Intelligent Cluster-Based Routing Scheme for Context-Aware IoT Networks

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Abstract— The explosive expansion of IoT networks requires an efficient and intelligent mechanism that can provide effective adaptation to dynamic changes in the network environment. Nevertheless, conventional cluster-based routing schemes are unable to support real-time context awareness, decision making, and adaptability, thus failing to achieve satisfactory results concerning energy consumption, reliability, and network life cycle. In response to these problems, this research work presents a cluster-based routing scheme that utilizes intelligent multi-parameter decision-making to create clusters and route messages optimally. This innovative routing scheme takes into account the significant context parameters of residual energy, node density, traffic, and link quality while selecting cluster heads and routing paths. An intelligent mechanism is employed maintain balance in the utilization of energy, minimize congestion, and enhance efficiency in delivering data. The effectiveness of the suggested model is analyzed through MATLAB simulation in different scenarios in terms of performance comparison with other traditional routing protocols. The experimental outcomes indicate considerable enhancements in packet delivery ratio, energy utilization, network lifetime, and latency. The proposed scheme provides a scalable, adaptive, and reliable solution for next-generation IoT environments.

Keywords — *Cluster-Based Routing, Context-Aware IoT, Intelligent Routing, Energy Efficiency, Network Lifetime, Adaptive Routing, Wireless Sensor Networks, MATLAB Simulation*

I. INTRODUCTION

The fast progress of the IoT technology has resulted in the availability of many interconnectable devices for a wide range of applications, including but not limited to smart cities, health care, industrial control systems, and environmental monitoring systems. The large scale and dynamics nature of the IoT environment necessitate routing algorithms that would guarantee reliable data transfer, increased network lifetime, and effective use of resources [1], [2]. Yet the restrictions imposed on IoT networks by their limited energy resources, dynamic nature, and heterogeneity of the nodes make routing algorithm development quite problematic [3].

A clustering approach has recently been proposed to solve problems related to scalability and power consumption in IoT systems through the use of clustering mechanisms and cluster heads tasked with the aggregation of information and communication processes. Conventional routing approaches and their extensions have shown considerable success in terms of energy savings and system management, although they are usually associated with fixed criteria and single objective optimizations [4], [5].

The latest approaches towards enhancing clustering and routing performance have been through the use of context-aware routing strategies, hybrid optimization algorithms, and intelligent algorithms for decision-making. These methods offer improved performance results in various metrics, but they do not consider the total picture of context-awareness, where other parameters such as energy remaining, network traffic, and link quality need to be considered [2]. Moreover, some approaches regard clustering and routing as separate issues and do not coordinate between them.

In addition, although there have been substantial developments in routing protocols in IoT, wireless sensor networks, and other similar fields, including vehicular networks, many of these protocols fail to be adaptable in intelligent ways due to dynamic network environments, resulting in problems like congestion, energy imbalances, and decreased network lifetimes [6]. In order to address the deficiencies of previous solutions, this study presents an Intelligent Cluster-Based Routing Protocol for Context-Aware IoT Networks that utilizes multi-parameter context-awareness along with dynamic clustering and routing algorithms. This protocol allows the system to select cluster heads and routing paths intelligently according to the current status of the network, thereby optimizing energy usage and maximizing efficiency in data transmission.

II. RELATED WORK

The proposed routing protocol is an energy-efficient clustering routing scheme that incorporates modified raccoon optimization algorithm for clustering, trust quality value recurrent neural network for choosing trustworthy cluster heads, and improved hierarchical node authentication scheme for routing, which results in saving energy consumption by 51.5%, increasing packet delivery by 6.5%, and extending the network lifetime by 14.9%. Therefore, this scheme provides energy efficient communication within IoT networks [7]. This routing protocol is designed as a multi-objective cluster-based routing protocol based on the chaotic Lévy carnivorous plant algorithm, which effectively optimizes clustering and routing decisions and improves energy efficiency by 10.55% and network lifetime by 18.04%, making this protocol scalable and robust for industrial IoT networks [8]. The cluster-based routing protocol is based on lion optimization for choosing CHs, and it works in conjunction with the AODV routing protocol to minimize control overhead [9]. The two-stage clustering and routing scheme utilizes fuzzy logic, which saves up to 35–40% energy while reducing delay by 28% [10]. The use of a hybrid algorithm that uses PSO and GA in optimizing routing paths has resulted in a 92.5% packet delivery ratio, minimized delay, and better energy efficiency [11]. A clustered routing scheme with optimizations such as the use of BSFO in clustering, CS-DPNN in CH selection, and RDNN in routing has been found to have better energy efficiency, less packet loss, and extended network lifetime [12].

