Energy Efficient Scheduling Algorithm to Increase the Life Time of Battery Power in Wireless Sensor Networks For Structural Health Building Monitoring Applications

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Abstract: Because of its ability to reduce the costs associated with the installation and maintenance of SHM systems, structural health monitoring using wireless sensor networks has piqued researchers' interest. These systems are used to monitor critical infrastructure like high-rise buildings, bridges, and stadiums, and they have the potential to extend the life of structures and improve public safety. WSNs for SHMs face unique network design challenges due to their high data collection rate. This paper provides a comprehensive overview of SHM using WSNs, including a description of the algorithms used in physical harm detection and localization, network design issues, and future systematic investigation directions. Time synchronization, sensor placement, data processing, and quantifiability are all discussed and compared as network design issues. For improving the lifespan of a wireless sensor network, the proposed framework includes four stages: node investigation and deployment, clustering nodes, shortest path construction, and data transmission. This paper proposes a novel framework that consists of four stages: optimal node deployment, clustering of nodes, shortest route construction, and data transmission. It's built into the NS2 software, and the results are double-checked. Finally, the proposed framework's performance is assessed by comparing its results to those of other approaches and demonstrating its efficiency.

Keywords: Structural health monitoring, sensor types, network data flow methods, network scalability, and energy harvesting are some of the key words

1. Introduction

Wireless sensor networks have emerged as a powerful and cost-effective platform for connecting large networks of sensors in the last decade. Sensors distributed throughout a structure are used to analyse the health of the structure in these networks, which have many applications in the health, military, business, and industrial fields. [1] to [2]. Traditionally, SHM systems have been built with wired sensor networks, but the lower installation and maintenance costs, as well as the high reliability of WSNs, have made them a compelling alternative platform. [4]-[7]. Significant reductions in the cost of exploitation WSNs for SHM would change their effective use in critical public and private infrastructure and expand applications such as short-term health monitoring. Sensors for SHM are deployed at multiple locations in WSNs via a structure. At 100 hertz sampling frequencies, these sensors collect data on acceleration, surrounding vibration, load, and stress. As a result, the sensing and sampling rates, as well as the quantity of data collected, are higher in WSNs than in other applications, and as a result, WSNs for New challenges are introduced by SHM. Designing a network presents a number of challenges. Sensing element nodes send detected data to the sink either directly or by forwarding each other's packet information collectively. This process is critical for the detection and localization of structural damage and can occur in a variety of places, including nodes, cluster heads, and central servers, depending on the situation. Structure’s topology Damage detection usually necessitates a comparison of the structure's current modal options with those associated with the structure's undamaged state. The mode shapes and natural vibration pattern for a given structure are the primary representations of a structure's modal options.

SHM has been used in vital structures such as aircraft, ships, high-rise buildings, dams, and bridges. Essentially, these installations are weird, but they have a growing range of WSNs. A research team from the University of California, Berkeley, placed one of the first SHM on the Sound Bridge in 2007.

