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IOT-Based Smart Healthcare Data Transmission Using Enhanced Clustering Strategies

Dr. Shashidhar P K#[1], Prof. Manjunath N L#[2], Prof. Arunakumar S Bhosale#[3]
[1-3]Department of ECE, [1-3]SKSVMACET,
[1-3] Lakshmeshwar
[1]pks197030@gmail.com , [2]manjunath@gmail.com, [3]sbarunkr@gmail.com

***Abstract*: The rapid growth of Internet of Things (IoT) technologies has significantly transformed healthcare monitoring systems by enabling continuous collection and transmission of patient data. However, efficient and reliable data transmission remains a major challenge due to network congestion, limited energy resources, and scalability issues in IoT environments. This paper proposes an enhanced clustering-based framework to improve healthcare data transmission in IoT networks.In the proposed approach, sensor nodes are initially organized into clusters using a middle-order clustering mechanism to optimize network structure and reduce communication overhead. An efficient data transmission strategy is then applied to select optimal paths within clustered networks. Additionally, a Routing Protocol for Low-Power and Lossy Networks (RPL) based routing mechanism with handshake computation is implemented to enhance communication reliability and extend the network lifetime in multimedia IoT environments.The proposed MOOR strategy is evaluated through simulation under multiple network conditions. Performance metrics such as control overhead and packet delivery ratio (PDR) are analyzed to measure the efficiency of the system. The simulation results demonstrate that the proposed approach achieves improved packet delivery performance and reduced control overhead compared with conventional methods, making it suitable for reliable healthcare data communication in IoT-based monitoring systems.**

Index Terms: Internet of Things (IoT), Healthcare Monitoring Systems, RPL Routing, Cluster-Based Communication, Trickle Timer Mechanism, Medical Data Transmission.

I. INTRODUCTION

The rapid development of the Internet of Things (IoT) has brought significant changes to healthcare systems by enabling continuous patient monitoring through interconnected medical sensors and wearable devices. These smart healthcare systems allow real-time collection of physiological data, which can support early diagnosis, remote monitoring, and improved medical decision-making. However, the large volume of data produced by IoT devices creates serious challenges for efficient data transmission, especially in networks with limited energy resources, bandwidth constraints, and dynamic network conditions.

To manage these challenges, clustering-based communication techniques are widely used in IoT networks. In a clustered network structure, sensor nodes are grouped together, and a cluster head is responsible for collecting and forwarding data to the base station or gateway. This method helps reduce redundant transmissions, lower communication overhead, and improve overall network efficiency. Nevertheless, traditional clustering approaches are generally designed for generic IoT applications and may not fully satisfy the strict reliability and security requirements of healthcare data transmission.

Medical information is highly sensitive and requires accurate, reliable, and timely delivery to ensure proper patient monitoring and treatment. Therefore, standard clustering mechanisms may not be sufficient for healthcare-oriented IoT systems. To address these limitations, this paper proposes a specialized architecture aimed at improving the efficiency and reliability of medical data transmission in IoT-based healthcare networks.

Due to the sensitive nature of healthcare data and the need for reliable and secure communication, conventional integration approaches may not be sufficient. This paper therefore proposes a customized architecture designed to enhance medical data transmission in IoT networks.

II. RELATED WORK:

The Routing Protocol for Low-Power and Lossy Networks (RPL) is a distance-vector routing protocol developed by the ROLL working group to support communication in resource-constrained wireless networks. These networks typically consist of devices with limited energy, processing capability, and unreliable communication links. RPL is designed to operate over the IEEE 802.15.4 standard and mainly supports multi-hop communication patterns such as many-to-one data transmission, which is common in sensor networks. In addition, it also enables one-to-one and one-to-many communication. The protocol was standardized by the Internet Engineering Task Force (IETF) as **RFC 6550** in March 2012. RPL was developed to meet routing requirements for several application domains of low-power and lossy networks, including home automation, building automation, industrial automation, and urban sensing systems [1]. The protocol supports three fundamental traffic patterns: multipoint-to-point (MP2P), point-to-multipoint (P2MP), and point-to-point (P2P) communication.

