An Energy-Efficient Routing Mechanism (EERM) for Wireless Sensor and Actor Networks

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An Energy-Efficient Routing Mechanism (EERM) for Wireless Sensor and Actor Networks

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Abstract - Wireless Sensor and actor networks (WSANs) are the most vital research area in the wireless communication field. It consists of sensors, actors, and the base station, where actor nodes work as these networks' spine. The network's main objective is to sense the critical information from the area of interest and then send it to the base station. After that, it can make accurate decisions. This project proposes an Energy-Efficient Routing Mechanism (EERM) technique for the effective routing process. It works in three phases, which are Network initialization, data gathering, and routing. Once the node senses the data and tries to forward it to the base station, it chooses the sensor/ actor nodes from its neighbors having more energy and less distance towards the base station, a final node. As a result, there are significantly fewer chances of data loss due to battery depletion. Moreover, it confirms that there is no data duplication. After successful data transmission, the node will be set as in sleeping mode to save energy. EERM evaluates with other gossiping routing techniques like FELGossiping, ELGossiping, and LGossiping. It notices that there is less data packet loss in it. More nodes are alive in additional iterations due to energy-efficient solutions, which increases the network lifetime.

Keywords: Wireless Sensor Networks, Routing protocol, Wireless Sensor and Actor Networks, Gossip Protocol, Nearest Neighbor, Energy efficient

1 INTRODUCTION

Wireless Sensor and Actor Networks (WSANs) consist of sensors, actors, and a base station where sensor nodes collect the data by sensing operations. These sensor nodes send the data to the actor nodes, which perform specific processing actions on the received data. After that, actor nodes send the data to the basestation[1-2]. Normal sensor nodes have limited resources, like the battery, transmission power, limited communication range, and processing powers. Actor nodes are powerful nodes than ordinary sensor nodes with

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more communication power, battery, and processing powers[3]. In WSANs, connectivity and efficient routing of data are the significant challenges of the time. Delay in data delivery could cause the worst effect on the network and maybe no use if it received late. Alarm in a fire accident, battlefield surveillance, biological attack detection, environmental monitoring, home automation, network robot, agriculture, and animal control[4].

In WSANs, an actor node can communicate with many sensor nodes. This communication can be from the sensor to sensor, sensor to the actor, actor, actor, or actor to sink. This coordination depends upon the network architecture. This coordination can be semi-automated to automated. In semi-automated architecture, the sensor sends the collected information to the base station, and after that, it sends data to the actor nodes. In automated network architecture, the sensor nodes send the collected data to other actor nodes, and these actor nodes process the data. It performs necessary actions and, after that, sends it to the sink[5]. In a network, there can be thousands of sensor nodes, while actor nodes are very few. WSANs are useful in many real-time applications like smart energy grids, cloud computing, medical, industrial, nuclear filed, and battlefield surveillance.

WSANs have many applications that require transmission protocols to send data from the source node to the base station or sink node once it receives an event. A sender node sends a message to its neighboring node in a typical chain-based algorithm, which is selected randomly. This node selects another adjacent node to forward this data and so on. This process continued until this message reaches its destination, which is the sink or base station. In this case, the destination node may receive the same data packet from different sources, which causes data redundancy.

A large number of nodes are involved in the data forwarding process; thus, more energy consumes. It is very critical to reduce the amount of these participatory nodes. This problem can be solved by selecting the small subset of nodes or chose the best node, which sends the data to the next neighboring node. There are different techniques to solve this problem, like in a probabilistic scheme; it randomly selects the neighborhood node and forwards data. In counter-based schemes, nodes are selected based on some hops to the final node. A distance-based technique uses the location information to select the node based on its distance from the neighboring nodes.

Our paper's principal objective is to present a new routing technique name "Energy-Efficient Routing Mechanism (EERM)." The proposed technique sends data to the best-selected node on the set criteria, and this process continues until the source data received to its final distance, which is called the sink or base station. Data redundancy is avoided and the best shortest route selected with the minimum energy consumption. The performance of the EERM is evaluated with other related techniques. The remainder of the paper is organized as follows. Section II discussed all the related work. The motivation and Problem statement explains in section III. In part IV, the proposed technique's methodology is discussed, whereas section V expresses the evaluation of the proposed work. Finally, section VI is the conclusion of the paper.

2 BACKGROUND AND RELATED WORK

In the literature, different routing techniques study because energy plays a leading role in successfully implementing the networks. Some essential methods are as followed:

In HERO (Hierarchical Efficient and Reliable Routing)[6], sensor nodes collect data from the area of interest and transmit it to CH, which can be actor/ sink. In this protocol, sensor nodes link the clusters from their neighborhood. Sensor nodes transfer data to the CH by finding the shortest path and energy consumption. A concept of "clue node" was introduced in the technique in which a CH is responsible for estimating the area where sensor nodes are located. QMR(QoS Multicast Routing)[7] uses the concept of clustering by handling multicast routing. CH selected based on the distance nearest to the actuator node. Initially, every sensor node is responsible for sending data to a single actuator node through its CH. With the passage of time, this transmission of data to multiple CHs as well as actuator node.

In Quang and Kim [8] introduced an algorithm for WSANs, a heuristic path-searching algorithm proposes selecting the intermediate nodes. A multi-level hierarchical structure is applied in it. A channel assignment technique for the sub-clusters presented to decrease the interference between the neighbors of sub-clusters. DECACM(Delay and Energy-Aware Coordination Mechanism) [9] is a two-level hierarchical k-hop clustering technique used to establish the sensor nodes and actor nodes for the proper communication. Sensor nodes form a k-hop cluster using actors as CHs, and after that, the sink is made as the CH to create a cluster among actors.