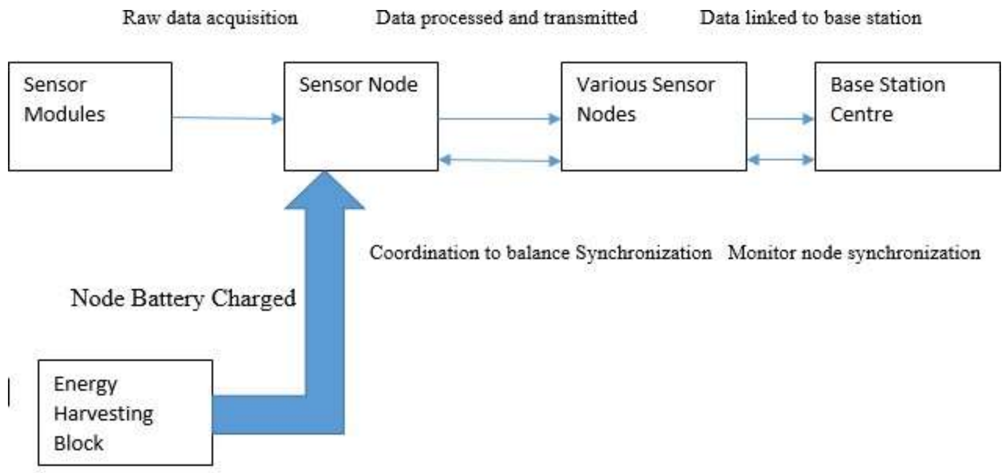


Figure a. Block diagram of SHM using WSN's

1.1 CHALLENGES IN WSN FOR SHM

In comparison to traditional WSNs, those designed for SHM nodes face a number of unique challenges. For example, WSNs for SHM nodes collect, process, and transmit large amounts of data, sensor node densities are frequently high, and the number of hops from node to base station is frequently large. According to the reviewed literature, real-world deployments of SHM systems have had sensor sampling rates ranging from 0.1 to 0.1.Although the top characteristics are comparatively distinctive, when compared to most WSN's, those used for SHM have similar reliability and quality of service requirements. Data transmission is expected to be reliable and lost packets should be recovered through Retransmission. Packet loss rates are often high in monitored structures as transmission could need Transmission of wireless signals through materials such as steel and concrete. Sensor nodes installed on structures, bridges, and wind turbines should be able to withstand severe weather conditions such as rain and snow. When compared to traditional WSNs, SHM WSNs have similar quality of service requirements. Mentioned on the top of the network, time synchronization errors should be decreased.

Table 1. Comparison of wired and wireless sensor networks

Parameter	Wired Sensor Networks	Wireless Sensor Networks
Data Rate	High sensor data rate	Low sensor data rate
Life Span	Long, depends on hardware lifespan	Short, depends on node battery lifespan
Number of Sensors	Typically, less due to difficulty in sensor installation	Typically, high due to ease of sensor installation
Connection Bandwidth	High bandwidth due to wired connection	Unreliable connection and limited bandwidth
InstallationTime	Very long time consuming, real time examples take several days	Short, real time examples take nearly half an hour.
Cost	Very High	Low
Sensor synchronization	Very high due to wired connections	Minimized due to wireless connection

Downsides and difficulties of utilizing wired SHM frameworks:

1. Huge cost of wiring and instrumentation.
2. Difficulties in conveying and keeping up the wiring plant.
3. Difficulties in the execution of huge measures of information.
4. Monitoring the structural building environment is done by wired frameworks.

Favorable circumstances of utilizing remote SHM frameworks:

1. Low expense and simple establishment and organization,

2. Higher unwavering quality than wired framework,
3. More adaptability for different kind of structures,
4. On-board computational facility.

Purpose of adapting the Structural building Monitoring framework:

1. Damages are the primary cause of structural failure and may happen at various portions of a structure.
2. Damage location at the beginning phase can upgrade the lifetime of the structure, which keeps it from abrupt breakdown and sudden collapse.
3. Application and arrangement of SHM frameworks can be helpful for building proprietors and governments.
4. Wireless Sensor Networks (WSN) can enable a low-effort, low-cost, reliable, and automated SHM framework.

Fundamental elements of Structural building checking:

1. Monitor and evaluate load conditions.
2. Examine the current plan.
3. Verify new systematic strategies and computer simulations
4. Assess basic structural performance and identify damage to the building components
5. Facilitate assessment and building support work
6. Help authorities to make quick and right decisions in emergency cases.

The different types of sensors and their role in maintaining a normal environment within an industrial building using actuators are given below.

2. Sensor Types:

The use of specific sensors is required for the sensing and acquisition of the critical parameters. The following is a list of commonly used sensors in SHM systems:

2.1Accelerometers: The piezoelectric and spring-mass accelerometers used in SHM are both piezoelectric. Electricity accelerometers are small, light, and operate over a wide range of acceleration and frequency. Spring mass accelerometers, on the other hand, are relatively large and operate over a limited range of accelerations and frequencies. They are, however, much more sensitive to small accelerations than electricity accelerometers and have a higher resolution. A mass is coupled to a supporting base in the electricity measuring system. The mass of the supporting base exerts an inertia force on the crystal component when it moves. The crystal component is subjected to a proportional electrical phenomenon as a result of the applied force. Accelerometers will have sampling rates that are higher than 100Hz.