To control routing message dissemination in RPL networks, the **Trickle algorithm** is widely used. Trickle is a self-regulating algorithm originally proposed for efficient code propagation in wireless sensor networks while maintaining minimal communication overhead. The algorithm follows a "polite gossip" mechanism in which nodes periodically transmit summarized information to neighboring nodes. If a node receives the same information from nearby nodes, it suppresses its own transmission, thereby avoiding unnecessary packet flooding. However, if a node detects outdated information, it broadcasts an update to maintain network consistency. In RPL, the trickle timer is responsible for scheduling the transmission of DODAG Information Object (DIO) control messages. Each node selects a transmission time randomly within the trickle interval, and the actual transmission depends on predefined parameters and suppression rules [2].

Despite its advantages, the traditional trickle algorithm does not inherently provide load balancing capabilities. Several improved versions of the trickle timer have been proposed to enhance different performance aspects. For instance, E-Trickle, Opt-Trickle, and A2-Trickle focus on reducing route convergence time, while Trickle-F, Adaptive-K, Trickle-D, Drizzle, and I-Trickle attempt to improve fairness among nodes and reduce energy consumption. However, most of these approaches focus on optimizing only a single performance parameter. As a result, achieving simultaneous improvements in energy efficiency, throughput, packet delivery ratio (PDR), and end-to-end delay remains a challenge, particularly for multimedia data transmission in IoT environments. Therefore, this work aims to integrate a middle-order clustering technique with the RPL protocol to achieve improved overall network performance [3].

Clustering techniques are commonly used in wireless sensor networks to enhance energy efficiency and extend network lifetime. One such approach introduces an improved cluster head selection strategy that considers factors such as residual energy, energy threshold, node density, and communication cost. During cluster formation, ordinary nodes join clusters based on their remaining energy and distance from cluster heads, resulting in a non-uniform cluster structure that balances energy consumption across the network. Simulation results demonstrate that this improved approach significantly extends network lifetime compared to the conventional LEACH protocol. In the traditional LEACH scheme, the first node dies after approximately 401 rounds and the network stops functioning after around 1028 rounds, whereas the improved protocol extends the first node death to 1081 rounds and the last node death to approximately 2935 rounds [4].

Another research direction focuses on improving cluster head selection and routing performance using cooperative communication techniques. The Multipath Cooperative Self-Scheduling Protocol (MCSSP) determines cluster head selection based on parameters such as residual energy, node connectivity, and network capacity. Similarly, the Life Time Duty Cycled Energy Efficient Protocol (LTDCEEP) improves network performance by considering link quality and transmission capability during route formation. Experimental results show that LTDCEEP achieves a throughput of 0.4104 kbps, a packet delivery ratio of 95.535%, and an average delay of 1.311 seconds. Compared with the existing EER-LPR approach, LTDCEEP also demonstrates higher throughput, reduced energy consumption, and lower routing overhead [5].

Recent studies have also explored clustering strategies based on mobility parameters. For example, the MOVC algorithm introduces a cluster formation mechanism that maintains stable clusters for longer durations. Cluster head selection is determined using mobility-related parameters such as positional variation, speed, and acceleration of nodes. This approach helps reduce the impact of node mobility and improves communication stability within the network. Simulation outcomes indicate that the MOVC algorithm achieves an average packet delivery ratio of 90.52%, while the average cluster head and cluster member lifetimes are approximately 91.3 seconds and 81.9 seconds, respectively [6].

Although several improvements have been proposed in routing and clustering techniques, achieving an optimal balance among energy efficiency, data reliability, and communication overhead remains an open research problem. Therefore, this study proposes an enhanced clustering mechanism combined with an optimized RPL routing strategy to improve healthcare data transmission performance in IoT networks.

