Asian Journal of Research in Computer Science

Volume 17, Issue 2, Page 51-64, 2024; Article no.AJRCOS.112053

ISSN: 2581-8260

Cross-Layer Energy Efficient (CLEE) Routing Algorithm for Mobile Ad-Hoc Networks

Iven Aabaah [a*], Peter Awonnatemi Agbedemnab [a] and Abdul-Mumin Salenwiah Salifu [a]

[a] *Department of Information Systems Technology, School of Computing and Information Sciences, C. K. Tedam University of Technology and Applied Sciences, Navrongo, Ghana.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJRCOS/2024/v17i2419

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/112053

Received: 12/11/2023
Accepted: 16/01/2024
Published: 20/01/2024

Original Research Article

ABSTRACT

Ad-hoc routing algorithms in Wireless Sensor Networks (WSN) rely on nodes' position awareness by regularly updating routing data of neighbouring nodes. Meanwhile, the transmission energy usage is not optimised as a result of this repeated updates and routing table deployment. Therefore, it is very critical to consider techniques of optimising or conserving energy in the design of wireless sensor networks (WSNs) in order to prolong the lifetime of the individual nodes. One of these techniques is the Cross-layer design which, is considered as an efficient method for addressing this challenge with WSNs. In this paper, we propose a Cross-Layer Energy Efficient (CLEE) routing algorithm to establish an optimal route from the source node to the destination node by selecting candidate nodes from neighbouring nodes based on the distance between these nodes and the rate of energy consumption by a possible candidate node. Then to select a designated node from the candidate nodes, the algorithm further computes the Signal Strength Quality (SQS) and the Link Lifetime (LL) as well as the Throughput (TH) rate of selected nodes. The proposed algorithm was simulated with a network size of 600×600 on Network Simulator 3 (NS3) in order to analyse its performance. An evaluation of the performance

*Corresponding author: E-mail: iaabaah@cktutas.edu.gh;

of the proposed CLEE protocol with existing similar protocols such as Ad-hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR) reveals that CLEE outperformes AODV and DSR by conserving about 44% of available energy.

Keywords: Cross-layer; Energy-efficient; Mobile Ad-Hoc networks; wireless sensor networks; Network-layer; physical layer.

1 INTRODUCTION

Mobile Ad-hoc Networks (MANET) are groups of cellular nodes that can act as routers and hosts within an ad-hoc wireless community. Nodes in MANETs can also dynamically self-arrange in a wireless community without the usage of any pre-set-up infrastructure. Nodes in MANETs generally transmit messages in a broadcast manner that is simply achieved by nodes closer to the source nodes. Battery power for mobile devices is a crucial resource in mobile ad-hoc networks (MANET). Therefore, when designing routing protocols, it is necessary to consider extending the network lifetime and conserving energy. For each node in MANET, the effective use of the available energy is a censorious need; hence, the ability to hold on to the level of energy consumption as minimal as possible is a crucial resource for the reliability of any routing protocol in the MANET community [1]. Also, the rampant broadcast of messages in the network causes collision, misplaced packets, and contention throughout the network, a situation popularly referred to as Broadcast Storm Problem [2].

The traditional layered design has its own benefits and functions excellently in a wired setup, however, it is not appropriate for a wireless setup particularly in an ad-hoc setup. This is true due to its design prohibition on direct communication between non-adjacent layers. More specifically, having a rigorous layered architecture will result in excessive energy consumption and poor performance since it is too rigid to handle the dynamism of MANET environments [3]. In recent times, cross-layer architectural designs are becoming progressively common in MANETS. As nodes in MANETS are limited in battery life, cross-layer designs are employed to eliminate such barriers [4]. By interfacing the various protocol levels, Cross-layer based design techniques overcome the disadvantages of traditional only one-layer-based techniques. The cross-layer design method facilitates the cooperative sharing of information between layers to provide the intended performance [5]. In every cross-layer design, there are two fundamental ways that information can be shared: layer-centric solution which, makes the variables of a particular layer transparent to the other layers. The other alternative, known as a centralised approach, depends on a shared middle-ware that offers all levels the ability to store and retrieve information [6]. The fundamental principles behind these two cross-layer solutions are:

1. The layer-centric approach permits a particular layer to function as the core layer, regulating cross-layer adaptation by having access to the underlying protocol settings and algorithms of the other layers as illustrated in Fig. 1 (a). This method demands access to the internal variables of other levels, which is against the layered architecture even though it greatly increases the achievable system performance.
2. With regard to the centralised approach, resource availability and environmental changes are estimated by a middle-ware or system-level monitor (centralised optimiser), which then coordinates resource distribution among diverse applications and nodes. In addition, it modifies the protocols' parameters inside each layer in response to the dynamics that arise as illustrated in Fig. 1 (b). With this method, every layer must send to the middle-ware or system monitor all of the data that describes its protocol parameters and algorithms. Every layer must also execute the commands given by the central optimiser. Additionally, this method goes against the layered architecture.

   The remainder of the paper is structured as follows: Section 2 presents review of related literature in the area of the study. Section 3 outlines the methodology of the proposed CLEE routing algorithm. Section 4 displays the findings and discussion of the research, and Section 5 wraps up the paper.