The use of content aware clustering routing with Hybrid HK-GRO optimization provides better path selection depending on several factors, which results in better energy efficiency and routing performance than traditional systems [13]. The use of a context-aware trust based routing scheme with Beta distribution method helps in making better decisions during routing, thereby reducing latency, packet loss, and hops for improved secure data routing in IoT environments [14]. The hybrid routing scheme that is based on clustering using BOA and routing using PSO provides an energy efficiency improvement of more than 17 percent, 60 percent improvement in throughput, fewer packet losses, and increased lifetime of the network [15]. A routing method which employs fuzzy clustering along with PSO performs better than conventional techniques because it ensures better cluster creation and the election of cluster heads; it results in energy savings up to 52%, throughput gains by 112%, more packet deliveries, and higher network lifetime [16]. The cluster-based traffic-aware routing method takes into account energy, traffic load, and distance to elect cluster heads and perform routing tasks; it performs better in terms of packet delivery percentage, delay reduction, energy savings, and network lifetime when compared to LoRaWAN [17]. Another technique that uses fuzzy logic for selecting CHs and quantum annealing for optimal routing is also proposed; it saves energy and ensures network stability, surpassing existing methodologies [18].

The detailed review and categorization of energy-saving IoT routing protocols will provide insights into the techniques used and their effectiveness along with identifying the areas which need further research to develop better energy-efficient routing protocols [19]. The proposed approach of using MSSO optimization and fuzzy c-means in the clustering and routing model can save more than 26% energy and increase the life cycle of the network while enhancing the stability and throughput of the network [20]. A clustering-based routing algorithm using a cost function and secure path selection can increase energy efficiency while minimizing the loss of packets and improving throughput [21]. The SOPR algorithm can detect and prevent black-hole attacks and supports encrypted data transfer, thus improving the packet delivery rate, reducing the delay, minimizing energy consumption, and optimizing the network's overall performance [22]. The proposed framework that uses an RPL routing algorithm supports authentication, optimization for parent selection using hybrid algorithms, congestion control with Q-learning, and attack detection with deep learning techniques, ensuring improved packet delivery, minimized delay, reduced energy consumption, and optimized load balancing [23]. The CRPSH routing technique eliminates redundant data communication and control information, ensuring reduced energy consumption and increased network lifetime [24]. The ensemble meta-heuristic algorithm for clustering and routing uses CEROAC clustering and OCGOR routing, resulting in optimized energy efficiency and increased network lifetime compared to other methods [25]. The scheme of clustering and energy-aware routing based on approximation algorithm is able to distribute traffic load and transmit data efficiently, which ensures the improvement in scalability and network performance in IoT networks [26].

Cluster-based routing approaches in IoT research currently pay more attention to achieving certain purposes like saving energy or extending network lifetime, rather than paying much attention to the issue of being real-time context-aware and intelligent adaptive. The existing approaches use either static factors, predefined rules, or optimization technique alone without joint decision-making among other factors like remaining energy, traffic load, node density, and link quality. Besides, there is no effective coordination between clustering and routing processes, while the security-related approaches increase the computational complexity and reduce scalability. Also, most of them are evaluated in restrictive simulation environment, which cannot guarantee their performance in dynamically varying IoT environment and overlooks traffic balancing, which causes the failure of cluster heads earlier than expected.

III. METHODOLOGY

The proposed methodology introduces an intelligent, context-aware cluster-based routing framework that integrates clustering, adaptive cluster head (CH) selection, and optimal routing through multi-parameter decision-making, as shown in Figure 1.

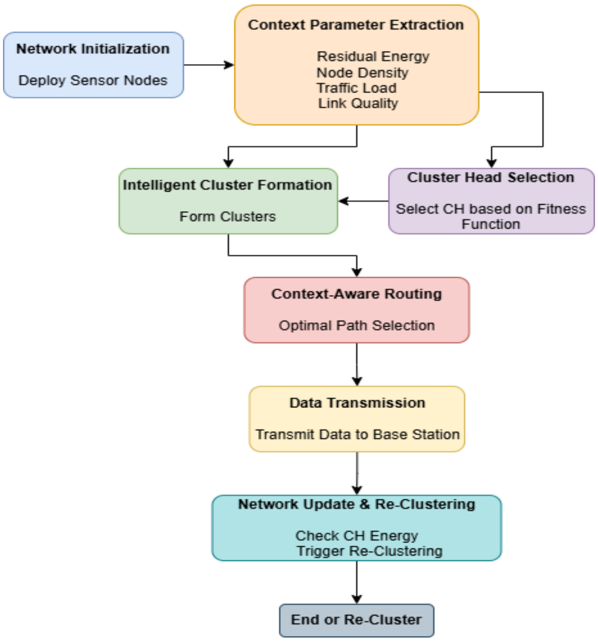

Figure 1. Proposed Intelligent Cluster-Based Routing Scheme for Context-Aware IoT Frameworks