Hybrid Clustering-based Application-Specific Low Power Routing Protocol (ASLPR)[10] is a LEACH based technique with energy prediction. It considers the distance between sensors and base station, the distance between the CHs in the election process, and the sensor nodes' remaining energy. ASLPR is based on a genetic algorithm to optimize the controllable parameters and simulated annealing used. Real-Time data Report and task Execution (RTRE) is a technique that takes care of delay, reliability, and energy. It is a self-organized sensor to actuator coordination technique developed to support real-time event data collection. It is a real-time scheme to make data collection and useful reaction to the sensed information [11].

Actor-Oriented Directional Anycast Routing Protocol (ADA) is a technique used to support arbitrary traffic. It exploits the directional antennas and actor nodes' capabilities to send the data to the base station. It takes an appropriate decision to send the information. ADA focus on the actor nodes to route the data, and as a result, data traffic on sensor nodes is reduced [12]. Li et al.[13] is presented as an asymmetric routing method used for wireless sensor and actor-networks. Sensing and actuation routes can configure freely. It uses different routing strategies for sensing and actuation. This routing technique works with the source routing for sensing and graph routing for the actor nodes.

A high-throughput disjoint multi-path (HTDM)[14] operates in two different stages. In the first stage, every sensor node obtains the shortest hop to each actor node. Multi-path routing is performed in the second phase of the technique. It can establish multiple disconnected paths quickly. As a result, throughput among the actor nodes and routing paths can adjust by knowing their actor nodes' energy level.

Sensor Protocols for Information via Negotiation (SPIN)[15] is an adaptive protocol that broadcast all the information to every node while considering that all the nodes in the network are BSs. Now a user can get information from any node. SPIN allocates a name to define the collected, which is called meta-data. It starts the negotiation process before the data transmission to avoid redundancy in the network. It has the energy level information of the nodes, which it checks before assigning a task. It sends information to networks, even when the user does not ask for any data.

Energy-Aware Routing [16] is a reactive routing protocol that provides a reliable data transmission with low energy consumption. It checks the nodes' energy level along with the quality of the link before transmitting data to its target node. It creates a routing table that includes all the possible routes and their costs. It provides a more extended network lifetime. Localized flooding is performed to keep the destination node's paths. This technique is used to gather location information and method for addressing mechanisms, which makes the route complicated.

Power-Efficient Gathering in Sensor Information System (PEGASIS)[17] uses the concept of a chain of sensor nodes to transmit data rather than cluster nodes. Data transmitted to neighbor nodes, and then this node sends data to its next neighboring node and so on. This process continues until the data reaches up to the last node, called the leader node. The leader node sends this data to the sink. Multi-hop routing performed in PEGASIS. There can be a delay in data transfer if the leader node is far from the first transmitting node. A bottleneck problem occurred at the leader node due to the number of transmissions among the non-leader nodes.

In this research paper, we select Gossiping as a target protocol for our research. Gossiping is a data relay method, which is base on flooding protocol. It does not require a routing table or topology repairs [20]. A node sends data to its adjacent nodes in flooding protocol without caring for duplication of data [21]. The data forwarding process continues until it reaches the destination node. Gossiping is a little bit different from flooding, in which the source node selects a node randomly from its neighboring node and forwards the data packet to this node. This procedure will carry on until the node reaches the destination. It performs fine in one to one communication scenario. In this process, only a few nodes participate in the data forwarding process, saving extra energy consumption by the nodes. However, gossiping suffer from latency; information sends slowly, one node use at every step. There are chances of packet loss in it. Different techniques are designed to counter far these drawbacks found in simple gossiping.

FLGossiping Protocol [22] is a mixture of gossiping and flooding routing protocols. When a source node wants to send the data, it keeps it in the packet header; after that, the neighboring node randomly sends a data packet in the gossiping mode. Meanwhile, other adjacent nodes attend this packet with a generation of a random number. Nodes having a random small-generated number than the threshold is responsible for sending data packets in flooding mode. Single Gossiping with Directional Flooding (SGDF) is another routing protocol that consists of the initialization of network topology and routing technique [23]. In the first step, every node calculates the number of hops to the base station, called gradient. The second segment uses a single gossiping and directional flooding routing technique: high packet delivery ratio, short packet delay, and low message complexity achieved in SGDF. Due to directional flooding, packet amount becomes more significant, and its delivery becomes difficult.

LGossiping (Location-based Gossiping) is a routing method in which data packet send to any neighboring nodes within its transmission radius. After receiving this event, it selects another node randomly within its transmission radius and sends it again. This method continues until it reaches the base station [24]. The delay problem is solved to some extent, but there are chances that some events do not reach up to the base station.

In ELGossiping (Energy Location base Gossiping) protocol, it chooses a node from its neighbors found in their transmission range with the lowermost distance after detecting an event. When a node collects the event, it selects an additional node from the same transmission range and lowest in the distance to the base station [25]. This process continues until it reaches the base station. Problems of latency and ratio of undelivered packets partially solved in this technique and its extensions, but still, there are chances of not delivering messages.

FELGossiping (Fair Efficient-based Gossiping) is proposed to handle the energy consumption during the communication. The selection of the nodes based on the distance to the sink and residual energy [26]. Once a node identifies an event to send information, it finds its next hop based on the neighboring nodes' residual energy and hops counts. This process will continue until the message delivered to the sink. High packet delivery ratio, reduced data delay, and increased network lifetime are observed in the FELGossiping routing protocol. It is useful to find nodes failure during the information gathering process. It uses hop counts as the measurement of distance, which is inaccurately associated with the distance.

3 MOTIVATION AND PROBLEM STATEMENT

3.1 Motivation and Problem Formulation

Designing an energy-efficient routing procedure for WSANs in a harsh environment where human interaction is not possible or difficult is not an easy task. Sending data from the field without an interception is a challenging job. If the data packet is lost or not reach the base station, it can be a problem. Retransmission of this data packet may achieve data reliability, but there can be an increase in the delay, and more energy is consumed [27]. This data packet not received or lost at any node may be due to the lousy link quality, buffer overflow, low level of energy, or node expired due to any reason. This problem can be solved by designing an energy-efficient routing protocol metric, which computed the packet loss, live nodes, quality, and delay in transmission.

