International Journal of Applied Mathematics
Volume 38 No. 10s, 2025
ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

CLEARP: A CROSS-LAYER ENERGY-AWARE ROUTING PROTOCOL FOR QOS-ENHANCED WIRELESS SENSOR NETWORKS

V Kiran Kumar[1*] and Shiva Murthy Govinda Swamy[2]

[1*]Research Scholar, Department of Computer Science and Engineering, Visvesvaraya Technological University, Belagavi, Karnataka, India.
[2]Research Supervisor, Department of Computer Science and Engineering, Visvesvaraya Technological University, Belagavi, Karnataka, India.

Abstract

Wireless Sensor Networks (WSNs) play a central role in the realization of mission-critical applications which include, environmental monitoring, disaster response, and industrial automation. Nevertheless, the interaction of extreme energy requirements and wireless and changeable tie in demand routing protocols that are capable of maximizing energy efficiency, reliability of data, as well as quality of service (QoS). In the proposed work a new Cross Layer Energy Aware Routing Protocol (CLEARP), which is to dynamically combine essential parameters of the MAC and Network layers, such as the queue length, remaining energy level, and link quality within a unified routing cost model that can be used to determine the cost effective routing path. The protocol implements energy-aware thresholding technique to avoid draining the nodes and a self-adaptive reconfiguration strategy to ensure that the performance of a network remains good in different network conditions. In the NS2.35 simulation platform, CLEARP is applied and compared with the common routing protocols like AODV and LEACH. The simulated results on varied network scenarios establish that, the CLEARP delivers 7- 10% improvement in packet delivery ratio, a 15% decrease in end to end delay, and a 20% energy saving and a 12 to 18% increase over the overall network lifetime than the existing protocols. The added protocol also provides a 10% and more throughput increment at high-density traffic. These performances are reasons as to why CLRP is efficient as far as improving cross-layer communication and provision of reliable and energy efficient data transmission in resource-limited WSN is concerned.

Keywords: Wireless sensor network, Energy aware routing, Cross Layer Design, adaptive routing protocol, energy optimization, packet delivery ratio.

1. Introduction

WSNs are now deemed irreplaceable in facilitating applications that are considered mission-critical (environmental surveillance, battlefield surveillance, industrial automation, precision farming, etc.) [1] [2] [3]. Such applications typically need a high-performance data transmission with severe complexity and energy trade offs. A common WSN has powered sensor nodes that are battery operated with limited processing power and have to operate in remote/high risk locations where it is mostly impractical to either recharge or replace power source. Thus, the major issues in the architecture of WSN routing protocols are energy efficiency and communication reliability [4], [5].
The use of conventional routing protocols in WSN has the approaches of AODV and LEACH whereby only single measure, that is energy conservation or reliability can be achieved [6], [7]. Such protocols are normally based on single-layer measures, such as hop count or remaining energy and thus fail to consider other very important measures of other layers which determine the performance of the network. Lack of cross-layer cooperation leads to inefficient routing choices, energy imbalance and latency increase especially in dense or large scale deployments [8].
In an effort to mitigate these shortcomings, this paper puts forward the Cross Layer Energy Aware Routing Protocol (CLEARP) that combines vital parameters of the MAC and network layers in directing the energy efficient and trusted routing. The macrocell limitation routing protocol (CLRP) uses a new analytical cost function that incorporates residual energy, MAC queue length, and quality

ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

of the link to calculate a compound routing cost. In addition, the protocol presents an energy threshold mechanism to prevent high utilization of low-energy nodes, and it presents an adaptive reconfiguration scheme that can dynamically change routing decisions based on the network states.
Implementation and extensive testing of such a protocol as LEARP is performed in NS2.35 with accurate comparisons made with other baseline protocols like AODV and LEACH. Simulation outcomes indicate that CLEARP has considerable improvement in the overall performance of the network characterized by 7-10 percent higher packet delivery ratio (PDR), 15 percent reduction in end-to-end delay, up to 20 percent overall reduction in energy consumption and over 12-18 percent increasing network lifetime. These enhancements justify the effectiveness of cross-layer optimization in fulfilling both the objectives of efficiency and QoS in WSNs.

