Pertanika J. Sci. & Technol. 34 (S1): 69 - 87 (2026)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Congestion Control Using Link Estimation and Energy-Awareness in Wireless Sensor Networks

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ABSTRACT

A WSN is a mobile node network that generates and configures its own data and transmits it wirelessly to the entire network. The topology of a network is constantly changing because nodes are mobile. Due to the instability of the link, dynamic topologies result in link failures, decreased bandwidth, and a decrease in QoS. Ensure that the wireless link is stable, the bandwidth is available, and the nodes have sufficient energy to communicate reliably. In WSN routing, packet loss increases delay and energy consumption for retransmission since multipath routing considers optimal hop counts. The paper proposes a Link Estimation Indicator and Energy-Awareness Routing Scheme (LEI-EA) for WSNs to address these issues. A link estimation indicator (LEI) is used to determine whether a link is stable or unstable. A LEI-EA scheme utilises the residual energy of neighbour nodes to determine multipath routing and maintain link stability, reliability, and network longevity. As part of the simulation, extensive testing has been conducted using the event-driven simulation tool (NS2), and the proposed LEI-EA scheme has been compared to existing dynamic routing schemes.

Keywords: Disjoint Links, link indicator (LEI-EA), link quality, WSN

ARTICLE INFO

Article history:
Received: 07 March 2026
Accepted: 13 April 2026
Published: 24 July 2026

DOI: https://doi.org/10.47836/pjst.34.S1.04

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INTRODUCTION

The development of wireless communication and internet services has been boosted by advances (Wang & Li, 2015; Yazıcı et al., 2014).

e-ISSN: 2231-8526

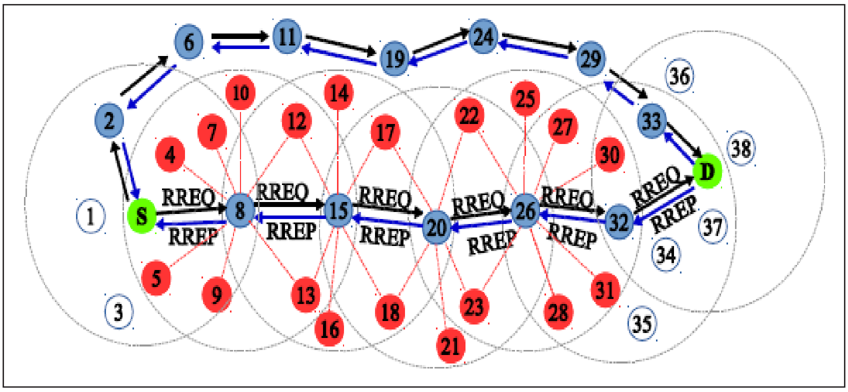

Figure 1. Routing process

Wireless communication technologies such as networks. Digital 5G networks will benefit from WSN 's features and functionalities (Agiwal et al., 2016; Huang et al., 2017). WSNs communicate wirelessly, and they are self-organised, configured, and controlled nodes (Helen et al., 2014; Suma & Harsoor, 2022d). Unlike traditional networks, WSNs have no constraints on how the nodes move or where they leave shows in Figure 1. The type of network topology and the energy resource determine this. Using mobile nodes as routers, packets are forwarded among the collaborating nodes. By incorporating routing functions into the routing protocol, packets are forwarded through single-hop or multi-hop routes. Within the transmission range, the node communicates directly with other nodes. When a node out of communication range cannot forward packets, intermediate nodes are selected. Dynamic links between nodes often break, resulting in packet loss (Suma & Harsoor, 2022b).

Recent studies have focused on fault-tolerant routing. When using fault-tolerant routing in the WMSN, reliability, availability, and consequent independence are typically ensured. Because a sensor node's energy remains low after a certain time, fault-tolerant routing algorithms are required to recover from the path loss. Furthermore, fault-tolerant routing is essential for critical monitoring applications. In contrast, it doesn't implement Request-To-Send or Clear-To-Send handshake mechanisms to solve the Hidden Node Problem (Koubâa et al., 2009). Vertex-disjoint multipath routing allows the Hidden Node Problem at sink nodes caused by its two different 1-hop neighbours (Cao et al., 2013). The HNP can result in severe repercussions for QoS performance. Despite RTS/CTS' capability to reduce hidden terminal problems (Barroca et al., 2014), it also controls heavy traffic, limiting the effective throughput.

In multipath routing, HNP nodes are disjoint at the sink node, and this should be avoided without the RTS/CTS method (Kuipers et al., 2005). In conventional single-layered (CSL) systems, this method allows interaction, but data exchange between non-adjacent layers is not possible. CSL provide quality of service but does not give optimum results.

