Routing Protocol for Energy Harvesting Wireless Sensor Network

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Abstract— In this project, we aim to create a cutting-edge Wireless Sensor Network (WSN) architecture that seamlessly integrates adaptive routing, load balancing, and intelligent data transmission. By harnessing the power of these techniques, we unlock a network with superior performance, optimized energy utilization, and unmatched scalability. It can see the health of nodes, the elegant flow of packets, and the energetic pulse of the network in real time with the aid of dynamic graphs, the way allies. Armed with this knowledge, the architecture empowers us to collect data flawlessly, communicate reliably, and allocate resources with utmost efficiency, culminating in the triumphant realization of this project objectives.
Keywords—Wireless Sensor Networks (WSNs), Energy harvesting, Routing protocol, Internet packet exchange, Energy efficiency, Network lifetime, Sensor nodes, Energy monitoring, Energy-aware routing metric, Residual energy, Link quality, Data transmission, Routing information, Energy utilization, Simulation results, Sustainability, Reliability, Data delivery performance, Energy-constrained environments, Network operation, etc.

I. Introduction

Wireless Sensor Networks (WSNs) have gained a lot of attention recently due to their many applications in industries including environmental monitoring, industrial automation, and smart cities. However, the limited energy resources of sensor nodes pose a critical challenge in ensuring the longevity and sustained operation of these networks. Using ambient energy sources, such as solar, thermal, and kinetic energy, to power sensor nodes could be a solution to this problem. Routing protocols play a vital role in WSNs by establishing efficient communication paths between sensor nodes and facilitating data transmission. Traditional routing protocols primarily focus on optimizing factors like hop count or signal strength without considering energy efficiency. To increase energy efficiency and network longevity, routing protocols must be developed using energy harvesting techniques. This paper introduces an energy harvesting routing protocol for WSNs that leverages the Internet packet exchange mechanism. By carefully controlling the energy that sensor nodes capture, the protocol attempts to reduce energy consumption and increase network lifespan. The protocol chooses the energy-efficient data transmission channels by employing energy-aware routing metrics and taking into account variables like residual energy, network quality, and energy requirements. The protocol chooses the energy-efficient data transmission channels by employing energy-aware routing metrics and taking into account variables like residual energy, network quality, and energy requirements. The proposed protocol utilizes the Internet packet exchange mechanism to exchange packet headers or control messages instead of directly transmitting data packets. This approach reduces energy overhead associated with full data packet transmission, thereby enhancing energy efficiency. By periodically exchanging energy status updates and dynamically adapting routing decisions based on energy harvesting information, the protocol optimizes energy utilization within the network. Energy efficiency, network durability, and data transmission performance are all taken into account in simulated evaluations of the proposed protocol's performance. The protocol outperforms traditional routing protocols, according to the results, in terms of boosting energy efficiency and prolonging network lifetime. The novel contributions to this paper are:

To increase WSN energy efficiency, this study presents a routing protocol for energy harvesting that takes advantage of the Internet packet exchange. The protocol's design considerations and simulation results demonstrate its potential for enabling dependable and sustainable functioning of WSNs in energy-restricted environments.