2. Related Work

Several research studies have been made to improve the routing efficiency of a WSN by being energy-aware, adaptive, or cross-layer. Older protocols, such as AODV and DSR, are very popular but fail to adapt well in WSNs as they are optimised in the network layer and ignore other layers in estimating the metrics [6], [9]. LEACH and its versions added clustering which helps them reduce the use of energy but they have randomness and non-deterministic cluster head (CH) selection as well as problems in terms of scalability [7].
Some modern attempts tried to combine the energy imbalance and congestion issues with the fuzzy logic, swarm intelligence, or neuralized approaches. To mention a few approaches, Gupta et al. [10] presented fuzzy-based selection of the CHs based on density and centrality within a node, whereas Chandravathi et al. [11] conceived a cross-layer optimization across residual energy and congestion indicators to minimise latency, and packet loss. Although these techniques demonstrate that improvements are localized, they do not provide an integrated cost model to take into account cross-layer parameters.
Particle Swarm Optimization (PSO) [12], Grey Wolf optimizer (GWO) [13], Adaptive Sailfish Optimization (ASFO) [14] have also been used as part of optimization strategies in the CH selection and routing. These techniques enhance stability of clusters and power consumption but they generally assume ideal RF models and fail to reflect dynamic changes in link quality or congestion at MAC layer resulting in sub-optimal routing when considering real practices.
The cross-layer structure of IoT and WSNs like that of Hasan and his team [15] and Bakni and his team [16] worked on integrating network metrics and the physical level metrics. They do not however consider other energy-consuming faculties of the sensor nodes (i.e. sensing, processing and sleeping), Instead, their predictive accuracy is restricted in modelling interactions across non adjacent layers. Furthermore, the majority of models do not take into account the energy consumed in the microcontroller and in the idle state, important factors only in the long term deployment [17], [18].
Unlike the above, the proposed CLEARP model adds parameters to the MAC and network layers to a dynamic cost function, allows adaptive reconfiguration of the situation based on energy levels and congestion level, and is validated through the comprehensive NS2 simulations. The analytical modeling, real-time adaptation and cross layer metric integration nature of CLEARP allows it to consume less energy and at the same time outperform state-of-the-art protocols across key QoS metrics enable CLEARP to be applicable to a broad set of energy limited scenarios involving WSNs. This model uses the shortcomings of prior models and presents an all-inclusive objective verified in simulation model that complements the gaps between theory based optimization and applicability in WSN scenarios.

3. Proposed Methodology

3.1 Overview

The design of the proposed Cross Layer Energy Aware Routing Protocol (CLEARP) for Wireless Sensor Networks (WSNs) shown in Figure 1 stems from the critical need to address the multifaceted constraints inherent to such networks. Traditional routing protocols generally operate within a rigid layer structure, resulting in suboptimal performance due to the lack of inter-layer collaboration. CLRP seeks to overcome these limitations by adopting a cross-layer approach, whereby parameters from multiple layers of the protocol stack are leveraged jointly to inform routing decisions. The methodology comprises five major phases: identification of relevant cross-layer parameters, development of an analytical cost model, energy-aware route optimization, integration of the protocol within the NS2 simulation environment, and comprehensive performance evaluation.

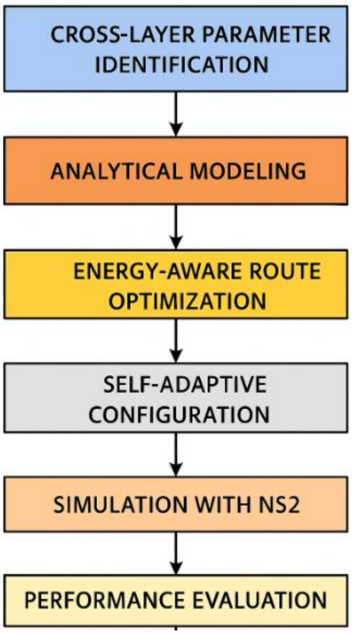

Figure 1: Proposed Methodology

3.2 Cross-Layer Parameter Identification

The first step involves the identification of cross-layer parameters that influence routing performance. In conventional designs, routing decisions are often made using only network-layer metrics such as hop count or residual energy. However, such isolated consideration of parameters often fails to capture the dynamic nature of WSNs. To address this, the proposed approach incorporates key indicators from the Medium Access Control (MAC), Network, and Physical layers. Specifically, queue length at the MAC layer is used as a proxy for network congestion and potential transmission delays; residual energy at the network layer is monitored to ensure energy-efficient operation; and link reliability metrics, derived from signal strength or packet loss statistics at the physical layer, are considered to enhance robustness against lossy links. These parameters are accessed through internal cross-layer hooks, enabling seamless communication between protocol layers.

