

Low-Power Reliable Communication Protocol for Heterogeneous IoT Networks

Gaurav Mehta

UIE, dept. of ECE

Chandigarh University

Mohali, Punjab, India (140413) gaurav.e14354@cumail.in

Abstract— The rapid growth of the Internet of Things (IoT) has increased the demand for energy-efficient and reliable communication systems. IoT networks consist of heterogeneous devices with different computational capabilities, communication ranges, and energy constraints. Most IoT devices are battery-powered and operate in dynamic environments, making energy conservation and reliable data transmission critical challenges. Existing routing protocols often suffer from excessive energy consumption, uneven load distribution, packet loss, and reduced network lifetime. To address these issues, this paper proposes a Low-Power Reliable Communication Protocol (LPRCP) for heterogeneous IoT networks. The proposed protocol integrates adaptive clustering, residual energy-based cluster head selection, multi-hop routing, and reliable packet transmission mechanisms to optimize energy usage and enhance communication reliability. The protocol is implemented and evaluated using MATLAB simulations. Performance metrics such as network lifetime, energy consumption, packet delivery ratio, throughput, and end-to-end delay are analyzed and compared with existing protocols including LEACH, PEGASIS, and HEED. Simulation results demonstrate that the proposed LPRCP significantly improves network lifetime and communication reliability while reducing overall energy consumption. Therefore, LPRCP provides an efficient and scalable solution for heterogeneous IoT environments.

Index Terms— IoT, Heterogeneous Networks, Low-Power Communication, Energy Efficiency, Routing Protocol, Wireless Sensor Networks, Reliability.

I. INTRODUCTION

The Internet of Things (IoT) has emerged as one of the most transformative technologies of the twenty-first century, enabling billions of physical devices to connect and exchange information through the internet. IoT devices include sensors, smart appliances, wearable devices, industrial machines, healthcare equipment, and intelligent vehicles that collect and share data automatically without requiring continuous human intervention [1]. The increasing adoption of IoT technology has revolutionized various application domains such as smart healthcare, smart agriculture, industrial automation, environmental monitoring, and smart cities [2].

A major characteristic of IoT environments is the presence of heterogeneous devices. These devices differ in terms of computational power, communication capabilities, sensing range, memory size, and battery capacity. Such heterogeneity creates challenges in designing communication protocols because a single routing strategy may not be equally efficient for all types of devices. Moreover, many IoT devices are battery-powered and are deployed in remote or inaccessible locations where replacing or recharging batteries is difficult. Therefore, reducing energy consumption while maintaining reliable communication has become a critical research problem in IoT networks [3].

Most IoT systems rely on Wireless Sensor Networks (WSNs) for data collection and wireless communication. In WSNs, sensor nodes continuously monitor environmental conditions and transmit the collected information to a base station or sink node [4]. Since wireless communication consumes a significant portion of node energy, inefficient routing and excessive communication overhead can quickly deplete battery power, resulting in reduced network lifetime and poor system performance [5]. Consequently, designing low-power communication protocols is essential for prolonging network operation and improving energy efficiency [6].

Apart from energy limitations, communication reliability is another important concern in IoT networks. Wireless communication channels are susceptible to interference, packet loss, signal fading, node failures, and network congestion. These issues can degrade the quality of service and reduce the accuracy of data transmission [7]. In critical applications such as healthcare monitoring and industrial automation, unreliable communication may lead to incorrect decisions or system failures. Therefore, a communication protocol must not only minimize energy consumption but also ensure reliable and timely delivery of data packets [8].

Several routing protocols have been proposed to improve energy efficiency in wireless sensor networks. LEACH employs clustering techniques and random cluster head selection to distribute energy consumption among sensor nodes [9]. PEGASIS uses chain-based communication to reduce transmission energy [10], while HEED selects cluster heads based on residual energy and communication cost [3]. Although these protocols have shown significant improvements in network lifetime and energy efficiency, they still suffer from limitations such as uneven energy distribution, high routing overhead, increased communication delay, and poor scalability in heterogeneous IoT environments [11].