2.2 Strain Sensors: The piezo resistive and embedment strain gauge sensors used in SHM are classified as piezo resistive and embedment strain gauge sensors, respectively. Strain sensors made of cement are typically piezo resistive and capable of measuring strain. Signals with a low frequency of less than 1Hz are generated by these sensors. Strain gauges embedded in concrete structures are used to measure strains. These gauges are made up of a 100mm long extended foil gauge embedded in a polymer concrete block. These are sensitive to changes in the environment, such as weather, and must be protected with enclosures.

2.3 Optical Fiber Sensors: Fiber Bragg Grating sensors [6], [7] are the most common type of optical fiber sensor. By changing a fiber so that the number to be measured modulates the intensity, phase, polarization, wavelength, or transmit time of natural light in the fiber, these sensors can be used to measure parameters such as strain, temperature, pressure, and other parameters. Using fiber Bragg gratings, fiber-optic sensors are being developed to measure strain and temperature at the same time with high accuracy.

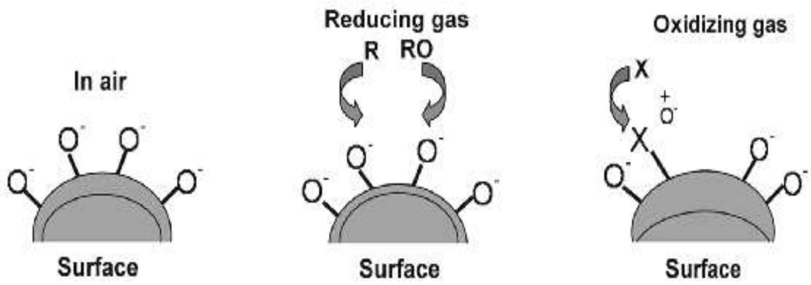
Due to their low cost and ease of use, piezoelectric accelerometers are the most commonly used of the sensor types listed above. As a result, techniques for detecting and localising maximum damage have been developed for these sensors.

2.4 Solid State Gas Sensors for Air Pollution

Gas sensors for detecting air pollutants must be able to function reliably in adverse conditions, such as chemical and/or thermal attack. As a result, in terms of sensible robustness, strong-state fuel sensors appear to be the best option. Sensors for air pollution detection are typically made by coating a sensing (metal oxide) layer and a substrate with two electrodes. Tin oxide (SnO2), zinc oxide (ZnO), titanium oxide (TiO2), and tungsten tri oxide (WO3) are common materials, with typical operating temperatures ranging from 200 to 400oC.

The absorption of atmospheric oxygen causes the depletion area on the surface of the steel oxide sensor. When a reducing fuel (CO, H2) is absorbed by the metal oxide sensor, the depletion area at the surface decreases, indicating increased conductivity. If a steel oxide sensor absorbs an oxidising fuel (NO2), however, the depletion zone at the surface improves, indicating reduced conductivity. As a result, a conductivity/resistance exchange is linked to fuel attention. The conductivity of a ZnO sensor decreases as the sensor absorbs NOx, indicating that the resistance will increase.

Figure2 represents how metal oxide semiconductor detects the pollutant gases.



2.5 Carbon Sensors

CNT spatial detecting skins: A consistent conductive skin (layer in structure) was framed inside the metal rods using CNT (for example, a glass-fiber composite) joined to small solid pillars.

Advantages of Carbon Sensors:

- A direct method for estimating the appropriated strain fields.
- High Sensitivity and Accuracy to recognize the presence, area and seriousness of structural breaks.
- Higher level of scaling.
- The information isolation node aggregates this sensory information and sends it to the sink node. The sink node conveys this information to a remote monitoring system via the cloud and receives necessary control information from the cloud and activates necessary devices in buildings.

Fig 3 Carbon Sensor

```
IF (Vibration detected)
{
        Send INFO to Information Isolation Node (IIN)
        Trigger on Alarm via cloud computing device
}
```

Natural disasters are also taken into account, allowing for a more efficient recovery process and alert. Consider the following building infrastructure. A remote sensor network is proposed for observing structures to evaluate natural disasters like earth , earthquakes and tsunamis. The sensor hubs utilize exceptionally created capacitive micro electro-mechanical frameworks. They record during a seismic tremor function utilizing a blend of the local speeding up information and far off setting off from the base station dependent on the quickening information from numerous sensors over the structure.