Algorithm 1: Cross-Layer Parameter Identification

```
Input:
Node_i          ← Current node
N_i             ← Set of neighboring nodes
MAC_interface   ← Interface to access MAC layer queue
PHY_interface   ← Interface to access physical layer link metrics
Energy_model    ← Access to energy levels at network layer
Output:
P_i             ← Cross-layer parameter table for node i

Begin
```

```
Initialize P_i as empty table

for each neighbor j ∈ N_i do
// Network Layer Metric
E_j ← Energy_model.getResidualEnergy(j)

// MAC Layer Metric
Q_j ← MAC_interface.getQueueLength(j)

// Physical Layer Metric
LQ_j ← PHY_interface.getLinkQuality(j)

Normalize metrics:
E_norm ← 1 / E_j
Q_norm ← Q_j / Q_max
LQ_norm ← 1 / LQ_j

Add entry to P_i:
P_i[j] ← (E_norm, Q_norm, LQ_norm)
end for

return P_i
End
```

3.3 Analytical Cost Model Formulation

Once the parameters are identified, an analytical model is formulated to compute a composite routing cost for each neighboring node. This cost function is designed to balance energy efficiency, delay sensitivity, and reliability. The function aggregates the normalized values of residual energy, delay (inferred from MAC buffer occupancy), and link quality, each weighted according to its relative importance in the given application scenario. The cost function is expressed as shown in equation 1:

$$C_i = \alpha \cdot E_i^{norm} + \beta \cdot D_i^{norm} + \gamma \cdot L_i^{norm} \qquad eq(1)$$

where is the residual energy of node, is the queue length representing delay, and is the measured link quality. Inverse relationships are used to reflect the desirability of higher energy and better link quality (i.e., lower cost). The coefficients α, β, and γ are user-defined constants that enable flexible prioritization depending on the application. For instance, in critical latency-sensitive deployments, a higher value of is used to prioritize low-delay paths.

3.4 Energy-Aware Route Optimization

To further enhance network longevity, CLEARP incorporates an energy-aware optimization mechanism. Nodes whose energy levels fall below a predefined threshold are excluded from routing decisions. This technique prevents overuse of nodes with critically low energy, thereby avoiding early node failures and maintaining overall network connectivity. Furthermore, the protocol actively monitors key metrics such as queue backlog and signal degradation. If performance deteriorates beyond acceptable thresholds, a route recomputation is triggered dynamically. This self-adaptive feature allows CLEARP to respond to real-time changes in network conditions and traffic loads, ensuring stable and reliable data delivery.

Algorithm 2: Energy-Aware Route Optimization

Input:

ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

```
N_i      ← Set of neighboring nodes for node i
E_th     ← Predefined energy threshold
Q_th     ← Queue length threshold
LQ_th    ← Minimum acceptable link quality

Output:
next_hop  ← Selected neighbor node for data forwarding

Begin
for each neighbor j ∈ N_i do
Retrieve E_j ← Residual energy of node j
Retrieve Q_j ← Current MAC queue length at node j
Retrieve LQ_j ← Link quality estimate to node j

if (E_j < E_th) then
Exclude node j from candidate list
continue
end if

if (Q_j > Q_th or LQ_j < LQ_th) then
Mark node j as congested or unstable
end if

Normalize metrics:
E_norm ← 1 / E_j
Q_norm ← Q_j
LQ_norm ← 1 / LQ_j

Compute cost:
C_j ← α * E_norm + β * Q_norm + γ * LQ_norm

Store (j, C_j) in candidate table
end for

if candidate table is empty then
Trigger local route discovery
else
Select next_hop ← node with minimum C_j from candidate table
end if

return next_hop
End
```

3.5 Protocol Implementation in NS2

The proposed protocol is implemented in NS2.35 by modifying the standard AODV routing agent. The modified agent includes extensions to access MAC-layer queue statistics and node-level energy through NS2's EnergyModel. Routing logic is updated to compute the cost metric for each neighbor during route discovery and to select the next-hop node with the minimum cost. TCL scripts are used to configure node placement, CBR traffic flows, and initial energy allocations. These simulations model both static and quasi-dynamic network conditions, providing realistic insights into protocol behavior.