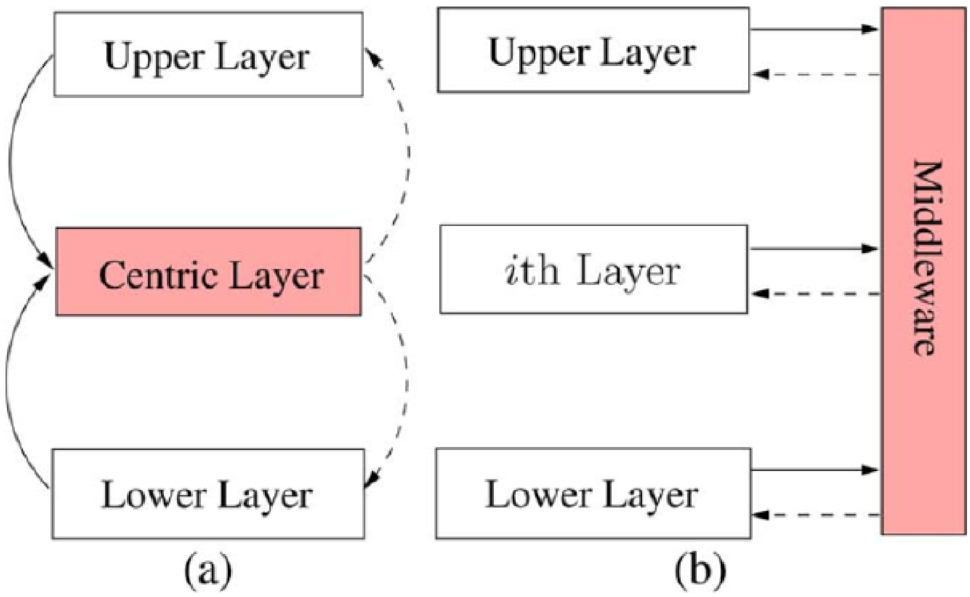

Fig. 1. Schematic rendering of multi-layer design techniques: (a) Layer-centred approach; (b) Centralised approach

2 RELATED WORKS

A recent study by [7] proposed a cross-layer authentication method that uses the advantages of geographically and temporally coupled wireless channels to enable key validation without jeopardising the confidentiality of the key. Using channel phase reactions to hide the time-stamped hashed key and applying it, a physical-layer signature is created thereby enabling the sender's true identity to be confirmed while using the associated route replies among its components to confirm the message's authenticity. in addition; a technique called Diffie-Hellman secret keys for extracting which employs the Chebyshev disordered projection to solve the computationally challenging challenges of channel testing was proposed. In order to produce flexible PHY-layer identities that provide forward and backward confidentiality, endpoints are able to generate a great deal of shared keys. The drawback of this proposed algorithm is that it has a very high latency rate. Another work by [8] suggested a low duty cycle cross-layer protocol (IRIS); a thin cross-layer technique called trustworthy routing that has cooperative media access control suitable for Wireless Sensor Networks with a lengthy distance pipeline and very low power supply. IRIS contains routing, Media Access Control (MAC), and network learning features developed for networks with severe energy constraints. IRIS combines the network layer and the MAC layer to reduce energy consumption. The IRIS algorithm is intended to enable network operation with no any preexisting neighbourhood knowledge or predefined structure. No information about the nodes' geolocations is known to the low-cost nodes. This means that The nodes can be placed in any physical sequence and at arbitrary places. IRIS collects monitoring data from the nodes that receive the pings as it propagates ping packets started by the sink via the pipeline network. The nodes are able to spend as much time they can in the energy-saving lightweight sleep mode thanks to an adjustable active / sleep duty cycle. One major drawback of the IRIS protocol is fact that it is not suitable for real time data transmission.This is due to the active/sleep behaviour of the sensor nodes.

The authors in [3], suggested a fuzzy logic system cross-Layer (FLSCL) architecture for MANET to enhance network quality of service (QoS) metrics like end-to-end (E2E) delay, throughput, and packet delivery ratio (PDR). Fuzzy logic and fuzzy judgements are used in conjunction with the concepts of difficulty and unpredictability to aid in decision-making. The proposed FLSCL uses the unknown principle base to create the controller of the cross-layer, which adjusts the variables from every single layer to obtain the best value that contributes to raising QoS and boosting MANET efficiency. FLSCL employs three different stages: The network properties, including each layer's settings and the environment to be analysed, are specified in this initial step. The development of a fuzzy logic framework for cross-layer (FLS-CL) validation and execution constitutes the final stage. It contains the parameter ranges, rule set, and membership function. According to the precise inputs of the antecedents, fuzzy logic systems offer the adjustment factor to obtain the best value for the consequent. The crisp inputs are transformed into the appropriate fuzzy set by a process called fuzzification. Three parameters are taken into consideration as the antecedent fuzzy variables in the model proposed. They include; (i) Packet Delivery PDR ratio expressed in percentage, (ii) Node speed (m/s), (iii) End-to-end delay (ms). The weakness of the FLSCL is that all five (5) layers of the network model were considered, thereby increasing the load overhead of the sensor nodes and ultimately increasing energy consumption of the network.