Structures can sustain dynamic mass harm during their operational lifetime as a result of seismic functions, unexpected establishment settlement, material maturing, plan errors, and so on. Intermittent observing of the structure for such harm is along these lines, a key advance in normally arranging the support expected to ensure a satisfactory degree of security and administration capacity. In any case, all together for the financial establishment of a perpetually introduced detecting framework in structures.

2.6 Sensor Module Architecture

The square graph of the SHM modules sensor is shown in fig 5. Here the stress and the Acceleration detecting variations of the module utilize a similar center part. For establishment into the structure these segments are put into a norm off-the-rack plastic packaging that can be advantageously placed on the divider or roof utilizing screws, and offering access for irregular battery substitution if necessary.

Fig 4 Strain sensor front-end module on polyimide carrier

2.7 Strain Sensing Front-End Module

The strain sensor is combined with the readout ASIC to create an exceptional front-end strain detecting module (Fig. 6) that is installed inside the fortified cement onto the strengthening bar, ideally prior to the solid pouring. The sensor is mounted on a polyimide transporter, which is then stuck to the strengthening bar, as shown in Fig. 6. There is a variation of this bundle in which the transporter is made of mild steel, which allows for more welding opportunities between the transporter and the fortifying bar. The module is made of PDMS silicone to protect the parts from the elements during installation and cement pouring, while remaining a precise bundle to avoid misshaping the strain sensor estimation. This front-end strain detecting module is connected to the rest of the module via a short 4-wire link with a maximum length of 1.5 m.

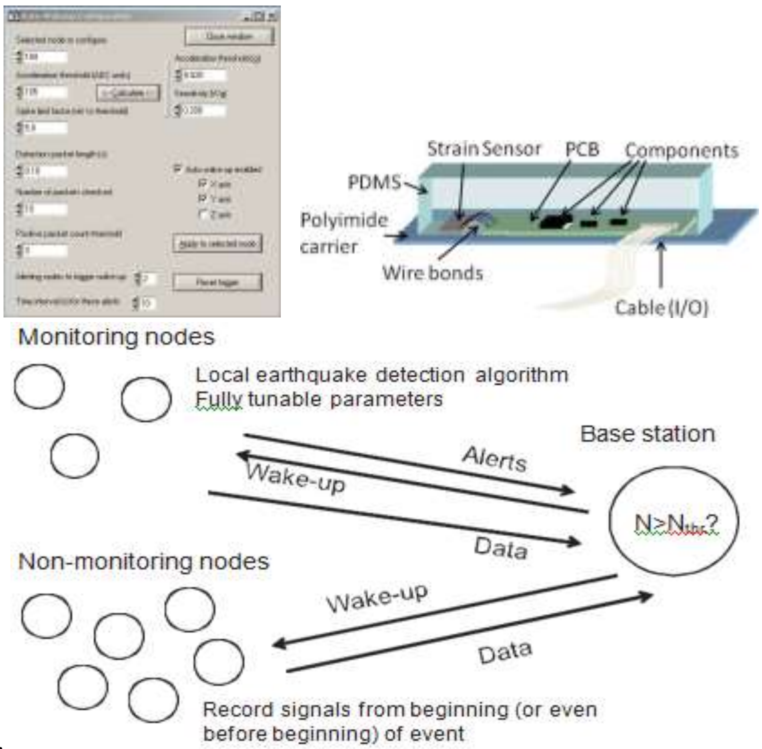


Figure 5 strain sensor Frond end module

3. Energy Harvesting

Because wireless sensor networks have traditionally been powered by batteries, the battery life time has always been the limiting factor in their total life duration. The battery lifetime in WSNs for SHM can be extended up to 6-18 months depending on energy management techniques and the type of battery used, as shown in [4] and [17], whereas the hardware can last many years. As a result, research has focused on increasing battery life by optimising routing, sensor placement, and scheduling. The use of such systems in WSNs has been motivated by cost reductions in energy harvesting.