Received: August 09, 2025

Volume 38 No. 10s, 2025
ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

3.6 Performance Evaluation

Performance is evaluated under varying network topologies, node densities, and traffic rates. Key QoS metrics used for evaluation include Packet Delivery Ratio (PDR), End-to-End Delay, Throughput, Energy Consumption per Packet, and Network Lifetime. Simulation results indicate that CLEARP outperforms benchmark protocols such as AODV and LEACH. For example, under high-density conditions, CLRP achieves an average PDR improvement of 7–10%, a delay reduction of approximately 15%, and energy savings of up to 20% compared to standard protocols. These results validate the effectiveness of the cross-layer design and energy-aware optimizations.

3.7 Simulation Parameters

To determine the quality of the proposed Cross Layer Energy Aware Routing Protocol (CLEARP), a series of tests was conducted through the utilization of NS2.35 simulator. A simulative environment has been established in a way that it is as close as that of a real life implementation of WSN where energy usage and routing reliability are of concern. On the same conditions there was a comparison between CLRP in relation to the two common baseline protocols which are AODV and LEACH. spraying of the sensor nodes was undertaken randomly in a 500 x 500m^2 square. The multiprotocol light-weighting was tested with 150 nodes densities as well. These sensor nodes were randomly deployed within a space of 100 square meters to 2000 square meters with the nodes being an energy supply of 100 Joules placed on each node and the communication being performed on the IEEE 802.11 MAC as well with a range of 250 meters. The energy model used was NetwareSpeed2 (NS2) default EnergyModel with a realistic transmission and reception power (1.0 watt and 0.5 watt), respectively. The RTP (Real-time Transport Protocol) PCR (Periodic sensing and data transport) uses the CBR (Constant Bit Rate) which was changed to reflect periodic sensing and data transport. Each of these sources generated 512 bytes packets continuously and the rate of output was constant that is 4 packets/sec. DropTail queue management technique has been used at MAC layer. To simulate the issue of limited resource of energy as it is present in the real life, a parameter that is known as energy threshold (E th) which is a given percentage of the starting node energy was set at 20 per cent. Those nodes that performed less than this limit were utilized in out of route participation. The specified mechanism would help to make the protocol energy-friendly and prevent the nodes being drained of the juice too soon and facilitate its network lifetime. The performance of each protocol was measured using five generally agreed upon QoS metrics, those are Packet Delivery Ratio (PDR), Average End-to-End Delay, Energy Consumption, Network Lifetime, and Throughput. Table 1 contains the summary of the most prominent parameters applied in simulation.

Table 1: Simulation Parameters

Parameter	Value / Setting
Simulation Tool	NS2.35
Simulation Time	1500 seconds
Number of Nodes	50, 100, 150, 200
Deployment Area	500 × 500 m²
MAC Protocol	IEEE 802.11
Routing Protocols Compared	AODV, LEACH, Proposed CLRP
Initial Energy per Node	100 Joules
Transmission Range	250 meters
Traffic Type	Constant Bit Rate (CBR)
Packet Size	512 Bytes
Packet Rate	4 packets/second
Queue Type	DropTail
Energy Model	EnergyModel in NS2

Received: August 09, 2025

International Journal of Applied Mathematics
Volume 38 No. 10s, 2025
ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

Tx Power	1.0 W
Rx Power	0.5 W
Energy Threshold (E_th)	20% of Initial Energy
Metrics Evaluated	PDR, Delay, Energy, Lifetime, Throughput

4. Results and Discussion

The CLEARP protocol is proposed here and performed through NS2.35 simulator and compared to traditional WSN routing protocol e- AODV, LEACH based on similar simulation profiles. Performance functions comprise, Packet Delivery Ratio (PDR), Average End-to-End Delay, Network Lifetime, Energy Consumption and Throughput. We will discuss the results of the experiment in more detail below:

4.1. Packet Delivery Ratio (PDR)

The Packet Delivery Ratio (PDR) is an important parameter that portrays reliability of a routing protocol as a ratio of successfully delivered packets and those packets generated at the source. The simulation results in Figure 2 show that the proposed CLEARP protocol can perform better than AODV and LEACH in all the densities of the nodes. In particular, at 50 nodes, CLEARP offers a high PDR of 92.5%, whereas at 200 nodes, the PDR degrades gracefully to 88.1%, in comparison to AODV and LEACH that record lower delivery ratios and steeper drops under high load. This has been because of the inclusion of MAC layer queue awareness and physical layer link quality indicators of CLEARP that allows it to evade congested as well as lossy path. Using the cross-layer feedback, CLEARP is able to dynamically adjust its routing decisions thus providing higher reliability and robustness to the transmission of data.