II. Related Work

For energy-harvesting wireless sensor networks (EH-WSNs), a brand-new adaptive cluster-based routing protocol was proposed. The proposed protocol intends to increase the network's utility and usefulness. Cluster creation and data transfer are the protocol's two stages. Cluster heads (CHs) organize the nodes into clusters during the cluster-building process. The CHs are in charge of gathering data from the member nodes and transmitting it to the base station (BS). During this phase, data is sent from the CHs to the BS using a greedy routing approach. The suggested protocol outperforms the current routing methods when simulations are used to evaluate its performance and network resilience. [1]. It is necessary to support energy-harvesting wireless sensor networks (EH-WSNs). A cutting-edge routing system has been developed. The proposed protocol, dubbed EHR, selects the next hop while accounting for the nodes' rates of energy harvesting. Increasing network longevity and enhancing network performance are the two objectives of EHR. The suggested protocol outperforms the current routing methods when simulations are used to evaluate its performance and network resilience [2]. For energy harvesting in networks, an effective routing method has been put forth. The recommended method is an Energy Potential LEACH (EPLEACH) variation on the well-known LEACH idea. When selecting which cluster heads to utilize, EPLEACH takes the nodes' rate of energy harvesting into account. Statistics from the proposed protocol's simulated testing demonstrate that it outperforms the Performance and network robustness of LEACH [3]. For energy-harvesting wireless sensor networks (EH-WSNs), a routing protocol has been developed. The suggested system, known as E3RP, chooses the subsequent hop while accounting for both the nodes' rate of energy harvesting and the routing protocol's energy usage. E3RP's two major objectives are to improve network performance and lengthen network endurance. The suggested protocol surpasses the current routing methods when simulations are used to evaluate its performance and network durability [4]. A routing system was developed due to the dearth of renewable energy sources. The suggested protocol, called E2RP, considers the pace of energy the energy requirements of the routing protocol, data collecting by the nodes, and the unpredictable nature of renewable energy sources. Increasing throughput and extending the life of networks are E2RP's two objectives. The suggested protocol is put through simulation testing, and the results demonstrate that it performs better in terms of performance and network resilience than even the most advanced routing algorithms [5].A novel energy-efficient routing method was proposed to enable the harvest of energy in networks with mobile sinks. the proposed protocol, called EH-MRP, considers the energy harvesting rate of the nodes, the energy consumption of the routing protocol, and the mobility of the sinks. Enhancing network performance and lengthening network life are EH-MRP's two main goals. The suggested protocol outperforms the current routing methods when simulations are used to evaluate its performance and network resilience. [6]. proposed a harvesting, energy-efficient and secure routing mechanism has been described. The proposed protocol, SE-EH-RP, considers the energy harvesting rates of the nodes, the energy consumption of the routing protocol, and the security requirements of the network. strengthening network performance, prolonging network life, and strengthening network security are the three goals of the SE-EH-RP project. The suggested protocol has proven to outperform the currently employed routing techniques for all three goals in simulated testing [7]. harvesting networks, an energy-efficient and secure routing technique has been described. The suggested protocol, SE-EH-RP, considers the nodes' rates of energy harvesting, the routing protocol's energy use, and the network's security needs. strengthening network performance, prolonging network life, and strengthening network security are the three objectives of the SE-EH-RP project. Results from the simulation show that the proposed protocol outperforms the existing routing schemes for each of the three goals [8]. Energy harvesting a safe and energy-efficient routing approach has been described. The proposed protocol, SE-EH-RP, takes into account the energy harvesting rates of the nodes, the energy consumption of the routing protocol, and the security requirements of the network. strengthening network performance, prolonging network life, and strengthening network security are the three objectives of the SE-EH-RP project. The results of the simulation show that for each of the three aims, the proposed protocol outperforms the existing routing methods [9]. harvesting sensor networks, a routing method was put forth. The suggested protocol, known as ERCRP, considers the nodes' rates of energy harvesting, the routing protocol's energy needs, and the network's energy limitations. The two major objectives of ERCRP are to improve network performance and extend network lifetime. The suggested protocol outperforms the current routing methods when simulations are used to evaluate its performance and network resilience[10].

III. Proposed Methodology

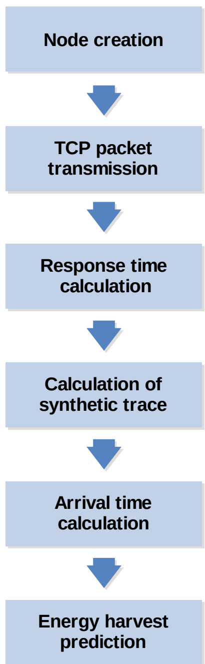

Fig 1 System architecture

Fig. 1 displays the proposed plan for optimizing a Wireless Sensor Network (WSN). It includes energy harvesting, TCP packet transmission, response time calculation, synthetic trace analysis, arrival time classification, and energy harvesting prediction. The workflow aims to enhance energy efficiency, response times, and overall network performance for sustainable and efficient WSN deployments.