3.1 Clustering and Distributed Processing

Clustering is a widely used technique in WSN design. Clustering sensors classify nodes into clusters, with each cluster containing a node chosen by the cluster head (CH). Except for the Cluster Head, all nodes in a cluster will only communicate with the Cluster Head. All nodes in the cluster, as well as CHs nearby, will communicate with the CH. Clustering improves scalability, eases routing, extends the life of a network, and saves bandwidth [13]. Wherever the networking processing is performed is an important consideration in WSNs for SHM. Data is transmitted from sensor nodes to a base station (BS) in centralized data processing [14], [15]. The BS analyses the data and, based on the findings, determines the structure's overall health. Data is processed locally, a structure decision is made locally, and the decision is transmitted from the SN to the BS in local processing [16]. This diagram depicts the overall network data flow for centralized, localized, and cluster-based processing.

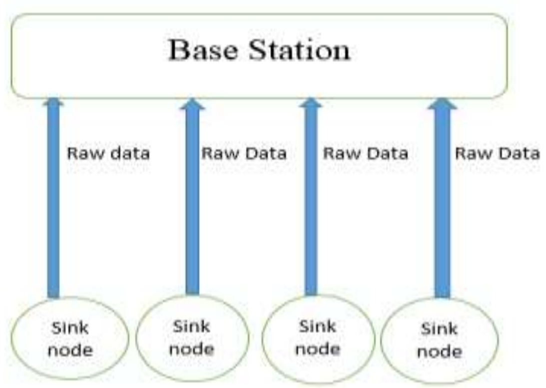


Figure i. Centralized Processing

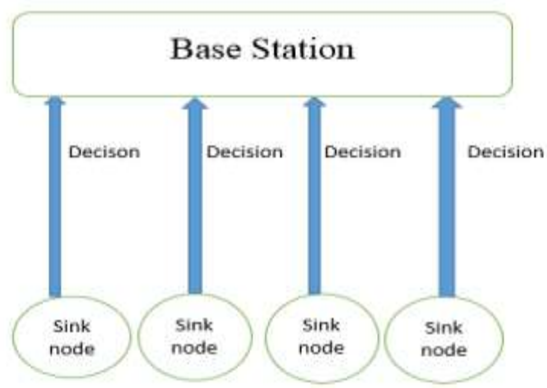


Figure ii. Local Processing

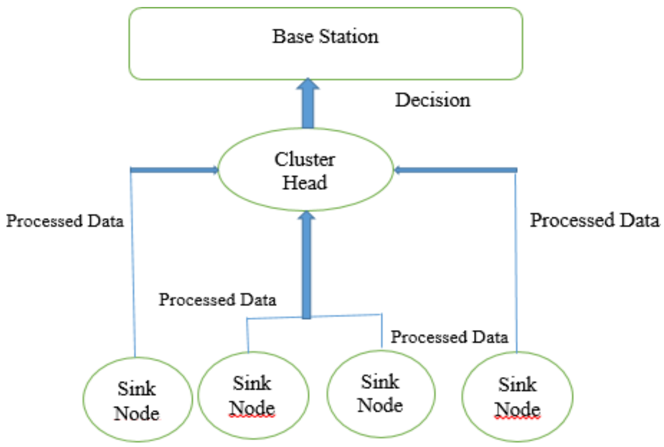


Figure iii. Cluster –Based Processing

Figure 6 cluster based processing

4. 4. Research Problem

The main problems in the constraints are known to be power as well as the deployment of nodes and these are reviewed by the literature survey. All the pre-existing algorithms follow the RFC standard, so it requires exchanging many packets to establish routes. To form the Routing Table, this algorithm floods the request message to each node till the entire routing table gets filled. Because there is no time constraint in forming the routing table, it takes longer to form the table.As the packets are flooded for a long time to form the routing table, it consumes a huge amount of energy.

4.1 Proposed Model

There are four steps that are applied sequentially in the overall WSN application. The steps are, 1. Investigated Node deployment, 2. Clustering and classification, 3. Shortest path route creation, and 4. Data transmission. The below figure-1 shows the overall flow of the proposed framework.