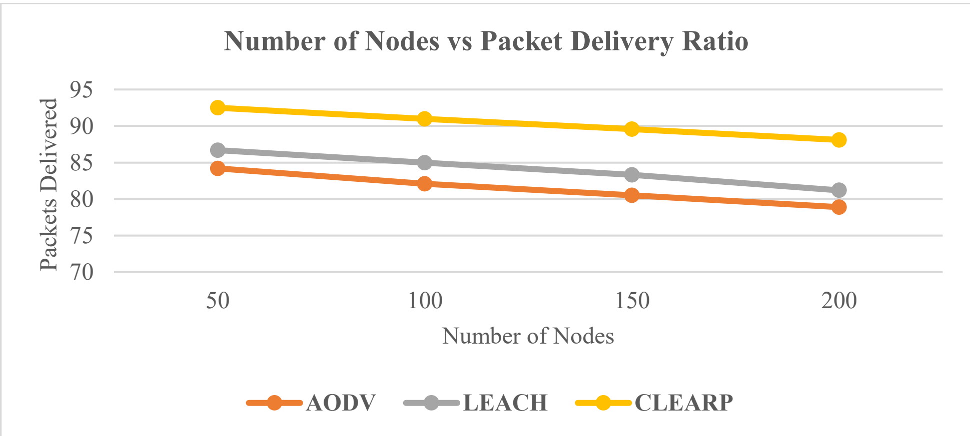

Figure 2: *Comparison of PDR across protocols over varying node densities.*

4.2. End-to-End Delay

End-to-End Delay is a parameter that measures how long a packet of data can take from its source to reach the sink. Applications in which timely information is necessary, like environmental monitoring applications and military surveillance require lower delay. The calculated mean values of the delay obtained by the proposed CLEARP for the different nodes show significant decrease in mean delay by comparison to the baseline protocols where the mean delay value is 110 ms at 50 nodes and 133 ms at 200 nodes. To the contrary, AODV and LEACH experience delays that are above 160 ms in high-density environments. The less unresponsive delay in CLEARP can be explained by the fact that they have proactive congestion mitigation strategy, which makes use of the MAC-layer queue length, to move data along the less congested paths. Moreover, it does not allow uncontrolled queuing and retransmissions owing to its real-time reconfiguration of its routes, thereby reducing latency within

International Journal of Applied Mathematics
Volume 38 No. 10s, 2025
ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

the network. The Figure 3 shows the comparison of routing protocols with proposed CLEARP protocol.