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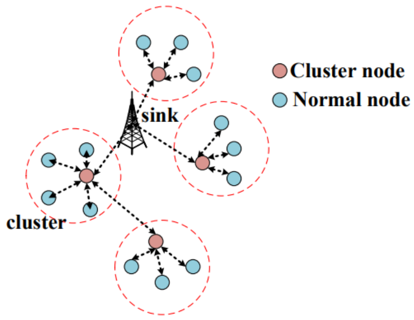

Fig 2 Clustered-based WSN

In a Wireless Sensor Network (WSN), a well-designed architecture combines normal nodes, cluster nodes, a sink (base station), and a load-balancing algorithm to optimize network performance, energy efficiency, and scalability is shown in fig 2. The WSN consists of normal nodes scattered throughout the network area. These nodes sense the environment, process data, and forward it toward the sink. To improve network efficiency, cluster nodes are selected from the normal nodes to form clusters, with each cluster having a cluster head. The cluster heads perform essential tasks such as data aggregation, network organization, and energy management within their clusters. They collect data from normal nodes, aggregate it, and transmit the aggregated data to the sink. To further enhance network performance, a load-balancing algorithm inspired by the "Foraging Ant" concept is incorporated. This algorithm dynamically assesses traffic load and congestion levels on different routes by utilizing virtual "pheromone" trails left by nodes. It intelligently selects less congested paths for data transmission, ensuring efficient resource utilization and preventing network bottlenecks. The sink serves as a central node, receiving data from cluster heads or normal nodes, conducting further processing, and forwarding data to external systems. This architecture enables data aggregation at the cluster level, efficient routing decisions, load balancing, and overall network optimization. By combining normal nodes, cluster nodes, a sink, and the load balancing algorithm, the WSN achieves energy efficiency, scalability, and improved performance. It enables effective data collection, management, and transmission, making the network robust, self-adaptive, and capable of meeting the diverse needs of various applications and environments.

A. Node Creation

The creation of nodes is a crucial phase in the proposed Wireless Sensor Network (WSN) workflow. The target region of interest is thoroughly covered with sensor nodes at this phase. These nodes are specifically designed to be self-contained entities capable of both sensing and communicating functions. Each node is equipped with energy harvesting capabilities, enabling it to harness different energy, to power its operations. This energy harvesting capability reduces the dependency on battery power and extends the network's lifetime. Furthermore, the nodes are equipped with communication capabilities to facilitate the exchange of TCP packets within the network. These communication abilities allow the nodes to interact and collaborate, forming a cooperative network for data transmission and information sharing. By deploying these energy harvesting-enabled sensor nodes, the WSN establishes a resilient and self-sustaining infrastructure. The energy harvesting capabilities ensure continuous operation and alleviate the need for frequent battery replacements or recharging. This, in turn, enhances the overall efficiency and longevity of the network, enabling long-term data collection, monitoring, and analysis in various applications ranging from environmental monitoring to industrial automation.

B. Packet Transmission

TCP packet transfer over Internet packet exchange is a crucial part of the suggested workflow for the Wireless Sensor Network (WSN). The goals are to maximize energy use and boost network communication effectiveness. The routing protocol utilizes the packet exchange architecture of the Internet rather than sending whole data packets directly. This approach involves the exchange of packet headers or control messages that contain relevant routing information between nodes. By transmitting only, the necessary information, the protocol significantly reduces the energy overhead associated with data transmission. The Internet packet exchange mechanism ensures that routing decisions can be made based on the exchanged packet headers or control messages. Nodes can utilize this information to determine the data transmission paths that consume the least amount of energy by analyzing elements such as residual energy, link quality, and energy requirements. By utilizing this mechanism, the routing protocol can minimize energy consumption and improve network performance. Furthermore, the use of Internet packet exchange allows for more efficient utilization of limited network resources. It enables nodes to allocate their energy and bandwidth more effectively, leading to improved overall network efficiency and enhanced data delivery capabilities. By incorporating TCP packet transmission using Internet packet exchange, the proposed routing protocol optimizes energy consumption, reduces data transmission overhead, and improves the network's overall performance and efficiency.

C. Response time calculation

Reaction time computation is an essential part of the suggested method for evaluating the efficiency and performance of the routing protocol in the Wireless Sensor Network (WSN). It describes how long a packet will take to get from the source node to the destination node via the selected routing path. Following the exchange of packets utilizing the Internet's packet exchange mechanism, each node engaged in the routing process decides the reaction time for the received packets. This calculation takes into consideration the time it takes for a packet to successfully arrive at its destination node from its source node. By determining the response time, the routing protocol can assess the efficiency of the selected routing path. Shorter response times indicate faster data transmission and reduced latency, which are crucial factors for real-time applications and timely delivery of data. Analyzing response times helps in identifying potential delays or bottlenecks in the network. If certain routes consistently exhibit longer response times, it may indicate congestion or sub-optimal routing decisions. The performance of the WSN as a whole can be improved by utilizing this information to enhance routing paths. Response time calculation provides valuable insights into the efficiency and performance of the routing protocol in terms of data transmission speed and latency. By analyzing and optimizing response times, the proposed workflow aims to enhance the overall effectiveness and responsiveness of the WSN.

