators for evaluating the end-to-end performance of various routing algorithms.

1. **Energy Consumption:** In a SN, the power usage depends on the average rate of power consumption of a node multiplied by the duration of operation. Figure 4 depicts the energy consumption of both the ECHERP and PDCH protocols during the transmission of a specified number of packets. For the maximum number of packets transferred across 100 nodes, PDCH consumes 26.15% less energy than ECHERP. Similarly, as shown in Figure 5, PDCH consumes 23.19% less power compared to MBC.



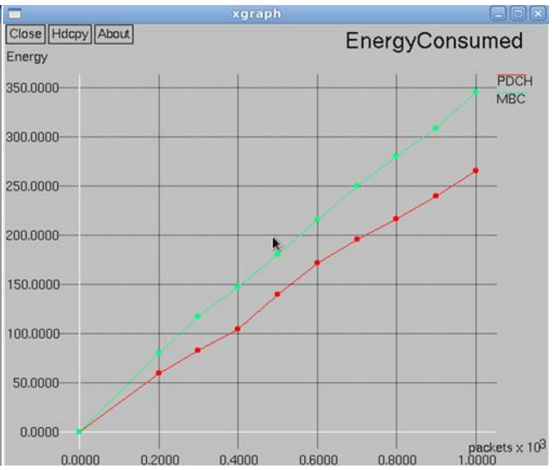


Figure. 4 Energy Consumption: PDCH & ECHERPFig. Figure 5 Energy Consumption: PDCH & MBC

2. Packet Drop Ratio: When considering the maximum number of packets transferred, Figure 6 illustrates the packet drop ratio observed in the PEGASIS Double CH and Equalized CH Election RPs, PEGASIS Double CH exhibits a 20% reduction in packet drop compared to Equalized CH Election RPs. In Figure 7 The comparison between PEGASIS Double CH and Mobile Base Cluster Protocols reveals that PDCH achieves a 14.29% improvement in packet loss reduction over MBC.

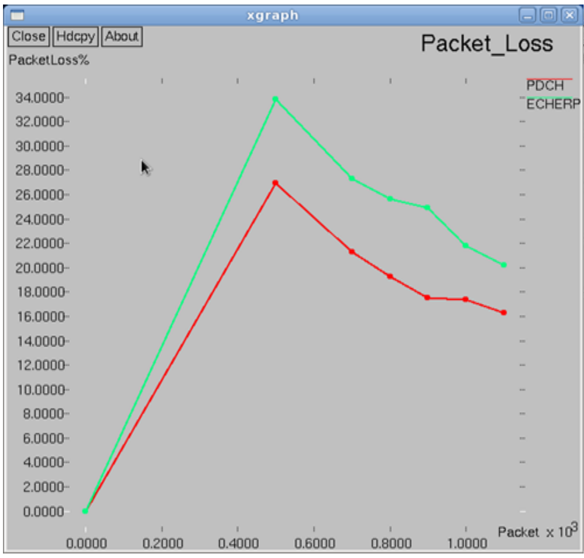


Figure 6 Packet Drop Ratio: PDCH & ECHERP

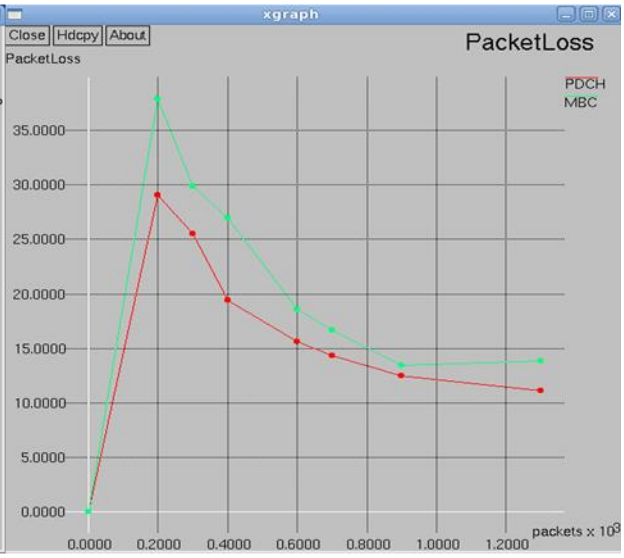


Figure 7 Packet Drop Ratio: PDCH & MBC

3. **Throughput:** The time it takes by the receiver to receive the last message is called as throughput. Figure 8 depicts the throughput comparison between the PEGASIS Double CH and Equalized CH Election RPs. PDCH demonstrates a 15.71% higher throughput than ECHERP. Additionally, as shown in Figure 9 PDCH exhibits a 4.87% improvement in throughput compared to MBC.