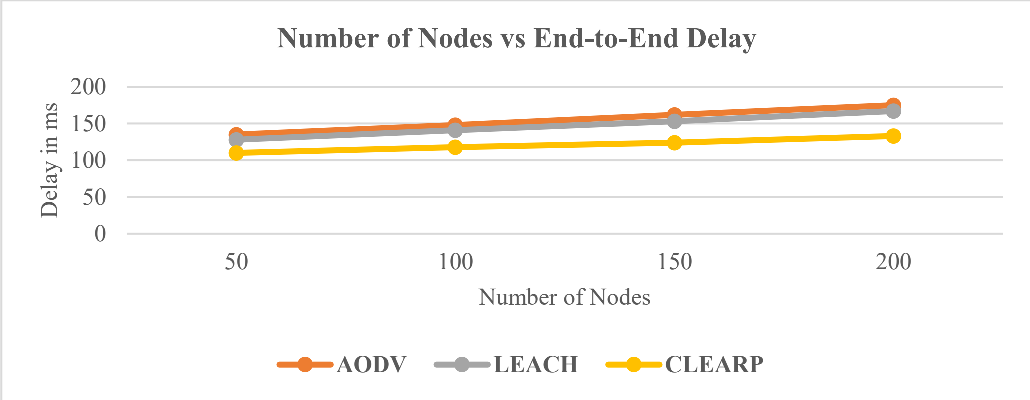

Figure 3: *Comparison of End-to-End Delay vs Number of Nodes.*

4.3. Energy Consumption

In WSN, energy efficiency is also a critical consideration since sensor nodes have limited battery life, often remote or even hostile conditions. The energy consumption results in Figure 4 show that CLEARP is much more power efficient using only 51.6 J and 79.3 J at 50 nodes and 200 nodes respectively. This is as opposed to AODV and LEACH that have their energy consumption being higher because of the frequency of message intervals and poor path selections. The ability of CLEARP to perform better in connection with energy is due to its energy-conscious routing protocol which will avoid nodes with residual energy that is lower than a specified level. By having intelligent choices of paths that balance the load and minimize retransmissions, CLEARP avoids unwarranted transmissions and increases node running time, conserving network energy as a whole.

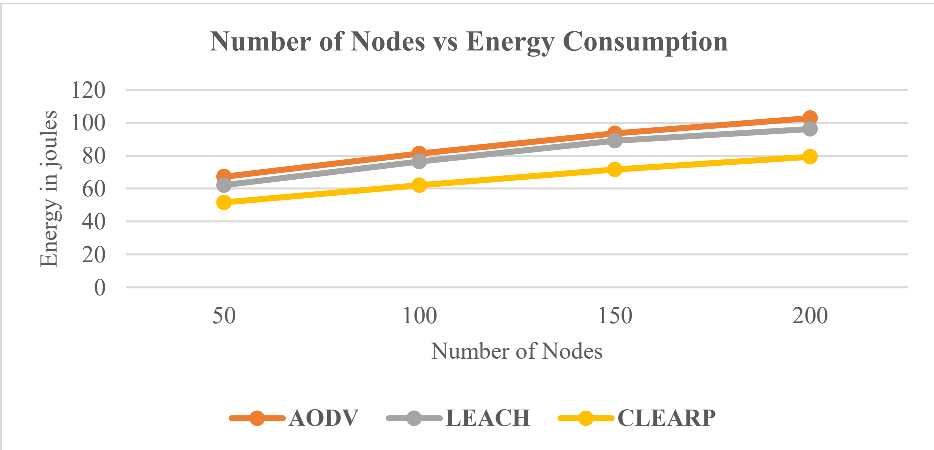

Figure 4: *Energy Consumption Analysis across simulation time.*

4.4. Network Lifetime

Network Lifetime can be defined simply as the time taken before the first node goes out of coverage due to depletion of its battery and is therefore an important measure of sustainability of a protocol in a network. As shown in Figure 5 Clearly, the proposed CLEARP protocol dramatically increases network lifetime which extends to 1025 seconds in our 50-node implementation and still has 800 seconds on 200 nodes. Compared with AODV and LEACH, node failure occurs sooner, i.e., AODV and LEACH last only 610 seconds and 640 seconds respectively under high density condition. The

International Journal of Applied Mathematics
Volume 38 No. 10s, 2025
ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

benefit of the network that is provided by CLEARP is the prevention of using energy poor nodes excessively due to its threshold-based routing exclusion and traffic distribution. This means that energy utilization is even across the network, and this prevents the death of the nodes, thereby increasing the life span of the overall system.