In the paper by [9], the authors employed a weighted sum approach with cross-layer design to enhance the sustainability of devices in SMART cities. Since between 70% and 80% of a device's energy is used for communication, the suggested architecture makes use of data from the physical layer and data link layer to examine energy-efficient IoT devices. In the suggested model, the weighted sum approach is applied, which is a powerful computation technique for analysing and identifying the routing metrics related to energy efficiency. With the use of control packets, the network layer calculates transportation parameters. Using the weighted sum approach, this control packet information on routing metrics is merged and weighted as a single value. The disadvantage of the proposed protocol is that it is implemented using a single routing technique. This Method is not suitable for large wireless mobile networks.

An article by [10] also suggested a cross-layer architecture using hybrid MAC layer protocol to enhance the lifetime of radio networks. A hybridization process is what gives the plan its originality. The network and MAC layers have been crossed to accomplish hybridization amongst the various control channel design methodologies. Between specialized unlicensed out-band methods and licensed in-band options, control channel designs can be broadly divided. The opportunistic usage of data channel as control channel in the in-band control channel design method upholds CR technological decorum. A cross-layer architecture is employed in the first section to communicate control information among the network and MAC layers. The Ad-hoc On-Demand Distance Vector (AODV) algorithm is employed for network layer routing. A PCL is the main component of the control information. The most recent state of authorised channels is kept in PCL. A channel's recorded state in PCL may indicate PU free or PU occupied. By exchanging PCL, node synchronisation can be improved. A hybrid CR-MAC approach is designed in the second section of the suggested algorithm. The hybrid MAC protocol's architecture is now based on the cross-layer transmission of control information. It is believed that the nodes in the cognitive radio scenario are randomly distributed and unrestricted in their movement throughout the network. This movement results in collision within the network and high energy consumption.

In [11], the authors used the particle swarm optimization (PSO) technique to develop a cross-layer routing protocol. To construct robust and energy-efficient systems, PSO is applied in creating pathways following network layer evaluations of node mobility, data success rate, and anticipated energy remaining. The remaining energy is estimated based on the volume of the current traffic load. The network congestion is monitored from the MAC level after the set of pathways has been established using PSO, and the dynamic modification of the contention window (CW) is dependent on the measured contention and anticipated remaining energy. The period of contention is constantly updated depending on the projected and measured contention leftover energy after the MAC layer has measured the network contention and established the set of pathways using PSO. Considering the variables of Data Success Rate (DSR), RND, and Rres, the route from the root node (S) to the target node (T) is set using the PSO method made up of a collection of nodes. The route with the highest success rate for data, least movement, and most unexhausted energy will be chosen. The MAC layer protocol, however, regulates pilot symbol transmission for channel gain estimation at the receiver end and signal synchronisation across all cooperative nodes. The MAC layer's actions result in additional energy overhead, thereby Using more energy and shortening the network lifetime.

In [12], the authors proposed a cross-layer energy consumption model in cooperative multiple-input and single-output (CMISO) wireless networks. In addition to transmitting power and circuit power, the proposed cross-layer model takes into account extra energy used for channel listening, sending control frames, and pilot signals. A constellation's size, contention window, cooperative node count, cluster radius, and minimal energy consumption are all determined by the model. CMISO employs a cluster-based strategy to efficiently minimise the amount of energy used by network nodes. It is presumed that all nodes within the network belong to a cluster based on some agreed rules such as the maximum number of nodes within a particular cluster and the radius of a cluster. A cluster head (CH)exists in each cluster. All nodes in a cluster forwards data to their CH. The CH then broadcast the data to all other CHs in the network. Communication between two clusters is only possible via the CHs. The cross-layer energy consumption model that is suggested takes into account the MAC level energy overhead of the entire transmission process in addition to the physical level of the data payload's transmitting power and circuit power. Each stage of the data transmission process must be thoroughly examined because the length of the entire transmission process directly affects energy usage. The volume of data that is transmitted to the CHs, increases the load overhead of the CHs, thereby resulting in high energy consumption in order to process and forward the data to the rest of the CHs in the network. Hence, reducing the network lifetime.

The authors in [13] suggested a novel adaptive Auto-Rate Anthocnet protocol to improve throughput and energy efficiency in MANETs. The Anthocnet protocol includes six different types of ant packets: proactive forward, proactive backward, repair forward, repair backward, and reactive backward, reactive forward. When there are no available relay path details to reach the destination node, the source node broadcasts reactive forward ant packets. In order to create reactive backward ant packets, the reactive forward ant packets must be translated and delivered toward the source whenever they are received by the target node. Reactive back ant packets establish the route by updating the pheromone in the source and intermediate nodes' routing databases as they travel back. Immediately the relay path is constituted, then the proactive route commences. Next, the root node will use an essential pheromone and standard pheromone to deliver proactive forward ant packets from the root node to the target node. The proactive forward ant packets are changed into proactive backward ant packets once they are received by the target nodes. On their route back to the source, the pheromone table is updated by these proactive backward ant transmissions. To address connection failure, this protocol uses repair forward ant and repair backward ant packets. An intermediate node selects the next hop node from the pheromone route table, else the intermediate node will have to select the next node based on probability. The back-and-forth transmission of data results in increased consumption of energy by the nodes, thereby, reducing the network lifespan.