1. Investigated Node Deployment
2. Clustering and Classification
3. Shortest Path Route Creation
4. Data Transmission

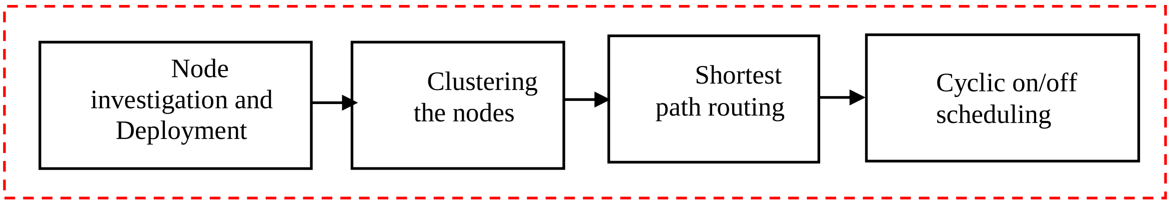


Figure-7. Overall Functional Flow of the Proposed Framework

1. Deployment methods

Recent technological advancements have made it a lot easier to deploy WSN nodes in different application scenarios. Methods of WSN deployment are highly specified for its applications. Deterministic deployment and random deployment are various types of deployment [4]. In deterministic deployment, the environment is known and the sensor nodes are relatively known. In deterministic deployment, the abstract is known and the mathematical model is transformed into a linear problem but not a static optimization problem. The Random deployment method is often an economical model but it doesn't guarantee full coverage of the network. Many redundant nodes need to be applied in order to cover a wide area of coverage. Full coverage is difficult in all environmental conditions [6]. In such cases, increasing sensor nodes is the only option. Many coverage problems occur while using traditional deployment methods. A new algorithm is proposed by Mohammed Abo-Zahhad et al. 2005 [7] for multi objective immune algorithm. This method is used for covering all the network coverage problems and improving its network coverage and energy efficiency. Unlike other deployments, this multi-objective immune algorithm is used to seal all problems.

2. Clustering and Classification:

Using K-hops clustering optimization is used for addressing the problem of energy consumption in Wireless Sensor Networks. In hierarchical networks, the clustering size is an important factor. Depending on the cluster size, small size is usually less computationally effective. For optimization of network, intra-cluster communication is used. But this type of communication consumes more power and less efficiency. For example, if two sensor nodes are placed far away from each other, but one of the nodes is closer to the base station, then the energy consumed by the nearer node to the base station than the node which is located far away. For data relaying, a multi-hop node is used as an intermediate. By doing so, the energy consumed is highly reduced. Computer complexity is considered when designing a cluster based models with the uneven data traffic in each cluster. While the data is being transmitted, the size of the cluster is not accurate, it is randomly deployed. In some cases, the cluster size is almost equal to the total number of nodes present. Energy is consumed more in some cases where the number of clusters is equal to the sensory nodes. The life of a cluster node is comparatively lower than other sensor nodes located nearly in base stations. Uneven computational traffic occurs while using such techniques. The communication delay between clusters from the base station occurs often.

3. Shortest Path Route Creation:

Efficient shortest path algorithm is used to find the shortest path for all nodes while communication. It consists of two types of tables. They are the distance table and the sequence table. The Distance table and sequential table are used to find the shortest distance between two nodes. This protocol generates a table of size N (Number of Nodes) with updates every O (N3) seconds.consumption is reduced by avoiding packet flooding. If the next path of node traversal is shorter than the current node path, then the next path is iterated or updated. This algorithm uses a matrix of length D0 as input. Matrix D0 contains its length, where the edge between nodes I and j are corresponding coordinates.

4. Proposed Shortest Path Routing: Data Transmission:

In data transmission, the shortest path is more important for conserving energy for long range data transmissions. In such case, finding shortest path is more important in problem. This can be done by using matrix types of computational process. If there is no edge between edges I and j and the diagonal of the matrix contains only zeroes, then the position I j) contains positive infinity. This matrix represents the lengths of all node-to-node paths that do not include any intermediate nodes. The energy efficient algorithm of the matrix is recalculated with each iteration process. For iteration one, the matrix D1 is created, and it contains almost all of the pair lengths. This pair uses one predefined intermediate node, while node D2 uses two intermediate nodes and matrix Dn uses n intermediate nodes.

$$D[i][j] = Min\ \{\ D[i][j]\ ,\ (\ D[i][k] + D[k][j]\ )\ \} \qquad (1)$$

In this above equation, the row index is denoted by ‘i’ and column index is denoted by ‘j’. The sequence number is denoted by ‘k’. If the current cost is relatively higher than the K^{th}sequence index, then the D[i][j] is updated. If the cost of sequence number gets updated then the sequence table also gets updated.