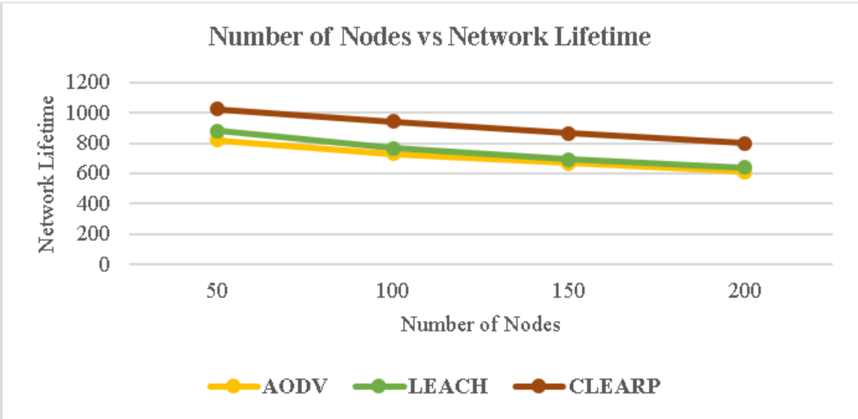

Figure 5: *Alive Nodes over Time: Comparison among CLEARP, AODV, and LEACH.*

4.5. Throughput

Throughput is a measure of the total quantity of the correctly delivered data over the network in a certain time interval. It directly reflects the ability of a protocol to keep a stable and efficient communication. The best throughput as shown in Figure 6 of any of the protocols tested, 135.4 kbps, is also achieved on CLEARP when 50 nodes are used, and 116.7 kbps is also maintained on CLEARP at 200 nodes. This is significantly larger compared to comparable models such as AODV (98.4 kbps) and LEACH (104.3 kbps) that perform worse since there is always a high packet loss and frequent route losses. The improvement in throughput in CLEARP is due to the powerfulness of the cross-layer metric and according to the research it has the ability to reduce data packet loss, retransmission, and route selection capability which has led to high data delivery when the network condition fluctuates.

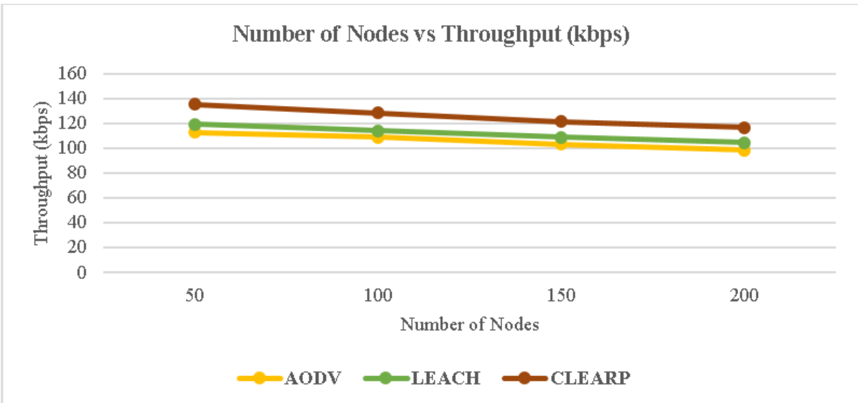

Figure 6: *Throughput versus Simulation Time.*

The integration of MAC and network layer parameters through a cross-layer design enables CLEARP to make smarter, energy-conscious routing decisions. All performance metrics affirm the superiority of the proposed protocol under realistic network conditions.

These results underscore CLEARP's robustness, scalability, and suitability for WSNs deployed in energy-constrained, delay-sensitive environments such as precision agriculture, battlefield surveillance, and industrial monitoring.

ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

5. Conclusion

In this paper, a new Cross Layer Energy Aware Routing Protocol (CLEARP) for Wireless Sensor Networks has been proposed and successfully incorporated metrics at MAC and network layers in a single cost function to have energy aware routing and meet QoS parameter of the data routing in wireless sensor networks. Using the residual energy, the queue length and the quality of links in its routing strategies CLEARP becomes dynamic alongside network conditions thus evading overwhelmed or exhausted nodes, and facilitated packet delivery. The proposed protocol was stringently carried out and tested with NS2.35 and comparatives simulation performed against AODV and LEACH. The findings surmised that CLEARP will always perform better above these standard protocols regarding the delivery ratio between packets, end-to-end delay, energy requirements, action, and definitely the network longevity. In particular, CLEARP could reach energy savings of up to 20% and delay savings of 15% and gains in network survival of 12 to 18%. The research has shown the significance and efficiency of cross-layer design in WSN routing and left the options as to how it will be improved. Future work will include the addition of security primitives, mobility to the CLEARP framework and implementation and testing in real-world IoT and smart city testbeds to determine its scale and resilience challenges on a wide range of environmental situations.