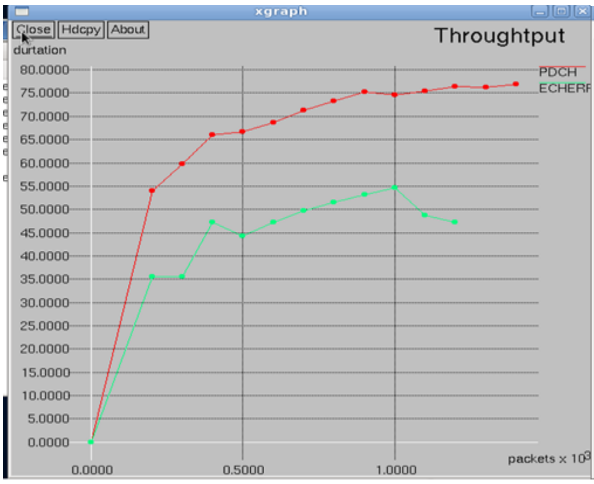


Figure 8. Throughput: PDCH & ECHERP

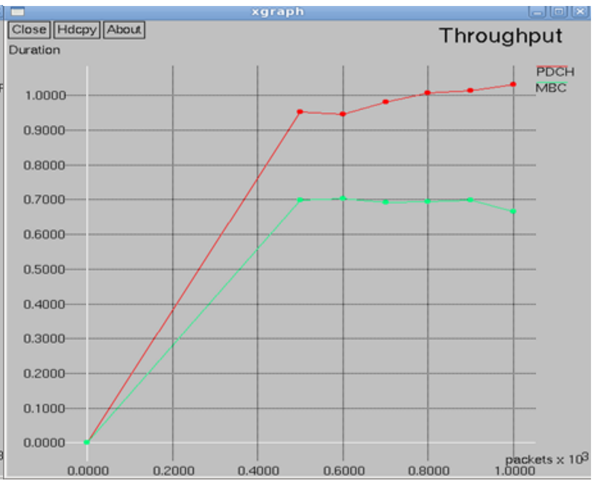
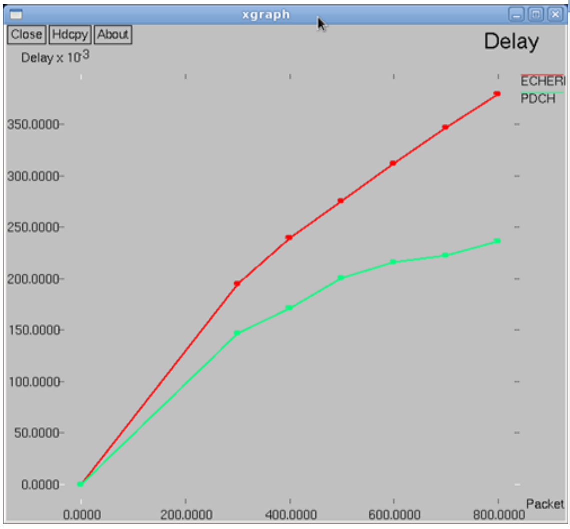


Figure 9. Throughput: PDCH & MBC

4. **Delay:** This includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue. This metric is calculated by subtracting time at which first packet was transmitted by source from time at which first data packet arrived to destination. Figure 10 illustrates the delay, measured in time taken, by both ECHERP and PDCH protocols for transmitting a specified number of packets. For the transmission of the maximum number of packets across 100 nodes, the PDCH protocol exhibits a 37.73% reduction in delay compared to ECHERP. Additionally, in Figure 11, the delay comparison reveals that PDCH surpasses MBC with a 15.13% decrease in delay.



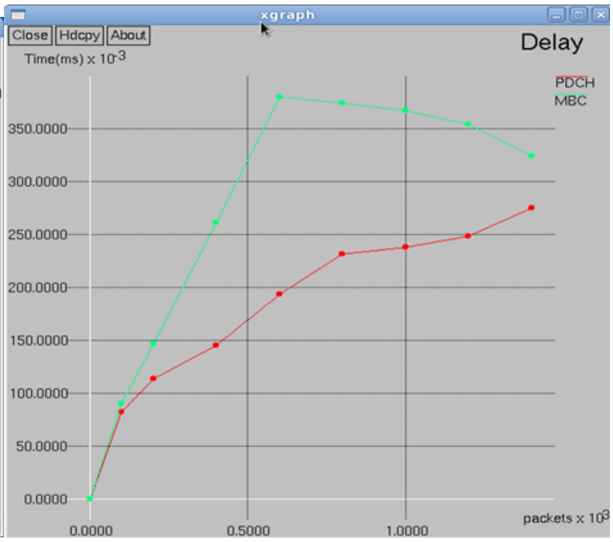


Figure 7 Delay: PDCH & ECHERP **Figure 8 Delay: PDCH & MBC**

4. Conclusion

This study delves into hierarchical RPs, specifically focusing on the PEGASIS double chain-based protocol as a solution surpassing the ECHERP Protocol. ECHERP employs a clustering approach, utilizing a GEA for CH selection. The comparison between PDCH & ECHERP, as well as PDCH and MBC hierarchical RPs, is conducted herein. Each clustering protocol boasts unique characteristics: PDCH adopts a double CH selection method, while Mobility Based Clustering employs TDMA scheduling. PDCH determines its CH based on proximity to the BS, whereas MBC selects the CH based on residual energy and mobility. Non-CHs in MBC are tasked with transmitting data before their transmission power depletes, necessitating adherence to the TDMA schedule for data transmission. Simulations are carried out using NS2 Software, evaluating QoS parameters including Energy consumption, Packet drop ratio, Throughput & Delay. The simulation results indicate PEGASIS Double CHs superiority over Equalized CH Election RP by 26.15%,20%,15.71% & 37.73% respectively Results also shows that PDCH Outperforms MBC by 23.19%,14.29%,4.87% & 15.13% respectively across aforementioned parameters.

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