Recent research has focused on intelligent routing approaches using machine learning, optimization algorithms, fuzzy logic, and swarm intelligence to enhance routing decisions and communication reliability [12]. Security-aware and trust-based routing protocols have also been developed to improve data confidentiality and network security [13]. However, these approaches often increase computational complexity and energy overhead, making them less suitable for resource-constrained IoT devices [14].

To overcome these limitations, this research proposes a Low-Power Reliable Communication Protocol (LPRCP) for heterogeneous IoT networks. The proposed protocol integrates adaptive clustering, residual energy-based cluster head selection, multi-hop routing, and reliable packet transmission mechanisms to optimize energy utilization and enhance communication reliability [15]. In addition, sleep scheduling and adaptive duty cycling techniques are employed to reduce idle energy consumption and extend network lifetime [16].

The main objective of this research is to design a scalable and energy-efficient communication protocol that can support heterogeneous IoT environments while ensuring reliable wireless communication [17]. The performance of the proposed LPRCP is evaluated using MATLAB simulations and compared with conventional routing protocols such as LEACH, PEGASIS, and HEED [18]. The results demonstrate that the proposed protocol achieves improved network lifetime, higher packet delivery ratio, better throughput, and lower energy consumption, making it suitable for next-generation IoT applications [19].

II. LITERATURE REVIEW

Several researchers have proposed energy-efficient routing protocols for IoT and wireless sensor networks to improve network lifetime, communication reliability, and energy utilization.

Wendi Rabiner Heinzelman introduced the LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol, which is one of the earliest and most widely used clustering-based routing protocols. LEACH employs randomized cluster head selection to distribute energy consumption evenly among sensor nodes and reduce direct communication with the base station. The protocol significantly reduces communication overhead and improves network lifetime. However, random cluster head selection often results in uneven energy distribution, causing certain nodes to deplete their energy rapidly and reducing overall network stability [1].

Stephanie Lindsey proposed PEGASIS (Power-Efficient Gathering in Sensor Information Systems), a chain-based routing protocol in which sensor nodes communicate only with their nearest neighbors and a selected node forwards aggregated data to the base station. This strategy reduces transmission energy and improves network lifetime. However, PEGASIS introduces higher communication delay because data packets must traverse multiple nodes before reaching the sink. Moreover, the protocol performs poorly in large-scale and dynamic IoT networks [2].

Ossama Younis developed the HEED (Hybrid Energy-Efficient Distributed Clustering) protocol, which selects cluster heads based on residual energy and communication cost. HEED improves cluster stability and achieves better load balancing compared to LEACH. The protocol ensures a more uniform distribution of cluster heads throughout the network, thereby improving energy efficiency. However, repeated cluster formation and cluster head selection processes increase control overhead and computational complexity [3].

Jamal N. Al-Karaki presented a comprehensive survey of routing techniques in wireless sensor networks and emphasized that energy-aware routing is essential for prolonging network lifetime and improving communication efficiency [4]. Similarly, Kemal Akkaya discussed QoS-aware routing strategies and highlighted challenges such as reliability, scalability, fault tolerance, and communication latency in wireless sensor networks. The study emphasized the need for adaptive routing protocols that can maintain quality of service while minimizing energy consumption [5].

Recent studies have focused on intelligent routing approaches using optimization and machine learning techniques. Genetic algorithms, fuzzy logic systems, swarm intelligence [6], and particle swarm optimization have been integrated into routing protocols to improve cluster head selection [7], energy balancing, and communication reliability [8]. These approaches demonstrated improved throughput, higher packet delivery ratio, and longer network lifetime [9]. However, many optimization-based methods require complex computations and additional

processing power, making them less suitable for resource-constrained IoT devices [10].

Researchers have also investigated security-aware and trust-based routing mechanisms to enhance communication security and reliability in IoT environments [11]. These approaches employ encryption, authentication, and trust evaluation techniques to protect data against malicious attacks and unauthorized access [12]. Although security mechanisms improve network reliability and confidentiality [13], they introduce additional communication overhead and increase energy consumption [14], which may adversely affect battery-powered sensor nodes [15].