Whereas CSL by Hamid and Hussain (2014) gives the optimum result for routing protocols. Triangle Interference Geographic Routing problem contributes to the node disjoint interreference for multiple paths by routing cost, which gives link quality, residual energy and distance. Choosing one-hop minimum hop distance and IEEE 802.15.4, the sink node of TIGMR overlooks the sink Hidden Node Problem, while RTC/CTS. The minimum distance is selected based on routing cost by a 1-hop neighbour node. HNP at the sink node in the IEEE 802.15.4 network (Yang et al., 2018). TIGMR ignores the HNP at the sink node without consideration of the hand-off, which provides link quality called triangle metric by Baono et al. (2010) and Baccour et al. (2013). TIGMR provides soft transition information exchange on another alternative path before the path is disconnected because of more usage of energy. Distinguishing TIGMR from the state-of-the-art Two-Phase Geographic (TPGF) by Bennis et al. al (2014) and link quality by Aswale and Ghorpade (2017).

There is a challenge in providing reliable routing due to WSN topologies and link failures (Barroca et al., 2014; Kuipers et al., 2005; Suma & Harsoor, 2022e). An energy-aware Link Estimation Indicator-based Ad hoc on Demand Routing scheme based on Link Estimation Indicator is proposed in this article for WSNs' adaptation of the AODV protocol. A link estimation indicator (LEI) is employed to ascertain the stability of links between nodes if node disjointness may result in a link failure. The objective of an LEI is to guarantee stable connections between nodes and to ascertain the amplitude of the signal. LEI-EA chooses forwarding nodes with high residual energy for dependable data transmission, fair bandwidth consumption, and energy balancing (Mafirabadza et al., 2016). The following are examples of contributions:

- Media access control (MAC) signals influence the quality of the link estimation indicator (LEI) for individual nodes.
- It optimises residual energy to extend network lifespan and enhance data transmission efficiency by guaranteeing the availability of link bandwidth for high-quality communication.

Nodes in a WSN are usually mobile, so they can adapt to topology changes constantly without relying on fixed infrastructure. Coordinating with each other, mobile nodes act as routers and hosts, establishing connections between sources and destinations (Ali et al., 2014). Congestion can be avoided by checking the status of intermediate nodes through route discovery between pairs of nodes. Routing breaks are common in dynamic behaviour, moving aspects, for example, bandwidth, energy resources, mobility, and channel decline (Kalansuriya et al., 2009). Stable links between two nodes are essential for dependable communication. There has been considerable research on the features of low-power radiocommunication links, and these links are error-prone, asymmetric, and unreliable due to the hardware and environment. Since topology changes dynamically, it is difficult to estimate link quality. Routing performance can be increased by estimating link quality or path stability. The challenge of determining path stability to avoid congestion is to recommend a scheme in which the path stability is determined between contributing nodes while founding a route. Path steadiness is determined by measuring the link quality of joining nodes by a link estimation indicator and the outstanding energy of nodes. Received signal strength from the MAC layer and offered bandwidth ensure high-quality communication and achieve QoS parameters like amplified throughput, higher packet delivery ratio, and low computational overhead. To prolong network lifespan and ensure reliable data transfer, forwarder nodes must be energy-aware.

The rest of this paper is organised as follows. Section II describes the problem statement and motivation. Section III describes the related works. The proposed mechanism scheme is described in Section IV. Section V describes the results and evaluation. Section VI describes the comparison results. A conclusion on the proposed scheme is drawn in Section VII.

Problem Statement and Motivation

Wireless sensor networks (WSNs) lack inherent fixed or centralised infrastructures, as their topologies are constantly evolving (Otero et al., 2011). The mobile node functions as a router and host, coordinating with other mobile nodes and establishing connections between a source and destination (Xu et al., 2018). Routing between two nodes necessitates an assessment of the condition of intermediate nodes before establishing a route. Route breakages in Wireless Sensor Networks (WSN) occur often and impact critical aspects including bandwidth, energy consumption, mobility, and channel fading. The reliability of communication between two nodes is contingent on the stability of the links. Hardware and environmental factors are responsible for the error-prone, asymmetric, and unstable properties of low-power wireless connections (Baccour et al., 2013; Yang et al., 2018). Estimating and maintaining connection quality can be problematic due to the continuous changes in routing topology (Girirajan et al., 2023; Suma & Harsoor, 2022e). Link quality or path stability must be precisely determined for optimal routing performance. Assessment of route stability is difficult. A way to evaluate the association stability between two nodes while establishing a route. The measurement of path stability is conducted by utilising link estimation indicators (LEIs) and the residual energy of nodes. The signal intensity at the MAC layer and the range of available bandwidth influence Quality of Service (QoS) characteristics, for example, increased data transfer rate, improved packet delivery ratios, and reduced computing burden (Suma et al., 2024). Energy-conscious forwarder nodes are chosen to guarantee dependable data transmission and promote network longevity.