III. METHODOLOGY:

A. Routing over Low-Power and Lossy Networks (RPL)

Routing Protocol for Low-Power and Lossy Networks (RPL) is widely used in IoT environments where devices operate with limited power, memory, and communication capability. RPL organizes network nodes into a hierarchical structure known as a Destination Oriented Directed Acyclic Graph (DODAG)**,** where data packets are forwarded toward a root node through multiple hops. The construction of the upward routing path in the DODAG follows a sequence of steps as described below.

Step 1: The formation of the DODAG begins with the root node, which periodically broadcasts a DOD Information Object (DIO) message to its neighboring nodes. This message contains important routing parameters that allow surrounding nodes to identify the presence of the DODAG and obtain initial routing information.

Step 2: When a node receives a DIO message, it first evaluates whether the message satisfies the required routing conditions defined by the protocol. If the received information does not meet the necessary criteria, the node discards the message. Otherwise, the node proceeds to process the received routing information.

Step 3: If a node accepts the DIO message and decides to participate in the network topology, it joins the DODAG and calculates its **rank value**, which indicates its relative position with respect to the root node. After updating its routing parameters, the node forwards the DIO message with the updated rank information to neighboring nodes using multicast transmission, thereby extending the DODAG structure throughout the network.

Step 4: when a node that has already joined a DODAG receives another DIO message, If the new node's rank is lower than its previous one, The node then updates the rank in the DIO message and broadcasts the latest version of this message to all of its neighboring nodes.

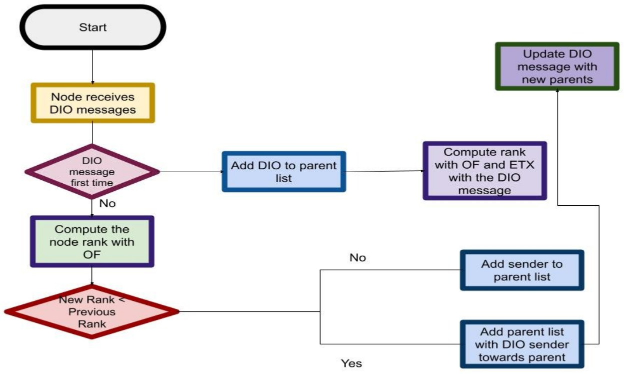

Fig. 1. .Routing over Low power and Lossy networks [RPL]

Step 5: The node will neither update the rank nor send any DIO message if its new computed rank is higher than its old one, but it will keep the previous preferred parent as the current preferred parent.

Step 6: This process will be repeated by all neighboring nodes, as it does in step 2, until all RPL nodes have joined the DODAG and terminated when the leaf node is reached.

Step 7: Note that the leaf nodes can only join the DODAG but should not transmit DIO messages except in some special cases, such as detecting an inconsistency when forwarding a packet, where in this case, they have to send DIO messages to repair the inconsistency.

Step 8: In the upward route when a new node intends to join an already defined DODAG.. When the new node receives the DIO messages, depending on the OF, it will choose one or more parent nodes and then select its preferred parent that has a lower rank.

B. *Trickle timer algorithm:*

The Trickle timer algorithm is used in RPL to control the transmission rate of routing control messages, particularly DODAG Information Object (DIO) messages. It dynamically adjusts the message broadcasting interval to reduce unnecessary transmissions while maintaining network consistency. The operation of the Trickle timer can be described through the following steps.

1.The algorithm begins by defining the timer interval I, which lies between two predefined limits: Imin and Imax. Initially, the interval is set to the minimum value I = Imin.

2.At the beginning of each interval, a counter c is initialized to zero. A transmission time t is then randomly selected within the range [I/2, I] to determine when the node may transmit a control message.

3. Whenever a node receives a consistent control message from neighboring nodes, the counter c is increased by one. This mechanism helps the node determine whether its own transmission is necessary.