An event is generated from the source node; after that, it broadcast an invitation message to get the necessary information from the other neighboring nodes found in the same communication range. These nodes send their information to the source node, which contains the adjacent node's residual energy. A table of neighboring nodes that will be part of the route towards the sink is updated. A source node selected a node from its neighboring nodes with the base station's minimum hop counts. A node having more residual energy from the adjacent nodes will be selected for the receiver of data. Suppose, if more than one nodes have a similar residual energy level, then a node having less hop count to the sink will be selected to participate in the data routing process. Once the next node is selected, a source node sends data towards this node, and this process repeats to the next-hop.

3.2 Problem Statement

WSANs consist of sensors, actors, and sink or base station. The sensor and actors are work together to respond to the environment and monitor it. When it detects an event from the surroundings, it needs to send to the sink. Data is routed through different nodes until it reaches the sink. If this link down due to nodes failure or any other reason, data will not reach its final destination. A smart and energy-efficient mechanism is required to send data from the source node to the sink or the base station.

3.3 Mathematical Model

Nodes find to find their neighboring nodes by heart messages in WSANs. It is supposed that every node saves the 1-hops information of the nodes. Every node sends the group of beacon messages of diverse strengths to check the forwarding capabilities. After that, other neighboring nodes in the range will listen to these messages and return the values. Distance between the nodes calculated by using the Received Signal Strength Indicator (RSSI) [18]. It uses less energy and simple technique with no time synchronization. It shows the relationship between received signal energy, transmitted energy, and distance between the nodes. Equation (1-5) are applied by RSSI in WSANs. Its use to find the quality of the link in WSN [19].

RSSI scheme is selected because of low complexity, no time synchronization, and low power consumption. Shows the relationship among the wireless signal energy received, energy transmitted, and required a distance of actor nodes[28]. It is used to finds a recovery process for the failure nodes. This relationship is given below in Equation 1, where E_r has received signals' energy, and E_t is a wireless signal transmitted energy. Moreover, r is the distance between the two actor nodes, and β is the path loss transmission factor, which can be different, purely depending upon the environment.

$$E_r = E_t \times \left(\frac{1}{r}\right)^{\boldsymbol{\beta}} \quad (1)$$

Than logarithm is calculated with the equation: $10\log E_r = 10\log E_t - 10\beta\log_r$ (2)

Where 10 log E is the energy that is changed into dBm so the above equation can be written as:

$$E_r(dBm) = \gamma - 10\beta log_r \quad (3)$$

Where γ and β show the link between received signal strength and signal transmission distance among sensor to sensor, a sensor to an actor nodes, or actor-to-actor nodes. It assumed that there is no hindrance between the forwarding actor and the receiving actor or sensor. This energy transmission of wireless signals at a distance 'r' calculated as:

$$\frac{E_t\, A_{gt} A_{gr}\, \lambda^2}{(4\pi)^2\, r^2 w^2} \quad (4)$$

Where nodes received energy signals placed at the distance, 'r' is calculated as:

$$Ew(dB) = 10\log\frac{A_{gt}}{A_{gr}} = -10\log\left[\frac{\lambda^2}{(4\pi)^2 r^2}\right] \quad (5)$$

λ	=	1/ frequency of a node
Agt & Agr	=	an antenna get
w	=	failure element of actor node

r = node distance

Residual Energy

$$E_{res} = \left[E_{in} - \left\{ \frac{n*(P_c*E_{red})+n*(E_{amp}*P_c)}{2\,E_{ra}} + r^2(N_n - 1) \right\} + \left\{ \frac{(\Delta\, C_P*E_{red})+(E_{amp}*P_c)}{2\,E_{ra}} \right\} + \left\{ \frac{\{n*(P_c*E_{red})+n*(E_{amp}*P_c)\}^2}{2\,E_{ra}} + h^2(N_n - 1) \right\} \right] \quad (6)$$

Notations	Description
n	No. of Packets
PC	Control Packets
Ein	Initial Energy
Eres	Residual Energy
Ered	Energy consumed against the radio signal
Eamp	Energy consumed for amplifying the signal
Era	Mean energy consumed to louden the signals and radio
h	Number of hopes
Nn	Number of nodes

TABLE 1
Residual Energy Notation and their description

3.4 Network Model

In the proposed algorithm, the following assumptions made:

- WSANs is composed of static sensor and mobile actor nodes.
- Sensor and actor nodes are randomly deployed in the area of interest.
- Sensor nodes are small and have limited resources used to monitor the environment.
- Actor nodes are the mobile nodes with a more extended transmission range and productive resources.
- Communication between sensors to sensors, sensors to actors, and actors to actors is possible via a communication link.
- Every node can send the data to the next sensor/ actor node.
- Actor nodes forward the data to the base station/ sink.
- Every sensor and actor node has the standard energy level at the start of the network.
- Every sensor and actor nodes have standard transmission ranges.

4 METHODOLOGY

4.1 Energy-Efficient Routing Mechanism (EERM) Setup

EERM proposes to modify the gossiping protocol by minimizing energy utilization, which can improve the network's lifetime. In EERM, a node with more residual energy and less distance to the destination node is selected. As a result, a higher delivery ratio and minimum packet delay ratio are achieved. It works in three phases, i.e., i) Network Initiizalarion ii) Data Gathering iii) Routing.

Network Initialization: Sensor and actor nodes are random deploys in the area of interest, where the sensors are static, and actors are mobile nodes. At the beginning of the process, a base station sends a 'HELLO' message to all the neighboring nodes, which has the base station's address and a number of hops. This process continues until it reaches all the sensor and actor nodes in the network.