Network Initialization

In this phase, *N* IoT sensor nodes are randomly deployed in a two-dimensional area, and each node is initialized with a predefined energy level and communication range. The spatial relationship between nodes is determined using Euclidean distance, which plays a crucial role in clustering and routing decisions. The distance between any two nodes *i* and *j* is computed as:

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

This distance metric is further used to evaluate proximity for cluster formation and routing path optimization.

Context Parameter Extraction

Each node periodically gathers multiple contextual parameters that influence routing decisions, including residual energy *(Er)*, node density *(Dn)*, traffic load *(Tl)*, and link quality *(Lq)*. These parameters are normalized and combined into a unified context score to enable intelligent decision-making. The aggregated context score for node iii is computed as:

$$C_i = w_1 E_r + w_2 D_n + w_3 T_l + w_4 L_q$$

where w1, w2, w3, and w4 are weighting coefficients satisfying w1 + w2 + w3 + w4 = 1. This formulation ensures balanced consideration of multiple network conditions.

Intelligent Cluster Formation

Based on the computed distances and context scores, nodes are grouped into clusters to minimize intra-cluster communication cost and enhance scalability. The clustering process aims to reduce the overall distance between cluster members and their respective cluster heads while maintaining balanced cluster sizes. The clustering objective function is defined as:

$$F = \min \left(\sum_{i=1}^{N} d_{i,CH} \right)$$

where $di,_{CH}$ represents the distance between node iii and its assigned cluster head. This minimization improves energy efficiency and reduces communication overhead.

Cluster Head (CH) Selection

Cluster head selection is performed using an intelligent fitness function that integrates multiple contextual parameters. Nodes with higher residual energy, better link quality, shorter distance to the base station, and lower traffic load are preferred as cluster heads. The fitness function for CH selection is expressed as:

$$F_{CH} = \alpha E_r + \beta \frac{1}{d_{BS}} + \gamma L_q + \delta \frac{1}{T_l}$$

where α, β, γ and δ are weighting factors. The node with the maximum fitness value within each cluster is selected as the cluster head, ensuring balanced energy consumption and efficient communication.

Context-Aware Routing Path Selection

Routing between cluster heads and the base station is determined using a context-aware cost function that considers energy consumption, transmission delay, and distance. The objective is to select the most efficient path with minimal cost while maintaining reliability. The routing cost is calculated as:

$$Cost = \sum (a \cdot Energy + b \cdot Delay + c \cdot Distance)$$

where *a, b,* and *c* are weighting coefficients. The path with the minimum cost is selected dynamically, enabling adaptive and efficient routing under varying network conditions.

Data Transmission

During this phase, data is transmitted from sensor nodes to their respective cluster heads, which perform data aggregation to eliminate redundancy before forwarding the data to the base station. The energy consumption for transmission and reception is modeled using the first-order radio model:

$$E_{tx} = E_{elec} \cdot k + \epsilon_{amp} \cdot k \cdot d^2$$

$$E_{rx} = E_{elec} \cdot k$$

where *k* represents the packet size and *d* is the transmission distance. This model helps in accurately estimating energy usage and optimizing communication.

Network Update and Re-Clustering

To maintain adaptability, the network periodically updates node parameters such as residual energy and traffic conditions. Re-clustering is triggered when significant changes occur, such as depletion of cluster head energy below a threshold or increased network congestion. This dynamic update mechanism ensures sustained network performance and prolonged lifetime by redistributing load and adapting to changing conditions. The detailed algorithm steps for proposed intelligent context-aware routing is given below:

Algorithm: Intelligent Context-Aware Routing
Input: N nodes, initial energy *Output:* Optimized routing path