4. At the selected time t, the node checks the value of the counter c against a predefined redundancy constant k. If $c \geq k$, the scheduled transmission is suppressed to avoid redundant communication. Otherwise, the node proceeds to broadcast a DIO message.

5. When the interval I expires, its value is doubled in order to gradually reduce the frequency of transmissions. This increase continues until the interval reaches the maximum limit Imax. For each new interval, the procedure described in Step 2 is repeated.

6. If a node detects an inconsistent message, indicating a possible change in the network topology, the interval I is reset to Imin. This action increases the transmission frequency temporarily so that updated routing information can propagate quickly through the network.

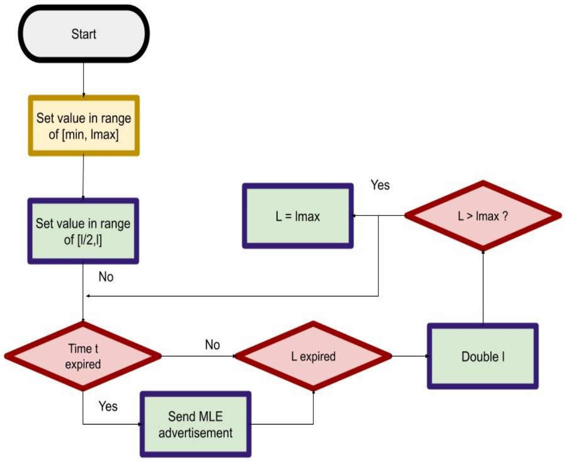

Fig. 2. Trickle Timer Algorithm

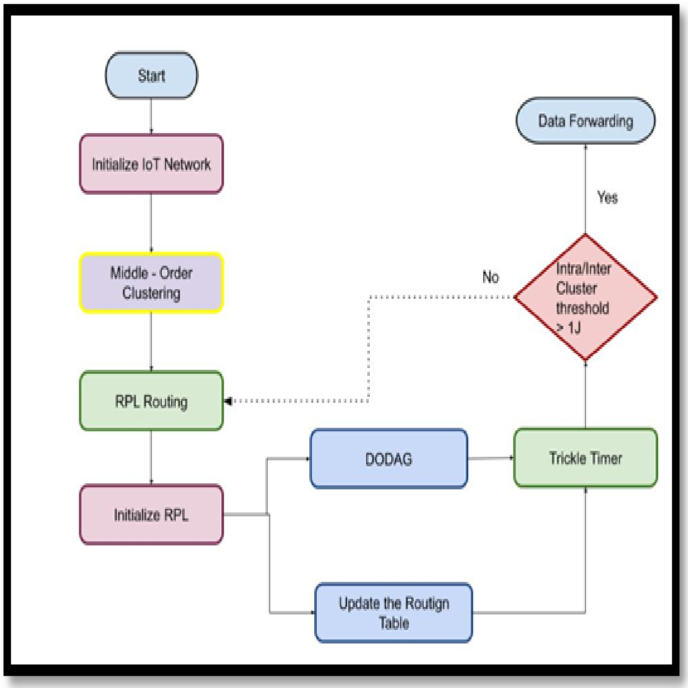

Fig. 3. Middle Order Optimal Routing(MOOR).

C. *Node Scheduling and Transmission Procedure*

The proposed methodology for node scheduling and data transmission in the IoT network can be summarized as follows:

Step 1: Initialize a network comprising 50 sensor nodes distributed within the coverage area.

Step 2: Assume that all nodes begin in a low-power sleep state to conserve energy.

Step 3: Determine the activity schedule for each node, accounting for its sleep and wake-up cycles to optimize energy usage and communication opportunities.

Step 4: If a node does not receive any schedule information, it participates in the network synchronization process to obtain a valid schedule.

Step 5: When a node is assigned multiple overlapping schedules, it is programmed to adhere to both schedules to maintain proper network operation.

Step 6: Nodes periodically monitor the channel during short listening mini-slots to detect any ongoing communication.