Data Gathering: After successfully transmitting this hello message, all the nodes collect the message and get addresses of the base station, hops, location, energy level, and distance to the sink. This complete network information is saved, which is useful for the next routing process.

Routing: All the nodes are sleeping by default to save energy. Once a node sense an event from the area of interest, it becomes active and ready to send this message to one of its neighboring nodes in the transmission range based on more residual energy and has less distance towards the base station. Before delivering a message to the next node, it will also check that this message is a new one and not delivered earlier. This messaging forwarding process continues until it reaches its final destination, which is a base station. After that, a message is generated to confirm data broadcasting. Figure 1 shows the routing mechanism from the source node towards its destination node, i.e., base station, whereas figure 2 shows the detailed flowchart of the proposed techniques.

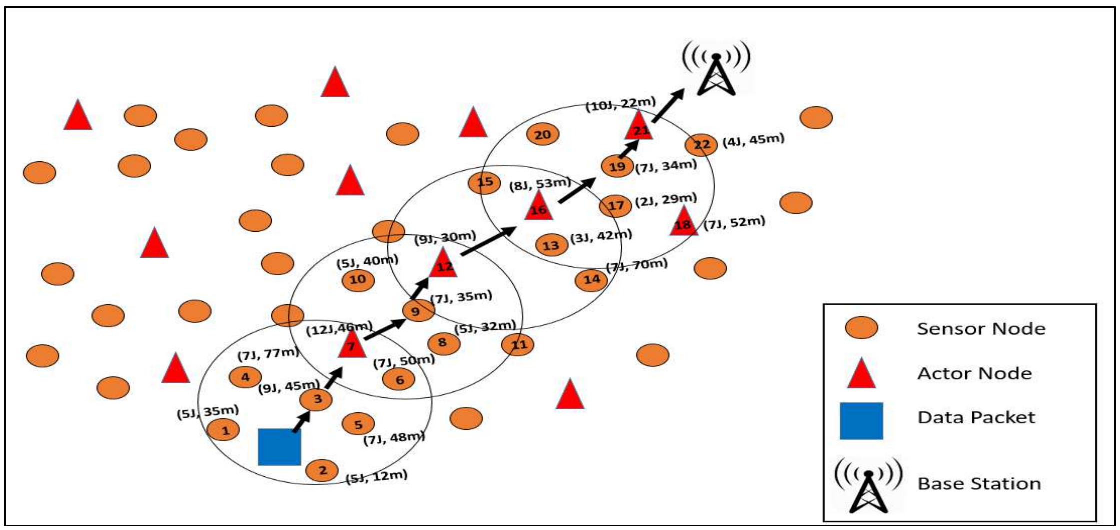

FIGURE 1: Data Routing Mechanism for EERM

Illustration of the technique: Reference figure 1, our network consists of sensors, actors nodes, and a base station. Sensors are static nodes, whereas actor nodes are dynamic nodes. After the random deployment of nodes, all the nodes have the necessary information on the network. A sensor/ actor nodes have information of its 1-hop neighbors information and residual energy of the nodes. This information is updated after a specific time interval or nodes move. Suppose a sensor node N3 sense data from the environment and send it to the base station. Now complete network information is available, so it is straightforward to find the shortest path towards the target node (base station). The beauty of the technique is that this transfer of the data to the next node will not be blind. It will ensure that data is transferred to such a node near the source node and has more residual energy to perform its process and may not exhaust because, in this situation, our data will be lost. Node N3 can send data to the nodes to sensor node N6 or actor node N7. Actor node N7 is selected to transfer data. It has more residual energy and also near to N3{N6(7J,50m), N7(12J,46m)}. Now, N7 has to select its next node to transfer data, selected on the same criteria. Therefore, sensor node N9 is selected, which has more residual energy {N8(5J,32m), N9(7J,35m)}. After that N8 and N12 nodes are neighboring nodes in which N12 is selected on the given criteria. N16 and N13 {(8J,53m), (3J, 42m)} are the two neighboring nodes out of which N16 is selected based on energy. Now N16 has to select the next node to transfer data. N17, N19 {(2J,29m), (7J,34m)} are the two neighboring nodes in which N19 is selected because it has more residual energy, and there is a significantly less distance. Now, this node finds its neighboring nodes, which are N21, N22 {(10J,22m), (4J,45m)}. N21 is the best suitable node to transfer the data. Once the data is transferred, it observes that it is near to the base station or sink and can send data directly to it. Finally, data is reached to its target node, and the message is delivered that data received.

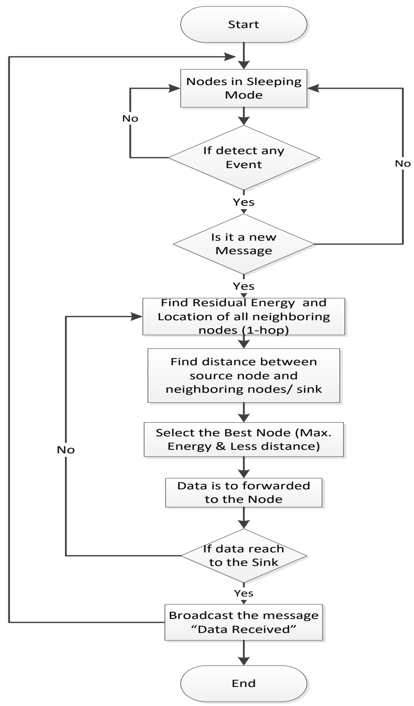

FIGURE 2: Flowchart of an Energy Efficient Routing Mechanism (EERM)

Algorithm 3.1: Energy Efficient Routing Mechanism (EERM)