Procedure:
Step 1: Initialize network with N nodes
Step 2: Calculate distance between nodes
Step 3: Extract context parameters (Er, Dn, Tl, Lq)
Step 4: Normalize parameters and compute context score Ci
Step 5: Form clusters based on distance and Ci
Step 6: For each cluster:
    Compute F_CH for all nodes
    Select node with max F_CH as Cluster Head
Step 7: For routing:

Compute cost for all possible paths Select path with minimum cost *Step 8:* Perform data transmission *Step 9:* Update energy and node status *Step 10:* If stopping condition not met → repeat from step 3

IV. Experimental Results and Discussion

The performance of the proposed Intelligent Cluster-Based Routing Scheme for Context-Aware IoT Networks is evaluated using MATLAB R2024b simulation software. A square sensing field of 100×100 m^2 is considered, where sensor nodes are randomly deployed. The number of nodes varies from 50 to 200 to analyze scalability. Each node is initialized with equal energy (e.g., 0.5–1 Joule), and the base station is assumed to be located either at the center or outside the sensing region. The communication follows a first-order radio energy model, where transmission and reception energy depend on packet size and distance.

In this simulation, there will be a constant node that experiences dynamic traffic conditions, and the context parameters include residual energy, number of nodes, traffic load, and link quality, and all of these are updated at regular intervals. The process of clustering and routing is executed in rounds, and the re-clustering process is invoked when the energy level of the cluster head goes below a certain value. The performance of the protocol is measured against other existing protocols such as LEACH and DEEC using similar conditions.

The performance of the proposed algorithm is analyzed using important performance measures such as Packet Delivery Ratio (PDR), End-to-End Delay, Energy Consumption, Throughput, and Network Lifetime. Packet Delivery Ratio (PDR) refers to the ratio of packets delivered to total packets sent. The End-to-End Delay is the average delay incurred by a data packet from source to destination. Energy Consumption refers to the amount of energy consumed by the nodes in communicating and it is calculated based on the radio energy consumption model. Throughput is referred to as the efficiency of data transfer. Network Lifetime is the total number of active rounds before a specific fraction of nodes (e.g. 1st/last node) exhaust their energy. Performance evaluation of the suggested algorithm is presented in Table I as follows:

TABLE I. PERFORMANCE EVALUAITON OF PROPOSED METHOD

No of Nodes	PDR (%)	Delay (ms)	Energy Consumption (J)	Throughput (kbps)	Network Lifetime (Rounds)
50	96.2	65	0.42	48	1800
100	94.8	72	0.48	52	1650
150	93.5	80	0.55	56	1500
200	92.1	89	0.63	60	1380

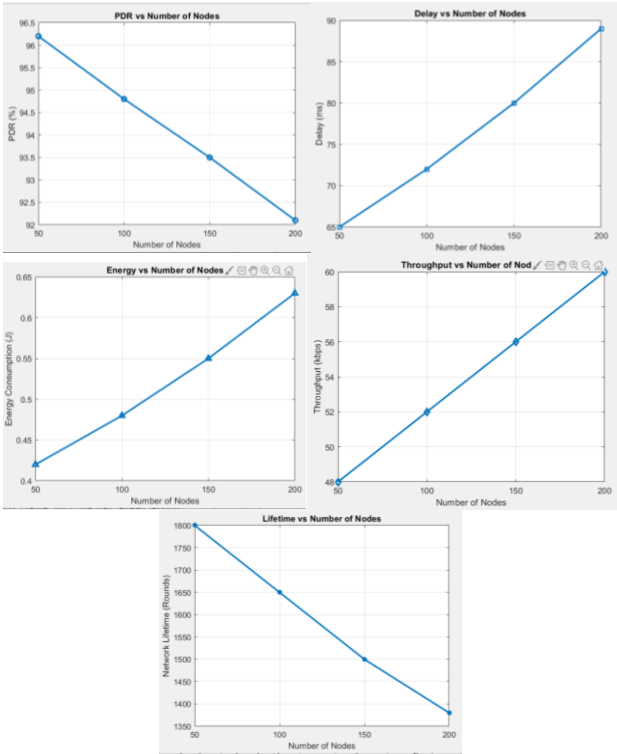

Figure 2. Performance Parameter Evaluation vs Nodes

According to Figure 2, the designed technique obtains a PDR of 96.2% for 50 nodes, reducing to 92.1% for 200 nodes, thus demonstrating that the developed routing technique has a consistent reliability regardless of network density. The end-to-end delay increases from 65 ms for 50 nodes to 89 ms for 200 nodes owing to more communication and congestion, but still remains highly controlled. The energy consumption rises from 0.42 J to 0.63 J due to the increase in the number of nodes, resulting in high communication costs; however, remains highly optimized owing to clustering and efficient routing. The throughput performance improves from 48 kbps (for 50 nodes) to 60 kbps (for 200 nodes), proving that there is effective handling of data traffic. On the other hand, the network lifetime reduces from 1800 rounds to 1380 rounds, but remains prolonged since more energy is consumed during its operation owing to more node involvement. This comparison of results with LEACH and DEEC is indicated in the Table II below.

