Energy Efficient Power-Aware DSR-based Routing for Homogeneous and Heterogeneous WSNs

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ABSTRACT

The research on managing resources and bandwidth evaluation within ad-hoc networks has highlighted energy-efficient routing protocols as a critical mechanism for conserving energy and prolonging the network's operational lifespan. This study introduces the Energy-Efficient Power Aware DSR (EEPW-DSR) routing protocol, which enhances Cluster Head (CH) selection by incorporating a distance-aware approach and addresses energy consumption challenges. The proposed method optimizes CH selection based on proximity to the Base Station (BS) and the node energy levels, significantly reducing communication distance and balancing energy consumption. Conventional methods, such as Standard DSR and Multi-hop Routing (MR), were considered for comparative performance analysis with the EEPW-DSR. Simulation results demonstrate that the proposed method outperforms conventional methods in network lifetime, network stability, and period of active node operation. These improvements highlight the robustness of the proposed approach in ensuring network longevity in both homogeneous and heterogeneous Wireless Sensor Networks (WSNs).

Keywords-wireless sensor networks; bandwidth; heterogeneous networks; routing; node energy

I. INTRODUCTION

In a Wireless Sensor Network (WSN), activities like data sensing, reporting, and information exchange with the Base Station (BS) are performed. Sensor nodes usually have limited energy, so a methodology for decreasing the node's energy consumption and improving the node's lifespan is always needed. Various protocols have been proposed to solve the energy insufficiency issue in homogenous WSNs. WSNs can be heterogeneous because diverse sensor types with diverse energy features are used [1]. WSNs are commonly used in controlling and monitoring of critical applications and are often employed for protection and productivity reasons [2-4]. WSN sensors can identify environmental risk factors like air concentration or temperature, or can monitor vibrations. However, in mining applications, monitoring operation performance tends to be decreased due to the long-term usage of the wireless nodes, leading to too much energy consumption [5-7]. Operations in underground work areas need stations for surface monitoring and proper communication. Productivity, safety, and production are ensured and facilities like monitoring everyday activities, product extraction, and transportation of minerals to the surface are made easier with the use of WSNs [8].

Nodes in WSNs possess only limited power, and the batteries present in the node are not necessarily designed to be replaced or recharged [9]. Furthermore, more energy is needed to communicate directly with the nodes that are far from the BS. So, the concept of node clustering was developed, where sensor nodes are cumulated into a cluster, which can send and receive information with a particular CH which performs the role of a gateway. A collection of sensor nodes can be placed close to each other using clustering-based protocols [10]. Data aggregation in the distribution centers decreases network power consumption significantly by reducing the messages passed on amongst the BS and the sender nodes [11]. To significantly minimize the energy consumption of the nodes, it is essential to configure the CH properly to their respective network parameters.

In this paper, the distributed energy-efficient clustering protocol Energy-Efficient Power Aware DSR (EEPW-DSR) is proposed to estimate the average amount of energy required by the WSN network for electing the CHs. In EEPW-DSR, the CH is selected depending on whether the nodes are advanced or standard. A node with high residual energy is more likely to be chosen as the CH [12]. Factors like the node's distance from the BS, and the high residual energy are considered when selecting CH. The EEPW-DSR strategy effectively distributes energy consumption among the WSN nodes [13].

II. METHODOLOGY

WSNs are commonly employed to monitor homogeneous and heterogeneous network environments. Due to many challenges, achieving reasonable monitoring through WSN is a challenging work due to sensor node power utilization, frequency selection, and channel propagation issues [14]. The technical background needed consists of three groups: First, the deployment of the monitoring system in WSNs, its topology and the methodology used. Second, the clustering-based WSNs [15] and their features for efficient energy usage are outlined, and third, the chief models in heterogonous WSNs are reviewed.