An article by [14] proposed a new energy-aware opportunistic routing system that employs solar energy forecasting using long-short-term memory (LSTM). The protocol creatively considers the short-term solar energy harvesting and the nodes' current residual energy, which are anticipated by an LSTM neural network to be important elements in the forwarding candidates election process of the opportunistic routing algorithm. Furthermore, to enhance the efficiency of both energy use and information transfer, a novel metric is suggested to support the selection of potential nodes. This metric takes into account the relay priority, which takes into account the nodes' past performance and residual energy. The prediction of solar energy harvesting is a time sequence forecasting issue where the projected solar energy prediction value is the output and the historical solar energy sample series is the input. In the desired function, the predicted outcome is computed as one of the variables of E_j. There are three layers in the network: input, hidden, and output. The LSTM layer is the hidden layer; it contains about 200 hidden units that can be modified in light of several datasets. The fully connected layer and regression layer make up the output layer, and the prediction value for the subsequent time step is the result of the LSTM network. The adaptive motion estimation (Adam) technique was employed for the gradient descent algorithm of the long short-term memory. The network's inability to sense and communicate was impacted by the imbalance between energy harvesting and consumption, which led to the network's high energy consumption.

An article by [15] suggested a Differentiated Secure Opportunistic Routing (DSOR) in MANETs using a

Game Theoretic Approach. The operation of DSOR is categorized into the following: The determination of the trust value, routing parameters established on auction, and changing discharge selection algorithm. The first part, which is the determination of trust value is achieved in two ways; (i) Direct determination of trust value, and (2) Indirect determination of trust value. In the determination of the trust value, the sum of the data forwarding ratio of the present forwarding discharge and the sum of the present discharge forwarding ratio is considered. A price mechanism is employed in establishing the route. The pricing is categorized into two groups (resources prices and services prices) based on the condition of the resources, the nodes' level of trust in the MANETs, and the quality of the links. The price and condition of resources are inversely related, according to economic theory. Using the example of node energy, the price is little when the node's unexhausted energy is enough, and vice versa. Prior to starting to forward data, the node first determines the price, which is then broken down into the cost of resources and the cost of services. The cost of resources is made up of two costs: the cost of energy and the cost of bandwidth. These costs rise as the remaining resources become scarcer and as the costs of resources for a given forwarding service rise. The relationship between service price and quality of service is inverse, suggesting a high likelihood that a good node will provide a significant benefit.

In the paper by [2] suggested an Energy Efficient Markov Prediction based Opportunistic Routing (EEMPOR) to enhance energy efficiency of wireless sensor networks. Potential Forwarder Set (PFS), nodes' priority, and packet forwarding are all determined by EEMPOR based on anticipated variables such as the node's amount of transactions and remaining energy. It selects and ranks the possible forwarder set by using a Markov prediction-based technique to estimate the quantity of transactions of each neighbour node of the source node. To provide energy-efficient routing, nodes with a low transaction count and a high residual energy are chosen and given priority. There are four main phases to the proposed EEMPOR scheme: (i) Using a Markov chain, anticipate how many transactions a node will have in the future. (ii) Calculating the energy utilised by the node (iv) Calculating the node's residual energy (iii) Markov prediction-based opportunistic routing for a possible forwarder set (v) Choosing and Setting Priorities. The proposed EEMPOR protocol did not take into consideration the distance between sensor nodes; thereby resulting in high energy consumption for nodes that are far apart from the source node.

The authors in [16] suggested An adaptive ranking based energy-efficient opportunistic routing protocol-AREOR. By applying adaptive participation criteria, AREOR determines which node is most suitable to act as a cluster leader. The process is centered on the dynamic node ranking, whereby the forwarder node in the AREOR is chosen based on the ranks. For dynamic ranking, the node's position—its distance from the closest forwarder node—and its residual energy are the two key factors. To determine which node should be the forwarder, AREOR sets up a ranking table and chooses a group of candidate nodes. Various criteria, including the distance between nodes and the node's residual energy, are utilised to select the forwarder node among the neighbours of the source node. A parameter's value is used to rank and prioritise all of the source node's neighbours in addition to the cluster head. The forwarding node is chosen from among the nodes that have the most remaining energy and are closest to the source node. Similarly, forwarders are chosen continually, working their way from sources to targets. The adaptive ranking nature of the proposed protocol involves so much computations and requires so much time; thereby resulting in high energy loss.

In the paper by [17] suggested an Optimized Multi-layered Self-assertive Routing as a way to cut time and improve communication link reliability. The primary benefit of the Optimized Multi-layered Self-assertive Routing scheme is that it fully utilizes the energy that is still present within networks to boost the power transmission of the majority of nodes, resulting in higher communication reliability or longer transmission distances. To enhance network performance, the Optimized Multi-layered Self-assertive Routing strategy is suggested to use two methods for optimization known as COOR(R) and COOR(P). In order to boost power for transmission, COOR(R) approach selects a sensor node with greater communication trustworthiness with the identical range as the next candidate relay node. The COOR(P) method, on the other hand, favors a node that has the same communication dependability over a greater distance.

It is obvious that several models have been provided by existing routing protocols to enhance network performance and efficiency. However, these models inherently possess some sort of weaknesses that do not make them wholly efficient. Retransmissions of data, Broadcast storm problem, availability of routing table, and active/sleep mode of nodes are the main factors influencing energy consumption and impacting the network's lifespan, identified challenges with existing protocols. This paper therefore proposes a cross-layer energy-efficient routing algorithm that chooses candidate nodes from nearby nodes based on their distance from one another and their rate of energy consumption in order to create the best possible route from the source node to the destination node.