Step 7: Transmission parameters are estimated based on the node schedule and channel sensing results to prepare for data transfer.

Step 8: Following a successful transmission, the node reduces its contention window size to improve channel access efficiency.

Step 9: If a transmission attempt fails, the node increases the contention window to reduce the likelihood of repeated collisions.

Step 10: When the channel is idle, the transmitter initiates communication by sending a **Request-to-Send (RTS)** message to the intended receiver.

Step 11: Upon waking, the receiver responds with a Clear-to-Send (CTS) message, establishing a temporary communication link.

Step 12: After the communication is established, neighboring nodes remain in a sleep state to minimize interference and conserve energy.

Performance parameters

Packet Delivery Ratio: Ratio of the number of packets received by the destination node divided by the total number of packets sent from the source node.

$$\mathbf{PDR_{avg}} = \frac{P_r}{P_s} \times 100\%$$

Delay: Time to transfer the packet from a source node to a destination node of the application layer

$$\mathbf{Delay_{avg}} = \frac{\sum_{i=1}^{n}(t_r - t_s)}{P_r}$$

Throughput: Multiplication of the data packet numbers and the packet size in a unit of time, unit: bit/second (bps), determined as follows

$$\mathbf{Throughput_{avg}} = \frac{P_r \text{ X } KT}{T}$$

Throughput (*KB/s*) = *Σsize* (*receivedpacket*) ∗ *Count* (*receivd/ packets/number of simulations*

Control Overhead: The ratio of the total control packet numbers and the total data packet numbers received in a simulation

$$\mathbf{Control\ Overhead_{avg}} = \frac{P_{Control}}{P_r} \text{ X } 100\%$$

T is the time of the measurement process, KT is the packet size.

Energy Consumption

$$E_{Total\ Residual} = \sum_{i=1}^{n} E_{i,k} - \sum_{i=1}^{n} (E_{iTX} + E_{iRX}$$

IV. RESULTS AND DISCUSSION:

A. *Routing Over Low power Lossy network[RPL]*

TABLE I. PACKET DELIVERY RATIO (%)

No. of Nodes	RPL	mRPL	mRPL + PSO	mRPL + ACO	mRPL + Firefly
21	172	52	175	101	210
42	344	105	350	203	420
63	517	157	525	304	630
84	689	210	700	406	840
105	861	262	875	508	1050
Avg	**516.6**	**157.2**	**525**	**304.4**	**630**

Observations:_The PDR of_mRPL + Firefly is 630 and mRPL + PSO algorithms is 525 and higher than other RPL variants.

TABLE II. END TO END DELAY (MSEC)

No. of Nodes	RPL	mRPL	mRPL + PSO	mRPL + ACO	mRPL + Firefly
21	68	69	71	60	33
42	136	138	143	121	67
63	204	207	215	182	100
84	272	277	287	243	134
105	340	346	359	304	168
Avg Value	**204**	**207.40**	**215**	**182**	**100.40**

Observations:_The latency of mRPL + ACO and mRPL + Firefly algorithms is 182 ms and 100.40 ms respectively and comparatively lower than other RPL variants.

TABLE III. ENERGY CONSUMPTION (MJ)

No. of Nodes	RPL	mRPL	mRPL + PSO	mRPL + ACO	mRPL + Firefly
21	0.72	1.70	0.72	1.70	0.84
42	1.44	3.40	1.44	3.40	1.67
63	2.16	5.10	2.16	5.10	2.51
84	2.88	6.80	2.88	6.80	3.35
105	3.60	8.50	3.60	8.50	4.18
Avg Value	**2.16**	**5.1**	**2.16**	**5.1**	**2.51**

The energy consumption of RPL and mRPL + PSO is found to be 2.16 mJ and minimal relative to other variants of RPL protocols.