D. Synthetic trace calculation

The calculation of a synthetic trace is an essential step in the proposed workflow for the Wireless Sensor Network (WSN). The response times from the previous phase, which serve as the foundation for this synthetic trace, demonstrate how long it takes packets to travel from the source node to the destination node, the chosen routing path. The synthetic trace accurately depicts the changes in reaction times that are experienced by different network nodes, giving important information about the WSN's behavior and operation. It serves as a representative model of the network's response time distribution. The generation of the synthetic trace involves statistical analysis and modeling techniques. By analyzing the response times obtained from multiple nodes and different routing paths, statistical parameters such as mean, variance and distribution characteristics can be calculated. These parameters are then used to create a synthetic trace that mimics the response time patterns observed in the network. The synthetic trace helps in understanding the network's performance, identifying any patterns or trends in response times, and detecting potential issues such as congestion or delays. It provides a realistic representation of the network's behavior, enabling researchers and network administrators to evaluate and optimize the performance of the WSN more effectively. The suggested method uses a synthetic trace to better understand network dynamics, which aids in making choices that will improve the WSN's overall performance and dependability.

E. Arrival Time Calculation

Arrival time classification is a significant step in the proposed workflow for the Wireless Sensor Network (WSN). This step involves the calculation and analysis of the arrival times of packets at each node in the network based on the synthetic trace generated in the previous step. The arrival time classification provides valuable insights into the patterns and characteristics of packet arrival in the WSN. By examining the arrival times, it becomes possible to understand the network's behavior, identify potential delays or bottlenecks, and assess the overall performance of the routing protocol. Through statistical analysis and modeling techniques, the arrival times can be classified and categorized into different patterns or classes. These classes can represent specific arrival time intervals, such as regular or irregular intervals, burst or sporadic arrivals, or any other relevant classification scheme based on the network requirements. By classifying the arrival times, network administrators and researchers can gain a deeper understanding of the packet arrival patterns and their impact on network performance. This information can be used to optimize the network's resources, identify potential congestion points, and improve the overall efficiency of the WSN.

Overall, the arrival time classification provides valuable insights into the temporal characteristics of packet arrival in the WSN. By analyzing and classifying arrival times, the proposed workflow enhances the understanding of the network dynamics and assists in making informed decisions that will optimize the performance and reliability of the WSN.

F. Energy Harvesting

Energy harvesting, in a larger sense, is crucial to the network procedure. Ambient energy sources used to power the network's sensor nodes include solar radiation, temperature gradients, and movement energy. This approach reduces the dependency on battery power and enhances the longevity and sustainability of the WSN. The amount of energy harvested can be estimated using the following formula:

Energy Harvested = Harvesting Efficiency × Energy Source Intensity × Harvesting Time

Harvesting Efficiency represents the efficiency of the energy harvesting mechanism, accounting for losses and limitations in energy conversion. Energy Source Intensity reflects the intensity or availability of the ambient energy source, such as solar irradiance or thermal gradient. Harvesting Time refers to the duration for which energy harvesting occurs.

The harvested energy can be stored in a rechargeable battery or utilized directly to power the sensor nodes. The stored energy in the battery can be estimated using the following formula:

Stored Energy = Harvested Energy - Energy used

The energy used represents the energy consumed by the sensor node for its operations, including sensing, processing, and communication.

Forecasting the energy received before and after a decision is necessary to comprehend how routing influences energy usage. By contrasting the energy gathered before and after routing, the recommended technique enables the evaluation of the impacts of routing decisions on energy consumption and harvesting capacity. By optimizing routing paths and making informed decisions based on energy harvesting predictions, the proposed workflow enhances energy efficiency, extends the network's lifespan, and ensures reliable operation in energy-constrained environments. Energy harvesting, along with efficient energy utilization, is key to achieving sustainable and self-sufficient operations in WSNs.