Related Works

The LQEAR protocol (Smail et al., 2014; Suma & Harsoor, 2022e). finds discontinuous connections over various pathways, extending network lifespan. The LQEAR evaluation estimates Link Quality (LQ) and residual energy measures using LQ indicators (Girirajan et al., 2023; Suma & Harsoor, 2022c). Superior one-hop forwarding nodes ensure transmission reliability. This protocol assesses LQ erroneously and provides useless wireless link features for routing. AOMR-LM is an energy-efficient multipath routing protocol that balances node energy usage. Multipaths are chosen using node residual energy. Energy harvesting is ensured by threshold energy and coefficient analysis. Despite being able to extend WSN 's lifetime and improve routing performance without relying on channel fading, this protocol does not depend on link failures to diminish network lifetime. Power-efficient AODV routing scheme (EPA-AODV) (Deepa et al., 2019; Suma et al., 2024). Route request packet headers (RREQ) are added with residual energy fields. RREQ packets are manipulated by intermediate nodes on arrival, and residual energy is checked. Data is sent to a qualifying neighbour if residual energy exceeds the threshold. Dogra et al. (2021) and Singal et al. (2014) introduced dynamic energy-efficient (DE-AODV) to reduce end-to-end latency and enhance network resilience. This protocol selects reliable, energy-efficient nodes using a battery-powered mechanism to dynamically supply external energy. Nodes consume less energy when they are supplied with external battery power whenever a link failure occurs, extending the life of the network. The strength of the signal received determines the link stability of a reliable path (Malwe et al., 2017; Suma & Harsoor, 2020a). An expiry time is calculated for each node in a path along with the expiry times for all other links. A zone-based routing scheme is proposed in Lin et al. (2012) and Marriwala (2022) that considers link availability and reduces the number of broadcast packets generated by RREQ. RSSI and a threshold are used to divide each node's transmission range into inner, middle, and outer zones. The middle zone performs route discovery. Route discovery takes place at nodes in the middle zone. Localisation and angular sectors within the transmission range are used to calculate the neighbouring link availability ratio. In this technique, packets loop, causing routing overhead. It also takes more hops, which increases the number of hops. Predicting connection failures before they happen might enhance service (Gupta & Marriwala, 2017; Yadav et al., 2015). Route availability is determined by the stability of the link. As a means of estimating the stability of the link and predicting the failure of the link, Newton divided difference interpolation is proposed in this scheme. A proactive connection failure between two nodes generates an alternate path.

Shu et al. (2010) describe the MPMP routing protocol as an extension of the TPGF routing protocol. A maximum amount of streaming data is transmitted, and an end-to-end delay guarantee is ensured. Streams of multimedia data are separated into streams of audio and images. Priorities are assigned based on multimedia content context and transmission delay. The path with the lowest delay is assigned to the stream with the highest priority. Despite this, processing overhead increases when multimedia data streams are decomposed and combined.

LIEMRO establishes interference-minimised node-disjoint paths for event-driven sensor networks (Radio et al., 2011). Energy remaining, ETX, and interference level determine the selection of nodes. Infusion of data traffic is achieved using a load-balancing algorithm. A highly competitive channel, however, significantly affects protocol performance. AGEN (Adaptive Greedy-compass Energy-aware Multipath) routing protocol improves network lifetime by implementing load-balancing. Smart greedy forwarding and walking backwards are both used in AGEM. Using the first mode, a 1-hop neighbour is always closer to the sink than the present node. An alternative mode if the 1-hop neighbour is unavailable. In addition to ensuring uniform energy consumption, AGEM also guarantees quality of service. The route divides the entire network topology into many districts and enables data to be transmitted simultaneously without interference (GEAM). The distance between districts is sufficiently large to avoid transmission interference. The methodology does not guarantee QoS, but it provides efficiency when the topology changes.

Unkai et al. al 2014 PASPEED dynamically adjust the transmission power on the reserve with the least distance delay. Thus, PASPEED improves the network efficiency and lifetime due to minimum delay. Along with three others, priorities of the packets with reliability requirements are assigned.

Magaia et al. (2015) WMSN routing considers QoS for multi-objective and evolutionary algorithms using a genetic algorithm by SPEA. ETX and delay give solutions to discover the minimum path. ETX uses parameters for routing decisions with asymmetric links. Wang et al. (2015) designed the PWDGR protocol to explain energy bottlenecks at sinks. When a sink has a 360 ° scope, PWDGR finds destination nodes in a pairwise manner. Therefore, the seriousness of the situation has increased. Efforts are made to minimise the energy burden around the sink. A dense WMSN performs better with PWDGR. While saving energy, it compromises on delay and energy. With the Cross-Layer Channel Utilisation and Delay Aware Routing protocol, evidence can be exchanged between the MAC and network layers to discover improved routing routes (Hamid et al., 2016). Packet Service Time (PST) and remaining energy determine which forwarding node would be used. CUDAR chooses nodes with the lowest PST and the lowest dispute during route discovery while maintaining the shortest possible path. As a result, CUDAR offers improved delay, jitter, and throughput. A Carrier Sense Aware Multipath Geographic Routing Protocol (CSA-MGR) uses a dynamic and distributed mechanism to identify multiple disjoint paths while avoiding any shared carrier sense ranges (Bennis et al., 2016).

Carriers sense ranges their place at the intrusion range or transmission range to deal with adjacent path interference effects during path discovery. By incorporating Number of Common Neighbours (NCN) metrics and zigzag avoidance mechanisms, CSA-MGR ensures additional efficient and faster route discovery. CSA-MGR is faster, more reliable, and more efficient than TPGF.