The shortest path between two nodes of a graph is already a sequence of connected nodes. This is done, so that the sum of the edges that are inter-connected is minimal. In figure-2, the example scenario of protocol is explained and provided the various shortest paths ale listed,

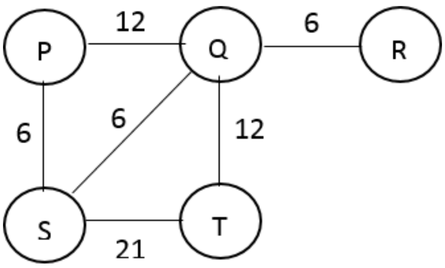


Fig 8. Example scenario of Protocol

Several paths are available P & T, they are,

Path 1 : P Q → T → Cost: 24
Path 2 : P S → T → Cost: 27
Path 3 : P Q → S → T → Cost: 39
Path 4 : P S → Q → T → Cost: 24

Here to find the shortest path between P and T, several iterations are performed, in which traversed through the node P to the node T via B is the best shortest past. According to energy consumption analysis, it is analysed delay of mean, ratio of packet delivery, packets losts, mean jitter, throughput and the energy intake of complete WSN.

Based on the NS2 simulation, the proposed shortest routing protocol provide the less mean delay, loss of packets and mean jitter and also provide the highest ratio of packet delivery.

5. Proposed Shortest Path Routing

5.1 Data transmission

The data transmission is carried out over the shortest route constructed (explained in the above section) the data is transmitted from source node to destination node.

5.2 Experimental Results

The performance of proposed work is compared with the existing protocols like EESRP and HEED are given below based on certain performance metrics such as: energy, ratio of packet delivery and throughput. And explained in the following charts,

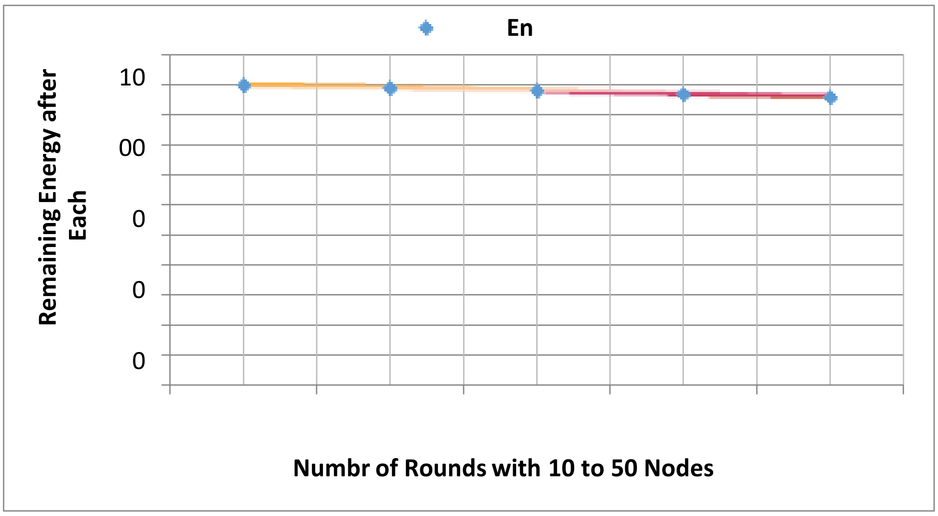


Figure-9: Remaining Energy

6. Conclusion

The proposed paper provides a thorough examination of WSN-based SHM systems. Background information on structural health monitoring, including common sensors, commonly measured factors such as energy harvesting, energy efficiency, network scalability, and WSN challenges for SHM. In addition, the framework includes four stages for improving the lifespan of a wireless sensor network, including node investigation and deployment, clustering nodes, shortest path construction, and data transmission. This paper proposes a novel framework that includes four stages: optimal node deployment, clustering nodes, constructing the shortest route, and data transmission. It is implemented in the NS2 software, and the results are verified. Finally, the proposed work's performance is compared to that of existing protocols such as EESRP and HEED using performance metrics such as energy, packet delivery ratio, and throughput. Here, the proposed work provides the highest throughput and ratio of packet delivery.

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