3 METHODOLOGY

The proposed CLEE algorithm operates in two phases. In the first phase, the algorithm selects Candidates Nodes from sensor nodes within the network by computing the distances and energy consumption of the nodes. The distances are computed using the Euclidean distance formula. In the second phase; a Designated Node is selected from the candidates nodes using a Cross-Layer Design Architecture to establish an optimal route from the source node to the target node.

3.1 Phase 1: Candidate Node selection

The algorithm begins with the candidate node selection from the sensor nodes within the network. A pseudocode of the algorithm for this first phase is presented in Algorithm 1.

Algorithm 1 Pseudocode for Candidates' Selection

```
Input: Function get_candidate_nodes(from_node)
Initialize distance_met_nodes as an empty list
Set lowest_distance to infinity each nodeID in nodes
Get the node corresponding to nodeID the node is not the same as from_node
Compute the distance from source_node and the other_nodes the computed distance is less than lowest_distance
Update lowest_distance with the computed distance the computed distance is less than or equal to distance_the_for_candidates
Add the node to distance_met_nodes distance_met_nodes is empty
Raise an exception stating no candidate node found for the given distance threshold and the closest candidate distance
Initialize candidate_nodes as an empty list
 Set lowest_consump to infinity
 For each node in distance_met_nodes
 Compute the energy consumption between from_node and the node the computed energy consumption is less than lowest_consump
 Update lowest_consump with the computed energy consumption the computed energy consumption is less than or equal to energy_consump_the_for_candidate
 Add the node to candidate_nodes If candidate_nodes is empty
 Raise an exception stating no candidate node found for the given energy consumption threshold and the lowest energy consumption
 Return candidate_nodes
 End Algorithm
```

3.1.1 Computation of Distance

In n-dimensional space, the Euclidean distance computes the shortest distance between any two locations. Consider the following generic point p, whose coordinates are: $p = (p_1, p_2, p_3, p_4, ...)$. To determine how far a given point (p) is from another point (q), the Euclidean Distance Formula is given as shown in equation (1).

$$d(p,q) = \sqrt{(q_1 - p_1)^2 + (q_2 - p_2)^2 + (q_3 - p_3)^2 + ...} \tag{1}$$

$$d(p,q) = \sqrt{\sum_{i=1}^{n}(q_i - p_i)^2} \tag{2}$$

Where n is the dimensionality of the space.

The Euclidean distance formula is used to compute the distances between the source node and its neighbour nodes. The Euclidean distance formula was able to accurately compute the distances between the nodes, and thereby was able to identify the shortest distance possible. The results obtained from the computation of the distances are used as an input variable to compute for the energy consumption of a node to transmit N number of bits of data.

3.1.2 Computation of Energy Consumption

When a node X transmits N bits of data to a node Y, the energy used is computed using equation (3).

$$E(_{xy}) = [E_l + (\epsilon_{f_s}/\epsilon_{mta})D(_{x,y})]N \quad (3)$$

Where $D(_{x,y})$ represents the distance from node "x" to node "y", E_l represents the current available energy, ϵ_{f_s} represents the free space, and ϵ_{mta} represents the multipath transmitter amplifier, and N represents the number of bits. Each of these variables ($D(_{x,y})$, E_l, ϵ_{f_s}, ϵ_{mta}, and N) are input values for the computation of the energy consumption.

3.2 Phase 2: Designated Node selection

The second phase of the algorithm to select the viable designated node in presented in Algorithm 2. The algorithm begins by identifying a set of candidate nodes for data transfer. It then calculates four key metrics for each candidate: Signal Quality Score (SQS), Throughput (TH), delay (D), and Link Lifetime (LL). SQS is computed for each candidate node, and the results are normalised to a range of 0 to 1. This normalisation is achieved by dividing each SQS by the range of all computed SQSs. The same process is applied to TH and LL. For delay, which ideally should be minimised, the algorithm first computes the sum of transmission delay and packet delay for each candidate. These values are then normalised in the same manner as the other metrics. However, to ensure that candidates with lower delay are given preference, the normalised delay values are subtracted from 1. The algorithm then calculates a score for each candidate node based on a weighted sum of the four normalised metrics. The weights allow the network to prioritise certain metrics over others based on its specific requirements. Finally, the algorithm sorts the candidates in descending order of their scores and returns this sorted list. This ensures that the node with the highest score, indicating the most suitable candidate for data transfer, is selected first. The normalisation process ensures that each metric contributes proportionally to the final score, preventing any single metric from dominating the others. This makes the algorithm adaptable to different network configurations and performance requirements.