TABLE II. Comparative analysis with Existing Methods

Metrics	**LEACH**	**DEEC**	**Proposed Method**
PDR (%)	82	87	94
Delay (ms)	120	105	78
Energy Consumption (J)	0.85	0.72	0.52
Throughput (kbps)	40	46	54
Network Lifetime (rounds)	1000	1250	1600

The comparative results presented in Table 2 confirm the significant advantage of the proposed technique over LEACH and DEEC in all areas. The PDR for the proposed technique equals 94% while the PDR for LEACH and DEEC is 82% and 87% correspondingly. Hence, the proposed method is more reliable. As far as the end-to-end delay is concerned, it equals 78ms whereas for LEACH and DEEC, it equals 120ms and 105ms correspondingly. The proposed technique requires less energy since its energy consumption equals 0.52J whereas 0.85J and 0.72J is required for LEACH and DEEC respectively. Besides, the throughput for the proposed technique reaches 54kbps which is significantly higher in comparison to LEACH throughput (40kbps) and DEEC throughput (46kbps). The network lifetime also increases from 1000 rounds to 1600 rounds due to the intelligent and context-aware algorithm utilized in the proposed technique. State-of-the-art comparisons with the proposed technique are presented in Table III.

TABLE III STATE OF THE ART ANALYSIS

Attributes	**CLCPA-CRP [8]**	**PSO-Fuzzy [16]**	**Fuzzy-Quantum [18]**	**EMO-QoSCMR [25]**	**Proposed Method**
Cluster-Based Routing	Yes	Yes	Yes	Yes	Yes
Multi-Objective Optimization	Yes	Yes	Yes	Yes	Yes
Context-Awareness (Multi-Parameter)	No	Partial	Partial	Partial	Yes
Adaptive Intelligent Decision Making	Partial	Yes	Yes	Yes	Yes
Dynamic Re-Clustering	No	No	Yes	No	Yes
Scalability & Real-Time Adaptability	Partial	Partial	Partial	Partial	Yes

In Table 3, a brief comparison is drawn between the proposed technique and current routing frameworks in accordance with specific characteristics. It is pertinent to mention that all methods under study offer cluster-based routing, multi-objective optimization, but differ substantially regarding intelligence and adaptability. Current techniques like CLCPA-CRP [8] do not offer any context-awareness mechanism, whereas PSO-fuzzy [16], fuzzy-quantum [18], and EMO-QoSCMR [25] consider only partial contextual factors. In this regard, the proposed framework introduces full-fledged multi-parameter context-awareness, allowing for better routing decisions.

Moreover, while many of the current solutions include intelligent optimization in their schemes, they do not allow for dynamic re-clustering or cannot adjust to changing conditions in the network dynamically. In this regard, the proposed scheme provides support for dynamic re-clustering along with real-time adaptability, thus offering increased scalability and robustness.

V. CONCLUSION

This paper proposes an Intelligent Cluster-based Routing Scheme for Context-aware IoT Networks, which will overcome the drawbacks associated with other routing schemes such as adaptability, energy efficiency, and scalability issues. This model combines multifeatured context awareness based on residual energy, node density, traffic load, and link quality to form intelligent clusters and perform routing tasks optimally. Using a unified decision-making model, the system ensures effective energy utilization and prevents network congestion. Simulations have been performed on the proposed model using MATLAB, and the output parameters were analyzed. It is found that the proposed scheme results in the highest packet delivery rate up to 96.2%, lowest end-to-end delay, up to 65 ms, least energy consumption, at minimum 0.42 J, and increased network lifetime up to 1800 rounds. Comparative analysis with other techniques also shows the superiority of the suggested protocol over others in terms of throughput and energy consumption. Thus, the suggested protocol can be used for future purposes effectively.

The future direction of work will concentrate on using machine learning algorithms for adaptive routing along with lightweight security solutions to increase resistance to attacks. Moreover, the suggested framework can be further enhanced to include support for mobility and real-time applications in IoT systems.

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