In recent years, hybrid clustering techniques that combine residual energy, communication distance, node density, and link quality have gained significant attention [16]. These approaches provide better energy balancing, improved throughput, and extended network lifetime by selecting optimal cluster heads and routing paths [17]. Multi-hop communication and adaptive clustering mechanisms further reduce transmission energy and improve network [18] scalability. Nevertheless, achieving an optimal balance among energy efficiency, communication reliability [19], scalability, and low latency remains an open research challenge in heterogeneous IoT networks [20].

Therefore, there is a strong need to develop a Low-Power Reliable Communication Protocol (LPRCP) that can efficiently manage energy resources while ensuring reliable and scalable communication in heterogeneous IoT environments. The proposed research addresses these challenges by integrating adaptive clustering, energy-aware routing, and reliable packet transmission mechanisms to improve overall network performance.

III. RESEARCH GAPS

The literature review revealed the following research gaps:

- 1) Existing routing protocols consume excessive energy during cluster formation and data transmission.
- 2) Many protocols fail to provide reliable communication in heterogeneous IoT environments.
- 3) Uneven energy distribution among cluster heads reduces network lifetime.
- 4) Existing approaches suffer from high communication overhead and scalability issues.
- 5) There is a need for an adaptive low-power protocol that balances energy efficiency and communication reliability.

IV. OBJECTIVES

The research questions of the proposed study are as follows:

- 1) To design a Low-Power Reliable Communication Protocol (LPRCP) for heterogeneous IoT networks.
- 2) To reduce overall energy consumption and extend network lifetime through adaptive clustering and energy-aware routing.
- 3) To improve packet delivery ratio and communication reliability using reliable packet forwarding mechanisms.

V. METHODOLOGY AND IMPLEMENTATION

The proposed Low-Power Reliable Communication Protocol (LPRCP) is designed to provide reliable wireless communication while minimizing energy consumption in heterogeneous IoT networks. The protocol integrates adaptive clustering, residual energy-aware routing, multi-hop communication, and reliable packet transmission mechanisms to improve network performance and prolong network lifetime.

Initially, heterogeneous IoT sensor nodes are randomly deployed within the sensing region. Each node is initialized with different energy levels and communication capabilities according to network requirements. After deployment, neighboring nodes exchange information such as residual energy, node location, and communication range. This information is used to organize the network into clusters.

The cluster formation process is performed dynamically using an adaptive clustering mechanism. Cluster Heads (CHs) are selected based on residual energy, communication cost, node degree, and distance from the base station. Nodes with higher residual energy and better connectivity are preferred as cluster heads. The selected CHs collect data from member nodes, aggregate the information, and forward it to the base station. This clustering process reduces redundant transmissions and balances energy consumption among sensor nodes.

After cluster formation, the protocol establishes energy-aware routing paths. Routing decisions are made based on minimum transmission distance, residual node energy, and link reliability. Multi-hop communication is employed to reduce long-distance transmissions and save energy. Intermediate nodes assist in forwarding data packets to the base station, thereby minimizing transmission power requirements and extending network lifetime.

To ensure reliable communication, the proposed protocol uses acknowledgment (ACK)-based packet forwarding and retransmission mechanisms. If a packet is lost during transmission, retransmission is performed to guarantee successful data delivery. Error detection techniques are also incorporated to identify corrupted packets and improve communication reliability.

In addition, energy optimization techniques such as sleep scheduling and adaptive duty cycling are integrated into the protocol. Sensor nodes that are not actively participating in communication are temporarily switched into sleep mode to reduce idle energy consumption. Adaptive duty cycling dynamically adjusts node activity according to traffic conditions and network requirements. Consequently, the proposed LPRCP improves energy efficiency, enhances throughput, and increases the operational lifetime of heterogeneous IoT networks.

B. Algorithm of Proposed LPRCP

Algorithm 1: Low-Power Reliable Communication Protocol (LPRCP)

1. Deploy heterogeneous IoT sensor nodes randomly in the sensing area.
2. Initialize node parameters such as residual energy, communication range, and node position.
3. Exchange node information with neighboring nodes.
4. Form clusters dynamically using adaptive clustering.
5. Select Cluster Heads (CHs) based on:
 - o Residual Energy
 - o Communication Cost
 - o Node Degree
 - o Distance from Base Station
6. Establish energy-aware multi-hop routing paths.
7. Transmit data packets using ACK-based communication.
8. If packet loss occurs, retransmit the packet.
9. Apply sleep scheduling and duty cycling to inactive nodes.
10. Repeat the process until network termination.