Remarks: In this study, a performance comparison of the standard RPL protocol and its various enhanced variants was conducted. The analysis reveals that no single RPL variant simultaneously satisfies all the desired QoS parameters required for energy-efficient and reliable data transmission in IoT networks. Although both RPL and mRPL+PSO achieve low energy consumption, approximately 2.16 mJ, the mRPL+PSO variant exhibits a higher end-to-end delay. This increased delay is particularly undesirable for medical data transmission, where timely delivery is critical. Therefore, there exists significant scope to further improve the standard RPL protocol and optimize it to support energy-efficient routing of multimedia healthcare data while meeting essential QoS requirements such as latency, reliability, and packet delivery ratio.

Trickle timer algorithm

TABLE IV. TRICKLE ALGORITHM FOR VARIOUS PARAMETERS

No of Nodes	Energy Consumption (mJ)	PDR (%)	Throughput (kbps)	Control Overhead	Lifetime of the CH (Hrs)
21	50.69	83.41	**Trickle works on control packets, not on data packets**	672	121.00
42	51.74	84.64		1457	123.53
63	57.18	88.84		2185	136.45
84	62.62	93.05		3240	149.38
105	63.42	98.70		3837	151.24
AVG	**57.13**	**89.728**		**2278.2**	**136.32**

TABLE V. TRICKLE TIMER ALGORITHM OF AVERAGE VALUES OF VARIOUS PARAMETERS.

No of Nodes(20-100)	Trickle	Trickle-F	FI-trickle	Parameters
Avg	57.13	57.148	57.222	Energy Consumption
Avg	136.32	129.846	129.956	Network life time
Avg	89.728	93.562	92.886	PDR
Avg	2278.2	2447.4	2468.8	Control Overhead

Remarks: The comparative analysis of various Trickle timer algorithms indicates that the standard Trickle algorithm achieves lower energy consumption, reduced control message overhead, and a longer network lifetime compared to alternative approaches. Based on these advantages, the standard Trickle timer has been selected as the preferred method for this study to ensure energy-efficient and reliable communication in the proposed IoT healthcare network.

Middle order Optimal Routing Protocol (MOOR**):**

TABLE VI. MOOR PROTOCOL FOR VARIOUS VALUES

No of Nodes	Energy (J)	PDR (%)	Throughput (kbps)	Control Overhead	Lifetime of the CH (s)	End-to-End (msec)
21	48	92	45	1000	660	10
42	49	93	46	2700	640	14
63	53	95	49	3900	630	23
84	64	96	50	4800	590	27
105	67	98	54	6300	570	32
Avg	57.20	94.8	48.8	3740	618	21.2

Our experimental results demonstrate the effectiveness of our enhanced clustering techniques in optimizing healthcare data transmission in IoT networks. We observe significant improvements in data transmission efficiency, with reduced PDR, Control Overhead and very less energy consumption is improved compared to traditional clustering methods. Moreover, our algorithms effectively mitigate the impact of network congestion and node failures, ensuring reliable data delivery even under adverse conditions. Furthermore, our enhanced clustering techniques exhibit scalability and adaptability, making them suitable for deployment in diverse healthcare IoT environments.

Future Directions: The findings of this study emphasize the critical role of clustering techniques in improving healthcare data transmission within IoT networks. By catering to the specific requirements of medical applications, the proposed enhanced clustering algorithms provide a robust framework to improve efficiency, reliability, and security of healthcare data communication.

Future research may focus on further refinement of the clustering algorithms, incorporating adaptive mechanisms to better handle dynamic network conditions and heterogeneous devices. Additionally, integrating advanced security solutions and privacy-preserving techniques can strengthen the protection of sensitive medical data. Exploring emerging technologies such as blockchain, edge computing, and AI-driven analytics offers promising opportunities to enhance the performance and trustworthiness of healthcare IoT systems.

Overall, this work lays the foundation for energy-efficient, secure, and reliable data transmission in healthcare IoT networks and contributes to the broader adoption of IoT technologies in the medical sector.

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