As a result of adaptive traffic shaping and the Real-Time Video Streaming Protocol (ARTVP), we can achieve optimal multimedia coding complexity and utilise multipath forwarding to provide optimal multimedia coding quality (Ahmed, 2017). The forwarding node is selected based on the RSSI (Received Signal Strength Indicator), the residual energy, and the delay of the signal. Depending on the multimedia content of the packet, packets are classified according to their priority and are directed down the most reliable path based on the priority of the packet. The ARTVP can switch from single-path to multi-path traffic based on the multimedia traffic being transmitted and vice versa. A high-performance protocol like this will ensure the longevity of a network and ensure high performance. Partitioning Multi-constrained Multipath Routing (PMMR) protocol is intended for real-time video flowing in WMSN (Hasan et al., 2017). In this protocol, a planned novel metric prioritises sensor nodes based on the link quality. Depending on the decision constraints, an objective function's path is selected. A mix of integer programming and mixed integer optimisation is used to control the adaptive switching. As a result of the PMMR protocol, network lifetime is increased, and QoS is guaranteed.

Aswale and Ghorpade (2017) demonstrate how the LQEAR protocol improves network lifetime by discovering node-disjoint multiple paths. The forwarding node is chosen according to its Link Quality Indicator (LQI), lingering energy, and distance from its one-hop neighbour to the sink (Marriwala et al., 2024; Venugopal et al., 2025). To provide reliability, it selects links with higher quality according to the LQI metric. However, the LQI metric does not provide accurate estimates of the quality of wireless links and therefore is unsuitable for link-quality-based routing protocols.

Proposed Mechanism

In Figure 2, the process of a blackhole attack on packet drop in a wireless sensor network. Initially, the system deployment of WSN where nodes are configured in network topology is established. The transmission of data packets takes place through a routing protocol. protocol checks for packet drops during the transmission process. If there is no packet drop is detected, then transmission proceeds directly to performance analysis. Performance is analysed by parameters like throughput, delay, and PDR. However, if a packet drop is observed, the event. In such cases, a malicious node initiates the blackhole attack by falsely advertising itself

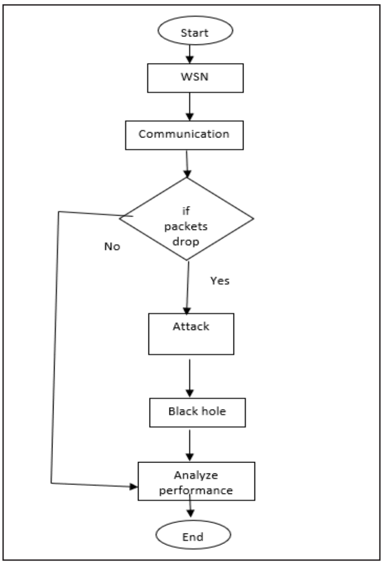

Figure 2. Flow chart on blackhole attack to analyse the performance of packet drop

as the optimal route to the destination. As a result, it attracts data packets and drops them instead of forwarding, causing packet loss. Thus, the network performance degrades. Finally, the system analyses the performance by parameters.

Network Model

Mobile nodes are randomly distributed and have many neighbours within their transmission range. A graph $G_n = (V_n, L_n)$ $V_{n_{speed}} = (distance_{V_n} / time_{V_n})$ mps where V_n is the number of nodes and Ln is their link, representing network communication. The link between source and represented as $(s_n, d_n) \in V_n$. Source node s_n direct interaction with the destination node d_n via a single hop if it is within communication range, or via multi-hop if not. Nodes are dynamic, so topology changes are unpredictable. Dynamic movement prevents two nodes from sharing a stable connection due to their varying speeds (Lin et al., 2012). A reliable network is necessary because node speed is independent of place and time. Slower nodes generate more stable links. Measuring the total distance travelled in that time frame yields a mobile node V_n with variable speed (Yazıcı et al., 2014).

During route discovery, the routing cost function finds the advancing node inside the transmission range r for two nodes, V_{n_a} and V_{n_b} $D_{V_{n_a},V_{n_b}} = \sqrt{(y_i - y_j)^2 + (x_i - x_j)^2}$. The 1-hop neighbour node of V_{n_a} is V_{N_a} and has coordinates (x_i, y_i) and(x_j, y_j) Goldsmith et al. (1997).

To calculate node transmission range r, use the RSSI threshold value and error probability of 10^{-3} 3) as stated as bit error rate $V_{N_a} = \left(V_{n_b} | D_{V_{n_a},V_{n_b}} \leq r\right)$.

The Mobility Model

Real-time nodes incorporate GPS to precisely determine their position, speed, and velocity within the transmission area. The localisation method provides information about the speed, position, and direction of mobile nodes at any given time. Real-time nodes utilise GPS to precisely determine their position, speed, and velocity within the transmission area.