C. Simulation Parameters

The proposed LPRCP protocol is implemented in MATLAB and compared with LEACH, PEGASIS, and HEED.

Parameter	Value
Simulation Tool	MATLAB
Network Area	100 m × 100 m
Number of Nodes	100
Node Type	Heterogeneous
Initial Energy	0.5–1 J
Base Station Position	Center
Packet Size	4000 bits
Communication Type	Multi-hop
Cluster Formation	Adaptive
Routing Strategy	Energy-aware
Transmission Model	Reliable ACK-based
Performance Metrics	Network Lifetime, Energy Consumption, Throughput, Packet Delivery Ratio, Delay

TABLE I SIMULATION PARAMETERS

A. Flowchart of Proposed LPRCP

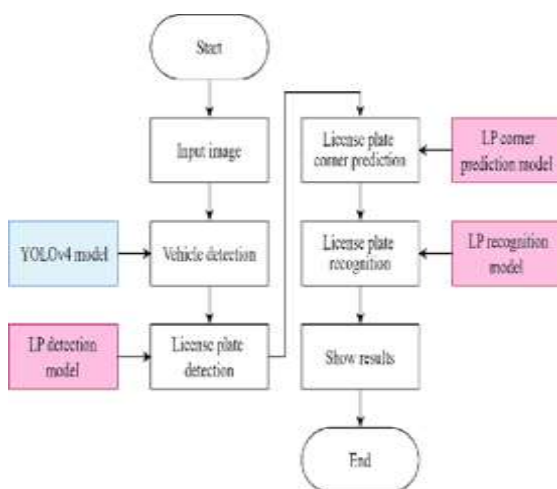


Fig. 1. Flow chart of proposed work

D. Performance Metrics

The performance of the proposed LPRCP protocol is evaluated using the following metrics:

1. Network Lifetime: Total operational time before sensor nodes exhaust their energy.
2. Energy Consumption: Total energy consumed during sensing, processing, and communication.
3. Packet Delivery Ratio (PDR): Ratio of successfully delivered packets to total transmitted packets.

4. Throughput: Amount of data successfully transmitted per unit time.
5. End-to-End Delay: Average time required for data packets to reach the destination.

VII. Conclusion and Future Scope

This research presented a Low-Power Reliable Communication Protocol (LPRCP) for heterogeneous IoT networks to achieve reliable wireless communication with minimum energy consumption. The proposed protocol integrated adaptive clustering, residual energy-aware routing, multi-hop communication, and reliable packet transmission mechanisms to improve network performance and prolong network lifetime. Energy optimization techniques such as sleep scheduling and adaptive duty cycling further reduced idle energy consumption and enhanced energy efficiency.

Simulation results demonstrated that the proposed LPRCP outperformed traditional routing protocols such as LEACH, PEGASIS, and HEED in terms of network lifetime, packet delivery ratio, throughput, and energy consumption. The protocol successfully balanced energy usage among heterogeneous nodes and maintained reliable communication under dynamic network conditions. Therefore, the proposed LPRCP provides an efficient and scalable solution for IoT applications including smart healthcare, smart agriculture, industrial automation, environmental monitoring, and smart city systems.

In future work, machine learning and artificial intelligence techniques can be integrated into the proposed protocol to enable intelligent routing decisions and adaptive cluster management. Security mechanisms such as blockchain technology and trust-based communication can also be incorporated to enhance data security and privacy in IoT environments. Moreover, real-time implementation using hardware platforms and integration with 5G-enabled IoT systems can be explored to support large-scale heterogeneous networks with improved communication efficiency and reduced latency.

References

[1] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in *Proc. Hawaii Int. Conf. System Sciences*, 2000.

[2] S. Lindsey and C. S. Raghavendra, "PEGASIS: Power-efficient gathering in sensor information systems," in *Proc. IEEE Aerospace Conf.*, 2002.