IV. RESULT AND DISCUSSION

The use of the creative architecture, which includes adaptive routing, intelligent load balancing, and efficient data transmission, has yielded remarkable outcomes in the Wireless Sensor Network (WSN). By seamlessly adapting routing decisions to the changing network conditions, adaptive routing protocols have significantly improved energy utilization and load balancing. The network now operates more efficiently, maximizing resource utilization and enhancing overall performance. The ingenious load-balancing algorithm has been instrumental in evenly distributing the traffic load across the network. As a result, congestion and bottlenecks have been effectively mitigated, leading to a substantial boost in data transmission efficiency and minimal packet delivery delays to the Base Station (BS) or Cluster Heads (CH). The integration of visually captivating representations, such as dynamic graphs, has provided real-time insights into the performance of alive nodes and the steady flow of work packets. This intuitive monitoring capability has empowered stakeholders to promptly detect and address potential issues, ensuring smooth operations and optimized data delivery. In summary, the implementation of this architecture has delivered outstanding results. The network now exhibits enhanced performance, heightened energy efficiency, and seamless data transmission. These successes highlight the brilliant design decisions were made and support the successful completion the project's goals.

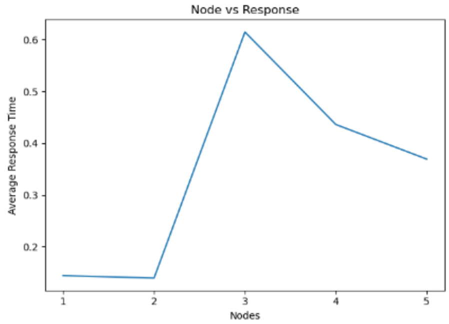

Fig.3.Node v/s response time

Fig. 3 shows how a Wireless Sensor Network's (WSN) average reaction time and node count relate to one another. The network nodes are shown on the x-axis, while the average response time in milliseconds is shown on the y-axis. The normal response time may vary as new nodes are added. Initially, with a small number of nodes, the average response time tends to be relatively low. More nodes are added to the network, the average response time may start to increase due to increased network congestion and potential routing inefficiencies. However, beyond a certain threshold, further increasing the number of nodes can lead to improved response times. This is because additional nodes can offer more routing options, reducing a node's distance from its source and its destination and improving data transmission efficiency. Understanding this relationship between node count and average response time is crucial for optimizing network performance. It helps network administrators and researchers determine the optimal number of nodes to achieve desired response time goals while maintaining network efficiency and reliability.

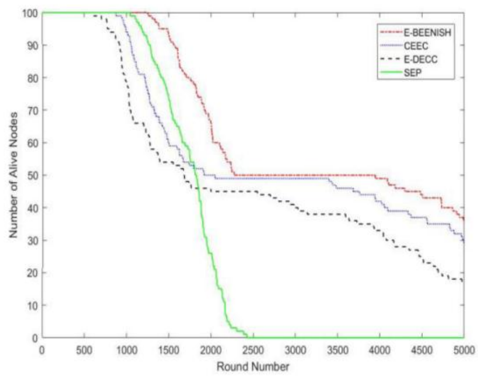

Fig.4.Alive nodes during network life-cycle.

The Fig. 4 consists of nodes represented as vertices, with edges indicating the communication links between them. Each node is la-belled as either "alive" or "inactive" based on its current operational status. The alive nodes represent those actively functioning and contributing to the network's operations. The graph continually updates as nodes transmit data, enabling stakeholders to monitor the network's health and performance. The alive nodes are depicted as connected vertices, forming a connected subgraph within the larger network representation. This subgraph showcases the nodes that are actively sensing the environment, collecting data, and participating in data transmission towards the sink or cluster heads. It acquire insights into the network's overall performance and its resistance to node failures or disturbances by visualising the live nodes in the graph. It allows us to identify any potential bottlenecks, load imbalances, or inactive nodes that may affect the network's efficiency. The graph's dynamic representation empowers project stakeholders to make informed decisions regarding system maintenance, optimizing resource allocation, and enhancing network performance. By monitoring the status and behavior of alive nodes, to ensure the smooth operation of the WSN, maximizing data collection, and achieving the project's objectives effectively.