A localisation algorithm gives the mobile node's speed, position, and direction. The random waypoint model (RWP) sometimes assesses network node mobility, connection failure, and stability. In an RWP-configured network area, nodes move randomly with minimum and maximum velocity, as well as pause periods. Nodes move based on their velocities $[v_{n_{max}}, v_{n_{min}}]$ and direction, δ, between [0, 1]. Assuming the node's current position at the time instant t_n is $((x_i(Vt_{n_i}), y_i(Vt_{n_i})))$, the original location after incrementing the time interval Δt is obtained.

The node's direction of signal is signified by $\delta_i(t_n)$ for the ith node at time instant t_n, and its speed is indicated by $v_i(t_n)$.When node velocity is at its highest, the value of $\delta_i(t_n)$ is 0; when it is at its lowest, it is 1 $\begin{cases} x_i(t_n + \Delta t) = x_i(t_n) + \Delta t * v_i(t_n) cos\delta_i(t_n) \\ y_i(t_n + \Delta t) = y_i(t_n) + \Delta t * v_i(t_n) cos\delta_i(t_n) \end{cases}$.

The Link Status and Stability

The Euclidean distance $DV_{n_{ij}} = \sqrt{\left(y_i(t_n) - y_j(t_n)\right)^2 + \left(x_i(t_n) - x_j(t_n)\right)^2}$ between pairs of nodes V_{n_i} and V_{n_J} at time t_n. can be used to determine the connection status of nodes.

This enables the estimation of mobile nodes' RSSI transmission range $r\tau_i$ or $r\tau_j$ for link status $L_{n_{ij}}(t_n) = \begin{cases} 1, & if DV_{n_{ij}}(t_n) \leq r\tau_i \text{ or } r\tau_j \\ 0, & otherwise \end{cases}$.

Hence, the network between the source and destination at any given moment t_n can be expressed as a matrix of $V_N \times V_N$, where the link status components enable connection determination. At time t_n, we represent a connection between a pair of nodes as '1' if it exists, and as '0' if it does not.

The Link Estimation Indicator (LEI)

Two mobile nodes V_{n_i} and V_{n_J} will be linked if they are in the transmission range rτ, have known speeds, phase angles, and beginning positions (x_i, y_i) and (x_j, y_j). Estimating the steady connection quality between two mobile nodes V_{n_i} and V_{n_J} is conceivable.

where $a = v_{n_i} cos\delta_i - v_{n_j} cos\delta_j$: $b = (x_i - x_j)$: $c = v_{n_i} sin\delta_i - v_{n_j} sin\delta_j$: $d = (y_i - y_j)$

When $v_{n_i} = v_{n_j}$ and $\delta_i = \delta_j$, where a and c become zero, a stable connection will exist. Nodes will remain during when the value of $LEI_{V_{n_{ij}}} = \infty$, $LEI_{V_{n_{ij}}} = \frac{-(ab+cd) + \sqrt{(a^2+c^2) r\tau^2 - (ad-bc)^2}}{(a^2+c^2)}$ if Nodes are travelling in the same direction and at the same speed. Since nodes can travel in various directions and speeds, the stability of a connection between two nodes is determined by the value of $LEI_{V_{n_{ij}}}$ value (). The following is one possible form of link stability $LS_{V_{n_{ij}}} = 1 - e^{\frac{-LEI_{V_{n_{ij}}}}{\alpha}}$.

The suggested technique predicts link failure by adding the RSSI parameter to the link state, where α is constant. Reduce T while finding the Hello message to prevent outdated information, given that T is inversely proportional; the next hop node to $LEI_{V_{n_{ij}}}$. The equation is: $LF_{V_{n_{ij}}} = 1 - e^{\frac{RSSI\,(V_{N_a}).LEI_{V_{n_{ij}}} V_{ND}}{\alpha . T}}$ indicates link failure prediction. $LEI_{V_{n_{ij}}}$

finds stable links, while RSSI checks the strength of signals at nodes in the transmission range during the route cost function for a neighbour V_{N_a}. Hello, the interval is T, and the node density is V_{ND}.

Energy Consumption

Optimising energy consumption and using energy-efficient intermediate nodes for reliable data delivery help extend the network's lifespan. Routing protocols connect nodes and identify data transmission pathways. Energy depletion causes some network nodes to fail. To ensure reliable data transmission, the proposed approach monitors intermediate-node residual energy. Because the network is homogeneous, all nodes start at the same time. At time instant, the initial enegy intermediated V_{n_i} is represented by e_{int} while e_{res} designates the residual energy for the specified period; determine the residual energy of the node V_{n_i} as $e_{res}\ (t_n + \Delta) = \ e_{int}\,(t_n) - e_{cons}\,(t_n + \Delta)$ represents the energy used by the node V_{n_i} to transmit, receive, and calculate internal activities. The implied method calculates node energy for data forwarding and reduces link fluctuation in unstable connections due to channel fading $e_{t_x}(t_n + \Delta) = d_s \times p_{t_x}(t_n + \Delta)$. In the above formula Δ , Watts per second $p_{t_x}(t_n + \Delta)$ measures the power consumption during data packet transmission and control message exchange with an intermediary node. To calculate the energy of the receiving node during packet reception $e_{r_x}(t_n + \Delta) = d_r \times p_{r_x}(t_n + \Delta)$.