A. Energy Models in Heterogeneous WSNs

The receiver's sensitivity and the transmitter's power are the factors that determine the energy budget of a WSN. Researchers have expressed an attenuation of 40 dB, which measures signal energy. Usually, we need to verify that in theoretical models of various applications, the sensor nodes can form a sensor network that will meet the QoS requirements and decrease total energy consumption. Categorization of the sensor nodes in the two-level model is made possible based on energy level. For example, $E_h = E_1(1 + \alpha)$ denotes the energy levels, with E_1 denoting the lowest energy level and α being a positive integer. Suppose that N nodes are present. The sensor nodes with high energy levels are denoted as N_h, the fraction of high-level energy nodes is presented as h, and the number of sensor nodes with less energy levels is $N(1 - h)$. The initial energy of the whole network with all the sensors is:

$$E_{total} = N(1-h)E_1 + Nh(1+\alpha)E_1 \quad (1)$$

$$E_{total} = NE_1 + (1+\alpha h) \quad (2)$$

Three types of sensor node energy levels are present in WSNs, namely, low, high, and super. When the same assumptions are considered as in the two-level energy model, the super energy level can be denoted as $E_S = E_l\,(1 + \beta)$, with β being the factor by which the super energy level surpasses the low energy level. The amount of sensor nodes possessing this energy can be given as $Nh(1 - S)E_1$. Using the three energy level models, the following expression shows the WSN's total initial energy.

$$E_{total} = N(1-h)E_1 + Nh(1+\alpha)(1-S)E_1 + NS(1+\beta)E_1 \quad (3)$$

$$E_{total} = N(1 + h(\alpha + S\beta)) \quad (4)$$

Concerning the sensor's energy level, more energy is used up by the CH nodes than by the simple member nodes. Since sensors with different energy level characteristics and multiple sensitivities are employed, sensors with heterogeneous energy levels are considered as a homogeneous network which is not a suitable approach. The critical task of the WSN is choosing the proper CH that provides data communication among the member nodes and the BS. Due to their extra workload, higher energy should be present in the CHs. The proposed mechanism describes an efficient way for selecting CH members. A distance-aware approach is added to enhance the EEPW-DSR's efficiency.

B. Energy-Efficient Power-Aware DSR-based Routing

Generally, a single-hop mode for long distances will lead to high energy usage by sensor nodes, which will cause many nodes to exhaust their energy quickly. Energy consumption can be reduced by splitting the long communication distances into short distances and employing multi-hop mode. Energy consumption can be balanced by clustering and distributing the CHs. However, the clustering scheme might increase energy consumption when it is used in a real-time network. CHs will receive data directly from the Cluster Members (CMs) in a multi-hop inter-cluster transmission scheme. When CMs and the BS are close, they exchange data. Using this approach, energy usage is calculated by considering the communication distance and the number of packets transmitted. The sensor node's energy consumption is calculated by (5) while (6) provides CH's power consumption:

$$E_{T_x} = k(E_{elec} + E_{elec} \times d^2) \quad (5)$$

$$E_{CM} = E_{init} + E_{T_x}(k, d) \quad (6)$$

The electronic circuit is represented by E_{elec} and E_{amp} represents the amplified signal energies transmitted. The data packets are denoted as k and the communication distance is denoted as d.

The sensor node's initial energy is represented by E_{init} and the node's standard energy consumption is represented by E_{std}. This node participates in the CH selection phase. In data aggregation, the node's energy consumption and the transmitted energy influence the E_{std} value. Using the EEPW-DSR method, the introduced approach computes the probability of various sensor energy levels for choosing the appropriate CHs. The likelihood of a node becoming a CH reduces with increased distance and vice versa. All the energy level probabilities are calculated using the initial energy level. Equation (8) gives the CH selection probability and (9) calculates the threshold of CH selection.

$$E_{CH} = E_{init} + E_{std} \quad (7)$$

$$P_i = \left(\frac{propEi(r)}{1 + h(\alpha + S\beta)E(r)} \right) \text{for all energy probabilities} \begin{cases} low level \\ high level \\ super level \end{cases} \quad (8)$$

$$Threshold = \left(\frac{P_i}{d(1 - pi(r \bmod \frac{1}{pi})} \right); \quad (9)$$

$$\text{for status} \begin{cases} d \gg low\ probability \\ d \ll high\ probability \end{cases}$$

The power required for transmitting the data regarding the distance from the BS and the node is determined by computing the average distance d between nodes eligible to become CHs. Assuming that coordinate $(0, H)$ is the location of the BS and coordinate (x, y) is the location of a node eligible to become a CH, depending on the average distance between the candidate's node and the BS, the estimated average residual energy can be computed by:

$$E\left[d^2\right] = \rho \iint x^2 + y^2 - 2yH + H^2 dxdy \quad (10)$$

According to (10), every node presents itself as the member group's temporary CH and each node works independently. By using the Received Signal Strength (RSS), the distance from the station to the selected node is identified.