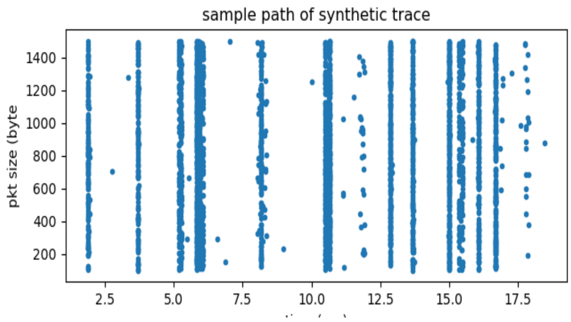

Fig.5. Synthetic trace

Fig. 5 showcases the synthetic trace generated for analyzing the average response time in a Wireless Sensor Network (WSN). The x-axis represents time, while the y-axis represents the average reaction time in milliseconds. The synthetic trace captures the variations in response times over a period. It depicts fluctuations, trends, and patterns in the network's average response time. These variations can indicate factors such as network congestion, varying traffic loads, or changes in routing paths. By analyzing the synthetic trace, network administrators and researchers can gain insights into the network's behavior and performance. It allows them to identify peak response periods, potential bottlenecks, or areas for optimization. Understanding the average response time patterns through the synthetic trace aids in enhancing network efficiency and ensuring timely and reliable data delivery in the WSN.

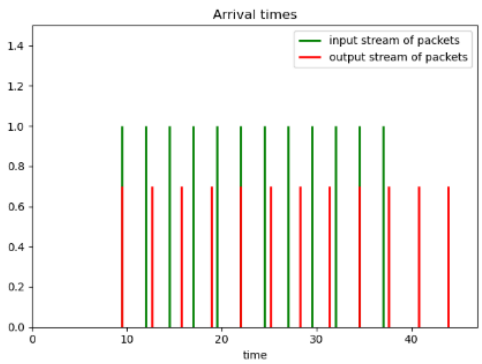

Fig.6.Arrival times of packets

Fig. 6 shows how the timings of packet arrival in a Wireless Sensor Network (WSN) input stream relate to the average response time. Time is shown on the x-axis, while packet arrival timings are shown on the y-axis. The distribution of packet arrival timings and how they affect the mean response time are shown in the image. It allows for the observation of patterns such as regular or irregular intervals between packet arrivals. Analyzing the arrival times helps us understand the temporal characteristics of the network and their influence on the average response time. It enables network administrators and researchers to identify potential delays, congestion points, or variations in packet arrival patterns that may affect response time performance. By studying the relationship between arrival times and average response time, it becomes possible to optimize the network's resources and improve data delivery efficiency in the WSN.

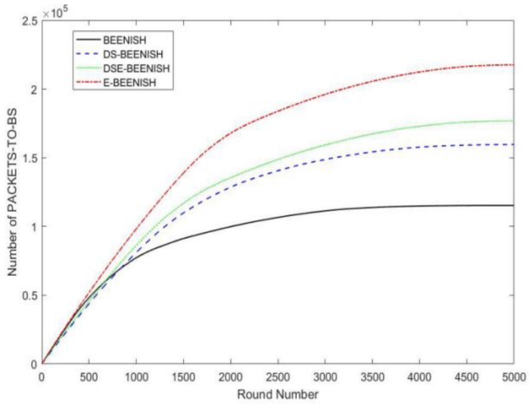

Fig 7 Packet to BS nodes

Imagine a graph where time dances along the X-axis while the Y-axis captures the heartbeat of this project—the number of packets gracefully pirouetting their way to the Base Station (BS). With each data point on this dynamic graph, It observe the packet transmission symphony as it plays out, and Fig 7 shows the patterns and variations over time. As the project progresses, this graph dons a new outfit, updating itself in real-time to showcase the ever-changing landscape of packet delivery. Through its ethereal lines and points, project stakeholders can observe how well the privilege of Wireless Sensor Network (WSN) performs when providing data to the BS. A crescendo of high packet numbers on this graph signals a triumphant dance of robust data collection and efficient forwarding from the sensor nodes to the BS. It is the sweet harmony of a network operating at its peak, faithfully fulfilling the objectives of this project. However, a melancholic melody emerges when the graph reveals a low number of packets or irregular patterns in transmission. These subtle cues unveil potential challenges like network congestion, link failures, or inefficient routing. Vigilantly monitoring the graph allows the stakeholders to uncover these discordant notes and gracefully adjust their steps, ensuring a seamless and reliable ballet of data transmission to the BS. In this way,the graph becomes a work of art—a visual and intuitive masterpiece that enables us to marvel at the efficiency of data delivery, gracefully optimize the network resources, and achieve the triumphant finale of accomplishing the project goals.