At time $(t_n + \Delta)$, $p_{r_x}(t_n + \Delta)$ represents the power used for receiving data packets d_r. The node consumes energy during internal computations, including processing digital signals, updating encoding, and decoding at time intervals Δ, indicated as $e_{comp}\ \ (t_n + \Delta)$. The total energy needed by a node V_{n_i} during the period Δ for transmission, reception, and computing is $e_{cons}\ (t_n + \Delta) = e_{t_x}(t_n + \Delta) + \ e_{r_x}(t_n + \Delta) + \ e_{comp}\ \ (t_n + \Delta)$.

Thus, node residual energy is computed as $e_{res}\ (t_n + \Delta) = \ e_{int}\,(t_n) - \ \{e_{t_x}(t_n + \Delta) + e_{r_x}(t_n + \Delta) + \ e_{comp}\ \ (t_n + \Delta)\}$. For efficient data packet forwarding, LEI-EA routing picks nodes with greater residual energy. Proposed LEI-EA routing scheme selects nodes with higher residual energy for forwarding data packets efficiently.

Link Estimation Indicator and Energy Aware (LEI-EA) Algorithm

Set_RTR_PROT = **LEI-EA**

Set_node = V_{n_i}

Set_Source = V_{n_s}

Set_Dest = V_{n_d}

LEI-EA_method( ) {

Proc broadcast Hello ($V_{n_{ij}}$) to find neighbour

Initialise route discovery process

Calculate RSSI (Received signal strength) distance between nodes:

$RSSI = -(10 * log_{10}\left(dV_{n_{ij}}\right) - A$

$dV_{n_{ij}} = 10^{\frac{RSSI-A}{-10*n}}$

where $dV_{n_{ij}}$ is distance between node V_{n_i} and V_{n_j} : $n = 2$ for propagation free space model : A= -32(dBm) signal strength between two nodes.

Get_Link_Status of two nodes by $L_{n_{ij}}(t_n)$

Predict link failure and estimate link quality by $LEI_{V_{n_{ij}}}$

Update routing information in routing table

Update energy levels of the nodes in the network

Check

If (e_{res} $(t_n + \Delta) >= High$ && $dist <= low$ && $hop\ count\ <= low$)

Select route for communication

else

check link stability

end if

RESULTS AND DISCUSSIONS

Simulation Parameters

Two scenarios are used to assess the proposed O-LEADM system and compare it to AODVLP. This scenario varies node speed and simulation duration while maintaining the node size at 50. Network Simulator (NS2) is used for simulation. CBR traffic is used. The network distributes nodes randomly within a 1000x1000 m region. Because of their varying speeds, mobile nodes change topology frequently. The node transmission range is 250 m, and its starting energy is 100 joules. The suggested method was tested in two situations. The energy threshold was 50 joules. Node speed is varied (10, 20, 30, 40 m/s), maintaining simulation time and packet size (100 seconds, 512 bytes). Other network settings are the same for all runs. The second scenario mimics 50, 100, 150, and 200 seconds at 30 mm/s and 512 bytes.

Performance Metrics

Packet Delivery Ratio

$PDR = \frac{number\ \ of\ received\ \ packets}{number\ \ of\ transmitted\ \ packets} * 100$, the Packet Delivery Ratio is a measure of how many packets were transmitted from the source to the receiver, in comparison with packets received at the receiver to the destination. This measure indicates how well a routing protocol transmits data packets from source to destination. The routing mechanism will be more efficient if the ratio is high.

Throughput

A destination's throughput is its bit success rate. $Throughput = (total\ received\ bytes\ * 8/\ time) * 1000\ Kbps$ the unit. An efficient routing protocol must be able to receive data packets at their destination for it to be measured. The following formula is used to calculate throughput.

End-to-end Delay

A network end-to-end delay is the time it takes to receive a packet of data and retransmit it to other nodes across the network $E2E = \sum T_1 - T_2 \,/\, N$.

A packet arrives at a given time T_1, is sent by the source at a specific time T_2, and is sent by the N total number of packets.

Energy Consumption

Simulated network node energy usage. Node energy consumption is the difference between initial energy assigned at simulation start and ultimate energy squandered $E_{cons} = \sum_{i=1}^{n}\big(ini(i) - ene(i)\big)$.

SIMULATION RESULTS

Packet Delivery Ratio

According to Figure 3a, AODVLP and Link Estimation Indicator and Energy Aware Routing Scheme (LEI-EA) deliver packets at different rates. Packet drop occurs when the link breaks at a high node speed, leading to a low packet delivery rate. A packet delivery ratio greater than 100 is observed in the AODVLP scheme as speed increases, but a greater packet delivery ratio is observed in the LEI-EA scheme when speed reaches its maximum. An alternate route will be dynamically selected if the original route has low residual energy