C. Routing for Establishing Energy Efficiency

EEPW-DSR makes use of source routing at every intermediate device. While AODV relies on a routing table, the EEPW-DSR does not. In ad hoc networks, most bandwidth is consumed by control packets, so the primary use of EEPW-DSR is to limit the bandwidth usage. Periodical broadcasting in the network is eliminated by utilizing the EEPW-DSR reactive approach, which is considered necessary in the table-driven approach. The algorithm for route maintenance and route discovery is given below.

```
Algorithm 1: EEPW-DSR
Start process and Initialize S and D;
Transmit RREQ from S and D to all the
networks;
If the route is identified, then
Message received by all intermediate
nodes;
Else
Initiate route discovery and send a
message
End
If RREQ is initiated again, then Abandon
route
Else
Include the address to maintain route
records
Transfer request message to nearby nodes
Receive RREQ to D
Maintain routing record and transfer
message to S→ RREP
End
End
//Route Maintenance
Start the process and Initialize S and D;
Initiate route discovery process and
transfer RREQ;
Acquire the request from intermediate
nodes;
If the transmission link is disconnected
among nodes,
then
Transfer error message to S;
Eliminate all invalid routes from the
buffer;
Initiate route discovery again
End
End
```

The route discovery procedure will start when the source node (S) wants a message sent to the destination node (D) in a definite route. The network will receive an RREQ from S, and the nearby nodes will also receive the RREQ request, so it will check for repetitiveness of the message and ignore the message if it is repeated. If the RREQ is not repeated, it will send an RREP to S. In such a scenario, destination node D is the adjacent node with the route information. When RREP is received by S consecutively, it will send the message in the route RREP has specified. When the link between S and D is disconnected, S will receive an error message, RERR, from the respective node. When the RRER is received by S, all the routes with invalid links will be deleted, and the route discovery process will start again. In this process, high energy is used during data transmission because many routes will be discovered from S to D, but the chosen route will not have a minimum hop.

The target of the proposed model is to extend network lifetime by reducing energy consumption during data transmission, route maintenance and route discovery. The proposed model is enhanced compared to the existing DSR-PSR [16] by considering transmission power, residual node energy and other energy metrics while selecting routes. The proposed EEPW-DSR adopts lower transmission power and eliminates depleted nodes.

D. Simulation Parameters

The considered simulation parameters are shown in Table I. The nodes were scattered randomly in the area and the BS was placed at its center. Communication ranges of 2 to 4 m were selected for clustering and MS communication. According to the operations of the sensor node, 200 to 1000 packets were considered for the total traffic load to be handled. The experiment was conducted considering a total of 200 to 600 messages, simulated under IEEE Zigbee/802.15.4 standard. The EEPW-DSR's performance metrics were assessed with factors like the number of alive nodes, network throughput, and network lifetime.

III. RESULTS

The EEPW-DSR's performance outcomes and the performance outcomes of the proposed approaches are presented. The energy loss due to the fading effects and dynamic random channel conditions are ignored. The proposed mechanism was evaluated for 50 sensor nodes. The high and super energy levels are given by $h = 0.5$ and $S = 0.4$ with the energy increased by $\alpha = 1.5$ and $\beta = 3$ times more than low energy, respectively. Table II shows the results of the evaluated energy-efficient base clustering mechanisms. Figure 1 shows the initial node placement and Figure 2 the route establishment. The proposed approach provides WSNs with a longer lifetime because the sensors with low energy levels will die faster, and the sensor nodes with super and high energy levels die later.