NID: Nodes ID, DP: Data Packet, NR: Nodes in Range, MsgID: Message ID, RE: Residual Energy, L: Location, BN: Best Node, BS: Base Station
Input: Nodes in an inactive mode
Output: Message transferred to Base Station

```
1   Begin
2        NodesStatus = Sleeping/Inactive
3         Send Message from BS to all nodes
4        Update Network Information (NID, L, RE)
5        IF event detected THEN
6          NodesStatus = Active
7          Allocate MsgID to the node
8           Select any two adjacent nodes from 1-hop
9           Select BN (Nodes having more energy and less distance to the sink)
10          DP forward to BN / BS
11              IF DP deliver to BS THEN
12              Display Message "Data Delivered to Base Station"
13              ELSE
14              REPEAT go to step 9
15              ENDIF
16        NodesStatus = Sleeping
16       ENDIF
17   END
```

5. SIMULATION RESULTS AND ANALYSIS

Sensor and actor nodes are deployed randomly in the field. ESCR technique simulated on the OMNET ++ simulator, which objective is to check the performance of the technique and its energy efficiency. EERM is compared with some well know like FELGossiping, ELGossiping, and LGossiping. Table 1 shows a comparison of these techniques. These Simulations were conducted based on the following metrics.

Protocol	Parameters	Evaluation Metric
LGossiping	Locations of Nodes	Energy Consumption, Packet Loss
ELGossiping	Distance to Sink, Residual Energy	Energy Consumption, Network Lifetime, Hop Count, Packet Loss
FELGossiping	Hop Count to Sink, Residual Energy	Delay, Energy Consumption, Packet Loss, Live Nodes

TABLE 2: Comparison of Gossiping Protocols

Radius:

Sensor nodes deployed in the area of interest are capable of covering about 50 meters. These sensors can easily communicate with other sensor nodes found in the transmission range.

Residual Energy:

The remaining energy of any node is called residual energy. It is supposed that every sensor node has an equal energy level at the beginning of the experiment.

Nodes Location:

Sensor nodes are normal nodes considered a static node in the experiment, whereas actor nodes are mobile nodes. The location and distance between the nodes can easily be calculated. EERM protocol performed well than other conventional routing techniques. The proposed technique (EERM) performance is evaluated in terms of packet losses, transmission delay, alive nodes, and total energy consumed every round.

Packet Loss:

It is observed during the simulation that packet loss is noticeably less than the other gossiping routing protocols. Moreover, figure 3 shows an increase in the packet loss rate after about 525 iterations.

Live Nodes:

FIGURE 4 shows that almost all the nodes are died soon, whereas EERM nodes remain alive in more iterations. Nodes energy is utilized smartly so that the network remains to perform its tasks for the maximum period.

Delay in Transmission:

Other protocols randomly select the next hop to forward the data packet, whereas, in the proposed scheme, the nearest node to the sink is selected for this job as a next ho. A minimal transmission delay is observed in the

EERM as compared to the rest of the techniques. The simulation result in FIGURE 5 tells that delay is stable approximately at 2msec.

Energy Consumption:

EER provides a more efficient solution by equalization, energy, and better utilization. As a result, network lifetime is increased more than the rest of other routing protocols, as shown in FIGURE 6.