Algorithm 2 Pseudocode for Designated Node Selection

```
Input: Function sorted_nodes(from_node, transfer_data_size, candidates) candidates is None then
candidates = get_candidate_nodes(from_node, transfer_data_size)
SQSs = array of compute_SQS(c) for each c in candidates
Return Return candidate_nodes
normalize SQSs
throughputs = array of throughput for each c in candidates
normalize throughputs
delays = array of (transmission_delay + packets_delay) for each c in candidates
normalize delays
link lifetimes = array of compute_link_lifetime(c) for each c in candidates
normalize link lifetimes
scores = SQSs * weights[0] + throughputs * weights[1] + lls * weights[2] + delays * weights[3]
sorted_data = sort (candidates, scores / sum(scores)) by score in descending order
Return sorted_data
End Algorithm
```

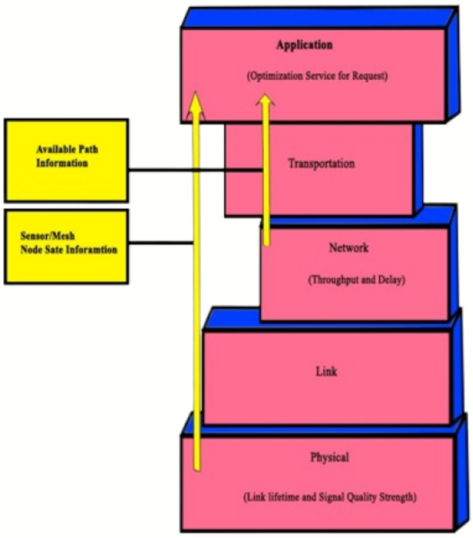

Fig. 2. The Proposed CLEE Architecture Design

3.3 Cross-Layer Metrics

Direct communication exchange between non-adjacent layers is the basis of cross-layer information transfer. Fig. 2. is a schematic diagram of the proposed CLEE Architecture design; as shown in the diagram, information obtained from the Physical layer is communicated directly to the application layer without altering the structure between layers. Likewise the information obtained from Network layer. The suggested cross-layer interaction technique computes the signal quality strength and link lifetime at the physical layer before transmitting the results to the application layer. Delay and throughput are also computed from the Network layer and transmitted to the Application layer. The Application layer then selects a designated node based on the transmitted values received from the Physical and Network. There will only be one active route accessible at any given moment.

Next, we present some definitions for the cross-layer measurements used in the proposed protocol.

- **Physical layer Metrics:** Link Lifetime and the Signal Quality Strength are the two metrics that are considered and computed for in the physical layer.

  1. *Link Lifetime:* Link lifetime is referred to as a variant of chance that represents the length of time a prospective node-to-node link could last between the moment a receiver enters a transmitter's communication region and the time it leaves the region [18].

     $$LL = \frac{d}{v} \tag{4}$$

     Where d represents the distance from the node and v represents the velocity of the node.

     Neighbours nodes with greater LL are more likely to be recognised when a node tries to form a link. As a result, a node chosen has a greater LL [18].

  2. *Signal Quality Strength:* Is defined as the wireless signal power level received by a sensor node in a wireless network [19].

     $$SQS = \omega + (\rho + \mu)\log_{10} D_{xy} \tag{5}$$

     Where ω represents weighting constant of the node, ρ represents path loss components of the source node and μ represents path loss components of the node that SQS is being computed.

- **Network Layer Metrics:** Throughput and the Delay are the two metrics that are considered and computed for in the network layer.

1. *Throughput:* Is the total time required for a sensor node within a wireless network to receive the very last packet [20].

$$TH = \frac{D_s}{D_{ts}} \quad (6)$$

Where D_s represents data size, and D_{ts} represents data transmission time.

$$D_{ts} = Packet\ Delay + Transmission\ Delay \quad (7)$$

2. *Delay:* The amount of time each packet takes to move from source to destination in a wireless network is referred to as the delay [21].

$$D = T_d(N - 1) + (\Im * P_d) \quad (8)$$

Where T_d represents transmission delay, N represents number of packets, $\Im$ represents number of hops and P_d represents packets delay.

In the event that two or more nodes are tied, the designated node will be the one with the shortest distance to the source node. This process is summarised in a pseudocode in Algorithm 3.

Algorithm 3 Normalization Function

```
1: function normalize(array)
2: range = max(array) - min(array) range == 0 then
3: array = array of ones with same shape as array
4: array = array / range
5: End Algorithm
```

4 RESULTS

A network of size 600 x 600 was created for a simulation experiment. Four separate simulations were conducted with the first simulation having 20 sensor nodes. The number of sensor nodes was varied by adding 10 nodes consecutively for each simulation. The network is built such that the least distance between any two nodes is 70m. The distance threshold for the selection of the candidate node was set to 300m and the energy consumption threshold was set to 7J. A summary of the simulation parameters is presented in Table 1. Network Simulator 3 (NS3) was used for the simulations.

Table 1. Simulation Parameters

Parameters	Values
Network Size	600m x 600m
Number of Nodes	50 max
Initial Energy	30J
Average Speed of Nodes	5m/s
Simulation time	500s

4.1 Performance Metrics

The proposed CLEE routing algorithm was compared with two state of the art routing algorithms: Ad-Hoc On-demand Distance Vector (AODV) Routing Algorithm, and Dynamic Source Routing (DSR) Algorithm. The following three performance metrics were assessed: Throughput, energy usage, and end-to-end delays. For each performance metrics, four different simulations were performed usings equations 9 - 11.

$$Energy\ Consumption = \frac{Total\ Energy\ Consumed}{Total\ Packets\ Received} \quad (9)$$

$$Throughput = \frac{Number\ of\ Packets\ Received}{Simulation\ Time} \quad (10)$$

$$Delay = \frac{Time\ between\ reception\ of\ first\ and\ last\ packet}{Total\ Packets\ Received} \quad (11)$$

The values obtained from the computation of the performance metrics: Energy Consumption, Throughput and Delay are summarised in Table 2, Table 3, and Table 4 respectively.