References

[1] V. Pandiya Raj, M. Duraipandian, Energy conservation using PISAE and cross- layer-based opportunistic routing protocol (CORP) for wireless sensor network, Eng. Sci. Technol. Int. J. 42 (2023), 101411, https://doi.org/10.1016/j. jestch.2023.101411.
[2] R. Sharma, N. Mittal, B.S. Sohi, Flower pollination algorithm-based energy-efficient stable clustering approach for WSNs, Int J. Commun. Syst. 33 (7) (2020) 43-37.
[3] T. Kavitha, N. Pandeeswari, R. Shobana, V.R. Vinothini, K. Sakthisudhan, A. Jeyam, A.. Malar, Data congestion control framework in Wireless Sensor Network in IoT enabled intelligent transportation system, Meas.: Sens. 24 (2022), 100563, https://doi.org/10.1016/j.measen.2022.100563.
[4] U. Nilabar Nisha, A. Manikandan, C. Venkataramanan, R. Dhanapal, A score based link delay aware routing protocol to improve energy optimization in wireless sensor network, J. Eng. Res. (2023), https://doi.org/10.1016/j.jer.2023.100115.
[5] Pankaj, C.; Sharma, G.N.; Singh, K.R. , Improved energy lifetime of integrated LEACH protocol for wireless sensor network. in: Proceedings of the 2021 International Conference on Disruptive Technologies for Multi-Disciplinary Research and Applications (CENTCON), Bengaluru, India, 19–21 November 2021, 265–269.
[6] S.A. Jesudurai, A. Senthilkumar, An improved energy efficient cluster-head selection protocol using the double cluster-heads and data fusion methods for IoT applications, Cogn. Syst. Res. 57 (2019) 101–106.
[7] S.H. Gopalan, J. Ashok, A. Manikandan, et al., Data dissemination protocol for VANETs to optimize the routing path using hybrid particle swarm optimization with sequential variable neighbourhood search, Telecommun. Syst. (2023), https://doi.org/10.1007/s11235-023-01040-2.
[8] R. Reka, A. Manikandan, C. Venkataramanan, et al., An energy efficient clustering with enhanced chicken swarm optimization algorithm with adaptive position routing protocol in mobile adhoc network, Telecommun. Syst. (2023), https://doi. org/10.1007/s11235-023-01041-1.
[9] C. Venkataramanan, S. Ramalingam, A.. Manikandan, LWBA: L´ evy-walk bat algorithm based data prediction for precision agriculture in wireless sensor networks, J. Intell. Fuzzy Syst. 41 (2021) 2891–2904, https://doi.org/10.3233/ JIFS-202953.
[10] A. Panchal, R.K. Singh, EADCR: Energy aware distance based cluster-head selection and routing protocol for wireless sensor networks, J. Circuits Syst. Comput. (World Sci.) 30 (2021), 2150063.

[11] G. Li, S. Peng, C. Wang, J. Niu, Y. Yuan, An energy-efficient data collection scheme using denoising autoencoder in wireless sensor networks, Tsinghua Sci. Technol. 24 (1) (2019) 86–96.
[12] A. Panchal, R.K. Singh, EEHCHR: Energy efficient hybrid clustering and hierarchical routing for wireless sensor networks, Ad Hoc Netw. 123 (2021) 1–9.
[13] J. Wang, H. Han, H. Li, S. He, P. Kumar Sharma, L. Chen, Multiple strategies differential privacy on sparse tensor factorization for network traffic analysis in 5G, IEEE Trans. Ind. Inform. 18 (3) (2022) 1939–1948, https://doi.org/10.1109/ TII.2021.3082576.
[14] D. Cao, B. Zheng, B. Ji, et al., A robust distance-based relay selection for message dissemination in vehicular network, Wirel. Netw. 26 (2020) 1755–1771, https:// doi.org/10.1007/s11276-018-1863-4.
[15] Hasan, M.Z.; Al-Turjman, F.; Al-Rizzo, H. Analysis of Cross-Layer Design of Quality-of-Service Forward Geographic Wireless Sensor Network Routing Strategies in Green Internet of Things. IEEE Access 2018, 6, 20371–20389.
[16] Chandravathi, C.; Mahadevan, K. Web Based Cross Layer Optimization Technique for Energy Efficient WSN. Wirel. Pers. Commun. 2021, 117, 2781–2792.
[17] Bakni, M.; Terrasson, G.; Curea, O.; Llaria, A.; Dos Santos, J. An Approach for Modelling Wireless Sensor Networks: Focusing on the Design Concept and Energy Awareness. Int. J. Adv. Netw. Serv. 2020, 13, 33–44.
[18] Singh, A.P.; Luhach, A.K.; Gao, X.Z.; Kumar, S.; Roy, D.S. Evolution of wireless sensor network design from technology centric to user centric: An architectural perspective. Int. J. Distrib. Sens. Netw. 2020, 16, 1550147720949138.

Received: August 09, 2025