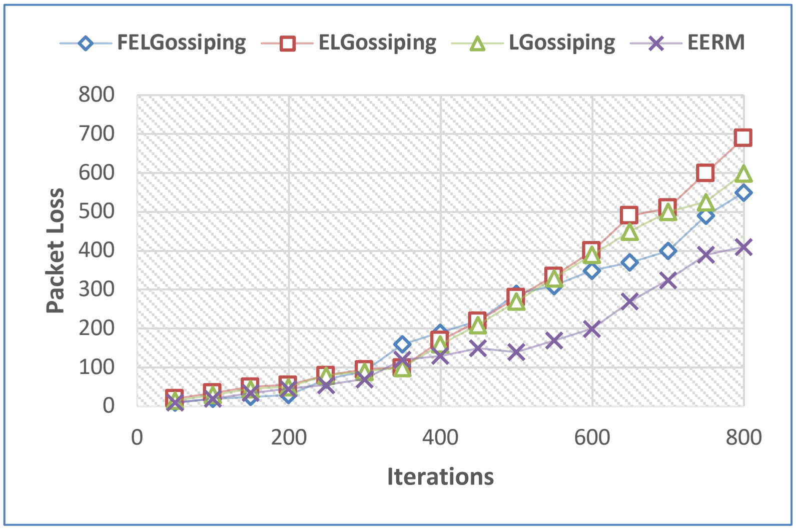

FIGURE 3: Packet Loss

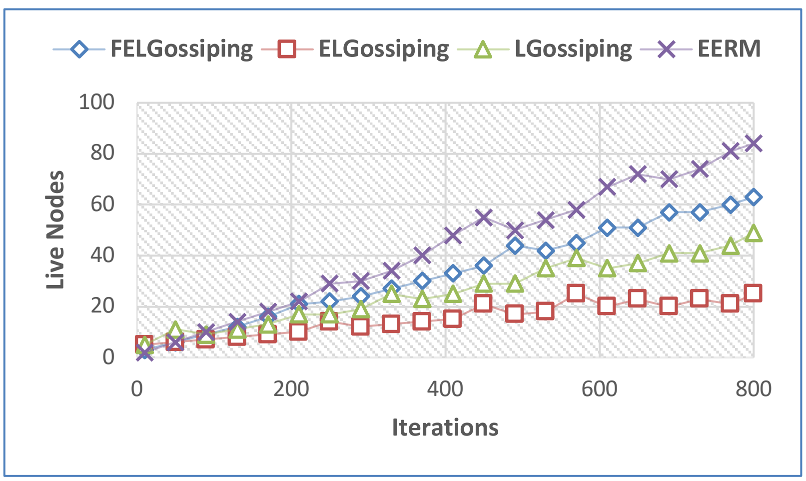

FIGURE 4: Live Nodes

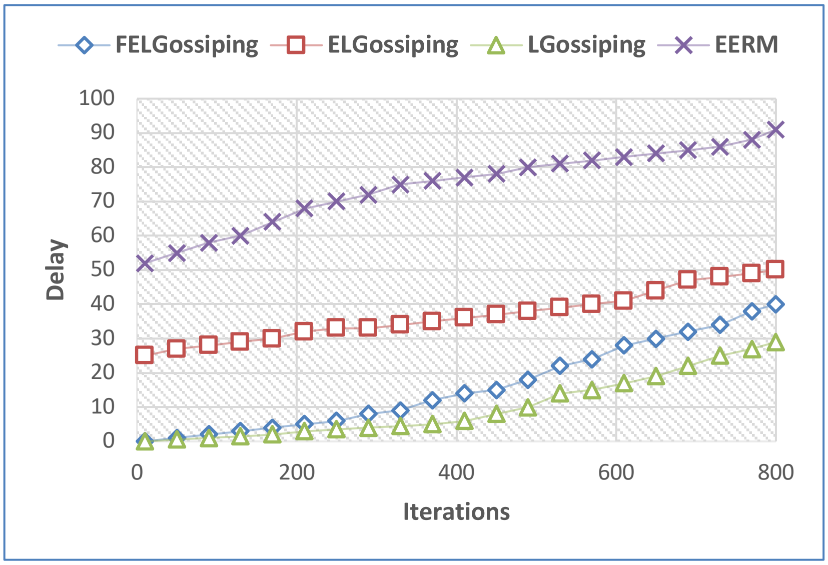

FIGURE 5: Delay

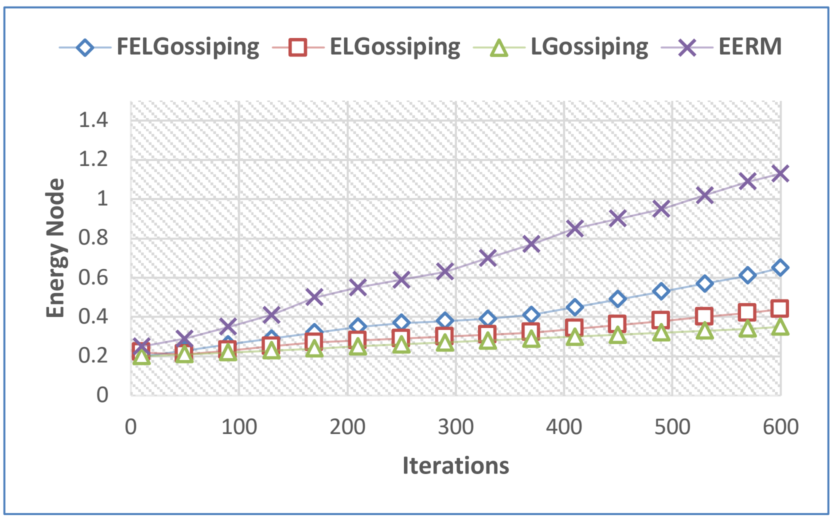

FIGURE 6: Energy Consumption

6. Conclusions

Wireless Sensor and Actor Networks have limited resources. The network's core object is the sense the data from the area of interest and send it to the base station. In this paper, we enhanced the gossiping routing protocol with low energy consumption. An Energy-Efficient Routing Mechanism (EERM) protocol is presented in the paper. The nodes selection process for the routing of the data is selected smartly. Nodes having maximum energy can perform their tasks for more periods, and there will be fewer chances of data loss due to battery depletion. Moreover, nodes are selected based on having less distance to the source node or base station. We enhanced the gossiping protocol elegantly. Due to the best nodes selection methodology, there are fewer data loss chances, and no duplicate data is forwarded. It is an energy-efficient technique that can send data for a more period; thus, network lifetime is also increased. Nodes can send data accurately to the base station. Moreover, we achieved a high packet delivery ratio and also reduced the packet delivery delay. We reduce the overhead message ratio, as well. EERM is evaluated with other routing techniques and shown that it performs well than others like FELGossiping, EFGossiping, and LGossiping.