Table 2. Energy Consumption Comparison

	20 nodes	30 nodes	40 nodes	50 nodes
ADOV	8.92	12.45	17.38	20.75
DSR	7.75	12.65	16.25	20.19
CLEE	8.50	12.05	16.05	18.95

Table 3. Throughput Comparison

	20 nodes	30 nodes	40 nodes	50 nodes
ADOV	8.74	12.91	16.98	21.43
DSR	9.27	13.11	17.68	21.94
CLEE	9.30	13.50	17.48	22.03

Table 4. Delay Comparison

	20 nodes	30 nodes	40 nodes	50 nodes
ADOV	0.09	0.06	0.05	0.04
DSR	0.11	0.07	0.06	0.05
CLEE	0.10	0.06	0.04	0.04

4.2 Simulation

4.2.1 Energy Consumption

Fig. 3. displays the energy usage curve for a range of node counts. The sum of energy consumption of CLEE, AODV, and DSR from Figure 3 are 55.55, 59.50, and 56.84 respectively. Representing the energy consumption values in percentages; CLEE had approximately 56% , AODV had approximately 60%, and DSR had approximately 57%.

4.2.2 Throughput

Fig. 4. illustrates how throughput changes in kbps as the number of nodes increases. The sum of throughput of CLEE, AODV, and DSR from Fig. 4. are 62.31, 60.06, and 62.00 respectively. Representing the throughput values in percentages; CLEE had approximately 62% , AODV had approximately 60%, and DSR had approximately 62%.

4.2.3 End to End Delay

Fig. 5. graph shows the comparison of CLEE, AODV, and DSR algorithms. The graph shows that as the number of nodes increases, the end-to-end delay for CLEE, AODV, and DSR algorithms reduces. The sum of end-to-end delay for CLEE, AODV, and DSR from Fig. 5. are 0.24, 0.24, and 0.29 respectively.

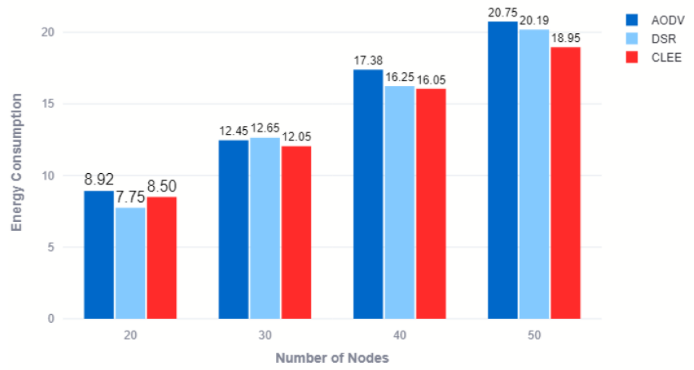

Fig. 3. Energy Consumption against Number of sensor nodes

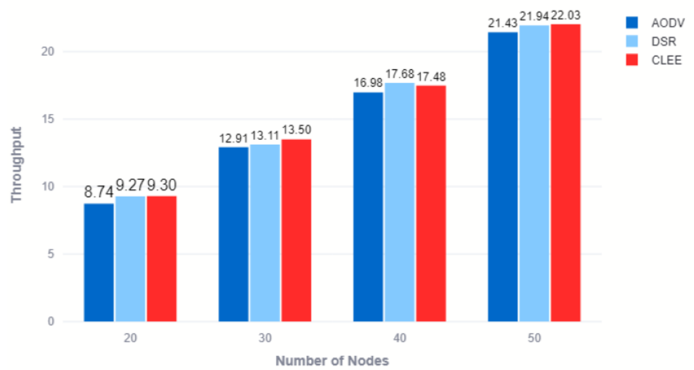

Fig. 4. Throughput against Number of sensor nodes

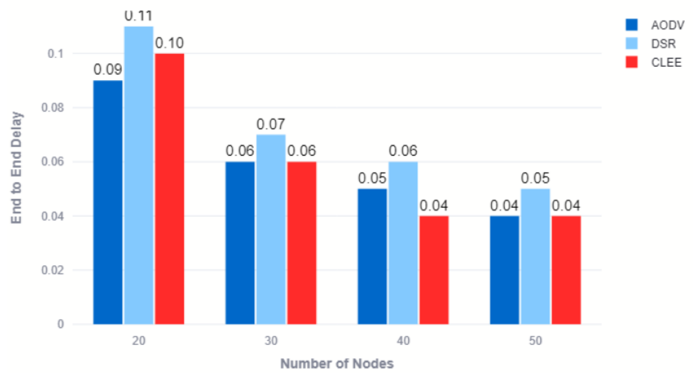

Fig. 5. Delay against Number of sensor nodes

5 CONCLUSION

The paper presented an opportunistic three-layered cross-layer routing algorithm: the physical, network, and application layers. The proposed algorithm establishes an optimal route between the source node and the destination node by selecting candidates from the neighbour nodes of the source node; after which, a designated node is selected from the candidates nodes using a cross-layer architecture design. The proposed algorithm avoids the use of routing tables and storing of route path by nodes in the network. Once a node forwards a data packet to another node, the route information is deleted from the memory of the forwarding node. This mechanism has resulted in a significant reduction in the usage of energy in the network. According to the simulation findings, the suggested method outperformed AODV and DSR in terms of energy usage. The proposed algorithm only performed better than AODV in terms of throughput, and performed better than DSR in terms of end-to-end delay. This improvement is attributable to the suggested algorithm's cross-layer design, which leads to the selection of routes with less energy and a lower distance.