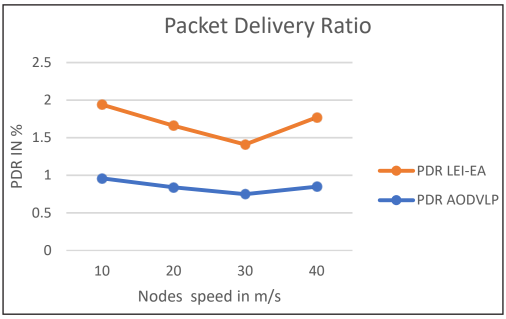

Figure 3a. PDR versus node speed

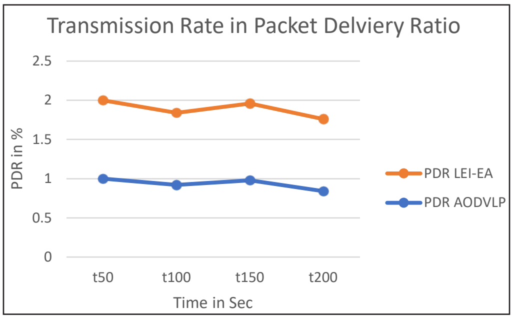

Figure 3b. PDR versus transmission rate

and if the link is considered stable. This method is used to ensure the reliability of the data transfer.

Figure 3b shows a simulated time-dependent packet delivery ratio. Longer simulations boost packet delivery. The plot demonstrates that both systems return the same packet ratio at 50, 100, and 150 seconds. In 200-second packet ratios, LEI-EA outperforms AODVLP. As simulation time increases, LEI-EA selects better data traffic pathways.

Throughput

The throughput graph is in Figure 4a Simulations show throughput differences between AODVLP and LEI-EA. LEI-EA and AODVLP have different throughput speeds. When nodes move randomly, LEI-EA calculates RSSI connection status, forwards data to the next node, and estimates link quality to identify more stable pathways.

Figure 4b shows simulation time variation. Compared to AODVLP, LEI-EA improved with simulation time. Increasing the simulation duration reduces packet dropouts. According to LEI, LEI-EA delivers packets to active nodes with better link quality via routes with higher energy and consistent connection quality.

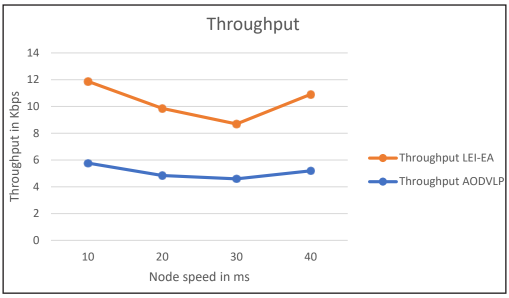

Figure 4a. Throughput versus node speed

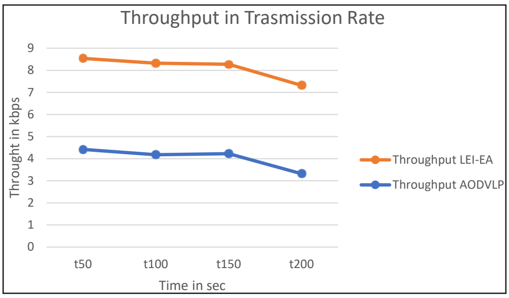

Figure 4b. Throughput versus transmission rate

End-to-End Delay

When choosing a route, the AODVLP does not consider intermediary node energy. Nodes with higher speeds are delayed. Based on mobility speed, LEI, and energy, LEI-EA chooses optimal routes and intermediate nodes. By stabilising the dynamic network, it regulates its end-to-end latency. With different simulation times, Figure 5a and 5b display the average end-to-end delay graph. Over time, LEI-EA becomes slower than AODVLP. LEI-EA selects routes with a minimum hop distance of 200 sec, reducing network transmission time.

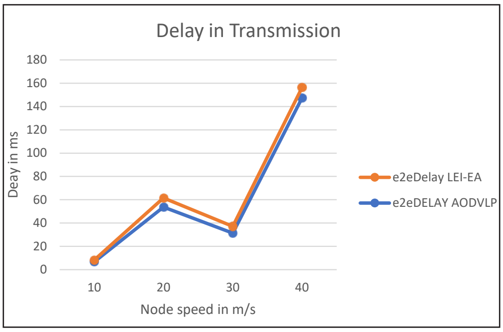

Figure 5a. End-to-end delay versus node speed

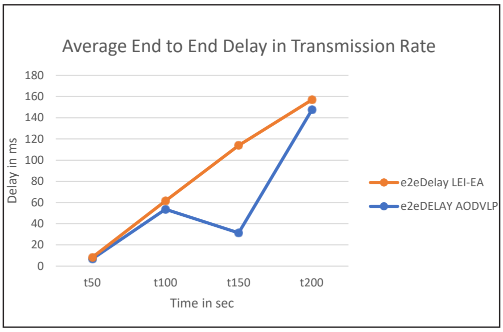

Figure 5b. End-to-end delay versus transmission rate

Energy Consumption

As shown in Figures 6a and 6b, network operations consume an average amount of energy. Nodes moving at different speeds are shown in Figure 6(a). Mobility speed increases the complexity of route computation for network topologies. In a network with higher average node density, retransmission and reroute discovery are reduced, saving time and extending the life of the network. Comparative analysis of LEI-EA versus AODVLP shows LEI-EA reduces energy consumption. The LEI-EA scheme maintains route stability and an energy balance that enables packets to be transmitted to relay or intermediate nodes with the highest residual energy. AODVLP consumes more energy because it reconstructs routes and sends more RREQ packets to find alternate routes. As displayed in Figure 6b, energy comparisons with varying simulation times are shown. According to LEI-EA, routes are classified, and nodes are selected based on the amount of energy they consume. Nodes in the network consume more energy as the simulation time increases. Comparing LEI-EA to AODVLP, simulation results indicate that LEI-EA delivers data packets more efficiently, prolonging network lifetime.