7. CONFLICT OF INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Figures

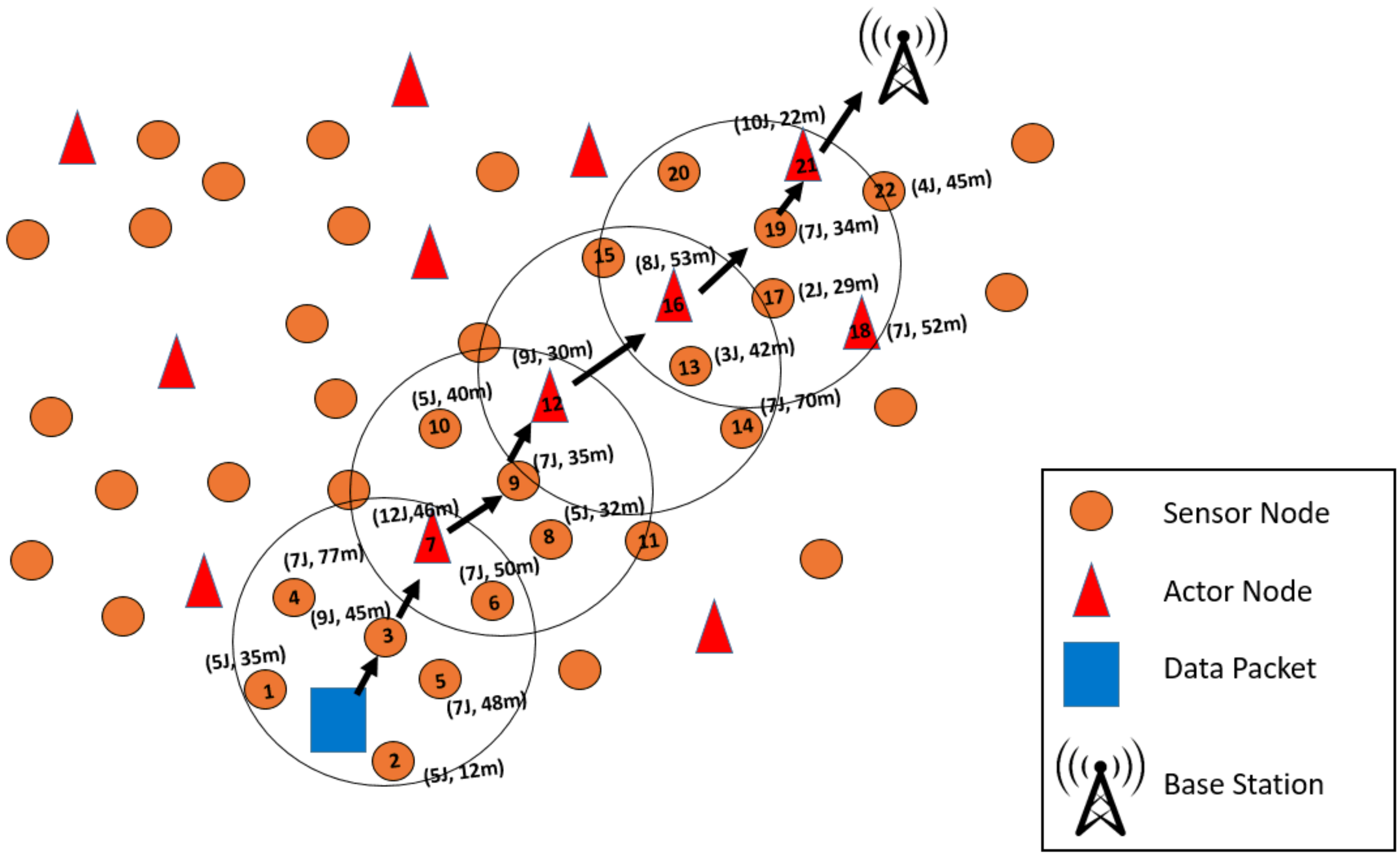

Figure 1

Data Routing Mechanism for EERM

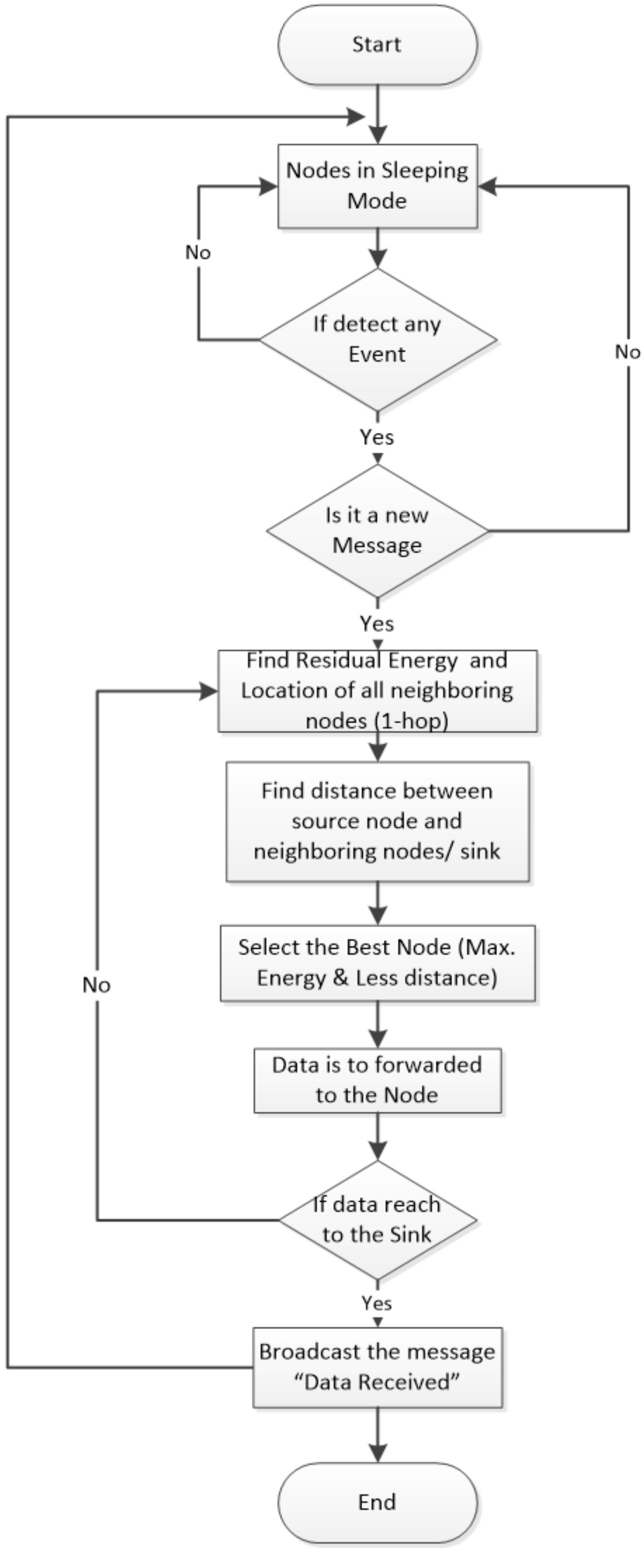

Figure 2

Flowchart of an Energy Efficient Routing Mechanism (EERM)