6 LIMITATIONS AND FUTURE SCOPE

The limitation of the proposed algorithm is its inability to support a large number of sensor nodes. CLEE is most suitable for small-scale mobile Ad-hoc Networks. We propose using artificial intelligence to determine the protocol's route in future improvements.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

[1] Paranavithana P, Jayakody A. Compromising aodv for better performance: Improve energy efficiency in aodv. In 2017 6th National Conference on Technology and Management (NCTM). 2017;201-204.

[2] Nagadivya S, Manoharan R. Energy efficient markov prediction based opportunistic routing (EEMPOR) for wireless sensor networks. In 2019 IEEE international conference on system, computation, automation and networking (ICSCAN). 2019;1-6.

[3] Hasan N, Mishra A, Ray AK. Fuzzy logic based cross-layer design to improve quality of service in mobile ad-hoc networks for next-gen cyber physical system. Engineering Science and Technology, an International Journal. 2022;35;101099.

[4] Bhusari AA, Jawandhiya P, Thakare V. Optimizing performance of anonymity based secure routing protocol utilizing cross layer design for mobile adhoc networks. In 2018 Fourth International Conference on Computing Communication Control and Automation (ICCUBEA). 2018;1-6.

[5] Shafi S, Bhandari B, Ratnam DV. A cross layer design for efficient multimedia message dissemination with an adaptive relay nodes selection in vanets. In 2018 Conference on Signal Processing and Communication Engineering Systems (spaces). 2018;81-84.

[6] Zuo J, Dong C, Ng SX, Yang LL, Hanzo L. Cross-layer aided energy-efficient routing design for ad hoc networks. IEEE Communications Surveys & Tutorials. 2015;17(3);1214-1238.

[7] Shawky MA, Usman M, Imran MA, Abbasi QH, Ansari S, Taha A. Adaptive chaotic map-based key extraction for efficient cross-layer authentication in vanets. Vehicular Communications. 2023;39;100547.

[8] Chu Y, Mitchell P, Grace D, Roberts J, White D, Mickus T. Iris: A low duty cycle cross-layer protocol for long-range wireless sensor networks with low power budget. Computer Networks. 2023;225;109666.

[9] Sarwesh P, Mathew A. Cross layer design with weighted sum approach for extending device sustainability in smart cities. Sustainable Cities and Society. 2022;77;103478.

[10] Rajpoot V, Tripathi VS. Cross-layer design based hybrid mac protocol for cognitive radio network. Physical Communication. 2022;50;101524.

[11] Shivakumar KS, Patil VC. An optimal energy efficient cross-layer routing in manets. Sustainable Computing: Informatics and Systems. 2020;28;100458.

[12] Lin Z, Li G, Li J. Cross-layer energy optimization in cooperative miso wireless sensor networks. Computer Communications. 2020;157;351-360.

[13] Mathew R, Amrutha P, Sahoo S, Kovoor BC, Nijagunarya Y. Manet with opportunistic auto-rate anthocnet protocol. In 2020 International Conference on Recent Trends on Electronics, Information, Communication & Technology (RTEICT). 2020;98-103.

[14] Lin Z, Li G, Li J. Cross-layer energy optimization in cooperative miso wireless sensor networks. Computer Communications. 2020;157:351-360.

[15] Zhong X, Lu R, Li L, Wang X, Zheng Y. Dsor: A traffic-differentiated secure opportunistic routing with game theoretic approach in manets. In 2019 IEEE symposium on computers and communications (ISCC). 2019;1-6.

[16] Chithaluru P, Tiwari R, Kumar K. AREOR-adaptive ranking based energy efficient opportunistic routing scheme in wireless sensor network. Computer Networks. 2019;162:106863.

[17] Xu X, Yuan M, Liu X, Liu A, Xiong NN, Cai Z, Wang T. A cross-layer optimized opportunistic routing scheme for loss-and-delay sensitive wsns. Sensors. 2018;18(5): 1422.

[18] Nayebi A, Sarbazi-Azad H. Analysis of link lifetime in wireless mobile networks. Ad Hoc Networks. 2012;10(7):1221-1237.

[19] Necsulescu P, Schilling K. Signal strength based manet routing protocol: Cost calculation and performance evaluation. IFAC Proceedings. 2013;46(29):144-149.

[20] Chen Y, Liu J, Jiang X, Takahashi O. Throughput analysis in mobile ad hoc networks with directional antennas. Ad Hoc Networks. 2013;11(3);1122-1135.

[21] Gao J, Shen Y, Jiang X, Li J. Source delay in mobile ad hoc networks. Ad Hoc Networks. 2015;24;109-120.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/112053