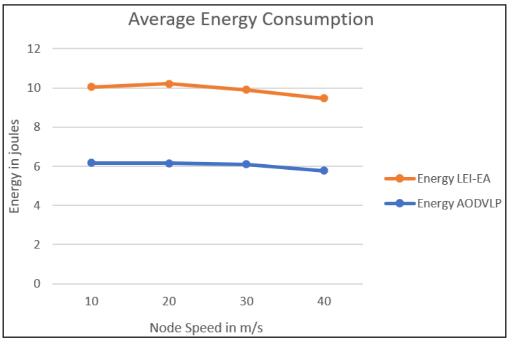

Figure 6a. Energy consumption versus node speed

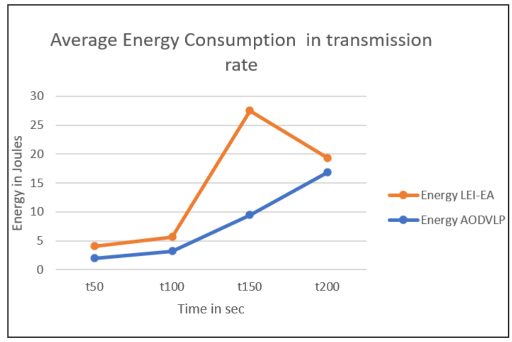

Figure 6b. Energy consumption versus transmission rate

Overhead

The overhead for LEI-EA is 5.10 to 17.6, while for AODVLP it is 5.11 to 12.1. LEI-EA shows remarkable improvements in mobility when compared to AODVLP Figure 7. Whenever a black hole is detected, LEI-EA shows lower overhead when it discovers the alternative paths. Therefore, path discovery in AODVLP has higher overhead when it is compared to LEI-EA.

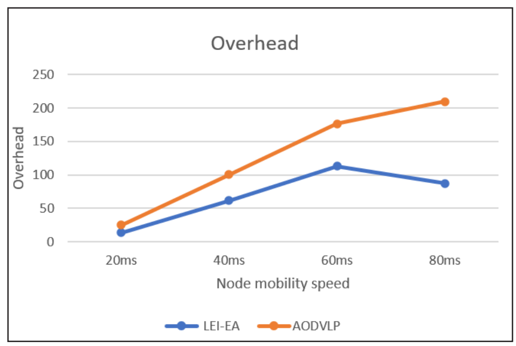

Figure 7. Overhead vs node mobility speed

CONCLUSION

Mobile ad hoc networks (WSNs) integrate routing capabilities into mobile nodes to allow reliable and effective mobile wireless network operation. Distributed nodes that communicate multi-hop with one another make up a WSN. When nodes move often, topological changes and link failures cause link disjoints and lower network performance. We must maintain path stability to identify the best multipath from source to destination and keep the path stable. A single parameter does not determine the efficiency of WSN data transmission. Packet loss, connection failures, and energy consumption plague WSNs. An energy-aware multipath routing strategy is suggested for WSN routing. Energy-aware routing scheme with link estimation indicator (LEI-EA). A link estimation indicator (LEI) can be used to compute the dependability of data transfer. The proposed LEI-EA system and the AODVLP scheme are compared in NS2 by altering nodes and simulation time. A network's performance is assessed by looking at things like throughput, average end-to-end latency, packet delivery ratio, and energy use. Simulation findings show that LEI-EA outperforms AODVLP. When compared to AODVLP, LEI-EA uses less energy, has a lower latency, and offers a higher packet count. As nodes can discard packets when attacked, future improvements might investigate and use a variety of situations to examine the behaviour of nodes during data routing. A trust-based routing strategy that evaluates node trust values to ensure secure routing to a destination can be used to enhance the quality-of-service criteria.

ACKNOWLEDGEMENT

The authors sincerely thank their institution for providing the necessary facilities and support to carry out this research. We also express our gratitude to the reviewers for their valuable comments and suggestions, which helped improve the quality of this manuscript.

LIST OF ABBREVIATIONS

WSN	:	Wireless Sensor Network
LEI-EA	:	Link estimation indicator and energy-awareness routing scheme
LEI	:	Link estimation indicator
AODVLP	:	Ad hoc on-demand distance vector (AODV) link prediction.
PDR	:	Packet delivery ratio
O-LEADM	:	On-demand using link estimation and energy-awareness
RWP	:	Random waypoint
RREQ	:	Route request packet headers
RSSI	:	Received signal strength

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