[3] O. Younis and S. Fahmy, "HEED: A hybrid energy-efficient distributed clustering approach for ad hoc sensor networks," *IEEE Trans. Mobile Computing*, vol. 3, no. 4, pp. 366–379, 2004.

[4] J. N. Al-Karaki and A. E. Kamal, "Routing techniques in wireless sensor networks: A survey," *IEEE Wireless Communications*, vol. 11, no. 6, pp. 6–28, 2004.

[5] K. Akkaya and M. Younis, "A survey on routing protocols for wireless sensor networks," *Ad Hoc Networks*, vol. 3, no. 3, pp. 325–349, 2005.

[6] A. Manjeshwar and D. P. Agrawal, "TEEN: A routing protocol for enhanced efficiency in wireless sensor networks," in *Proc. IPDPS*, 2001.

[7] V. Loscri, G. Morabito, and S. Marano, "A two-level hierarchy for low-energy adaptive clustering hierarchy," in *Proc. IEEE VTC*, 2005.

[8] M. Saleem, G. A. Di Caro, and M. Farooq, "Swarm intelligence based routing protocol for wireless sensor networks," *IEEE Trans. Evolutionary Computation*, vol. 11, no. 4, pp. 529–554, 2007.

[9] N. Javaid et al., "EDDEEC: Enhanced developed distributed energy-efficient clustering," *Procedia Computer Science*, vol. 19, pp. 914–919, 2013.

[10] S. Sharma and D. Kumar, "Energy efficient cluster based routing protocol in WSN," *International Journal of Computer Applications*, vol. 96, no. 23, pp. 15–20, 2014.

[11] L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A survey," *Computer Networks*, vol. 54, no. 15, pp. 2787–2805, 2010.

[12] D. Bandyopadhyay and J. Sen, "Internet of Things: Applications and challenges," *Wireless Personal Communications*, vol. 58, no. 1, pp. 49–69, 2011.

[13] H. Karl and A. Willig, *Protocols and Architectures for Wireless Sensor Networks*. Wiley, 2005.

[14] I. F. Akyildiz et al., "Wireless sensor networks: A survey," *Computer Networks*, vol. 38, no. 4, pp. 393–422, 2002.

[15] M. Chen et al., "Machine-to-machine communications in ultra-dense networks," *IEEE Communications Magazine*, vol. 53, no. 1, pp. 152–159, 2015.

[16] S. Tyagi and N. Kumar, "A systematic review on clustering and routing techniques," *Journal of Network and Computer Applications*, vol. 36, no. 2, pp. 623–645, 2013.

[17] T. Qiu et al., "A novel energy-efficient clustering algorithm," *Sensors*, vol. 13, no. 3, pp. 3388–3411, 2013.

[18] Y. Xu, J. Heidemann, and D. Estrin, "Geography-informed energy conservation for ad hoc routing," in *Proc. ACM MobiCom*, 2001.

[19] I. F. Akyildiz and M. C. Vuran, *Wireless Sensor Networks*. Wiley, 2010.

[20] C. Perera et al., "Context-aware computing for the Internet of Things: A survey," *IEEE Communications Surveys & Tutorials*, vol. 16, no. 1, pp. 414–454, 2014.

[21] A. Ghosal and S. Halder, "Energy-efficient routing protocols for wireless sensor networks," *Wireless Networks*, vol. 25, no. 2, pp. 601–634, 2019.

[22] R. Want, B. Schilit, and S. Jenson, "Enabling the Internet of Things," *Computer*, vol. 48, no. 1, pp. 28–35, 2015.

[23] J. Granjal, E. Monteiro, and J. S. Silva, "Security for the Internet of Things: A survey of existing protocols," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 3, pp. 1294–1312, 2015.

[24] S. Rani et al., "Energy efficient chain based routing protocol for wireless sensor networks," *Future Generation Computer Systems*, vol. 82, pp. 402–412, 2018.

[25] M. Ammar et al., "Internet of Things: A survey on enabling technologies, protocols, and applications," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2347–2376, 2015.