TABLE I. SIMULATION PARAMETERS

Parameter	Values
Protocols	EEPW-DSR
Simulation region	200 m × 200 m
Number of nodes	50 – 150
Initial energy	1 J
Transmission energy	0.01 J
Receiving energy	0.01 J
Mobility Speed	1 m/s
Mobility model	Random movement

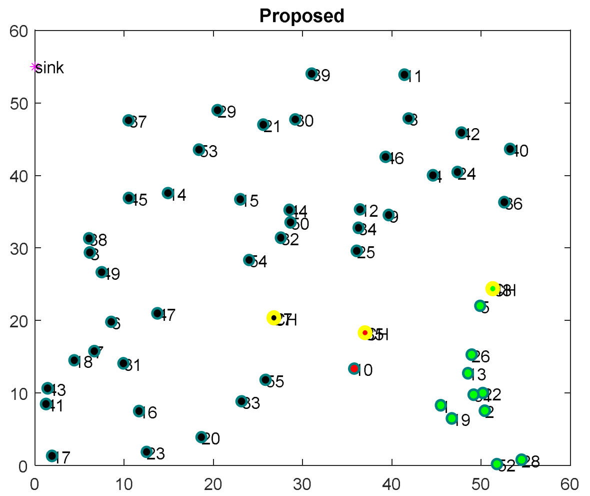

Fig. 1. Node creation.

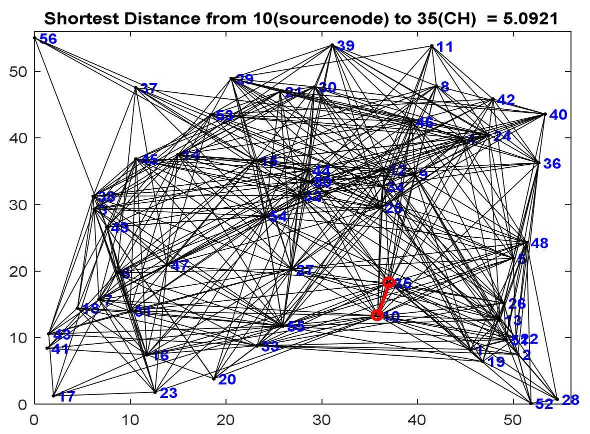

Fig. 2. Energy-aware route establishment.

Tables II-VII show the comparison results of the proposed and other known algorithms. The proposed mechanism offers a longer network operation time as it keeps more nodes live for longer periods.

TABLE II. TOTAL ENERGY CONSUMPTION, mJ

No. of nodes	SF	DSR	MR	EEPW-DSR
100	3	2	9	5
200	4	2	7	4
300	7	5	3	0
400	2	9	7	5
500	8	6	5	3
600	3	2.5	2	1

TABLE III. IDLE ENERGY, mWh

Packet size (bytes)	SF	DSR	MR	EEPW-DSR
12	0.10	0.20	0.30	0.50
24	0.50	0.60	0.90	0.80
48	0.80	0.20	0.50	0.50
96	0.90	0.98	0.95	0.9

TABLE IV. NETWORK LIFETIME, ms

No. of nodes	SF	DSR	MR	EEPW-DSR
100	100	120	160	220
200	120	160	220	320
300	150	220	265	400
400	200	250	320	420
500	210	300	340	460
600	250	320	360	500

TABLE V. PDR COMPARISON, %

No. of nodes	TDMA	CSMA/CA	AHADV	EEPW-DSR
250	89	87	94	96.1
500	77	82	93	94
750	82	83	89	90.2
1000	78	81	86	88.6
1250	68	76	85	87.8

TABLE VI. E2E DELAY COMPARISON, ms

No. of nodes	TDMA	CSMA/CA	AHADV	EEPW-DSR
250	0.0016	0.0015	0.002	0.002
500	0.0020	0.0018	0.0011	0.0010
750	0.0043	0.0038	0.0034	0.0031
1000	0.0060	0.006	0.0042	0.005
1250	0.0182	0.018	0.0086	0.015

TABLE VII. NO. OF HOPS TOWARDS DESTINATION

No. of nodes	TDMA	CSMA/CA	AHADV	EEPW-DSR
250	6	4.6	4.5	3.5
500	6.9	8	6.4	5.3
750	8	7.5	6.6	5.4
1000	8.3	8	7.5	7.3
1250	9	9	8.6	8.5