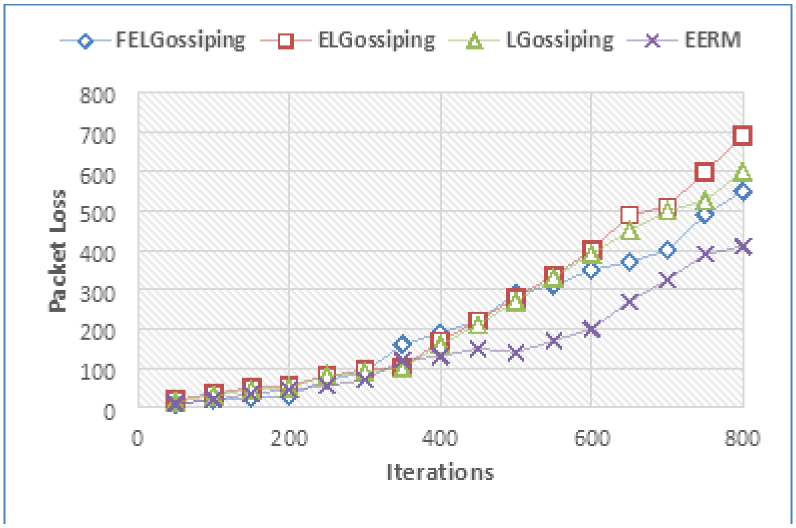

Figure 3

Packet Loss

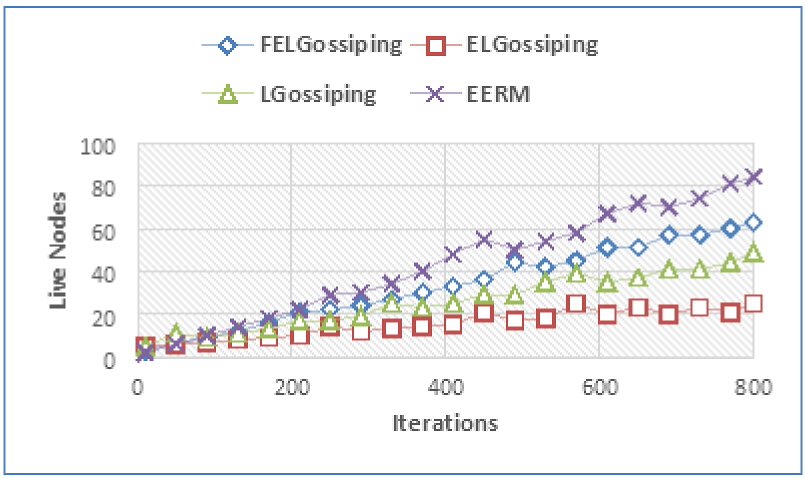

Figure 4

Live Nodes

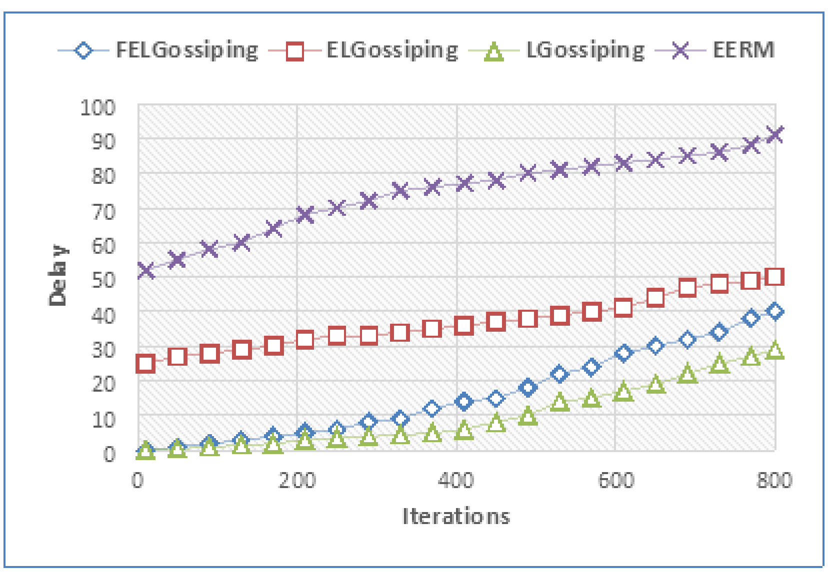

Figure 5

Delay

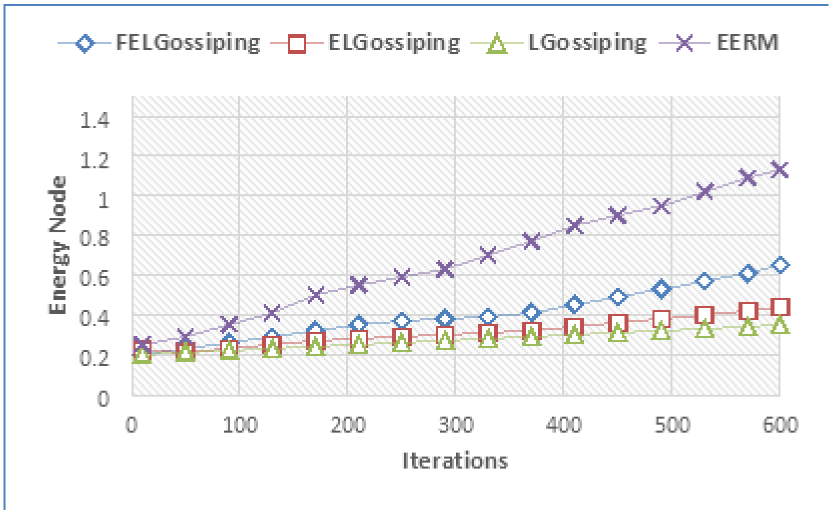

Figure 6

Energy Consumption