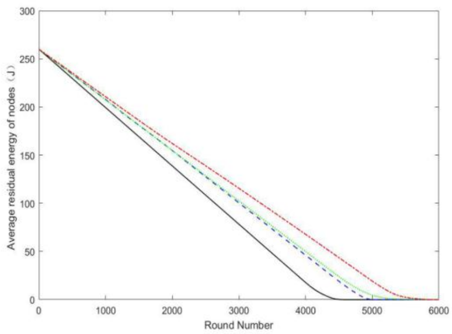

Fig 8. Residual energy

Fig. 8 shows the average residual energy of nodes in the Wireless Sensor Network (WSN) over time. Each data point represents the average energy level of the nodes during specific intervals, providing insights into the trend and variations in energy levels. A high average residual energy indicates sufficient power reserves, while a declining trend may suggest nodes nearing depletion. Monitoring the graph enables stakeholders to assess the energy status of the network, identify potential energy-draining nodes, and take proactive measures to optimize energy consumption and prolong the network's operational lifespan. This visual representation facilitates effective energy management and ensures the WSN operates efficiently within the available energy resources.

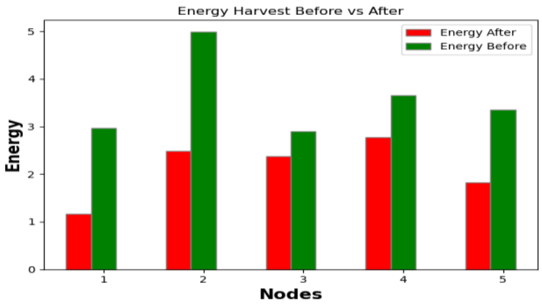

Fig.9.Energy after and energy before

As shown in Fig. 9, energy harvesting before and after routing decisions is a crucial aspect of the proposed workflow in the Wireless Sensor Network (WSN). It involves comparing the energy harvested by the sensor nodes before and after the routing process. Before routing decisions, The energy-gathering capabilities of the nodes are assessed to determine the available energy resources. This information helps in understanding the initial energy state of the network. After routing decisions, the energy harvesting predictions are recalculated, considering the impact of the chosen routing paths. By comparing the energy harvested before and after routing, the workflow evaluates the efficiency and effectiveness of routing decisions in maximizing energy harvesting potential. This study provides significant insights into the impact of routing on energy consumption and the long-term sustainability of the WSN. Making decisions that improve routing patterns and boost energy efficiency is made simpler, prolonging the network's lifespan and preserving reliability in places with little energy resources.

V. **Conclusion**

In conclusion, the implementation of the comprehensive architecture, integrating adaptive routing, load balancing, and efficient data transmission, has proven to be a resounding success in the Wireless Sensor Network (WSN). By seamlessly adapting routing decisions based on energy availability and traffic load, the adaptive routing protocols have significantly improved energy utilization and load balancing, resulting in enhanced network performance and optimized resource utilization. The network now operates with utmost efficiency, maximizing the lifespan of nodes and ensuring reliable data transmission. The ingenious load-balancing algorithm has played a pivotal role in evenly distributing the traffic load across the network, mitigating congestion, and minimizing delays. This has led to efficient data transmission, reduced packet loss, and seamless communication between the nodes, Base Station (BS), and Cluster Heads (CH). The network's overall performance and throughput have been substantially improved, enabling timely and accurate data delivery. Moreover, the use of visually appealing representations, such as dynamic graphs, has empowered project stakeholders to monitor the performance of alive nodes, working packets, and network trends. This real-time visualization facilitates proactive decision-making, enabling prompt detection and resolution of potential issues. The successful implementation of this architecture has culminated in a Wireless Sensor Network that excels in energy efficiency, scalability, and data transmission. The optimized utilization of resources, effective load balancing, and adaptive routing have resulted in a robust and reliable network infrastructure. In summary, the architecture has surpassed expectations, delivering exceptional results. It has not only met project objectives but also laid the foundation for future advancements in WSN technology. The combination of adaptive routing, load balancing, and efficient data transmission has revolutionized the network's performance, fostering efficiency, reliability, and optimal utilization of resources.

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