The algorithm proposed in this study makes the active nodes die slower. This results from EEPW-DSR's modification in node energy heterogeneity to calculate the optimal CH selection probability. Rather than repeatedly utilizing the same route, which can lead to excessive strain on specific nodes, EEPW-DSR dynamically adapts its path selection based on real-time energy levels and network conditions. This adaptive approach helps mitigate the risk of network partitioning caused by energy depletion. Additionally, EEPW-DSR incorporates a weighted metric that evaluates residual energy, link quality, and hop count, facilitating a more balanced and energy-efficient routing strategy. Along with that, there is a close-distance dependence between the BS and the nodes. The proposed approach also improves the throughput of the WSN because the lifetime of the WSN will be higher, and energy consumption will be less, as illustrated in Table II. The outcome shows the proposed algorithm's efficiency. The proposed algorithm chooses a node with high/super power as the CH. The obtained result shows that more sensor nodes can be active for more duration when the proposed method is used. The proposed methodology provides a safe way to choose CHs with enough energy to send the aggregated data to the BS.

Depending on the number of sensor nodes employed in the WSN, Table II illustrates that the proposed algorithm performs better when the number of nodes increases in the stable operating period. When the proposed algorithm is used, the percentage of nodes eligible to become CHs increases. The network's performance improves with an increase in the number of nodes, which proves that the energy consumption is distributed fairly on the network, which also increases the stability period. Our main concern is to enhance the operation time of the WSN, through which the proposed algorithm's performance is evaluated.

DSR employs a source routing mechanism, where the complete path is embedded within the packet header. However, it does not account for the energy levels of the nodes, resulting in rapid depletion and potential failures when frequently utilized nodes exhaust their energy. In contrast, the proposed EEPW-DSR enhances this approach by integrating energy-aware, priority-based route selection. It prioritizes paths with higher residual energy, thereby extending the network's lifespan and enhancing reliability by preventing excessive reliance on specific nodes. In a heterogeneous environment, predicting the number of nodes to be employed in the network and optimum network operating time can be achieved by maintaining a balance between them and considering deploying acceptable costs. The proposed model incorporates a weighted metric that evaluates residual energy, link quality, and hop count, facilitating a more balanced and energy-efficient routing strategy. However, the existing model DSR-PSR [16] does not consider energy during path discovery. The DSR-PSR consumes more time during the path discovery.

Furthermore, the network's pressure on total data can be reduced by employing more sensor nodes to collect more data by evaluating PDR, E2E delay and no. of hops as in Tables V-VI. In a particular cluster node, the energy consumption percentage increases with an increase in the volume of data the network has to handle. However, the stability of the network is increased to the most extended period possible by the proposed algorithm.

The EEPW-DSR protocol represents a significant advancement over the conventional DSR protocol, specifically designed to enhance energy efficiency, network longevity, and overall performance in WSNs.

IV. IV CONCLUSION

In this study, the enhanced EEPW-DSR protocol is presented and compared with existing protocols. The EEPW-DSR is an energy-aware clustering approach. The energy levels are based on the average and residual energy calculations. Due to sensor energy fluctuations, a high-performance rate is not provided for heterogeneous WSNs. However, three kinds of energy levels can be handled by the mechanism proposed in this study, and it also performs a distance-aware selection of cluster heads. Concerning parameters like the throughput of the network and the number of live and dead sensors, the proposed algorithms' performance is analyzed and compared. The analysis outcomes show that the proposed algorithm performs better than the traditional DSR. Extending the node's lifetime and stabilizing the WSN for longer periods is challenging due the node's energy restrictions. The proposed algorithm brings the network's performance to a stabilized phase. However, deploying sensor nodes in an underground environment is a subject of further research to be conducted in that area. We will recognize as many parameters as possible to improve CH selection accuracy and the proximity-related study of the nodes and BS. Also, we plan to determine the amount of data flow exchanged to cluster heads based on the type of sensors deployed in real-time environments.

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